FOR THE INCREASE AND DIFFUSION OF KNOWLEDGE AMONG MEN

PER ORBEM

SMITHSONIAN INSTITUTION

WASHINGTON 1846

ANNUAL REPORT OF THE BOARD OF REGENTS OF THE SMITHSONIAN INSTITUTION

SHOWING THE

OPERATIONS, EXPENDITURES, AND CONDITION OF THE INSTITUTION FOR THE YEAR ENDING JUNE 30

1911

WASHINGTON
GOVERNMENT PRINTING OFFICE
1912

LETTER

FROM THE

SECRETARY OF THE SMITHSONIAN INSTITUTION,

SUBMITTING

THE ANNUAL REPORT OF THE BOARD OF REGENTS OF THE INSTITUTION FOR THE YEAR ENDING JUNE 30, 1911.

SMITHSONIAN INSTITUTION,
Washington, April 3, 1912.

To the Congress of the United States:

In accordance with section 5593 of the Revised Statutes of the United States, I have the honor, in behalf of the Board of Regents, to submit to Congress the annual report of the operations, expenditures, and condition of the Smithsonian Institution for the year ending June 30, 1911. I have the honor to be,

Very respectfully, your obedient servant,

CHARLES D. WALCOTT, *Secretary.*

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SUBJECTS.

1. Annual report of the secretary, giving an account of the operations and conditions of the Institution for the year ending June 30, 1911, with statistics of exchanges, etc.

2. Report of the executive committee, exhibiting the financial affairs of the Institution, including a statement of the Smithsonian fund, and receipts and expenditures for the year ending June 30, 1911.

3. Proceedings of the Board of Regents for the sessions of December 8, 1910, and February 9, 1911.

4. General appendix, comprising a selection of miscellaneous memoirs of interest to collaborators and correspondents of the Institution, teachers, and others engaged in the promotion of knowledge. These memoirs relate chiefly to the calendar year 1911.

THE SMITHSONIAN INSTITUTION.

JUNE 30, 1911.

Presiding officer ex officio.—William H. Taft, President of the United States.
Chancellor.—James S. Sherman, Vice President of the United States.
Members of the Institution:

William H. Taft, President of the United States.
James S. Sherman, Vice President of the United States.
Edward Douglass White, Chief Justice of the United States.
Philander C. Knox, Secretary of State.
Franklin MacVeagh, Secretary of the Treasury.
Henry L. Stimson, Secretary of War.
George W. Wickersham, Attorney General.
Frank H. Hitchcock, Postmaster General.
George von L. Meyer, Secretary of the Navy.
Walter L. Fisher, Secretary of the Interior.
James Wilson, Secretary of Agriculture.
Charles Nagel, Secretary of Commerce and Labor.

Regents of the Institution:

James S. Sherman, Vice President of the United States, Chancellor.
Edward Douglass White, Chief Justice of the United States.
Shelby M. Cullom, Member of the Senate.
Henry Cabot Lodge, Member of the Senate.
Augustus O. Bacon, Member of the Senate.
John Dalzell, Member of the House of Representatives.
James R. Mann, Member of the House of Representatives.
William M. Howard, former Member of the House of Representatives. Regent until December 27, 1911.
James B. Angell, citizen of Michigan.
Andrew D. White, citizen of New York.
John B. Henderson, Jr., citizen of Washington, D. C.
Alexander Graham Bell, citizen of Washington, D. C.
George Gray, citizen of Delaware.
Charles F. Choate, Jr., citizen of Massachusetts.

Executive Committee.—A. O. Bacon, Alexander Graham Bell, John Dalzell.
Secretary of the Institution.—Charles D. Walcott.
Assistant Secretary in charge of National Museum.—Richard Rathbun.
Assistant Secretary in charge of Library and Exchanges.—Frederick W. True.
Chief Clerk.—Harry W. Dorsey.
Accountant and Disbursing Agent.—W. I. Adams.
Editor.—A. Howard Clark.

THE NATIONAL MUSEUM.

Keeper ex officio.—Charles D. Walcott, Secretary of the Smithsonian Institution.
Assistant Secretary in charge.—Richard Rathbun.
Administrative Assistant.—W. de C. Ravenel.
Head Curators.—William H. Holmes, Leonhard Stejneger, G. P. Merrill.
Curators.—R. S. Bassler, A. Howard Clark, F. W. Clarke, F. V. Coville, W. H. Dall, B. W. Evermann, J. M. Flint, U. S. N. (retired), W. H. Holmes, Walter Hough, L. O. Howard, Alěs Hrdlička, G. P. Merrill, Gerrit S. Miller, Jr., Richard Rathbun, Robert Ridgway, Leonhard Stejneger, Charles D. Walcott.
Associate Curators.—J. N. Rose, David White.
Curator, National Gallery of Art.—W. H. Holmes.
Chief of Correspondence and Documents.—Randolph I. Geare.
Superintendent of Construction and Labor.—J. S. Goldsmith.
Editor.—Marcus Benjamin.
Photographer.—T. W. Smillie.
Registrar.—S. C. Brown.

BUREAU OF AMERICAN ETHNOLOGY.

Ethnologist in charge.—F. W. Hodge.
Ethnologists.—J. Walter Fewkes, J. N. B. Hewitt, Francis La Flesche, Truman Michelson, James Mooney, Matilda Coxe Stevenson, John R. Swanton.
Philologist.—Franz Boas.
Editor.—Joseph G. Gurley.
Illustrator.—De Lancey W. Gill.

INTERNATIONAL EXCHANGES.

Assistant Secretary in charge.—Frederick W. True.
Chief Clerk.—C. W. Shoemaker.

NATIONAL ZOOLOGICAL PARK.

Superintendent.—Frank Baker.
Assistant Superintendent.—A. B. Baker.

ASTROPHYSICAL OBSERVATORY.

Director.—C. G. Abbot.
Aid.—F. E. Fowle, Jr.

REGIONAL BUREAU FOR THE UNITED STATES, INTERNATIONAL CATALOGUE OF SCIENTIFIC LITERATURE.

Assistant in charge.—L. C. Gunnell.

REPORT

OF THE

SECRETARY OF THE SMITHSONIAN INSTITUTION

CHARLES D. WALCOTT,

FOR THE YEAR ENDING JUNE 30, 1911.

To the Board of Regents of the Smithsonian Institution:

GENTLEMEN: I have the honor to submit a report showing the operations of the Institution and its branches during the year ending June 30, 1911, including the work placed by Congress under the direction of the Board of Regents in the United States National Museum, the Bureau of American Ethnology, the International Exchanges, the National Zoological Park, the Astrophysical Observatory, and the United States Bureau of the International Catalogue of Scientific Literature.

The general report reviews the affairs of the Institution proper, with brief paragraphs relating to the several branches, while the appendix presents detailed reports by those in direct charge of the work. Independently of the present report, the operations of the National Museum and the Bureau of American Ethnology are fully treated of in separate volumes.

THE SMITHSONIAN INSTITUTION.

THE ESTABLISHMENT.

The Smithsonian Institution was created an establishment by act of Congress approved August 10, 1846. Its statutory members are the President of the United States, the Vice President, the Chief Justice, and the heads of the executive departments.

THE BOARD OF REGENTS.

The Board of Regents consists of the Vice President and the Chief Justice of the United States as ex officio members, three Members of the Senate, three Members of the House of Representatives, and six citizens, "two of whom shall be resident in the city of Washington, and the other four shall be inhabitants of some State, but no two of them of the same State."

On July 4, 1910, Chief Justice Fuller died and was succeeded on December 19 by Chief Justice Edward Douglass White as ex officio member of the board.

At a meeting of the Board of Regents on December 8, 1910, the Hon. James S. Sherman, Vice President of the United States, was elected Chancellor.

The personnel of the board has been further changed by the resignation of Hon. John B. Henderson and the appointment of John B. Henderson, jr., as a Regent.

GENERAL CONSIDERATIONS.

The Smithsonian Institution has had a powerful influence for more than 60 years in the development of science in the United States. Its achievements in many lines of research and exploration have been of great good in the promotion of the welfare of the human race. The Institution and its branches continue to be engaged in a wide range of activities, covering practically the entire field of natural and physical science, as well as anthropological and archeological researches.

In my last report I referred to the establishment of a trust fund, through the generosity of Mrs. E. H. Harriman, which yields an annual income of $12,000, to be devoted to the definite purpose of carrying on scientific studies, particularly of American mammals and other animals, the donor specifying Dr. C. Hart Merriam as the investigator to carry on the work during his lifetime. I believe it desirable to establish a number of such research associateships, whereby especially capable men in other branches of science may be afforded opportunities for research work without the care and burden of administrative duties, and with full assurance that as long as their work is properly conducted it will be continued and that provision will be made for them when incapacitated for active service. The field for scientific investigation is extensive, and there are numbers of worthy projects that can not now be undertaken because of lack of means—projects that could not properly be carried on through Government appropriation, but which the Smithsonian Institution could readily undertake were the means available.

Friends of the Institution have from time to time generously provided funds for carrying on important explorations and researches, as in the case of the Smithsonian African expedition, and more recently by largely supporting the Smithsonian biological survey of the Panama Canal Zone.

It seems proper that I should here call special attention to the motive which led the late George W. Poore, of Lowell, Massachusetts, who died December 17, 1910, to make the Smithsonian Institution his residual legatee. By the terms of the will the estate, esti-

mated to be about $40,000, is bequeathed under the condition that the income from this sum should be added to the principal until a total of $250,000 should have been reached, and that then the income only should be used for the purposes for which the Institution was created. The fund will be known as the Lucy T. and George W. Poore fund. The closing words of this item of the will read as follows:

> I make this gift not so much because of its amount as because I hope it will prove an example for other Americans to follow, by supporting and encouraging so wise and beneficent an institution as I believe the Smithsonian Institute to be, and yet it has been neglected and overlooked by American citizens.

ADMINISTRATION.

On account of the large increase in the administrative work of the Institution and its branches, brought about by the natural growth of their activities and the addition of new interests, it appeared advisable to appoint an additional Assistant Secretary, to have immediate charge of the Library and International Exchanges. With the approval of the Regents, I appointed to that position Dr. Frederick William True, who entered the service of the Institution in 1878 and for several years had been head curator of biology in the United States National Museum. Dr. True entered upon the active duties of his office on June 1, 1911.

FINANCES.

The permanent fund of the Institution and the sources from which it was derived are as follows:

Deposited in the Treasury of the United States.

Bequest of Smithson, 1846		$515,169.00
Residuary legacy of Smithson, 1867		26,210.63
Deposit from savings of income, 1867		108,620.37
Bequest of James Hamilton, 1875	$1,000.00	
Accumulated interest on Hamilton fund, 1895	1,000.00	
		2,000.00
Bequest of Simeon Habel, 1880		500.00
Deposit from proceeds of sale of bonds, 1881		51,500.00
Gift of Thomas G. Hodgkins, 1891		200,000.00
Part of residuary legacy of Thomas G. Hodgkins, 1894		8,000.00
Deposit from savings of income, 1903		25,000.00
Residuary legacy of Thomas G. Hodgkins		7,918.69
Total amount of fund in the United States Treasury		944,918.69
Registered and guaranteed bonds of the West Shore R. R. Co. (par value), part of legacy of Thomas G. Hodgkins		42,000.00
Total permanent fund		986,918.69

In addition to the above, there are four pieces of real estate bequeathed to the Institution by the late R. S. Avery, some of which yield a nominal rental and all are free from taxation.

That part of the fund deposited in the Treasury of the United States bears interest at 6 per cent per annum, under the provisions of the act organizing the Institution and an act of Congress approved March 12, 1894. The rate of interest on the West Shore Railroad bonds is 4 per cent per annum.

The income of the Institution during the year, amounting to $83,435.30, was derived as follows: Interest on the permanent foundation, $58,375.12; contributions from various sources for specific purposes, $14,518.43; and from other miscellaneous sources, $10,541.75; all of which was deposited in the Treasury of the United States to the credit of the current account of the Institution.

With the balance of $35,364.88 on July 1, 1910, the total resources for the fiscal year amounted to $118,800.18. The disbursements, which are given in detail in the annual report of the executive committee, amounted to $86,374.52, leaving a balance of $32,425.66 on deposit June 30, 1911, in the United States Treasury.

The Institution was charged by Congress with the disbursement of the following appropriations for the year ending June 30, 1911:

International exchanges	$32,000
American Ethnology	42,000
Astrophysical Observatory	13,000
National Museum:	
Furniture and fixtures	125,000
Heating and lighting	50,000
Preservation of collections	300,000
Books	2,000
Postage	500
Building repairs	15,000
Building	77,000
National Zoological Park	115,000
International Catalogue of Scientific Literature	7,500
Elevators, Smithsonian Building	10,000
Total	789,000

EXPLORATIONS AND RESEARCHES.

Various scientific explorations and researches have been carried on during the past year by the Institution as far as its limited income and the generosity of its friends would permit. There have also been important biological, ethnological, and astrophysical researches by the National Museum, the Bureau of American Ethnology, and the Astrophysical Observatory, respectively, which are discussed elsewhere in this report.

STUDIES IN CAMBRIAN GEOLOGY AND PALEONTOLOGY.

During the field season of 1910 I continued the study of the Cambrian strata of the section of the Rocky Mountains adjacent to the main line of the Canadian Pacific Railway, special attention being given to the Stephen formation. The outcrop of this formation was carefully examined for many miles along the mountain sides, with the hope of finding a locality where conditions had been favorable for the preservation of the life of the epoch. The famous trilobite locality on the slope of Mount Stephen above Field had long been known and many species of fossils collected from it, but even there the conditions had not been favorable for the presence and preservation of examples of much of the life that, from what was known of older faunas and the advanced stage of development of the Upper Cambrian fauna, must have existed in the Middle Cambrian seas. The finding, during the season of 1909, of a block of fossiliferous siliceous shale that had been brought down by a snowslide on the slope between Mount Field and Mount Wapta led us to make a thorough examination of the section above in 1910. Every layer of limestone and shale above was examined, until we finally located the fossil-bearing band. After that for 30 days we quarried the shale, slid it down the mountain side in blocks to a trail, and transported it to camp on pack horses, where the shale was split, trimmed, and packed and then taken down to the railway station at Field, 3,000 feet below.

A number of sections of the Cambrian rocks were studied and measured in the mountains north and south of Laggan, Alberta, and many beautiful panoramic photographs secured.

BIOLOGICAL SURVEY OF THE PANAMA CANAL ZONE.

At the date of my last annual report the Institution contemplated an exhaustive biological survey of the Panama Canal Zone, and it was then hoped that definite plans would soon be completed and the survey undertaken within a few months. I am glad now to report that chiefly through the generosity of friends of the Institution the necessary funds for carrying on the work became available. With the cooperation of several of the executive departments, and of the Field Museum of Natural History, a party of about 10 naturalists was accordingly sent to the zone, and the results so far accomplished have been very satisfactory. Large collections of biological material have been received, including specimens of a considerable number of genera and species new to science.

Much interest is manifest in the survey both here and in the zone. The Republic of Panama was so impressed with the importance of the work that it invited the Institution to extend the survey within

the bounds of that country, which was done with gratifying results as far as the limited means and time permitted.

As stated in my last report, it seemed to be highly important to science that such a survey of the Canal Zone be made, for, although it was known in a general way that a certain number of species of animals and plants in the fresh-water streams on the Atlantic side of the Isthmus were different from those on the Pacific side, no definite knowledge of the extent of these differences had been acquired. It also seemed important to determine exactly the geographical distribution of the various organisms inhabiting the Isthmus, which is one of the routes by which the animals and plants of South America have entered North America and vice versa. When the Panama Canal is completed the organisms of the various watersheds will be offered a ready means of mingling together, the natural distinctions as regards distribution now existing will be obliterated, and the data for a true understanding of the fauna and flora will be placed forever out of reach. Moreover, a great fresh-water lake will be created by the construction of the Gatun Dam, and the majority of the animals and plants inhabiting that locality will be driven away or drowned, and quite possibly some species may be exterminated before they become known to science.

BIOLOGICAL EXPEDITION IN CANADA.

Through the courtesy of the Canadian Government and of Dr. A. O. Wheeler, president of the Alpine Club of Canada, the Smithsonian Institution was enabled to send a small party of naturalists to accompany Dr. Wheeler on his topographical survey of the British Columbia and Alberta boundary line and the Mount Robson region. The party started in June, 1911.

The region to be surveyed includes a most rugged and broken country in the midst of the Canadian Rockies, abounding in a great variety of animals and plants, and it is expected that the expedition will result in a large and valuable collection of birds, mammals, insects, and plants to be added to the National Museum series.

RAINEY EXPEDITION IN AFRICA.

Mr. Paul J. Rainey, of New York City, having planned a hunting and collecting trip of several months' duration in Africa, offered to present to the Institution the natural history material obtained during the trip if there could be sent with him some person skilled in the preparation of specimens. Mr. Rainey generously offered to bear all the expenses of the trip. The route of travel was to be north of that of the recent Smithsonian African expedition, through the country lying between the northern portion of British East Africa and the southern part of Abyssinia. Mr. Edmund Heller, who was

one of the field naturalists of the Smithsonian African expedition under the direction of Col. Roosevelt, was accordingly detailed to accompany Mr. Rainey, and letters have been received indicating very successful results.

BIRD STUDIES IN THE ALEUTIAN ISLANDS AND BERING SEA.

A small party of naturalists made a brief visit to the Aleutian Islands and Bering Sea during the season of 1911, chiefly in the interest of the Smithsonian Institution and the Biological Survey of the Department of Agriculture, especially for a study of land and marine birds. Through the cooperation of the Treasury Department the party was afforded transportation on the revenue cutter *Tahoma*.

The principal results of the visit were the collection of a good series of all the land birds of the islands visited, including a particularly fine series of ptarmigan, and a large number of eggs, and the securing of some interesting observations on the distribution and habits of the birds of that region. These observations will be made use of by Mr. A. C. Bent, who has undertaken to complete the work on the life histories of North American birds, two volumes of which, by the late Maj. Charles Bendire, have been published by the National Museum and the Smithsonian Institution.

ANTHROPOLOGICAL RESEARCHES IN PERU.

During the summer of 1910 Dr. Aleš Hrdlička, of the National Museum, visited the great ruins of the temples and city of Pachacamac, about 18 miles south of Lima, and also the ruins and cemeteries in the district of Trujillo, Peru, where he collected upward of 3,400 crania and a quantity of other skeletal parts. A large percentage of the gathered skulls are free from artificial deformation and therefore afford a much better opportunity than previous collections for a critical study of the peoples who centuries ago occupied and congregated in these regions.

Pachacamac was a religious center, much like the Egyptian Thebes and the Mohammedan Mecca, to which pilgrims flocked from all parts of Peru. After the destruction of the Temple of the Sun by the Spaniards, the place became a desolate pile of ruins, with from 60,000 to 80,000 graves of pilgrims who had come from widely separated regions. The Valley of Chicama, near Trujillo, with the neighboring country, was the seat of the powerful people known after one of their chiefs as Chimu.

As to the importance of the material collected, Dr. Hrdlička remarks:

Peru may well be regarded, even in its present territorial restrictions, as the main key to the anthropology of South America. Due to the numbers of its ancient inhabitants, and to their far-reaching social differentiations, indi-

cating long occupancy, a good knowledge of the people of Peru from the earliest times is very desirable, and would constitute a solid basis from which it would be relatively easy to extend anthropological comparison to all the rest of the native peoples of the southern continent. Such anthropological comparisons will be greatly facilitated by the collections acquired on this expedition.

Some of the interesting results of his work are described by Dr. Hrdlička in a pamphlet recently published by the Institution.

RESEARCHES UNDER THE HODGKINS FUND.

With a view to aiding in the establishment of an international scale for the measurement of solar radiation, as mentioned in my last report, a limited grant from the Hodgkins fund has been approved for the construction, in the Smithsonian workshops, of several silver disk pyrheliometers, after the design of Mr. C. G. Abbot, Director of the Smithsonian Astrophysical Observatory.

The International Solar Union has for some time been interested in the establishment of an international standard scale of radiation, and pyrheliometers of varying types have been in use at different observatories. The desire, however, for still another simple but accurate instrument seemed general, and the Institution has been gratified to learn that, by the use of the Abbot pyrheliometer, a more exact knowledge of solar radiation and the influence of the terrestrial atmosphere upon it have been promoted.

Arrangements have been made whereby the Abbot pyrheliometer is now in use in widely separated localities. There is one in the astronomical observatory established by Harvard College at Arequipa, Peru; another in the observatory at Teneriffe; and two have been sent to the minister of agriculture in Buenos Aires for meteorological stations in Argentina. The Department of Agriculture, the Bureau of Standards, and the United States Weather Bureau in Washington are supplied with the instruments; Prof. Chistoni, of the Royal University of Naples, has installed one there, and the Imperial College of Science and Technology at South Kensington, London, has secured one. Prof. Violle, of the National Observatory of Arts and Crafts, Paris, was among the first to install one of the Abbot instruments, and one has been sent to Dr. Hellmann, director of the Royal Prussian Meteorological Institute, Berlin. The University of Toronto, Canada, the University of Wisconsin, and the Central Physical Observatory of St. Petersburg also have them, and inquiries from other institutions as to the mode of securing them are frequent, so that the establishment of the desired international standard of estimating and recording the variations of solar radiation seems to have been already aided by the use of uniform instruments in many widely separated localities.

The distinguished specialists who form the committee on award for the examination of the memoirs submitted in the Hodgkins prize competition, announced in connection with the Congress on Tuberculosis of 1908, have not yet submitted their decision. This delay is regretted by the Institution as sincerely as by the competitors, but has seemed to be unavoidable as the large number of papers presented and their technical character make it very difficult to render a prompt decision.

Then, too, it is to be remembered that, according to the terms of the competition, the successful paper is to embody an original theory or discovery for the treatment of tuberculosis, not before published, a difficult task at a time when the attention of the medical world is so generally directed to the same subject.

The Langley Memoir on Mechanical Flight, the publication of which by the Hodgkins fund of the Institution was unfortunately delayed by causes beyond the control of the Institution, was completed just at the close of the fiscal year, as mentioned on another page.

SMITHSONIAN TABLE AT NAPLES ZOOLOGICAL STATION.

The Smithsonian Institution for 18 years past has maintained a table for the use of American biologists at the Naples Zoological Station. Exceptional opportunities are there afforded for the study of marine life, and it is believed that the cause of biological science has been thereby much advanced.

The application of Dr. R. S. Williams, of Miami University, mentioned in the Secretary's Report for 1910, was approved for March and April, 1911. Dr. Williams was chiefly occupied at Naples in ascertaining the rate of growth of recent encrusting organisms, especially bryozoans, with a view to the use of this information in researches on the Richmond division of the Ordovician period. The results thus far obtained by him he considers preliminary, and he proposes to continue the same research at some future time on a float anchored in the open sea.

In addition to his work on the bryozoan fauna, Dr. Williams secured a representative collection of the jaw apparatus of the free-swimming annelids belonging to the Eunicidea and the Glyceridea.

The appointment of Dr. Sergius Morgulis, a Parker Traveling Fellow from Harvard for 1911, was approved for the Smithsonian seat at Naples for the months of May, June, and July of this year.

Dr. C. W. Hargitt, of Syracuse University, a Smithsonian appointee at Naples for three months in 1903, was accorded a second occupancy during the present year. Several papers, among which

may be mentioned "The Hydromedusae of the Bay of Naples" and "Regeneration in Rhizostoma pulmo," were published by Dr. Hargitt as a result of his former appointment, and a report of his work during the present year is now in hand. He mentions with appreciation the cordial welcome accorded him by the director and staff of the laboratory, and the generosity with which the facilities for his work were provided.

Two papers embodying the results of Dr. Hargitt's recent investigations have been completed since his term at Naples, and are now in course of publication in the Journal of Experimental Zoology.

The application of Dr. Ch. Zeleny, associate professor of zoology in the University of Illinois, was approved for one month's occupancy, to cover part of June and July, 1911. No summary of the work accomplished during this period has yet been received from Dr. Zeleny.

When the same period is selected by more than one student the earliest application is considered first, the approval of the later ones becoming necessarily dependent on the ability of the station to provide for more than one Smithsonian appointee at the same time. It should be added that the obliging courtesy shown in this connection to appointees of the Smithsonian Institution by the director of the station often permits appointments to the seat which would otherwise be impracticable.

The prompt and efficient aid of the advisory committee in examining and reporting on applications for the table is still, as it has always been, of great service to the Institution and is very thoroughly appreciated.

PUBLICATIONS.

The Smithsonian Institution and its branches distributed during the past year nearly 200,000 copies of their various publications. These were sent chiefly to libraries and learned institutions throughout the world and to a limited list of specialists in the subjects discussed. It would be impracticable, without a very great increase in the size of the editions, to meet the popular demand for copies of Smithsonian publications. In the case, however, of the publications issued by the Government bureaus under direction of the Institution, which are printed under congressional appropriations, the law provides that they may be purchased by all who desire them at a slight advance over the cost of printing by application to the Superintendent of Documents.

It is through its publications that the Smithsonian Institution performs one of its principal functions—the diffusion of knowledge. Two series of works are issued by the Institution proper at the expense of the Smithsonian funds, namely, Smithsonian Contributions

to Knowledge, in quarto, and Smithsonian Miscellaneous Collections, in octavo form. The editions of these series are necessarily limited in number for distribution almost entirely to a carefully selected list of libraries throughout the world, where they may be readily consulted by students and investigators. There is also issued, at the cost of Government appropriations, an annual report, in the general appendix of which is included a considerable number of papers, either original or selected from more or less inaccessible sources, reviewing the progress and present condition of the natural and physical sciences and other branches of human knowledge. Although the edition of the report is considerable, yet the supply is each year exhausted within a very short time after its publication.

Contributions to Knowledge.—The Langley Memoir on Mechanical Flight, referred to in my last report, had been put to press and was nearly ready for distribution at the close of the fiscal year. This work forms a quarto volume of over 300 pages and a hundred plates. The memoir was in preparation at the time of Mr. Langley's death in 1906 and part of it had been written by him, bringing the work down to May, 1896, the date of his demonstration that a machine heavier than air could be made to fly under its own power. The account of later experiments, from 1897 to 1903, was written by Mr. Charles M. Manly, who became Mr. Langley's chief assistant in 1898.

Miscellaneous Collections.—Twenty papers on various subjects have been added to the series of Smithsonian Miscellaneous Collections, including descriptions of a number of new species of animals obtained by the Smithsonian African expedition and the biological survey of the Panama Canal Zone, and several papers, mentioned elsewhere, giving some results of my studies and field work in Cambrian geology and paleontology, besides an interesting paper by Dr. Hrdlička on his anthropological investigations in Peru.

Smithsonian Tables.—In connection with the system of meteorological observations established by the Smithsonian Institution about 1850, a series of meteorological tables was compiled by Dr. Arnold Guyot at the request of Secretary Henry, and the first edition was published in 1852. Though primarily designed for meteorological observers reporting to the Smithsonian Institution, the tables were so widely used by physicists that it seemed desirable to recast the entire work. It was decided to publish three separate sets of tables, each containing the latest knowledge in the field which it covered, but together forming a homogeneous series. The first of the new series, Meteorological Tables, was published in 1893; the second, Geographical Tables, in 1894; and the third, Physical Tables, in 1896. In 1909 another volume was added, so that the series now comprises: (*a*) Smithsonian Meteorological Tables, (*b*) Smithsonian Geographical Tables, (*c*) Smithsonian Physical Tables, and (*d*)

Smithsonian Mathematical Tables. Each of these works has been published in revised editions, with such corrections and additions as became necessary by the advance of scientific knowledge.

The years that had elapsed since the publication of the first edition of the Physical Tables in 1896 had brought such changes in the material upon which these tables must be based that it became necessary to almost wholly recast the work for the fifth revised edition, which was published during the past year. Recent data and many new tables have been added, including several mathematical tables especially computed for this work, which forms a volume of about 350 pages.

Opinions on Zoological Nomenclature.—As stated with some detail in my last report, the Institution cooperates with the International Commission on Zoological Nomenclature by providing clerical assistance for its secretary and by the publication of the commission's opinions. During the past year two pamphlets were issued containing opinions 1 to 25 and 26 to 29, covering important questions of nomenclature that had been matters of discussion among zoologists. In connection with the summary of each opinion there is printed a statement of the case and the discussion thereon by members of the commission. The rules to be followed in submitting cases for opinion[1] as laid down by the commission are as follows:

(1) The commission does not undertake to act as a bibliographic or nomenclatural bureau, but rather as an adviser in connection with the more difficult and disputed cases of nomenclature.

(2) All cases submitted should be accompanied by (*a*) a concise statement of the point at issue, (*b*) the full arguments on both sides in case a disputed point is involved, and (*c*) complete and exact bibliographic referepces to every book or article bearing on the point at issue.

The more complete the data when the case is submitted the more promptly can it be acted upon.

(3) Of necessity, cases submitted with incomplete bibliographic references can not be studied and must be returned by the commission to the sender.

(4) Cases upon which an opinion is desired may be sent to any member of the commission, but—

(5) In order that the work of the commission may be confined as much as possible to the more difficult and the disputed cases, it is urged that zoologists study the code and settle for themselves as many cases as possible.

Harriman Alaska series.—The Institution has received from Mrs. Edward H. Harriman several thousand copies of volumes descriptive of the results of the Harriman expedition to Alaska in 1899. The expedition was organized in cooperation with the Washington Academy of Sciences, but entirely at the expense of Mr. Harriman. He invited as his guests 3 artists and 25 men of science representing various branches of research. The expedition sailed from Seattle

[1] Cases should be forwarded to the secretary of the commission, Dr. Ch. Wardell Stiles, U. S. Hygienic Laboratory, Washington, D. C.

on May 30, 1899, on a special steamer, and was gone about two months, visiting the Aleutian Islands, the Pribilof Islands, and the Eskimo settlements on the Asiatic and American shores. The journey was extended through Bering Strait and return, and covered 9,000 miles. Large and important collections were made of mammals, birds, insects, marine animals, fossil shells, and fossil plants. Studies were also made of the great glaciers and of the geological formations of the regions visited. The contents of the volumes received by the Institution are enumerated by the editor in the appendix to the present report. The series consists of 11 volumes, printed and illustrated in the best manner. These books, now known as the Harriman Alaska Series of the Smithsonian Institution, have been distributed, under special Smithsonian title pages, to a selected list of libraries throughout the world, the few copies of certain volumes remaining after such a distribution being held for sale in accordance with the terms of the agreement.

Museum publications.—The National Museum published its annual report, two volumes of proceedings and several bulletins, covering the usual wide range of subjects, but chiefly pertaining to zoology and botany.

Ethnological publications.—The Bureau of American Ethnology issued several bulletins, including part 2 of the Handbook of American Indians North of Mexico; part 1 of the Handbook of American Indian Languages; Antiquities of Central and Southeastern Mississippi Valley; Antiquities of the Mesa Verde National Park, and bulletins on other ethnological subjects.

Publications of historical and patriotic societies.—Annual reports of the American Historical Association and the National Society of the Daughters of the American Revolution were as usual communicated to Congress in accordance with law.

Advisory committee on printing and publication.—The committee on printing and publication has continued to examine manuscripts proposed for publication by the branches of the Institution, and has considered various questions concerning public printing and binding. Twenty-four meetings of the committee were held during the year and 115 manuscripts were passed upon. The personnel of the committee is as follows: Dr. Frederick W. True, Assistant Secretary of the Smithsonian Institution, chairman; Mr. C. G. Abbot, Director of the Astrophysical Observatory; Mr. W. I. Adams, disbursing officer of the Smithsonian Institution; Dr. Frank Baker, superintendent of the National Zoological Park; Mr. A. Howard Clark, editor of the Smithsonian Institution; Mr. F. W. Hodge, ethnologist in charge of the Bureau of American Ethnology; Dr. George P. Merrill, head curator of geology, United States National Museum;

and Dr. Leonhard Stejneger, head curator of biology, United States National Museum.

Allotments for printing.—The allotments to the Institution and its branches, under the head of "Public printing and binding," during the past fiscal year, aggregating $72,700, were, as far as practicable, expended prior to June 30. The allotments for the year ending June 30, 1912, aggregating $72,900, are as follows:

For the Smithsonian Institution, for printing and binding annual reports of the Board of Regents, with general appendixes	$10,000
For the annual reports of the National Museum, with general appendixes, and for printing labels and blanks, and for the bulletins and proceedings of the National Museum, the editions of which shall not exceed 4,000 copies, and binding, in half turkey or material not more expensive, scientific books and pamphlets presented to or acquired by the National Museum library	34,000
For the annual reports and bulletins of the Bureau of American Ethnology and for miscellaneous printing and binding for the bureau	21,000
For miscellaneous printing and binding:	
International exchanges	200
International Catalogue of Scientific Literature	100
National Zoological Park	200
Astrophysical Observatory	400
For the annual report of the American Historical Association	7,000
Total	72,900

LIBRARY.

The libraries of the Smithsonian Institution and of its several branches show an increase of about 18,000 volumes and pamphlets during the last year, being largely additions to the National Museum library and the Smithsonian deposit in the Library of Congress.

During the last five years improved methods and consolidation of work have been adopted in the interest of economy and efficiency, as discussed by the Assistant Secretary in the appendix to this report.

The library of the Bureau of Ethnology has been transferred from its former quarters in a rented building to the galleries of the main hall in the Smithsonian Building where it is much more convenient for reference, though the books are still arranged on temporary wooden shelves. It is hoped that this hall, which was originally planned for library purposes, may in the near future become available for such use. It is proposed, if necessary funds become available, to remove the wooden galleries, stairways, window sashes and frames, and book cases in this hall and substitute fireproof bookstacks, stairways, and windows. The new stacks and cases would accommodate the books belonging to the several bureaus under the direction of the Institution, including a part of the library of the National Museum, which should be kept in a central location. They would also provide a safe place to assemble the

Smithsonian books constantly used by the bureaus, of which several thousand are now scattered through various rooms in the Smithsonian Building.

LANGLEY MEMORIAL TABLET.

The memorial tablet authorized by the Regents to be erected in the Smithsonian building commemorative of the aeronautical work of the late Secretary Langley has not yet been completed. A design for the tablet has, however, been prepared and is under consideration by the committee appointed for the purpose.

INTERNATIONAL CONGRESSES AND CELEBRATIONS.

The Institution each year receives invitations to numerous scientific congresses and celebrations in the United States and abroad, but as funds are not available for the expenses of delegates few of these invitations can be accepted. In some instances, however, it is possible to arrange for representation by collaborators of the Institution who are visiting the localities on official or private business.

Congress of Americanists.—Dr. Aleš Hrdlička was appointed representative of the Smithsonian Institution and the National Museum and delegate on the part of the United States at the second session of the Seventeenth International Congress of Americanists, held in the Museo Nacional, Mexico City, September 8 to 14, 1910. He presented an account of his recent explorations in Peru, and also described the uncovering of an especially interesting sepulchre which he had been invited by the Mexican authorities to open in the ancient ruins of San Juan Teotihuacan.

The meeting was held in the Museo Nacional, and was well attended, especially by scientific men from the United States.

Dr. C. W. Currier, of Washington, was also designated delegate of the United States and a representative of the Smithsonian Institution at the above congress.

International American Scientific Congress.—Mr. Bailey Willis, as delegate on the part of the Smithsonian Institution, attended the International Scientific Congress which was held at Buenos Aires, Argentina, July 10 to July 25, 1910.

Geological Congress.—In August, 1910, the Eleventh International Geological Congress met in Stockholm. Dr. George F. Becker, of the United States Geological Survey, was a delegate on the part of the Smithsonian Institution. The congress was more largely attended than any of its predecessors, and nothing could exceed the hospitality of its reception. The principal subjects of discussion were the distribution and extent of the iron ore deposits of the world, Cambrian paleontology, and the change of climate since the last maximum of glaciation. To all of these subjects painstaking

contributions were made from every quarter of the globe, and the publications of the congress contain the most authoritative exposition of the present state of knowledge on these vital questions. Among the papers presented to the congress was one expressing my view on "the abrupt appearance of the Cambrian fauna."

Zoological Congress.—The Seventh International Zoological Congress was held at Graz, Austria, in August, 1910. The delegates on the part of the United States and the Smithsonian Institution and National Museum were Dr. H. H. Field, Dr. W. R. Kellicott, Dr. Ch. Wardell Stiles, and Mr. Austin H. Clark. About 600 members were present at this congress, of whom about 60 were from the United States, the majority of these representing scientific societies or educational institutions. To facilitate its labors, the congress was divided into sections, each section representing a definite subject or group of subjects. Papers of general interest were read in the Stephaniensalle, a large hall in the center of the city, while papers of more restricted scope were presented in the various lecture rooms of the university. Taken as a whole, the papers read were of a distinctly progressive nature, the authors, especially the younger ones, showing a marked disposition to depart from the time-honored and accepted lines of work and thought, and to approach their subjects from entirely new view points.

Congress of Bibliography and Documentation.—Mr. Paul Brockett, assistant librarian of the Institution, who was appointed a delegate to the International Congress of Bibliography and Documentation at Brussels, August 25 to 27, 1910, attended the congress and submitted a report on its proceedings, which is printed in the appendix.

Congress of Archivists and Librarians.—An International Congress of Archivists and Librarians was held at Brussels August 29 to 31, 1910, when the Institution was represented by Mr. Paul Brockett, whose report appears in the accompanying appendix.

MISCELLANEOUS.

Hambach collection of fossils.—The Institution has secured from Dr. Gustav Hambach, of St. Louis, a collection of about 20,000 specimens of fossil echinoderms and other animals, with more than 100 types. Almost all the fossils were collected in the Mississippi Valley and are the choicest obtainable. The series of Blastoids, a group of fossil echinoderms, is unique. The collection contains representatives of the various classes of animals, among which may be mentioned many insects from the Cenozoic formation in Colorado; many specimens of Paleozoic fishes, including an especially interesting series of teeth and spines; a complete series of fossil sea-urchins; the jaws of a Carboniferous batrachian over a foot long, and of a mastodon.

Chinese photographs.—The Institution has received a valuable series of large photographic negatives taken by Mr. Bailey Willis in connection with his geological work in China. These photographs represent scenery, particularly landscapes in which the loess formation is conspicuous, and also Chinese buildings, monuments, and the people themselves. The route of the expedition through the Provinces of Chihli, Shansi, and Shensi led through the district of the loess formation and some remote mountain regions of great interest and scenic beauty. Copies of many of these photographs have been furnished at cost to various institutions for educational purposes.

NATIONAL MUSEUM.

The most important item of interest in connection with the National Museum during the year was the completion on June 20, 1911, of all structural work on the new building, just six years after the excavations for the foundation were commenced. On another page the Assistant Secretary in charge of the Museum mentions the very superior character of the building for museum purposes. It is massive and imposing in appearance. It is well lighted. There is little room that can not be utilized. More than one-half of the 10 acres of floor space is placed at the service of the public in the interest of popular education, while the remaining space is used for reserve collections and laboratories of the scientific departments and divisions and for the maintenance of the building and the operation of the heating, lighting, and ventilating plant. The greater part of the natural-history collections, including ethnology, have been removed to the new structure; while in the old building space is now afforded for the proper display of objects pertaining to the arts and industries, including the collection illustrating the graphic arts and the art textiles, and also for the large and interesting series illustrative of American history. Although there has as yet been no formal dedication of the new building, the exhibition halls are being opened to the public one after another as the reinstallation of the exhibits progresses. It is planned in the near future to admit visitors to the new building, for a portion of the day at least, on Sundays in order that the people of Washington may be afforded a long-desired opportunity to study the national collections in their leisure hours.

The number of visitors to the new building during the year was 151,112 and to the old building 207,010.

The auditorium in the new building has been utilized for meetings of various scientific bodies and important lectures. The First American International Humane Congress was held there from October 10 to 15, 1910, and in connection therewith an interesting exhibit was displayed.

The accessions received by the Museum during the year include more than 200,000 specimens of animals and plants, besides 6,600 specimens relating to geology and paleontology, and about 17,000 anthropological objects. To the National Gallery of Art were added 94 paintings and engravings. In addition, about 1,600 objects of art and anthropology were accepted by the Museum as loans for exhibition. Among important accessions that merit special mention was a collection of 3,400 ancient crania, 6,000 bones, and 1,500 archeological objects, gathered chiefly in Peru by Dr. Hrdlička, as mentioned on another page. Other interesting archeological objects were received from the ancient pueblos of Arizona and New Mexico, besides a valuable series of skulls and skeletons from Arkansas and Mississippi. About 50,000 specimens of mollusks, collected in Alaska by Dr. William H. Dall between the years 1871 and 1899, were received during the year, together with many thousands of Japanese mollusks from the Imperial University of Japan.

Many other interesting accessions of objects of zoology, botany, geology, and anthropology are referred to by the Assistant Secretary in his report.

The paintings of the National Gallery of Art, exhibited in the middle hall of the new building, continue to attract much public attention. Mr. William T. Evans has added 13 canvases to his notable gift, which now comprises 127 pictures, representing 90 contemporary American painters.

Mr. Charles L. Freer has also added a large number of objects of oriental art to his most important gift to the Nation, the entire collection remaining, however, in his keeping at Detroit, Mich.

The great exhibition halls of the new building will afford opportunity for the proper display of the national collections illustrative of natural history, and especially such large and striking objects as groups of mammals, skeletons of fossil vertebrate animals, and groups representing the habits and customs of the races of mankind. The collections pertaining to the ethnology of America had increased year by year so rapidly in extent that they long ago outgrew the space that could be allotted to them in the old building. In the new structure they are installed with adequate regard to their size and importance.

The loan collection of laces and other art textiles has been largely increased numerically and in variety of contents under the able supervision of Mrs. James W. Pinchot, who initiated the movement.

The Museum has continued the distribution of collections of duplicate specimens to schools and colleges throughout the country. About 3,000 specimens, chiefly recent and fossil animals, were thus distributed during the year, and about 23,500 duplicate specimens were used in making exchanges.

Considerable progress has been made in arranging the large quantities of natural-history specimens collected by the Smithsonian African expedition and the Smithsonian biological survey of the Panama Canal Zone. Some of the African mammals of greatest public interest have been mounted in groups.

BUREAU OF AMERICAN ETHNOLOGY.

The Bureau of American Ethnology has been engaged for a number of years in scientific studies of the American aborigines, including their arts and industries, government, religious and sociological systems, and languages, as well as their mental and physical characteristics, their history, and antiquities. Much has been accomplished in this direction, and many of the results have been permanently recorded and disseminated by means of publication; but a large body of material still awaits final study and arrangement, and much work remains to be done both in the field and in the office.

The investigations of the bureau have, however, reached a stage at which it has been found possible to summarize some of the results in the form of handbooks, designed especially for the use of schools and unprofessional students. The demand for those already issued, or about to be published, is very large. Many changes are taking place among the Indians, owing to their advance in civilization, and for that reason the researches are being pressed with all possible speed while knowledge of primitive conditions is still available. The Indians form one of the great races of mankind, and the world properly looks to our Government to gather and record accurate knowledge of this branch of the human family, while by many the work of the Bureau of American Ethnology is regarded as the basis of American history.

One of the immediate demands upon the bureau is vigorous activity in the exploration and preservation of antiquities, especially in Arizona, Colorado, and New Mexico, before these important and most interesting ruins are entirely destroyed by vandalism or the elements.

Another important work that should speedily be undertaken is an ethnological study of the Indians and Eskimo of Alaska before the advent of greater numbers of white people shall have so modified them as to destroy their primitive character. So also there is need of further activity in the study of the few survivors of Indian tribes in the Middle West.

The bureau has conducted various lines of field work among the tribes which composed the Creek Confederacy of the Southern States; the Tewa Indians of the Rio Grande Valley, New Mexico;

the Winnebago Indians of Wisconsin and Nebraska; the Piegan, Blackfeet, Cheyenne, and Menominee Indians of the Algonquian family; the Chippewa Indians, especially with reference to their music; the Osage Indians, now in Oklahoma, and the Iroquois in New York.

A study of the past and present population of the Indians, with the various causes of their decrease is being conducted.

Some very interesting studies were made in Cuba, indicating that the western end of the island, including the Isle of Pines, was once inhabited by a cave-dwelling people of low culture and without agriculture. It is believed that these people were in that condition at the time of the visit of Columbus, and that they were the survivors of a cave-dwelling population once occupying all of Cuba and represented in Porto Rico and elsewhere in the West Indies.

The Smithsonian Institution, through its Bureau of American Ethnology in cooperation with the Archæological Institute of America, has carried on excavations in prehistoric cliff dwellings and pueblo ruins in New Mexico. In one locality these dwellings extend along the walls of a canyon for about 2 miles. In cooperation with the Colorado Cliff Dwellers' Association, the Institution excavated and repaired the celebrated Balcony House in Colorado. Excavations have also been made in newly discovered cliff dwellings and other archeological remains in northwestern Arizona.

INTERNATIONAL EXCHANGES.

An idea of the magnitude of the work conducted by this branch of the Institution may be obtained from the statement that 228,698 packages were handled during the year, an increase over the number for the preceding 12 months of 7,073. The weight of these packages was 560,808 pounds, a gain of 76,124 pounds.

The total available resources for carrying on this work were $36,954.99, $32,200 of which was appropriated by Congress, and $4,754.99 was derived from the exchange repayments to the Institution.

Several changes made during the year in the routine of the Exchange Office have resulted in a more economical and efficient administration of the service.

It was stated in the last report that the German authorities had under consideration the founding in Berlin of an establishment to promote cultural relations between Germany and the United States, and that one of its functions would be to conduct on behalf of Germany the international exchange of publications which the Smithsonian Institution carries on for the United States. This establishment, which is known as the Amerika-Institut, was organized in the fall of 1910 and the exchange duties were assumed by it on January

1, 1911. The exchange agency maintained by the Smithsonian Institution in Leipzig was discontinued on the latter date.

Packages for Luxemburg and Roumania have heretofore been distributed through the Leipzig agency. Since its discontinuance the Amerika-Institut has been good enough to assume charge of the distribution of packages in Luxemburg, and the Academia Romana at Bucharest has been asked to act as the Roumanian exchange intermediary.

The Japanese Government has transferred the exchange agency of that country from the Department of Foreign Affairs to the Imperial Library at Tokyo. The regular series of United States official documents, which had been sent to the former for a number of years, has also been deposited in the Imperial Library.

The Government of the United Provinces of Agra and Oudh, Allahabad, India, has, at its request, been listed to receive a partial set of United States official publications, the total number of such depositories being now 34. The number of depositories of full sets of governmental documents remains the same as at the close of last year, namely, 55.

The Governments of the Argentine Republic, Denmark, and Great Britain have entered into the immediate exchange of their parliamentary record during the past year, 29 countries now taking part in this exchange with the United States.

Important collections of foreign publications have, through the efforts of the Exchange Office, been obtained during the past year for the Library of Congress and for several other establishments of the Government.

NATIONAL ZOOLOGICAL PARK.

The accessions to the Zoological Park during the past year were 335 animals, and the total number of animals on hand June 30, 1911, was 1,414, representing 376 species of mammals, birds, and reptiles, about 20 species being new to the park.

Among the important additions to the collections I may mention a pair of northern fur seals from Alaska, a hippopotamus, an East African buffalo, three prong-horn antelopes, a pair of reindeer, and a large Asiatic macaque monkey.

The number of visitors was 521,440, or a daily average of 1,428. As an indication of the educational value of the park, it may be mentioned that it was visited by 169 schools, classes, etc., with 4,966 pupils, an increase of about a thousand over the year preceding. While most of the classes were from the District of Columbia, some of them belonged in various parts of the country, including all the New England States, New York, Pennsylvania, and North Carolina.

The equipment of the Zoological Park, both as regards the accommodations for the collections and facilities for visitors, is still inadequate and is inferior to that of other establishments of the kind of equal importance.

Many of the animals are kept in temporary quarters that are insufficient in size, more or less insanitary, and quite costly to maintain. This is particularly true of the fine series of birds, which includes some of exceptional interest and rarity. The rough temporary building in which they are now kept is too small for the exhibition of the entire collection and the conditions are such that it is difficult to keep the birds in a good state of health. In a suitable structure the bird collection would be one of the most attractive features of the park.

Permanent paddocks are also needed for the hardy deer, wild sheep, goats, and cattle, which are now scattered in temporary inclosures, some of them altogether unsuitable.

A new bridge across Rock Creek is urgently needed to replace the present temporary log structure, and it should be of a permanent character and sufficiently wide to provide for the greatly increased travel when the valley of Rock Creek is fully developed.

The roadways and walks in the park were greatly improved at the cost of a special appropriation for that purpose. Nearly a mile of the roads were treated either by reshaping and supplying a top layer of stone or by regrading and furnishing the entire thickness of roadbed metal. About 1¾ miles of walks were also laid or repaired and steps were constructed where grades had before been too steep. A considerable amount of work was also done to provide proper drainage.

ASTROPHYSICAL OBSERVATORY.

The Astrophysical Observatory has been engaged in three principal lines of work during the year.

Observations by the spectrobolometric method were continued in order to confirm the view referred to in last year's report that the determinations of the intensity of the solar radiation outside the earth's atmosphere are independent of the observer's altitude above sea level, provided the conditions are otherwise good. Observations for the "solar constant" were accordingly taken on Mount Whitney in the summer of 1910, where opportunity was afforded also for measurements of the brightness of the sky by day and by night, the influence of the water vapor on the sun's spectrum, and the distribution of the sun's energy spectrum outside the atmosphere. The results of these observations show no discrepancy due to altitude between Mount Wilson (5,840 feet) and Mount Whitney (14,502 feet).

It also seemed important to confirm by further observation the variability of the solar constant of radiation. Observations were accordingly continued daily at Mount Wilson until November 10, 1910,

and renewed again on June 11, 1911, which tend to confirm the conclusion that the sun's output of radiation varies from day to day in a manner irregular in period and quantity. Assurance seems now complete that this latter result will be tested during the next fiscal year by long-continued daily observations taken simultaneously at two widely separated stations, where the atmosphere is believed to be specially favorable for such research. The definite determination of the laws governing the apparent variability of the "solar constant" it is expected will be of much value in the probable forecast of climatic conditions from year to year.

Measurements have also been made of the transparency, for long wave radiation, of columns of air containing known quantities of water vapor. This line of research promises highly interesting results.

As mentioned on another page, arrangements have been made with several observatories, widely separated through the world, for the use of the standard silver-disk secondary pyrheliometer designed by the director of the Smithsonian Astrophysical Observatory. It is hoped to thus secure not only uniformity of radiation measures, but also a more exact knowledge of solar radiation and the influence of the terrestrial atmosphere upon it.

INTERNATIONAL CATALOGUE OF SCIENTIFIC LITERATURE.

The International Catalogue of Scientific Literature publishes, through the cooperation of countries in all parts of the world, a current classified index to the literature of science. Seventeen volumes have been published annually, beginning with the literature of 1901. The organization consists of a central bureau in London and regional bureaus established in and supported by the 32 countries taking part in the enterprise. Supreme control of the catalogue is vested in an international convention, which met in London July, 1905, and July, 1910, and is to meet every tenth year hereafter. The second international convention met in London at the rooms of the Royal Society on July 12 and 13, 1910, and Mr. Leonard C. Gunnell, assistant in charge of the United States regional bureau, was sent by the Institution as the delegate from the United States. The convention decided that on account of the success already achieved by the International Catalogue and the great importance of the objects promoted, the enterprise would be continued. Attention was called to the urgent need of a permanent fund to aid in carrying on and extending the work. It was pointed out that although various regional bureaus for the collection of material were supported by the countries in which they were located, the maintenance of the central bureau for general administration and actual publication of the 17 annual volumes was dependent entirely on the funds derived from the sub-

scribers to the published volumes. Though every care has been used to edit and publish the work in the most economical way, the income of the central bureau has proved to be insufficient to meet current expenses and in addition pay interest on approximately $35,000 of borrowed capital.

As a more detailed report of the work of the bureau and of the proceedings of the convention will be found in the appendix to this report, it will be sufficient here to call attention to the great value and importance of the work, and to say that it would be difficult to find an enterprise more deserving of endowment. A capital fund, yielding an annual income of from $5,000 to $10,000, would enable the central bureau not only to broaden the scope of the catalogue but also to reduce the subscription price now charged for the annual volumes. This charge is $85 per year which, although not large when the amount of matter published is considered, is found to be far beyond the means of many who would otherwise be glad to avail themselves of this important aid to scientific research.

The Smithsonian Institution has a peculiar interest in the International Catalogue, for the reason that the original idea was conceived by the first Secretary of the Institution in 1855. The Royal Society through its Catalogue of Scientific Papers later partly carried out Secretary Henry's idea. Experience proved that the enterprise was too great for any one society, or, indeed, any one nation, to undertake, and the Smithsonian Institution, representing the United States, joined in the movement to make the work international.

The history of this international movement is briefly as follows:

The British foreign office in 1894, at the instance of the Royal Society, requested the United States Government, through the Department of State, to send delegates to a conference to be held in London in 1896. The matter was referred to the Smithsonian Institution, and the late Prof. Simon Newcomb and Dr. John S. Billings were sent as delegates. The second conference was held in 1898, and Dr. Cyrus Adler, librarian of the Smithsonian Institution, attended as a delegate.

In 1901, when success or failure depended on obtaining the cooperation of the United States in the enterprise, the Smithsonian Institution agreed to and did support a regional bureau from that time until 1906, when Congress made its first annual appropriation to carry on the work in this country. It will thus be seen that in each step the United States has, through the Smithsonian Institution, been prominent in the movement, and it would be a matter of much gratification if now that the enterprise has been so auspiciously started it could be further aided by an endowment fund originating in this country.

NECROLOGY.

Melville Weston Fuller.

It becomes my duty to record here the death of Chief Justice Melville Weston Fuller, Chancellor of the Smithsonian Institution, who was born at Augusta, Maine, February 11, 1833, and died at his summer home, Sorrento, Maine, July 4, 1910. For 22 years prior to his death, Chief Justice Fuller had been deeply interested in the welfare of the Institution, and only on one occasion was he absent from a meeting of the Regents during the entire period of his service as a member of the board.

During his long and useful life Justice Fuller served his country faithfully in several civil offices of trust and as Chief Justice of the Supreme Court of the United States. His achievements as a jurist were most adequately portrayed by the resolutions and eulogies pronounced in his memory at a meeting of members of the bar of the Supreme Court on December 10, 1910, and at the session of the Supreme Court on January 3, 1911.

The Board of Regents of the Smithsonian Institution expressed their sorrow in the following words of tribute adopted at the annual meeting of the board on December 8, 1910:

Whereas the Board of Regents of the Smithsonian Institution have received the sad intelligence of the death, on July 4, 1910, of Melville Weston Fuller, Chief Justice of the United States, and for twenty-two years chancellor of the Institution: Therefore be it

Resolved, That we desire here to record our profound sorrow at the severing of the tie that has bound us to him for so long a period of honored service; that we feel keenly the loss of a wise presiding officer, whose vast store of learning and gracious dignity have proved so invaluable in the deliberations of this board, and whose loyal interest in the Smithsonian Institution has been a source of inspiration to his colleagues.

Resolved, That we share in the grief of the Nation at the passing away of one who was at once a distinguished leader of the greatest legal tribunal of our land, an eminent jurist, a patriotic citizen, a shining example of Christian gentleness, and who also possessed so charming a personality as a man and as a friend.

Resolved, That we respectfully tender to the members of the family of our late associate our sincerest sympathy in their great bereavement.

Resolved, That an engrossed copy of these resolutions be transmitted to the family of the late chancellor.

Respectfully submitted,

Charles D. Walcott, *Secretary*.

APPENDIX I.

REPORT ON THE UNITED STATES NATIONAL MUSEUM.

SIR: I have the honor to submit the following report on the operations of the United States National Museum for the fiscal year ending June 30, 1911:

COMPLETION AND OCCUPATION OF THE NEW BUILDING.

It is gratifying to be able to report the completion of all structural work on the new building for the Museum on June 20, 1911, just six years after the excavations for its foundations were commenced. While the time limit originally estimated was somewhat exceeded on account of delays in the fulfillment of certain contracts, the work was purposely conducted slowly in order to insure entire stability and permanency of construction, which it is confidently believed have been secured. The building is massive and imposing in appearance, a notable addition to the group of Government structures at the Capital, and has already been proved to be admirably adapted to the purposes for which it was designed.

There is comparatively little room in the building that can not be utilized. Of the approximately 10 acres of floor space which it contains, fully one-half has been allotted to the public in the interest of popular education. The other half, after deducting the area required for the maintenance and operation of the building, is assigned to the storage of the reserve collections and to the laboratories. The occupation of the building did not await its final completion, but was begun during the summer of 1909, and has been continued as rapidly as the necessary furniture could be provided.

The work done on and in connection with the building during last year comprised the finishing of the rotunda, the south approaches, and the auditorium; the painting of the interior plastered walls and ironwork; and, under the direction of the officer in charge of public buildings and grounds, the grading and sodding of the grounds immediately surrounding the building and the construction of roads and walks leading to the several entrances.

By the close of the year essentially all of the reserve collections and all of the laboratories of the several divisions of anthropology, zoology, geology, and paleontology had been established in the new building, as had also most of the administrative offices which are to be located there. The collections had, moreover, been nearly all arranged in a manner convenient for study and reference, and in greater part had received their permanent systematic installation. Much remains to be done, however, in perfecting this arrangement and in completing the catalogues and indexes.

The exhibition collections had also been moved with the exception of the American mammals, the birds, the marine invertebrates, the osteological specimens, the fossil plants, the building stones, the gems, and a small section of ethnology. The only public installations that had been completed in the new building, besides the paintings of the National Gallery of Art, were, however, of ethnology, which occupied the sides and ends of the middle hall on the

main floor, and most of the two adjacent ranges. To these halls in greater or less part the public had been admitted from March 17, 1910, when the building was first opened. Work was actively progressing in the preparation of the exhibits for all of the other branches, the delays being due in large measure to the slow rate at which furniture was supplied, and had been well advanced for archeology, mineralogy, and the fossil vertebrates.

ADDITIONS TO THE COLLECTIONS.

The permanent acquisitions received during the year comprised approximately 228,642 specimens and objects, of which 204,540 were of animals and plants, 6,647 were geological and paleontological, 17,361 belonged to the several divisions included in the department of anthropology, and 94 were paintings and engravings presented to the National Gallery of Art. In addition, 1,629 objects of art and anthropology were accepted as loans for exhibition.

One of the most important accessions of the year resulted from an investigation in Argentina, conducted under the auspices of the Smithsonian Institution by Dr. Aleš Hrdlička, curator of physical anthropology, partly in conjunction with Mr. Bailey Willis as geologist, for the purpose of determining the nature and value of the evidence relating to man's antiquity in that country. The skeletal and archeological remains attributed to early man or his forerunners preserved in the museums were studied, the more important localities where such remains have been discovered were visited, and on the journey to and from Argentina short stops were made in Brazil, Peru, Panama, and Mexico. Some 3,400 ancient crania, 6,000 long and other bones, and 1,500 archeological objects of human manufacture composed the collection brought to Washington. A large number of prehistoric utensils, implements, ornaments, examples of weaving, etc., obtained by Dr. J. W. Fewkes during excavations in the Navaho National Monument and at the ancient Hopi pueblo of Wukoki at Black Falls, Little Colorado River, Ariz., were transferred by the Bureau of American Ethnology. Collections of a similar character, but including ancient human crania and skeletons, from the northeastern pueblo region of New Mexico, were received from the School of American Archæology of the Archæological Institute of America, at Santa Fe, and a valuable series of skulls and skeletons from Arkansas and Mississippi was presented by Mr. Clarence B. Moore.

Two interesting ethnological collections, one from Liberia the other from Abyssinia, were lent for exhibition by Mr. George W. Ellis, jr., and Mr. Hoffman Philip, respectively, and a number of specimens relating to the Indians of North America were acquired by gift and purchase.

The final shipments from the Smithsonian African expedition, which arrived in the early part of the year, contained several thousand specimens of mammals, birds, reptiles, fishes, and mollusks. The notable collection of mammals belonging to Dr. C. Hart Merriam and consisting of about 5,800 skins, 6,000 skulls, and 100 complete skeletons, was secured through the generosity of Mrs. Edward H. Harriman, of New York, by whom it was purchased and donated to the Institution. The other principal additions of mammals were from British East Africa, Abyssinia, and China; while of birds the more important contributions were from North and Central America, the Philippine Islands, and China. The United States Biological Survey and the United States Bureau of Fisheries transmitted many reptiles from various parts of the United States and Mexico, and the latter also an interesting series from the Philippines. The fishes received were mainly from explorations by the Bureau of Fisheries in the eastern part of the United States. Large numbers of

insects were deposited by the Bureau of Entomology, and important collections of hymenoptera were presented by Mr. S. A. Rohwer and Mr. P. R. Myers.

An especially noteworthy accession consisted of the collection of mollusks made in Alaska by Dr. William H. Dall while in the field for the United States Coast and Geodetic Survey, and later for the United States Geological Survey, between 1871 and 1899. It comprises about 15,000 lots and 50,000 specimens, and is undoubtedly the largest collection of the shells of moderate depths of water that has ever been assembled from that region. Another extensive contribution of mollusks, consisting of many thousands of Japanese specimens, was obtained from the Imperial University of Tokyo. Important type collections, recently described, of isopod crustaceans, medusæ, hydroids, and siphonophores, from explorations by the steamer *Albatross* in the Pacific Ocean and at the Philippine Islands, were transferred by the Bureau of Fisheries. Decapod crustaceans, representing a large number of species, were received from the Indian Museum at Calcutta; many isopods from several French explorations, including the Charcot expedition to the Antarctic Ocean, were obtained from the Muséum d'Histoire Naturelle at Paris; and an interesting series of recent crinoids was secured from the Zoological Museum at Copenhagen.

The collection of plants was increased by over 38,000 specimens, of which the largest contributions were from the biological survey of the Panama Canal Zone and the Department of Agriculture, though many specimens were obtained from the Bureau of Fisheries, and by gift and exchange. On the biological survey of the Canal Zone, which is being carried on under the auspices of the Smithsonian Institution, the Museum was represented during the year by one member of its staff, Mr. W. R. Maxon, assistant curator of plants. Mr. Maxon spent about two and one-half months in the field, working in conjunction with Mr. Henry Pittier, who is in charge of the botanical investigations, and in view of the richness of the region the exploration yielded exceedingly important results. Dr. J. N. Rose, associate curator of plants, and Dr. Paul Bartsch, assistant curator of mollusks, were members of an expedition by the Bureau of Fisheries steamer *Albatross*, which visited Guadaloupe Island, proceeded down the outer coast of Lower California and ascended the Gulf of California for a considerable distance. Valuable series of marine animals and of plants were secured, the former mostly by means of dredging, the latter during stops made along the coast.

The accessions in geology and mineralogy from the Geological Survey and other sources contained much interesting material and a number of type specimens. Especially important were several type series of Cambrian fossils described by Dr. Charles D. Walcott, and included in the noteworthy discoveries resulting from his recent explorations in British Columbia. Investigations in Kentucky and Tennessee by Dr. R. S. Bassler and Mr. Frank Springer yielded valuable collections of Silurian and Mississippian fossils. In vertebrate paleontology the more important additions consisted of mammalian and reptilian remains obtained in exchange.

An interesting series of articles of nickel produced by the late Joseph Wharton, of Philadelphia, who was recognized as the leader in the technology of this metal, was received as a donation from the executors of his estate. This collection, which had been preserved by Mr. Wharton in a cabinet at his home, comprises over 60 pieces, including pure nickel in several forms, harness and door trimmings, household utensils, forceps, magnetic needles, coinage blanks, etc., and is of much historical value.

The historical collection was greatly enriched, mainly by loans, and, by extending the exhibition space into a second hall, its installation has been much

improved. Rear Admiral R. E. Peary, United States Navy, retired, deposited the many medals conferred upon him by various geographical societies in recognition of his service to science in arctic exploration; the silver model of a ship and three loving cups presented to him; and two of the flags that he carried to the North Pole in 1909; all of which have been arranged together in a single case. Important additions to the collection of memorials of the Bailey-Myers-Mason family were received from Mrs. Julian James; valuable memorials of the Salter and Codwise families of colonial and revolutionary New York and New Jersey were lent by Miss Louise Salter Codwise; and interesting relics of the Schenck family of New Jersey dating back three generations were contributed by Dr. Clara S. Ludlow. The Gustavus Vasa Fox collection of Russian memorials was materially increased, and 11 pieces of furniture that once belonged to Gen. Rufus Putnam were received as a gift from his great-grandson, the late Judge E. M. P. Brister. An inhaler of the type used by Dr. William T. G. Morton in 1846, in the first operation which he performed with the use of ether as an anesthetic, and two busts of Dr. Morton were presented.

NATIONAL GALLERY OF ART.

The paintings of the National Gallery of Art continue to be exhibited in the large middle hall of the new building, the central part of which was specially fitted up for the purpose in 1910. While these quarters are already too restricted for the needs of the Gallery, the excellent lighting of this space makes possible an entirely satisfactory installation, which has attracted much attention.

Mr. William T. Evans, of New York, added 13 canvases to his notable collection of the works of contemporary American painters, which now comprises 127 pictures representing 90 artists. Mr. Evans also presented 81 examples of a series of 100 proofs designed to illustrate the work of the foremost American wood engravers, which he announced some time ago his intention to contribute. Mr. Charles L. Freer, whose important gift to the Nation of American and oriental art still remains in his keeping at Detroit, Mich., secured many valuable additions for his collection during an extended trip abroad, much of which was spent in China. The Gallery was fortunate in obtaining several interesting loans, including numerous examples of the paintings of early masters, and contributed to a number of important exhibitions held in other cities.

ART TEXTILES.

The loan collection of laces and other art textiles, which occupies one of the northern ranges in the older Museum building, was very largely increased both numerically and in the variety of its contents. Thirty-two loan contributions and three gifts, comprising 249 specimens, many of great beauty and value, brought the total number of specimens on exhibition up to 1,007. The supervision of the collection has been continued by Mrs. James W. Pinchot, to whose initiative and subsequent efforts, with the active cooperation of a number of ladies of Washington, the movement owes its success.

MISCELLANEOUS.

Of duplicate specimens taken from the collections, over 3,000, principally of recent animals and fossils, were distributed to schools and colleges, and about 23,500 were used in making exchanges. Approximately 24,600 specimens of various kinds were sent for study to specialists both in this country and abroad, mainly to be worked up and identified for the Museum.

The total number of visitors to the older Museum building was 207,010, to the Smithsonian building 167,085, and to the new Museum building 151,112. Considering that the buildings have been opened only during working hours on week days, this is to be regarded as a fair attendance. That it was smallest at the new building was owing to the fact that less than one-sixth of the exhibition space had been made ready for the public.

The publications issued comprised the annual report for 1910, two volumes of Proceedings, five bulletins, one volume of Contributions from the National Herbarium, and a large number of separate papers belonging to three unfinished volumes of Proceedings and two of Contributions. With the exception of the annual report, all were descriptive of material in the Museum collections. The number of copies of the various publications distributed was over 110,000.

By the addition of 6,127 books, pamphlets, and periodicals, the Museum library was increased to 40,211 volumes and 66,074 unbound publications.

The auditorium in the new building was used on several occasions for meetings of important scientific bodies. The sessions of the First American International Humane Congress, in connection with which an interesting exhibit was installed, were also held here from October 10 to 15, 1910.

The position of head curator of the department of biology, made vacant by the designation of Dr. F. W. True as an Assistant Secretary of the Institution on June 1, was filled by the appointment of Dr. Leonhard Stejneger, curator of reptiles and batrachians. For convenience of administration, the divisions of invertebrate paleontology, vertebrate paleontology, and paleobotany were combined, under the title of sections, in a single division of paleontology, with Dr. R. S. Bassler as curator.

Respectfully submitted.

RICHARD RATHBUN,
Assistant Secretary in Charge, U. S. National Museum.

DR. CHARLES D. WALCOTT,
Secretary of the Smithsonian Institution.

NOVEMBER 18, 1911.

Appendix II.

REPORT ON THE BUREAU OF AMERICAN ETHNOLOGY.

Sir: I have the honor to present the following report on the operations of the Bureau of American Ethnology during the fiscal year ending June 30, 1911, conducted in accordance with the provisions of the act of Congress approved June 25, 1910, authorizing the continuation of ethnological researches among the American Indians and the natives of Hawaii, under the direction of the Smithsonian Institution, and in accordance with the plan of operations approved by the Secretary June 15, 1910.

The systematic ethnological researches of the bureau were continued during the year with the regular scientific staff, consisting of nine ethnologists, as follows: Mr. F. W. Hodge, ethnologist in charge; Mr. James Mooney, Dr. J. Walter Fewkes, Mrs. Matilda Coxe Stevenson, Mr. J. N. B. Hewitt, Dr. John R. Swanton, Dr. Truman Michelson, Dr. Paul Radin, and Mr. Francis La Flesche. In addition the services of several specialists in their respective fields were enlisted for special work, as follows:

Dr. Franz Boas, honorary philologist, with several assistants, for research in connection with the preparation and publication of the Handbook of American Indian Languages.

Miss Alice C. Fletcher and Mr. Francis La Flesche, for the final revision of the proofs of their monograph on the Omaha Indians for publication in the twenty-seventh annual report.

Miss Frances Densmore, for researches in Indian music.

Mr. J. P. Dunn, for studies of the tribes of the Middle West.

Mr. John P. Harrington, for researches among the Mohave Indians of the Colorado Valley.

Rev. Dr. George P. Donehoo, for investigations in the history, geography, and ethnology of the tribes of Pennsylvania for incorporation in the Handbook of American Indians.

Mr. William R. Gerard, for studies of the etymology of Algonquian place and tribal names and of terms that have been incorporated in the English language for use in the same work.

Prof. H. M. Ballou, for bibliographic research in connection with the compilation of the List of Works Relating to Hawaii.

Mr. James R. Murie, for researches pertaining to the ethnology of the Pawnee Indians.

The systematic ethnological researches by members of the regular staff of the bureau may be summarized as follows:

Mr. F. W. Hodge, ethnologist in charge, in addition to conducting the administrative work of the bureau, devoted attention, with the assistance of Mrs. Frances S. Nichols, to the final revision of the remaining proofs of Part 2 of the Handbook of American Indians (Bulletin 30), which was published in January, 1911. This work met with such great popular demand that the edition of the two parts became exhausted immediately after publication, causing the bureau much embarrassment owing to the thousands of requests that it has

not been possible to supply. To meet this need in part, the Senate, on May 12, adopted a concurrent resolution authorizing the reprinting of the entire handbook, and at the close of the fiscal year the resolution was under consideration by the Committee on Printing of the House of Representatives. The Superintendent of Documents has likewise been in receipt of many orders for the work, necessitating the reprinting of part 1 some months after its appearance, and about the close of the fiscal year another reprint of this part was contemplated. Much material for incorporation in a revised edition for future publication was prepared during the year, but lack of funds necessary for the employment of special assistants prevented the prosecution of this work as fully as was desired.

The bureau has been interested in and has conducted archeological explorations in the Pueblo region of New Mexico and Arizona for many years. Since the establishment of the School of American Archæology in 1907, following the revival of interest in American archeology, by the Archæological Institute of America, that body likewise commenced systematic work in the archeology of that great region. In order to avoid duplication of effort, arrangements were made between the bureau and the school for conducting archeological investigations in cooperation, the expense of the field work to be borne equally, a moiety of the collections of the artifacts and all the skeletal remains to become the property of the National Museum, and the bureau to have the privilege of the publication of all scientific results.

Active work under this joint arrangement was commenced in the Rito de los Frijoles, northwest of Santa Fé, New Mexico, in July, 1910, work having already been initiated there during the previous summer by the school independently, under the directorship of Dr. Edgar L. Hewett. In August, 1910, Mr. Hodge visited New Mexico for the purpose of participating in the work on the part of the bureau, and remained in the field for a month.

The great prehistoric site in the Rito de los Frijoles is characterized by an immense circular many-celled pueblo ruin, most of the stone walls of which are still standing to a height of several feet, and a series of cavate dwellings hewn in the soft tufa throughout several hundred yards of the northern wall of the canyon. Accompanying the great community ruin and also the cavate dwellings are underground kivas, or ceremonial chambers. In front of the cavate lodges were originally structures of masonry built against the cliff and forming front rooms, but practically the only remains of these are the foundation walls and the rafter holes in the cliff face. The débris covering these structures has been largely cleared away and the foundations exposed, and the walls of about two-thirds of the great pueblo structure in the valley have been bared by excavation. At the western extremity of the canyon, far up in the northern wall, is a natural cavern, known as Ceremonial Cave, in which are a large kiva, remarkably well preserved, and other interesting remains of aboriginal occupancy. This great archeological site in the Rito de los Frijoles is important to the elucidation of the problem of the early distribution of the Pueblos of the Rio Grande Valley, and there is reason to believe that when the researches are completed much light will be shed thereon. There is a paucity of artifacts in the habitations uncovered, aside from stone implements, of which large numbers have been found.

At the close of the work in the Rito de los Frijoles the joint expedition proceeded to the valley of the Jemez River, near the Hot Springs, where a week was spent in excavating the cemetery of the old Jemez village of Giusiwa. About 30 burials were disinterred here, and a few accompaniments of pottery vessels and other artifacts were recovered; but in the main the deposits had been completely destroyed by aboriginal disturbance, caused in part by covering the burials with heavy stones and partly by displacing the skeletons pre-

viously buried when subsequent interments were made. Giusiwa was inhabited in prehistoric times and also well within the historical period, as is attested by its massive, roofless church, built about the beginning of the seventeenth century. Nevertheless, no indication of Spanish influence was found in the ancient cemetery, and it is assumed that burial therein ceased with the coming of the missionaries and the establishment of the campo santo adjacent to the church. All collections gathered at Giusiwa have been deposited in the National Museum.

Other immense ruins on the summits of the mesas bounding the valley on the west were examined with the view of their future excavation. The exact position of the Jemez tribe among the Pueblo peoples is a problem, and both archeological and ethnological studies thereof are essential to its determination.

On completing this reconnoissance excavation was conducted in a cemetery at the great stone pueblo of Puye, on a mesa 8 miles west of the Tewa village of Santa Clara. About 50 burials were exhumed and sent to the National Museum, but artifacts were not found in abundance here, and as a rule they are not excellent in quality. In the joint work in the Rito de los Frijoles the expedition was fortunate in having the cooperation of Prof. Junius Henderson and Prof. W. W. Robbins, of the University of Colorado at Boulder, who, respectively, while the excavations were in progress, conducted studies in the ethno-zoology and the ethno-botany of the Tewa Indians, and also on the influence of climate and geology on the life of the early inhabitants of the Rito de los Frijoles. At the same time Mr. J. P. Harrington continued his researches in Tewa geographic nomenclature and cooperated with Professors Henderson and Robbins in supplying the native terms for plants and animals used by these Indians as food and medicine in ceremonies and for other purposes. The expedition was also fortunate in having the services of Mr. Sylvanus G. Morley in connection with the excavations in the Rito, of Mr. K. M. Chapman in the study of the decoration of the pottery and of the pictographs of the entire upper Rio Grande region, of Mr. Jesse L. Nusbaum in the photographic work, and of Mr. J. P. Adams in the surveying. Valued aid was also rendered by Messrs. Neil M. Judd, Donald Beauregard, and Nathan Goldsmith.

The scientific results of the joint research are rapidly nearing completion and will be submitted to the bureau for publication at an early date.

Throughout almost the entire year Mr. James Mooney, ethnologist, was occupied in the office in compiling the material for his study of Indian population covering the whole territory north of Mexico from the first white occupancy to the present time. By request of the Nebraska State Historical Society he was detailed in January, 1911, to attend the joint session of that body and the Mississippi Valley Historical Association, at Lincoln, Nebraska, where he delivered three principal addresses bearing particularly on the method and results of the researches of the bureau with the view of their application in local historical and ethnological investigations.

On June 4 Mr. Mooney started for the reservation of the East Cherokee in North Carolina to continue former studies of the sacred formulas and general ethnology of that tribe, and was engaged in this work at the close of the month.

At the beginning of the fiscal year Dr. J. Walter Fewkes, ethnologist, was in northern Arizona examining the great cave pueblos and other ruins within the Navaho National Monument. He found that since his visit in 1909 considerable excavation had been done by others in the rooms of Betatakin, and that the walls of Kitsiel, the other large cliff ruin, were greatly in need of repair. Guided by resident Navaho, he visited several hitherto undescribed cliff dwellings and gathered a fairly good collection of objects illustrating prehistoric culture of this part of northern Arizona, which have been deposited in the

National Museum. In order to faciliate the archeological work and to make the region accessible to students and visitors it was necessary to break a wagon road from Marsh Pass through the middle of the Navaho National Monument to the neighborhood of Betatakin, and by this means the valley was traversed with wagons for the first time.

On the return journey to Flagstaff, Dr. Fewkes visited the ruins in Nitsi, or West Canyon, and examined Inscription House, a prehistoric cliff dwelling of considerable size, hitherto undescribed, the walls of which are built of loaf-shaped adobes strengthened with sticks. On account of the size and great interest of these ruins, it is recommended that the area covered thereby be included in the Navaho National Monument and the ruins permanently preserved, and that either Betatakin or Kitsiel be excavated, repaired, and made a "type ruin" of this culture area. Along the road to Flagstaff from West Canyon, Dr. Fewkes observed several ruins and learned of many others ascribed to the ancient Hopi. He visited the Hopi pueblo of Moenkopi, near Tuba, and obtained considerable new ethnological material from an old priest of that village regarding legends of the clans that formerly lived in northern Arizona. He learned also of a cliff, or rock, covered with pictographs of Hopi origin, at Willow Spring, not far from Tuba, the figures of which shed light on Hopi clan migration legends.

Returning to Flagstaff, Dr. Fewkes reoutfitted in order to conduct investigations of the ruins near Black Falls of the Little Colorado River, especially the one called Wukoki, reputed to have been the last habitation of the Snake clans of the Hopi in their southern migration before they finally settled near the East Mesa. A little more than a month was spent at these ruins, during which time extensive excavations were made in numerous subterranean rooms, or pit dwellings, a new type of habitations found at the bases of many of the large ruined pueblos on the Little Colorado. Incidentally several other pueblo ruins, hitherto unknown, with accompanying reservoirs and shrines, were observed. The excavations at Wukoki yielded about 1,800 specimens, consisting of painted pottery, beautiful shell ornaments, stone implements, basketry, wooden objects, cane "cloud blowers," prayer sticks, a prayer-stick box, an idol, and other objects. The results of the excavations at Wukoki will be incorporated in a forthcoming bulletin on Antiquities of the Little Colorado Basin.

On the completion of his work at the Black Falls ruins, Dr. Fewkes returned to Washington in September and devoted the next three months to the preparation of a monograph on Casa Grande, Arizona.

At the close of January, 1911, Dr. Fewkes again took the field, visiting Cuba for the purpose of gathering information on the prehistoric inhabitants of that island and their reputed contemporaneity with fossil sloths, sharks, and crocodiles. A fortnight was devoted to the study of collections of prehistoric objects in Habana, especially the material in the University Museum from caves in Puerto Principe Province, described by Drs. Montoné and Carlos de la Torre. With this preparation he proceeded to the Isle of Pines and commenced work near Nueva Gerona. In this island there are several caves from which human bones have been reported locally, but the Cueva de los Indios, situated in the hills about a mile from the city named, promised the greatest reward. A week's excavation in this cave yielded four fragments of Indian skulls, not beyond repair; one undeformed, well-preserved, human cranium; and many fragments of pelves, humeri, and femora. The excavations in the middle of the cave indicated that the soil there had previously been dug over; these yielded little of value, the best-preserved remains occurring near the entrance, on each side. The skulls were arranged in a row within a pocket sheltered by

an overhanging side of the cave, and were buried about 2 feet in the guano and soil; beneath these crania were human long-bones, crossed. Several fragments of a single skull or of several skulls were embedded in a hard stalagmitic formation over the deposit of long-bones. No Indian implements or pottery accompanied the bones, and no fossils were found in association with them. So far as recorded this is the first instance of the finding of skeletal remains of cave man in the Isle of Pines. Their general appearance and mode of burial were the same as in the case of those discovered by Drs. Montoné and Carlos de la Torre.

Dr. Fewkes also examined, in the Isle of Pines, about 30 structures known as cacimbas, their Indian name. These are vase-shaped, subterranean receptacles, averaging 6 feet in depth and 4 feet in maximum diameter, generally constricted to about 2 feet at the neck, and with the opening level with the surface of the ground. Although these cacimbas are generally ascribed to the Indians, they are thought by some to be of Spanish origin, and are connected by others with buccaneers, pirates, and slavers. They are built of masonry or cut in the solid rock; the sides are often plastered and the bottoms commonly covered with a layer of tar. On the ground near the openings there is generally a level, circular space, with raised periphery. The whole appearance supports the theory that these structures were used in the manufacture of turpentine or tar, the circular area being the oven and the cacimba the receptacle for the product.

Dr. Fewkes found that the Pineros, or natives of the island, employ many aboriginal terms for animals, plants, and places, and in some instances two Indian words are used for the same object. An acknowledged descendant of a Cuban Indian explained this linguistic duality by saying that the Indians of the eastern end of the Isle of Pines spoke a dialect different from those of the western end, and that when those from Camaguey, who were Tainan and of eastern Cuban origin, came to the Isle of Pines at the instance of the Spanish authorities they brought with them a nomenclature different from that then in use on that island.

Several old Spanish structures of masonry, the dates of which are unknown, were also examined in the neighborhood of Santa Fé, Isle of Pines. The roof of a cave at Punta de Este, the southeastern angle of the island, bears aboriginal pictographs of the sun and other objects, suggesting that it is comparable with the cave in Haiti, in which, in Indian legend, the sun and the moon originated and from which the races of man emerged.

Dr. Fewkes has now collected sufficient material in Cuba to indicate that its western end, including the Isle of Pines, was once inhabited by a cave-dwelling people, low in culture and without agriculture. His observations support the belief that this people were in that condition when Columbus visited the Isle of Pines and that they were survivors of the Guanahatibibes, a cave-dwelling population formerly occupying the whole of Cuba and represented in Porto Rico and other islands of the West Indies.

Dr. Fewkes also visited several of the coral keys southwest of Isle of Pines, but, finding no aboriginal traces, he crossed the channel to Cayman Grande, about 250 miles from Nueva Gerona. The Cayman group consists of coral islands built on a submarine continuation of the mountains of Santiago Province, Cuba. A cave with Indian bones and pottery, probably of Carib origin, was found near Boddentown on the eastern end of the island, and a few stone implements were obtained from natives, but as these specimens may have been brought from adjacent shores they afford little evidence of a former aboriginal population of Cayman Grande. The elevation of the Cayman Islands, computed from the annual accretion, would indicate that Cayman

Grande was a shallow reef when Columbus visited Cuba, and could not have been inhabited at that time. The discoverer passed very near it on his second voyage, when his course lay from the Isle of Pines to Jamaica, but he reported neither name nor people.

Dr. Fewkes returned to Washington in April and spent the remainder of the year in completing his report on Casa Grande.

Dr. John R. Swanton, ethnologist, devoted the first quarter of the year chiefly to collecting material from libraries and archives, as the basis of his study of the Creek Indians. From the latter part of September until early in December he was engaged in field research among the Creek, Natchez, Tonkawa, and Alibamu Indians in Oklahoma and Texas, and also remained a short time with the remnant of the Tunica and Chitimacha in Louisiana, and made a few side trips in search of tribes which have been lost to sight within recent years. On his return to Washington, Dr. Swanton transcribed the linguistic and ethnologic material collected during his field excursion, read the proofs of Bulletins 44, 46, and 47, added to the literary material regarding the Creek Indians, collected additional data for a tribal map of the Indians of the United States, and initiated a study of the Natchez language with the special object of comparing it with the other dialects of the Muskhogean family. Dr. Swanton also spent some time in studying the Chitimacha and Tunica languages.

From July, 1910, until the middle of April, 1911, Mrs. M. C. Stevenson, ethnologist, was engaged in the completion of a paper on Dress and Adornment of the Pueblo Indians, in the elaboration of her report on Zuñi Plants and Their Uses, and in transcribing her field notes pertaining to Zuñi religious concepts and the mythology and ethnology of the Taos Indians.

Mrs. Stevenson left Washington on April 12 and proceeded directly to the country of the Tewa Indians, in the valley of the Rio Grande in New Mexico, for the purpose of continuing her investigation of those people. Until the close of the fiscal year her energies were devoted to the pueblo of San Ildefonso and incidentally to Santa Clara, information particularly in regard to the Tewa calendar system, ceremonies, and material culture being gained. Mrs. Stevenson finds that the worship of the San Ildefonso Indians includes the same celestial bodies as are held sacred by the Zuñi and other Pueblos. From the foundation laid during her previous researches among the Tewa, Mrs. Stevenson reports that she has experienced little difficulty in obtaining an insight into the esoteric life of these people, and is daily adding to her store of knowledge respecting their religion and sociology. A complete record of obstetrical practices of the Tewa has been made, and it is found that they are as elaborate as related practices of the Taos people. The San Ildefonso inhabitants do not seem to have changed their early customs regarding land tenure, and they adhere tenaciously to their marriage customs and birth rites, notwithstanding the long period during which missionaries have been among them. It is expected that, of her many lines of study among the Tewa tribes, the subject of their material culture will produce the first results for publication.

After completing some special articles on ethnologic topics for the closing pages of Part 2 of the Handbook of American Indians, Mr. J. N. B. Hewitt, ethnologist, pursued the study of the history of the tribes formerly dwelling in the Susquehanna and upper Ohio valleys. Progress in these researches was interrupted by the necessity of assigning him to the editorial revision and annotation of a collection of 120 legends, traditions, and myths of the Seneca Indians, recorded in 1884 and 1885 by the late Jeremiah Curtin. At the close of the year this work was far advanced, only about 150 pages of a total of 1,400 pages remaining to be treated. It is designed to publish this material,

with Mr. Hewitt's introduction, notes, and explanatory matter, in a forthcoming annual report. As opportunity afforded, Mr. Hewitt also resumed the preparation of his sketch of the grammar of the Iroquois for incorporation in the Handbook of American Indian Languages.

As in previous years, Mr. Hewitt prepared and collected data for replies to numerous correspondents requesting special information, particularly in regard to the Iroquois and Algonquian tribes. Mr. Hewitt also had charge of the important collection of 1,716 manuscripts of the bureau, cataloguing new accessions and keeping a record of those withdrawn in the progress of the bureau's researches. During the year, 378 manuscripts were thus made use of by the members of the bureau and its collaborators. Exclusive of the numerous manuscripts prepared by the staff of the bureau and by those in collaboration with it, referred to in this report, 12 items were added during the year. These pertain to the Pawnee, Chippewa, Zuñi, and Tewa tribes, and relate to music, sociology, economics, and linguistics.

The beginning of the fiscal year found Dr. Truman Michelson, ethnologist, conducting ethnological and linguistic investigations among the Piegan Indians of Montana, whence he proceeded to the Northern Cheyenne and Northern Arapaho, thence to the Menominee of Wisconsin, and finally to the Micmac of Restigouche, Canada—all Algonquian tribes, the need of a more definite linguistic classification of which has long been felt. Dr. Michelson returned to Washington at the close of November and immediately commenced the elaboration of his field notes, one of the results of which is a manuscript bearing the title "A Linguistic Classification of the Algonquian Tribes," submitted for publication in the twenty-eighth annual report. Also in connection with his Algonquian work Dr. Michelson devoted attention to the further revision of the material pertaining to the Fox grammar, by the late Dr. William Jones, the outline of which is incorporated in the Handbook of American Indian Languages. During the winter Dr. Michelson took advantage of the presence in Washington of a deputation of Chippewa Indians from White Earth, Minnesota, by enlisting their services in gaining an insight into the social organization of that tribe and also in adding to the bureau's accumulation of Chippewa linguistic data. Toward the close of June, 1911, Dr. Michelson proceeded to the Sauk and Fox Reservation in Iowa for the purpose of continuing his study of that Algonquian group.

The months of July and August and half of September, 1910, were spent by Dr. Paul Radin, ethnologist, among the Winnebago Indians of Nebraska and Wisconsin, his efforts being devoted to a continuation of his studies of the culture of those people, with special reference to their ceremonial and social organization and their general social customs. Part of the time was devoted to a study of the Winnebago material culture, but little progress was made in this direction, as few objects of aboriginal origin are now possessed by these people, consequently the study must be completed by examination of their objects preserved in museums and private collections. A beginning in this direction was made by Dr. Radin during the latter half of September and in October at the American Museum of Natural History, New York City. During the remainder of the fiscal year Dr. Radin was engaged in arranging the ethnological material gathered by him during the several years he has devoted to the Winnebago tribe, and in the preparation of a monograph on the Medicine Ceremony of the Winnebago and a memoir on the ethnology of the Winnebago tribe in general. In June, 1911, he again took the field in Wisconsin for the purpose of obtaining the data necessary to complete the tribal monograph. Both these manuscripts, it is expected, will be finished by the close of the present calendar year.

By arrangement with the Commissioner of Indian Affairs the bureau was fortunate in enlisting the services of Mr. Francis La Flesche, who has been frequently mentioned in the annual reports of the bureau in connection with his studies, jointly with Miss Alice C. Fletcher, of the ethnology of the Omaha tribe of the Siouan family. Having been assigned the task of making a comparative study of the Osage tribe of the same family, Mr. La Flesche proceeded to their reservation in Oklahoma in September. The older Osage men, like the older Indians generally, are very conservative, and time and tact were necessary to obtain such standing in the tribe as would enable him to establish friendly relations with those to whom it was necessary to look for trustworthy information. Although the Osage language is similar to that of the Omaha, Mr. La Flesche's native tongue, there are many words and phrases that sound alike but are used in a different sense by the two tribes. Having practically mastered the language, Mr. La Flesche was prepared to devote several months to what is known as the No^{n}'ho^{n}zhi^{n}ga Ie'ta, the general term applied to a complex series of ceremonies which partake of the nature of degrees, but are not, strictly speaking, successive steps, although each one is linked to the other in a general sequence. While at the present stage of the investigation it would be premature to make a definite statement as to the full meaning and interrelation of these Osage ceremonies, there appear to be seven divisions of the No^{n}'ho^{n}zhi^{n}ga Ie'ta, the names, functions, and sequence of which have been learned, but whether the sequence thus far noted is always maintained remains to be determined. From Saucy-Calf, one of the three surviving Osage regarded as past masters in these ceremonies, phonographic records of the first of the ceremonies, the Waxo'be-awatho^{n}, have been made in its entirety, consisting of 80 songs with words and music, and 7 prayers. All these have been transcribed and in part translated into English, comprising a manuscript exceeding 300 pages. In order to discuss with the Osage the meaning of these rituals, Mr. La Flesche found it necessary to commit them to memory, as reading from the manuscript disconcerted the old seer. At Saucy-Calf's invitation Mr. La Flesche witnessed in the autumn, at Grayhorse, a performance of the ceremony of the Waxo'be-awatho^{n}, the recitation of the rituals of which requires one day, part of a night, and more than half of the following day. It is Mr. La Flesche's purpose to record, if possible, the rituals of the remaining six divisions of the No^{n}'ho^{n}zhi^{n}ga Ie'ta. He has already obtained a pharaphrase of the seventh ceremony (the Nik'ino^{n}k'o^{n}), and hopes soon to procure a phonographic record of all the rituals pertaining thereto.

In connection with his ethnological work Mr. La Flesche has been so fortunate as to obtain for the National Museum four of the waxo'be, or sacred packs, each of which formed a part of the paraphernalia of the No^{n}'ho^{n}zhi^{n}ga Ie'ta, as well as a waxo'be-to^{n}'ga, the great waxo'be which contains the instruments for tattooing. Only those Osage are tattooed who have performed certain acts prescribed in the rites of the No^{n}'ho^{n}zhi^{n}ga Ie'ta. The rites of the tattooing ceremony are yet to be recorded and elucidated. While the waxo'be is the most sacred of the articles that form the paraphernalia of the No^{n}'ho^{n}zhi^{n}ga Ie'ta rites, it is not complete in itself; other things are indispensable to their performance, and it is hoped that these may be procured at some future time.

While not recorded as one of the ceremonial divisions of the No^{n}'ho^{n}zhi^{n}ga Ie'ta, there is a ceremony so closely connected with it that it might well be regarded as a part thereof—this is the Washa'beathi^{n} watsi, or the dance of the standards. The introductory part of this ceremony is called Akixage, or weeping over one another in mutual sympathy by the members of the two great divisions of the tribe. There is no regular time for the performance of the Washa'beathi^{n} ceremony. It is given only when a member of the tribe loses

by death some specially loved and favored relative and seeks a ceremonial expression of sympathy from the entire tribe. It is the intention to procure the songs and rituals of this ceremony, and specimens of the standards employed in its performance.

Altogether Mr. La Flesche has made excellent progress in his study of the Osage people, and the results are already shedding light on the organization and the origin and function of the ceremonies of this important tribe.

The special researches of the bureau in the field of linguistics were conducted by Dr. Franz Boas, honorary philologist, one of the immediate and tangible results of which was the publication of Part 1 of the Handbook of American Indian Languages. It seems desirable to restate at the present time the development of the plan and the object of this work.

Through the efforts of the late Maj. Powell and his collaborators a great number of vocabularies and a few grammars of American Indian languages had been accumulated, but no attempt had been made to give a succinct description of the morphology of all the languages of the continent. In order to do this, a series of publications was necessary. The subject matter had to be represented by a number of grammatical sketches, such as are now being assembled in the Handbook of American Indian Languages. To substantiate the inductions contained in this grammar, collections of texts are indispensable to the student, and finally a series of extended vocabularies are required. The plan, as developed between 1890 and 1900, contemplated the assembling in the bulletin series of the bureau of a series of texts which were to form the basis of the handbook. Of this series, Dr. Boas's Chinook, Kathlamet, and Tsimshian Texts, and Swanton's Haida and Tlingit Texts, subsequently published, form a part, but at the time Swanton's Texts appeared it was believed by Secretary Langley that material of this kind was too technical in character to warrant publication in a governmental series. It was, therefore, decided to discontinue the text series in the bulletins of the bureau and to divert them to the Publications of the American Ethnological Society and the Columbia University Contributions to Anthropology. Other series were commenced by the University of California and the University of Pennsylvania. The method of publication pursued at the present time, though different from that first planned, is acceptable, since all the material is accessible to students, and the bureau is saved the expense of publication.

Dr. Boas has been enabled to base all the sketches in the first volume of his handbook on accompanying text series, as follows:

(1) Athapascan. Text published by the University of California.

(2) Tlingit. Text published by the Bureau of American Ethnology, but too late to be used systematically.

(3) Haida. Texts published by the Bureau of American Ethnology.

(4) Tsimshian. Texts published by the Bureau of American Ethnology and the American Ethnological Society.

(5) Kwakiutl. Texts published by the Jesup Expedition and in the Columbia University series.

(6) Chinook. Texts published by the Bureau of American Ethnology.

(7) Maidu. Texts published by the American Ethnological Society, but too late to be used.

(8) Algonquian. Texts published by the American Ethnological Society.

(9) Sioux. Texts in Contributions to North American Ethnology.

(10) Eskimo. Texts in "Meddelelser om Grønland," but not used systematically.

Although Dr. Boas has urged the desirability of undertaking the publication of the series of vocabularies, no definite steps have yet been taken toward the

realization of this plan, owing largely to lack of funds for the employment of assistants in preparing the materials. It is hoped, however, that such a series of vocabularies, based on the published grammars and on the series of texts above referred to, may be prepared for publication in the near future. Much of the preliminary work has been done. There are, for example, extended manuscript dictionaries of the Haida, Tsimshian, Kwakiutl, Chinook, and Sioux, but none of them is yet ready for the printer.

The work on Part 2 of the Handbook of American Indian Languages is progressing satisfactorily. The sketch of the Takelma is in page form (pp. 1–296), but Dr. Boas has undertaken the correlation of this sketch with the Takelma Texts which meanwhile have been published by the University of Pennsylvania, and a considerable amount of work remains to be done to finish this revision. The Coos grammar is in galleys. The Coos Texts are at the present writing being printed by the American Ethnological Society, and here also references are being inserted. Dr. Leo J. Frachtenberg has continued his collection of material for the handbook with commendable energy and intelligence. The field work has been financially aided by Columbia University, partly through a gift made by Mrs. Henry Villard and partly through funds provided by Mr. Homer E. Sargent. It has also been possible to utilize for the work on the Alsea the collections made at a former time by Prof. Livingston Farrand on an expedition supported by the late Mr. Henry Villard. On his last expedition Dr. Frachtenberg was able to determine that the Siuslaw is an independent stock, although morphologically affiliated with the Alsea, Coos, and Siuslaw group. He also collected extensive material on the Alsea and Molala.

The most important result, which is appearing more and more clearly from the investigations carried out under the direction of Dr. Boas, lies in the fact that it will be possible to classify American languages on a basis wider than that of linguistic stocks. In 1893 Dr. Boas called attention to the fact that a number of languages in northern British Columbia seem to have certain morphological traits in common, by which they are sharply differentiated from all the neighboring languages, although the evidence for a common origin of the stocks is unsatisfactory. Dr. Boas and his assistants have followed this observation, and it can now be shown that throughout the continent languages may be classed in wider morphological groups. It is interesting to note that phonetic groups may be distinguished in a similar manner, but these do not coincide with the morphological groups. These observations are in accord with the results of modern inquiries in Africa and Asia, where the influence of Hamitic phonetics on languages of the Sudan and the influence of Sumerian on early Babylonian have been traced in a similar manner. Analogous conditions seem to prevail also in South Africa, where the phonetics of the Bushman languages have influenced the neighboring Bantu languages. In this way a number of entirely new and fundamental problems in linguistic ethnography have been formulated, the solution of which is of the greatest importance for a clear understanding of the early history of the American Continent.

The Handbook of American Indian Languages as planned at the present time deals exclusively with an analytical study of the morphology of each linguistic family, without any attempt at a detailed discussion of phonetic processes, their influence upon the development of the language, and the relation of dialects. Dr. Boas recommends that the present Handbook of American Indian Languages be followed by a series of handbooks each devoted to a single linguistic stock, in which the development of each language, so far as it can be traced by comparative studies, should be treated.

The study of aboriginal American music was conducted among the Chippewa Indians by Miss Frances Densmore, who extended her field of work previously

begun among that people and elaborated the system of analyzing their songs. After spending several weeks on the Lac du Flambeau Reservation in Wisconsin she accompanied the Chippewa from that reservation to the Menominee Reservation in the same State, where the Lac du Flambeau Chippewa ceremonially presented two drums to the Menominee. This ceremony was closely observed, photographs being taken and the speeches of presentation translated, and the songs of the ceremony were recorded by Miss Densmore on a phonograph after the return of the drum party to Lac du Flambeau. Many of the songs are of Sioux origin, as the ceremony was adopted from that people; consequently the songs were analyzed separately from those of Chippewa origin. Numerous old war songs were recorded at Lac du Flambeau, also songs said to have been composed during dreams, and others used as accompaniments to games and dances. The analytical tables published during the year in Bulletin 45, Chippewa Music, have been combined by Miss Densmore with those of songs collected during the year 1910–11, making a total of 340 Chippewa songs under analysis. These are analyzed in 12 tables, showing the structure, tone material, melodic progression, and rhythm of the songs, the rhythm of the drum, the relation between the metric unit of the voice and drum, and other points bearing on the development and form of primitive musical expression. This material is now almost ready for publication. The Sioux songs of the drum presentation ceremony, similarly analyzed, constitute the beginning of an analytical study of the Sioux music, which will be continued and extended during the fiscal year 1911–12.

Miss Alice C. Fletcher and Mr. La Flesche conducted the final proof revision of their monograph on the Omaha tribe, to accompany the twenty-seventh annual report, which was in press at the close of the fiscal year. This memoir will comprise 658 printed pages and will form the most complete monograph of a single tribe that has yet appeared.

Mr. J. P. Dunn, whose studies of the Algonquian tribes of the Middle West have been mentioned in previous reports, deemed it advisable, before continuing his investigation of the languages of the tribes comprising the former Illinois confederacy, to await the completion of the copying of the anonymous manuscript Miami-French Dictionary, attributed to Père Joseph Ignatius Le Boulanger, in the John Carter Brown Library at Providence, Rhode Island. Through the courteous permission of Mr. George Parker Winship, librarian, the bureau has been enabled to commence the copying of this manuscript, the difficult task being assigned to Miss Margaret Bingham Stillwell, under Mr. Winship's immediate direction. At the close of the fiscal year 20½ pages of the original (comprising 95 pages of transcript), of the total of 155 pages of the dictionary proper, were finished and submitted to the bureau. It is hoped that on the completion of the copying the bureau will have a basis for the study of the Miami and related languages that would not be possible among the greatly modified remnant of the Indians still speaking them.

Prof. Howard M. Ballou, of Honolulu, has continued the preparation of the List of Works Relating to Hawaii, undertaken in collaboration with the late Dr. Cyrus Thomas, and during the year submitted the titles of many early publications, including those of obscure books printed in the Hawaiian language.

Mr. John P. Harrington, of the School of American Archæology, proceeded in March to the Colorado Valley in Arizona and California for the purpose of continuing his studies, commenced a few years before, among the Mohave Indians, and incidentally to make collections for the United States National Museum. Mr. Harrington was still among these Indians at the close of July, and the results of his studies, which cover every phase of the life of this interesting people, are to be placed at the disposal of the bureau for publication.

PUBLICATIONS.

The general editorial work of the bureau continued in immediate charge of Mr. J. G. Gurley, editor. The editing of Part 2 of Bulletin 30, Handbook of American Indians, was conducted by Mr. Hodge, while the editorial supervision of Bulletin 40, Handbook of American Indian Languages, was in charge of Dr. Boas. At the close of the fiscal year the twenty-seventh annual report was nearly ready for the bindery; more than one-third of Bulletin 40, Part 2, was in type (mostly in pages); and Bulletin 47, a Dictionary of the Biloxi and Ofo Languages, by Dorsey and Swanton, was in page form. Some progress had been made in the revision of the galley proof of Bulletin 46, Byington's Choctaw Dictionary, a work requiring the expenditure of considerable time and labor. Much of Mr. Gurley's time during the year was given to the work of editing and proof reading the twenty-seventh annual report and its accompanying paper, the monograph on the Omaha tribe, by Miss Fletcher and Mr. La Flesche, above referred to. The following publications were issued during the year:

Bulletin 30. Handbook of American Indians North of Mexico (F. W. Hodge, editor), Part 2.

Bulletin 37. Antiquities of Central and Southeastern Missouri (Gerard Fowke).

Bulletin 40. Handbook of American Indian Languages (Franz Boas, editor), Part 1.

Bulletin 43. Indian Tribes of the Lower Mississippi Valley and Adjacent Coast of the Gulf of Mexico (J. R. Swanton).

Bulletin 44. Indian Languages of Mexico and Central America and their Geographical Distribution (Cyrus Thomas and J. R. Swanton).

Bulletin 45. Chippewa Music (Frances Densmore).

Bulletin 50. Preliminary Report on a Visit to the Navaho National Monument, Arizona (J. Walter Fewkes).

Bulletin 51. Antiquities of the Mesa Verde National Park: Cliff Palace (J. Walter Fewkes).

The preparation of the illustrations for the publications of the bureau and the making of photographic portraits of the members of visiting deputations of Indians were in charge of Mr. De Lancey Gill, illustrator. Of the 246 negatives made, 120 comprise portraits of visiting Indians. In addition 372 photographic films, exposed by members of the bureau in connection with their field work, were developed and printed. Photographic prints for publication and exchange were made to the number of 1,469, and 22 drawings for use as illustrations were prepared. Mr. Gill was assisted, as in the past, by Mr. Henry Walther.

LIBRARY.

The library of the bureau has continued in the immediate charge of Miss Ella Leary, librarian. During the year that part of the southeastern gallery of the lower main hall of the Smithsonian Building which was vacated by the National Museum, was assigned to the use of the bureau library, and three additional stacks were built, providing shelf room for about 2,500 volumes. Nearly that number of books which had been stored, and consequently made inaccessible, were placed on the new shelves. The policy carried out from year to year of increasing the library by exchange with other institutions has been continued, and special effort made to complete the collection of serial publications. Especially to be noted is the completion of the sets of publications of the Maine Historical Society and the Archives of Pennsylvania, both rich in

material pertaining to the Indians. As in the past, it has been necessary for the bureau to make use of the Library of Congress from time to time, about 200 volumes having been borrowed during the year. Twelve hundred books and approximately 650 pamphlets were received, in addition to the current numbers of more than 600 periodicals. Of the books and pamphlets received, 148 were acquired by purchase, the remainder by gift or exchange. Six hundred and eighty-nine volumes were bound by the Government Printing Office, payment therefor being made from the allotment "for printing and binding * * * annual reports and bulletins of the Bureau of American Ethnology, and for miscellaneous printing and binding," authorized by the sundry civil act. This provision has enabled the bureau, during the last two years, to bind many volumes almost in daily use which were threatened with destruction. The catalogue of the bureau now records 17,250 volumes; there are also about 12,200 pamphlets, and several thousand unbound periodicals. The library is constantly referred to by students not connected with the bureau, as well as by various officials of the Government service.

PROPERTY.

As noted in previous reports the principal property of the bureau consists of its library, manuscripts, and photographic negatives. In addition it possesses a number of cameras, phonographic machines, and ordinary apparatus and equipment for field work, stationery and office supplies, a moderate amount of office furniture, typewriters, etc., and the undistributed stock of its publications. The sum of $304.62 was expended for office furniture (including bookstacks at a cost of $205) during the fiscal year.

RECOMMENDATIONS.

For the purpose of extending the systematic researches of the bureau and of affording additional facilities for its administration, the following recommendations are made:

A question having arisen in the Committee on Appropriations of the House of Representatives as to the purpose for which an increase of $2,000 in the bureau's appropriation in 1909 was intended, the work of excavating and repairing antiquities existing in national parks and monuments has been curtailed. The importance of elucidating the archeological problems connected with these ancient remains and of repairing the more important of them for visitors and for future students is so apparent that the need of continuing this work is generally recognized, consequently an estimate of $4,000 "for the exploration and preservation of antiquities" has been submitted for the next fiscal year.

Ethnological research in Alaska is urgently needed by reason of the great changes taking place among the Indians and the Eskimo since the influx of white people a few years ago. Unless this investigation is undertaken at once the aboriginal inhabitants will have become so modified by contact with whites that knowledge of much of their primitive life will be lost. It is recommended that the sum of $4,500 be appropriated for this work.

The more speedy extension of ethnological researches among the remnants of the Algonquian tribes formerly occupying the Middle West is desired. In a number of cases these tribes are represented by only a few survivors who retain any knowledge of the traits, language, and customs of their people, hence it will be impossible to gather much of this information unless the work is extended more rapidly, as the funds now at the bureau's disposal for this purpose are inadequate. The additional sum of $1,000 is recommended for this purpose.

As previously stated, the demand for the Handbook of American Indians has been so great that many schools and libraries have necessarily been denied. The need of a revised edition is urgent, but the revision can not be satisfactorily undertaken and the latest information incorporated without the employment of special ethnologic assistants—those who have devoted special study to particular tribes—and editorial and clerical aid. It is recommended that the sum of $3,800 be appropriated for this purpose.

The bureau is constantly in receipt of requests from schools, historical societies, compilers of textbooks, etc., for photographic prints of Indian subjects, since it is generally known that the bureau possesses many thousands of negatives accumulated in the course of its investigations. As no funds are now available for this purpose, it is recommended that a reasonable sum, say $1,000, be appropriated for the purpose of furnishing prints for educational purposes. In most cases applicants would doubtless be willing to pay the cost, but at present the bureau has no authority for selling photographs.

The manuscripts accumulated by the bureau form a priceless collection; indeed many of them, if lost, could not be replaced, since they represent the results of studies of Indians who have become extinct or have lost their tribal identity. It is therefore urgently recommended that the sum of $1,350 be appropriated for fireproofing a room and for providing metal cases for the permanent preservation of the manuscripts.

Respectfully submitted.

F. W. Hodge, *Ethnologist in Charge.*

Dr. Charles D. Walcott,
Secretary of the Smithsonian Institution.

Appendix III.

REPORT ON THE INTERNATIONAL EXCHANGES.

Sir: I have the honor to submit the following report on the operations of the International Exchange Service during the fiscal year ending June 30, 1911, which was prepared under the direction of Mr. C. W. Shoemaker, chief clerk, who was in charge of the service from January, 1910, until June 1, 1911.

The congressional appropriation for the support of the service during 1911 was $32,200 (the same amount granted for the past three years), and the sum collected on account of repayments was $4,754.99, making the total available resources for carrying on the system of international exchanges $36,954.99.

The total number of packages handled during the year was 228,698—an increase over the number for the preceding year of 7,073. The weight of these packages was 560,808 pounds—a gain of 76,124 pounds. For purposes of comparison the number and weight of packages of different classes are indicated in the following table:

	Packages.		Weight.	
	Sent.	Received.	Sent.	Received.
			Pounds.	*Pounds.*
United States parliamentary documents sent abroad	103,769		116,219	
Publications received in return for parliamentary documents		1,752		18,467
United States departmental documents sent abroad	55,104		216,686	
Publications received in return for departmental documents		8,715		18,837
Publications from miscellaneous sources sent abroad	28,834		56,165	
Publications received from abroad for miscellaneous distribution		30,524		134,434
Total	187,707	40,991	389,070	171,738
Grand total	228,698		560,808	

The disparity between the number of packages received and those sent may be accounted for, in part, by the fact that many returns for publications sent abroad are forwarded to their destinations by mail and not through the exchange service. This difference is further due to the fact that whereas packages sent are made up in most cases of separate publications, those received contain several volumes—in some instances the term "package" being applied to large boxes often containing 100 or more publications.

By referring to the above statement it will be noted that 66 per cent of the work of the office has been conducted in behalf of the United States governmental establishments.

Of the 2,380 boxes used in forwarding exchanges to foreign bureaus and agencies for distribution (an increase of 347 boxes over 1910), 385 boxes contained full sets of United States official documents for authorized depositories and 1,995 were filled with departmental and other publications for depositories of partial sets and for miscellaneous correspondents.

Several changes have been made during the year in the routine of the Exchange Office looking to the economical and efficient administration of the service. These changes are here briefly referred to.

It had been the practice for many years to keep a card record of both incoming and outgoing packages—a credit and debit account with each establishment or individual using the facilities of the Exchange Service—thus enabling the Institution to answer inquiries concerning the transmisson of any particular package without delay. As the keeping of these cards involved a great deal of labor—quite out of proportion to the benefits derived therefrom—and also as most of the information given thereon could, with the expenditure of a little more time, be obtained from other records in the office, the detailed statement of outgoing packages has been discontinued. This curtailment in the work has made it possible to dispense with the services of one of the clerks in the record room. The discontinuance of these cards has, furthermore, brought about a change in the work in the shipping room whereby the preparation of consignments for transmission abroad is facilitated.

Since the fiscal year 1897 there has been printed in the report on the exchanges, under the caption "Interchange of Publications between the United States and Other Countries," a statement showing in detail the number of packages sent to and received from each country through the International Exchange Service. In most instances, the statistics contained in these statements indicated that a much larger number of packages were sent abroad than were received in return. While it is true that a certain disparity exists, the statements were misleading, since, as already explained, a great many packages are received through other channels by correspondents in this country in return for those sent through the Exchange Service. In view of this fact, and also because the statistics contained in these statements were seldom required for the use of the Exchange Office, the keeping of the detailed record from which they were derived has been discontinued. The time saved by this and other minor changes in the receiving room has enabled the clerical force in that room to keep the work required in handling and recording the large number of packages received for transmission through the service more nearly up to date.

Mention was made in the last report that the German authorities had in contemplation the founding of an institution at Berlin to further cultural relations between Germany and the United States, and that one of its functions would be the transmission and distribution of German exchanges. This establishment, which is known as the "Amerika-Institut," was organized in the fall of 1910, and the exchange of publications was taken up by it on January 1, 1911. On the latter date the exchange agency maintained by the Smithsonian Institution in Leipzig at the publishing house of Karl W. Hiersemann was discontinued.

Prior to the discontinuance of the Leipzig agency the interchange of publications between correspondents in Luxemburg and Roumania and those in the United States was conducted through that medium. In compliance with the Institution's request, the Amerika-Institut has been good enough to assume charge of the distribution of packages in Luxemburg. The Academia Romana at Bucharest—the depository of a partial set of United States governmental documents—has been approached with a view to enlisting its services in the interchange of publications between Roumania and the United States, and it is hoped that the academy may find it convenient to have this work conducted under its auspices.

The Japanese exchange agency and the depository of a full set of United States governmental documents was transferred by the Japanese Government, during the latter part of the year, from the Department of Foreign Affairs to

the Imperial Library at Tokyo. The regular series of official documents, as well as all publications for distribution in Japan, are therefore now forwarded to that library.

An application received by the Institution from the under secretary to the Government of the United Provinces of Agra and Oudh, Allahabad, India, for copies of such United States official publications as might be of interest to it was favorably acted upon by the Library of Congress, and that Government was added to the list of those countries receiving partial sets of governmental documents. The first shipment, consisting of six boxes, was forwarded to the under secretary on October 11, 1910.

Two cases forwarded from Washington in October, 1910, containing exchanges for miscellaneous addresses in New South Wales, were destroyed in transit to that country, the steamship by which the consignment was transmitted having been burned at sea. The senders of the packages contained in these cases were communicated with, and it is gratifying to state that it was possible for most of them to supply copies of the lost publications.

The work inaugurated in 1908 of actively seeking returns from foreign countries for the exchanges sent to them by this Government has resulted during the year in the acquisition of important collections of publications for the Library of Congress and for several other establishments of the Government.

About 10,000 foreign governmental documents of a statistical character, returned by the Library of Congress as duplicates, have been stored for some time in the Smithsonian Institution. These books were arranged and listed during the year under the direction of the assistant librarian, while the Exchange Service, through which the documents were received from abroad, provided the extra clerical assistance required. Upon completion of this work most of the documents were forwarded to the New York Public Library to complete its series of foreign governmental publications.

FOREIGN DEPOSITORIES OF UNITED STATES GOVERNMENTAL DOCUMENTS.

In accordance with treaty stipulations and under the authority of the congressional resolutions of March 2, 1867, and March 2, 1901, setting apart a certain number of documents for exchange with foreign countries, there are now sent regularly to depositories abroad 55 full sets of United States official publications and 34 partial sets, the United Provinces of Agra and Oudh having been added during the year to the list of countries receiving partial sets.

The recipients of full and partial sets are as follows:

DEPOSITORIES OF FULL SETS.

Argentina: Ministerio de Relaciones Exteriores, Buenos Aires.
Argentina: Biblioteca de la Universidad Nacional de La Plata.
Australia: Library of the Commonwealth Parliament, Melbourne.
Austria: K. K. Statistische Central-Commission, Vienna.
Baden: Universitäts-Bibliothek, Freiburg.
Bavaria: Königliche Hof- und Staats-Bibliothek, Munich.
Belgium: Bibliothèque Royale, Brussels.
Brazil: Bibliotheca Nacional, Rio de Janeiro.
Canada: Parliamentary Library, Ottawa.
Cape Colony: Government Stationery Department, Cape Town.
Chile: Biblioteca del Congreso Nacional, Santiago.
China: American-Chinese Publication Exchange Department, Shanghai Bureau of Foreign Affairs, Shanghai.
Colombia: Biblioteca Nacional, Bogota.
Costa Rica: Oficina de Depósito y Canje de Publicaciones, San José.

Cuba: Secretaria de Estado (Asuntos Generales y Canje Internacional), Habana.
Denmark: Kongelige Bibliotheket, Copenhagen.
England: British Museum, London.
England: London School of Economics and Political Science, London.
France: Bibliothèque Nationale, Paris.
France: Préfecture de la Seine, Paris.
Germany: Deutsche Reichstags-Bibliothek, Berlin.
Greece: Bibliothèque Nationale, Athens.
Haiti: Secrétairerie d'État des Relations Extérieures, Port au Prince.
Hungary: Hungarian House of Delegates, Budapest.
India: Department of Education (Books), Government of India, Calcutta.
Ireland: National Library of Ireland, Dublin.
Italy: Biblioteca Nazionale Vittorio Emanuele, Rome.
Japan: Imperial Library of Japan, Tokyo.
Manitoba: Provincial Library, Winnipeg.
Mexico: Instituto Bibliográfico, Biblioteca Nacional, Mexico.
Netherlands: Library of the States General, The Hague.
New South Wales: Board for International Exchanges, Sydney.
New Zealand: General Assembly Library, Wellington.
Norway: Storthingets Bibliothek, Christiania.
Ontario: Legislative Library, Toronto.
Peru: Biblioteca Nacional, Lima.
Portugal: Bibliotheca Nacional, Lisbon.
Prussia: Königliche Bibliothek, Berlin.
Quebec: Legislative Library, Quebec.
Queensland: Parliamentary Library, Brisbane.
Russia: Imperial Public Library, St. Petersburg.
Saxony: Königliche Oeffentliche Bibliothek, Dresden.
Servia: Section Administrative du Ministère des Affaires Etrangères, Belgrade.
South Australia: Parliamentary Library, Adelaide.
Spain: Servicio del Cambio Internacional de Publicaciones, Cuerpo Facultativo de Archiveros, Bibliotecarios y Arqueólogos, Madrid.
Sweden: Kungliga Biblioteket, Stockholm.
Switzerland: Bibliothèque Fédérale, Berne.
Tasmania: Parliamentary Library, Hobart.
Transvaal: Government Library, Pretoria.
Turkey: Department of Public Instruction, Constantinople.
Uruguay: Oficina de Canje Internacional de Publicaciones, Montevideo.
Venezuela: Biblioteca Nacional, Carácas.
Victoria: Public Library, Melbourne.
Western Australia: Public Library of Western Australia, Perth.
Württemberg: Königliche Landesbibliothek, Stuttgart.

DEPOSITORIES OF PARTIAL SETS.

Alberta: Legislative Library, Edmonton.
Alsace-Lorraine: K. Ministerium für Elsass-Lothringen, Strassburg.
Bolivia: Ministerio de Colonización y Agricultura, La Paz.
Bremen: Senatskommission für Reichs- und Auswärtige Angelegenheiten.
British Columbia: Legislative Library, Victoria.
Bulgaria: Minister of Foreign Affairs, Sofia.
Ceylon: United States Consul, Colombo.
Ecuador: Biblioteca Nacional, Quito.

Egypt: Bibliothèque Khédiviale, Cairo.
Guatemala: Secretary of the Government, Guatemala.
Hamburg: Senatskommission für die Reichs- und Auswärtigen Angelegenheiten.
Hesse: Grossherzogliche Hof-Bibliothek, Darmstadt.
Honduras: Secretary of the Government, Tegucigalpa.
Jamaica: Colonial Secretary, Kingston.
Liberia: Department of State, Monrovia.
Lourenço Marquez: Government Library, Lourenço Marquez.
Malta: Lieutenant-Governor, Valetta.
Montenegro: Ministère des Affaires Étrangères, Cetinje.
Natal: Colonial Secretary's Office, Pietermaritzburg.
New Brunswick: Legislative Library, St. John.
Newfoundland: Colonial Secretary, St. John's.
Nicaragua: Superintendente de Archivos Nacionales, Managua.
Northwest Territories: Government Library, Regina.
Nova Scotia: Provincial Secretary of Nova Scotia, Halifax.
Orange River Colony: Government Library, Bloemfontein.
Panama: Secretaria de Relaciones Exteriores, Panama.
Paraguay: Oficina General de Informaciones y Canjes y Commisaria General de Inmigracion, Asuncion.
Prince Edward Island: Legislative Library, Charlottetown.
Roumania: Academia Romana, Bucarest.
Salvador: Ministerio de Relaciones Exteriores, San Salvador.
Siam: Department of Foreign Affairs, Bangkok.
Straits Settlements: Colonial Secretary, Singapore.
United Provinces of Agra and Oudh: Under Secretary to Government, Allahabad.
Vienna: Bürgermeister der Haupt- und Residenz-Stadt.

INTERPARLIAMENTARY EXCHANGE OF THE OFFICIAL JOURNAL.

As mentioned in previous reports, a resolution of the Congress was approved March 4, 1909, setting aside such number as might be required, not exceeding 100 copies, of the daily issue of the Congressional Record for exchange, through the agency of the Smithsonian Institution, with the legislative chambers of such foreign governments as might agree to send to the United States in return current copies of their parliamentary record or like publication. The purpose of this resolution was to enable the Institution, on the part of the United States, to more fully carry into effect the provisions of the convention concluded at Brussels in 1886, providing for the immediate exchange of the official journal.

The Governments of the Argentine Republic, Denmark, and Great Britain have entered into this exchange during the year. A complete list of the countries to which the Congressional Record is now sent is given below:

Argentine Republic.
Australia.
Austria.
Baden.
Belgium.
Brazil.
Canada.
Cape of Good Hope.
Cuba.
Denmark.
France.
Great Britain.
Greece.
Guatemala.
Honduras.
Hungary.
Italy.
New South Wales.
New Zealand.
Portugal.
Prussia.
Roumania.
Russia.
Servia.
Spain.
Switzerland.
Transvaal.
Uruguay.
Western Australia.

There are at present 29 countries with which the immediate exchange of the official journal is carried on. To some of these countries two copies of the Congressional Record are sent—one to the upper and one to the lower house of parliament—the total number transmitted being 34.

It may be repeated in this connection that the exchange here alluded to is separate and distinct from the exchange of official documents which has existed between the United States and other countries for many years. It is interparliamentary, and provides for the immediate transmission, direct by mail, of the official journal as soon as published.

LIST OF BUREAUS OR AGENCIES THROUGH WHICH EXCHANGES ARE TRANSMITTED.

The following is a list of bureaus or agencies through which the distribution of exchanges is effected. Those in the larger and many in the smaller countries forward to the Smithsonian Institution, in return, contributions for distribution in the United States:

Algeria, via France.

Angola, via Portugal.

Argentina: Comisión Protectora de Bibliotecas Populares, Reconquista 538, Buenos Aires.

Austria: K. K. Statistische Central-Commission, Vienna.

Azores, via Portugal.

Barbados: Imperial Department of Agriculture, Bridgetown.

Belgium: Service Belge des Échanges Internationaux, Rue du Musée 5, Brussels.

Bolivia: Oficina Nacional de Estadística, La Paz.

Brazil: Serviço de Permutações Internacionaes, Bibliotheca Nacional, Rio de Janeiro.

British Colonies: Crown Agents for the Colonies, London.[1]

British Guiana: Royal Agricultural and Commercial Society, Georgetown.

British Honduras: Colonial Secretary, Belize.

Bulgaria: Institutions Scientifiques de S. M. le Roi de Bulgarie, Sofia.

Canary Islands, via Spain.

Cape Colony: Government Stationery Department, Cape Town.

Chile: Servicio de Canjes Internacionales, Biblioteca Nacional, Santiago.

China: Zi-ka-wei Observatory, Shanghai.

Colombia: Oficina de Canjes Internacionales y Reparto, Biblioteca Nacional, Bogota.

Costa Rica: Oficina de Depósito y Canje de Publicaciones, San José.

Denmark: Kongelige Danske Videnskabernes Selskab, Copenhagen.

Dutch Guiana: Surinaamsche Koloniale Bibliotheek, Paramaribo.

Ecuador: Ministerio de Relaciones Exteriores, Quito.

Egypt: Director-General, Survey Department, Giza (Mudiria).

France: Service Français des Echanges Internationaux, 110 Rue de Grenelle, Paris.

Germany: Amerika-Institut, Berlin, N. W. 7.

Great Britain and Ireland: Messrs. William Wesley & Son, 28 Essex Street, Strand, London.

Greece: Bibliothèque Nationale, Athens.

Greenland, via Denmark.

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[1] This method is employed for communicating with several of the British colonies with which no medium is available for forwarding exchanges direct.

Guadeloupe, via France.
Guatemala: Instituto Nacional de Varones, Guatemala.
Guinea, via Portugal.
Haiti: Secrétaire d'Etat des Relations Extérieures, Port au Prince.
Honduras: Biblioteca Nacional, Tegucigalpa.
Hungary: Dr. Julius Pikler, Municipal Office of Statistics, City Hall, Budapest.
Iceland, via Denmark.
India: India Store Department, India Office, London.
Italy: Ufficio degli Scambi Internazionali, Biblioteca Nazionale Vittorio Emanuele, Rome.
Jamaica: Institute of Jamaica, Kingston.
Japan: Imperial Library of Japan, Tokyo.
Java, via Netherlands.
Korea: His Imperial Japanese Majesty's Residency-General, Seoul.
Liberia: Department of State, Monrovia.
Lourenço Marquez: Government Library, Lourenço Marquez.
Luxemburg, via Germany.
Madagascar, via France.
Madeira, via Portugal.
Montenegro: Ministère des Affaires Étrangères, Cetinje.
Mozambique, via Portugal.
Natal: Agent-General for Natal, London.
Netherlands: Bureau Scientifique Central Néerlandais, Bibliothèque de l'Université, Leyden.
New Guinea, via Netherlands.
New South Wales: Board for International Exchanges, Public Library, Sydney.
New Zealand: Dominion Museum, Wellington.
Nicaragua: Ministerio de Relaciones Exteriores, Managua.
Norway: Kongelige Norske Frederiks Universitet Bibliotheket, Christiania.
Panama: Secretaria de Relaciones Exteriores, Panama.
Paraguay: Ministerio de Relaciones Exteriores, Asuncion.
Persia: Board of Foreign Missions of the Presbyterian Church, New York City.
Peru: Oficina de Reparto, Depósito y Canje Internacional de Publicaciones, Ministerio de Fomento, Lima.
Portugal: Serviço de Permutações Internacionaes, Bibliotheca Nacional, Lisbon.
Queensland: Board of Exchanges of International Publications, Parliament House, Brisbane.
Russia: Commission Russe des Echanges Internationaux, Bibliothèque Impériale Publique, St. Petersburg.
Salvador: Ministerio de Relaciones Exteriores, San Salvador.
Servia: Section Administrative du Ministère des Affaires Etrangères, Belgrade.
Siam: Department of Foreign Affairs, Bangkok.
South Australia: Public Library of South Australia, Adelaide.
Spain: Servicio del Cambio Internacional de Publicaciones, Cuerpo Facultativo de Archiveros, Bibliotecarios y Arqueólogos, Madrid.
Sumatra, via Netherlands.
Sweden: Kongliga Svenska Vetenskaps Akademien, Stockholm.
Switzerland: Service des Echanges Internationaux, Bibliothèque Fédérale Centrale, Bern.
Syria: Board of Foreign Missions of the Presbyterian Church, New York.
Tasmania: Royal Society of Tasmania, Hobart.
Transvaal: Government Library, Pretoria.

Trinidad: Victoria Institute, Port of Spain.
Tunis, via France.
Turkey: American Board of Commissioners for Foreign Missions, Boston.
Uruguay: Oficina de Canje Internacional, Montevideo.
Venezuela: Biblioteca Nacional, Caracas.
Victoria: Public Library of Victoria, Melbourne.
Western Australia: Public Library of Western Australia, Perth.

I may add here, as a matter of record, that I was appointed assistant secretary in charge of Library and Exchanges on June 1, 1911.

Respectfully submitted.

F. W. True,
Assistant Secretary in Charge of Library and Exchanges.

Dr. Charles D. Walcott,
Secretary of the Smithsonian Institution.

Appendix IV.

REPORT ON THE NATIONAL ZOOLOGICAL PARK.

Sir: I have the honor to present herewith a report of the operations of the National Zoological Park for the fiscal year ending June 30, 1911.

The general appropriation made by Congress for that year was $100,000, and in addition to this an appropriation of $15,000 was made for roads and walks.

The cost of maintenance was $81,325, and the amount remaining from the general appropriation, $18,675, was expended in various improvements and repairs.

ACCESSIONS.

Among the important accessions of the year were a pair of Haytian solenodons, a rare insectivorous mammal, presented by Mr. and Mrs. Franklin Adams of the Pan American Union. A pair of northern fur seals was received from the United States Bureau of Fisheries, a fine female grizzly bear from Maj. H. C. Benson, acting superintendent of the Yellowstone National Park, and four Virginia deer from Gen. Joseph S. Smith, manager of the National Soldiers Home, Bangor, Maine. By purchase, the park obtained a hippopotamus, an East African buffalo, three prong-horn antelopes, a pair of reindeer, a large Asiatic macaque monkey, and various other animals. Some important animals were also obtained by exchange, as noted below. The accessions included about twenty species not before represented in the collection.

Early in its history the park exhibited for two years a hippopotamus which had been received as a loan. Since that was withdrawn the species has not been represented in the collection. The present animal, a female about 2 years old, is from East Africa and weighs 850 pounds. The buffalo was captured in German East Africa and is believed to be the form described as *Buffelus neumanni*. The African buffalo has for some time been rather difficult to obtain, and the park was fortunate in being able to secure a specimen at comparatively small cost. It was also fortunate in obtaining in western Texas a male and two female prong-horn antelopes, all adult, from which two vigorous young have been born. Through an animal dealer on the Pacific coast the large brown macaque monkey of southeastern Asia and several other species new to the collection were obtained which had not been procurable elsewhere.

EXCHANGES.

Surplus animals were disposed of by exchange as usual, in accordance with the terms of the act establishing the park. They were sent to the New York Zoological Park, the London Zoological Garden, and various dealers and private individuals. In return for these, the park secured a number of important animals, including a fine specimen each of bontebok, blessbok, and springbok, a small anteater, a pair of tenrecs (insectivorous mammals of Madagascar), and other mammals and birds. The bontebok and blessbok, which are very beautiful African antelopes, are especially valued, as the former now exists only in a few

semiwild herds in Cape Colony, 300 individuals, perhaps, remaining from the "thousands upon thousands" described by early hunters in South Africa, while the latter has been greatly reduced in numbers.

Whenever possible, direct exchange was made, but where the person who desired to obtain an animal from the park had nothing acceptable to offer, the exchange was effected through some one of the responsible dealers in animals.

Black-crowned night herons had bred so freely in the flying cage that it became a necessity to materially reduce their number and some were sent (as gifts) to the New York Zoological Park, London Zoological Garden, and the park departments of St. Louis and Rochester.

Animals in the collection June 30, 1911.

MAMMALS.

Grivet monkey (*Cercopithecus sabæus*)	1
Green monkey (*Cercopithecus callitrichus*)	1
Mona monkey (*Cercopithecus mona*)	2
Diana monkey (*Cercopithecus diana*)	1
Sooty mangabey (*Cercocebus fuliginosus*)	2
White-collared mangabey (*Cercocebus collaris*)	1
Bonnet monkey (*Macacus sinicus*)	1
Macaque monkey (*Macacus cynomolgus*)	5
Pig-tailed monkey (*Macacus nemestrinus*)	3
Rhesus monkey (*Macacus rhesus*)	15
Brown macaque (*Macacus arctoides*)	4
Japanese monkey (*Macacus fuscatus*)	4
Formosan rock-macaque (*Macacus cyclopis*)	1
Black ape (*Cynopithecus niger*)	1
Anubis baboon (*Papio anubis*)	1
East African baboon (*Papio cynocephalus*)	1
Chacma (*Papio porcarius*)	1
Mandrill (*Papio maimon*)	4
Drill (*Papio leucophæus*)	1
Gray spider monkey (*Ateles geoffroyi*)	1
White-throated capuchin monkey (*Cebus hypoleucus*)	3
Brown monkey (*Cebus fatuellus*)	3
Weeper monkey (*Cebus capucinus*)	1
Ruffed lemur (*Lemur varius*)	1
Ring-tailed lemur (*Lemur catta*)	2
Tenrec (*Centetes ecaudatus*)	2
Polar bear (*Thalarctos maritimus*)	3
European brown bear (*Ursus arctos*)	3
Kadiak bear (*Ursus middendorffi*)	1
Yakutat bear (*Ursus dalli*)	1
Alaskan brown bear (*Ursus gyas*)	5
Kidder's bear (*Ursus kidderi*)	1
Himalayan bear (*Ursus thibetanus*)	1
Grizzly bear (*Ursus horribilis*)	4
Black bear (*Ursus americanus*)	9
Cinnamon bear (*Ursus americanus*)	3
Sloth bear (*Melursus ursinus*)	1
Kinkajou (*Cercoleptes caudivolvulus*)	1
Cacomistle (*Bassariscus astuta*)	1
Gray coatimundi (*Nasua narica*)	3
Raccoon (*Procyon lotor*)	17
American badger (*Taxidea americana*)	4
Common skunk (*Mephitis mephitica*)	2
Wolverine (*Gulo luscus*)	1
American marten (*Mustela americana*)	2
Fisher (*Mustela pennantii*)	1
Common ferret (*Putorius putorius*)	1
Black-footed ferret (*Putorius nigripes*)	3
North American otter (*Lutra canadensis*)	5
Eskimo dog (*Canis familiaris*)	2
Dingo (*Canis dingo*)	4
Gray wolf (*Canis occidentalis*)	6
Black wolf (*Canis occidentalis*)	1
Coyote (*Canis latrans*)	4
Woodhouse's coyote (*Canis frustror*)	5
Crab-eating dog (*Canis cancrivorus*)	1
Red fox (*Vulpes pennsylvanicus*)	4
Swift fox (*Vulpes velox*)	2
Arctic fox (*Vulpes lagopus*)	2
Gray fox (*Urocyon cinereo-argenteus*)	6
Striped hyena (*Hyæna striata*)	1
African palm civet (*Viverra civetta*)	1
Common genet (*Genetta genetta*)	2
Sudan lion (*Felis leo*)	3
Kilimanjaro lion (*Felis leo sabakiensis*)	5
Tiger (*Felis tigris*)	2
Cougar (*Felis oregonensis hippolestes*)	2
Jaguar (*Felis onca*)	1
Mexican jaguar (*Felis onca goldmani*)	1
Leopard (*Felis pardus*)	2
Black leopard (*Felis pardus*)	1
Serval (*Felis serval*)	1
Ocelot (*Felis pardalis*)	1
Canada lynx (*Lynx canadensis*)	1
Bay lynx (*Lynx rufus*)	4
Spotted lynx (*Lynx rufus texensis*)	1
Florida lynx (*Lynx rufus floridanus*)	1
Steller's sea lion (*Eumetopias stelleri*)	1
California sea lion (*Zalophus californianus*)	2
Harbor seal (*Phoca vitulina*)	3
Fox squirrel (*Sciurus niger*)	10
Western fox squirrel (*Sciurus ludovicianus*)	8
Gray squirrel (*Sciurus carolinensis*)	40
Black squirrel (*Sciurus carolinensis*)	20
Prairie dog (*Cynomys ludovicianus*)	71
Alpine marmot (*Arctomys marmotta*)	3

Woodchuck (*Arctomys monax*)	3
American beaver (*Castor canadensis*)	4
Coypu (*Myocastor coypus*)	3
Hutia-conga (*Capromys pilorides*)	2
Indian porcupine (*Hystrix leucura*)	2
Mexican agouti (*Dasyprocta mexicana*)	1
Azara's agouti (*Dasyprocta azaræ*)	2
Golden agouti (*Dasyprocta aguti*)	1
Hairy-rumped agouti (*Dasyprocta prymnolopha*)	5
Paca (*Cœlogenys paca*)	1
Guinea pig (*Cavia cutleri*)	13
Patagonian cavy (*Dolichotis patagonica*)	2
Domestic rabbit (*Lepus cuniculus*)	41
Cape hyrax (*Procavia capensis*)	2
Indian elephant (*Elephas maximus*)	1
Brazilian tapir (*Tapirus americanus*)	2
Grevy's zebra (*Equus grevyi*)	1
Zebra-donkey hybrid (*Equus grevyi-asinus*)	1
Grant's zebra (*Equus burchelli granti*)	1
Collared peccary (*Dicotyles angulatus*)	8
Wild boar (*Sus scrofa*)	1
Northern wart hog (*Phacochœrus africanus*)	2
Hippopotamus (*Hippopotamus amphibius*)	1
Guanaco (*Lama huanachus*)	3
Llama (*Lama glama*)	6
Alpaca (*Lama pacos*)	2
Vicugna (*Lama vicugna*)	2
Bactrian camel (*Camelus bactrianus*)	3
Muntjac (*Cervulus muntjac*)	1
Sambar deer (*Cervus aristotelis*)	1
Philippine deer (*Cervus philippinus*)	1
Hog deer (*Cervus porcinus*)	4
Barasingha deer (*Cervus duvaucelii*)	10
Axis deer (*Cervus axis*)	5
Japanese deer (*Cervus sika*)	9
Red deer (*Cervus elaphus*)	13
American elk (*Cervus canadensis*)	9
Fallow deer (*Cervus dama*)	8
Reindeer (*Rangifer tarandus*)	2
Virginia deer (*Odocoileus virginianus*)	5
Mule deer (*Odocoileus hemionus*)	2
Columbian black-tailed deer (*Odocoileus columbianus*)	1
Cuban deer (*Odocoileus* sp.)	1
Prong-horn antelope (*Antilocapra americana*)	5
Coke's hartebeest (*Bubalis cokei*)	2
Bontebok (*Damaliscus pygargus*)	1
Blessbok (*Damaliscus albifrons*)	1
White-tailed gnu (*Connochætes gnu*)	1
Defassa water buck (*Cobus defassa*)	1
Indian antelope (*Antilope cervicapra*)	3
Springbuck (*Antidorcas euchore*)	1
Grant's gazelle (*Gazella granti*)	1
Nilgai (*Boselaphus tragocamelus*)	2
Congo harnessed antelope (*Tragelaphus gratus*)	3
East African eland (*Oreas canna pattersonianus*)	1
Chamois (*Rupicapra tragus*)	3
Tahr (*Hemitragus jemlaicus*)	6
Common goat (*Capra hircus*)	4
Angora goat (*Capra hircus*)	4
Barbary sheep (*Ovis tragelaphus*)	13
Barbados sheep (*Ovis aries-tragelaphus*)	1
Anoa (*Anoa depressicornis*)	1
East African buffalo (*Buffelus neumanni*)	1
Zebu (*Bibos indicus*)	3
Yak (*Poephagus grunniens*)	6
American bison (*Bison americanus*)	12
Hairy armadillo (*Dasypus villosus*)	2
Wallaroo (*Macropus robustus*)	4
Red-necked wallaby (*Macropus ruficollis*)	1
Brush-tailed rock kangaroo (*Petrogale penicillata*)	2
Virginia opposum (*Didelphys marsupialis*)	2

BIRDS.

European blackbird (*Merula merula*)	1
Catbird (*Dumetella carolinensis*)	1
Brown thrasher (*Toxostoma rufum*)	1
Japanese robin (*Liothrix luteus*)	2
Laughing thrush (*Garrulax leucolophus*)	2
Orange-cheeked waxbill (*Estrelda melpoda*)	8
Cordon-bleu (*Estrelda phœnicotis*)	8
Cut-throat finch (*Amadina fasciata*)	4
Zebra finch (*Amadina castanotis*)	2
Black-headed finch (*Munia atricapilla*)	2
White-headed finch (*Munia maja*)	5
Nutmeg finch (*Munia punctularia*)	4
Java sparrow (*Munia oryzivora*)	10
White Java sparrow (*Munia oryzivora*)	6
Parson finch (*Poëphila cincta*)	1
Bearded finch (*Spermophila* sp.)	2
Madagascar weaver (*Foudia madagascariensis*)	4
Red-billed weaver (*Quelea quelea*)	8
Whydah weaver (*Vidua paradisea*)	4
Painted bunting (*Passerina ciris*)	2
Red-crested cardinal (*Paroaria cucullata*)	10
Common cardinal (*Cardinalis cardinalis*)	1
Rose-breasted grosbeak (*Zamelodia ludoviciana*)	1
Siskin (*Spinus spinus*)	2
European goldfinch (*Carduelis elegans*)	1
Yellow hammer (*Emberiza citrinella*)	2
Common canary (*Serinus canarius*)	12
Bullfinch (*Pyrrhula europæa*)	13
Cowbird (*Molothrus ater*)	1
Purple grackle (*Quiscalus quiscula*)	1
Red-winged blackbird (*Agelaius phœniceus*)	2
Common mynah (*Acridotheres tristis*)	1
European raven (*Corvus corax*)	1
American raven (*Corvus corax sinuatus*)	1
Blue jay (*Cyanocitta cristata*)	3

European magpie (*Pica pica*)	1
American magpie (*Pica pica hudsonica*)	2
Piping crow (*Gymnorhina tibicen*)	2
Giant kingfisher (*Dacelo gigas*)	1
Sulphur-crested cockatoo (*Cacatua galerita*)	3
White cockatoo (*Cacatua alba*)	6
Leadbeater's cockatoo (*Cacatua leadbeateri*)	1
Bare-eyed cockatoo (*Cacatua gymnopis*)	2
Roseate cockatoo (*Cacatua roseicapilla*)	3
Gang-gang cockatoo (*Callocephalon galeatum*)	1
Yellow and blue macaw (*Ara ararauna*)	2
Red and yellow and blue macaw (*Ara macao*)	3
Red and blue macaw (*Ara chloroptera*)	3
Great green macaw (*Ara militaris*)	1
Kea (*Nestor notabilis*)	1
Mexican conure (*Conurus holochlorus*)	1
Carolina paroquet (*Conuropsis carolinensis*)	2
Tovi parrakeet (*Brotogerys jugularis*)	1
Cuban parrot (*Amazona leucocephala*)	2
Orange-winged amazon (*Amazona amazonica*)	1
Porto Rican amazon (*Amazona vittata*)	1
Yellow-shouldered amazon (*Amazona ochroptera*)	2
Yellow-fronted amazon (*Amazona ochrocephala*)	2
Yellow-headed amazon (*Amazona levaillanti*)	1
Lesser vasa parrot (*Coracopsis nigra*)	2
Pigeon parrakeet (*Palæornis columboides*)	1
Love bird (*Agapornis pullaria*)	3
Green parrakeet (*Loriculus* sp.)	2
Pennant's parrakeet (*Platycercus elegans*)	1
Pale-headed parrakeet (*Platycercus pallidiceps*)	1
Shell parrakeet (*Melopsittacus undulatus*)	1
Great horned owl (*Bubo virginianus*)	13
Arctic horned owl (*Bubo virginianus subarcticus*)	2
Screech owl (*Otus asio*)	2
Barred owl (*Strix varia*)	2
Barn owl (*Aluco pratincola*)	1
Sparrow hawk (*Falco sparverius*)	1
Bald eagle (*Haliæetus leucocephalus*)	13
Alaskan bald eagle (*Haliæetus leucocephalus alascanus*)	1
Short-tailed eagle (*Terathopius ecaudatus*)	1
Harpy eagle (*Thrasaëtus harpyia*)	1
Crowned hawk eagle (*Spizaëtus coronatus*)	1
East African hawk (*Buteo* sp.)	1
Red-tailed hawk (*Buteo borealis*)	2
Red-shouldered hawk (*Buteo lineatus*)	1
Sharp-shinned hawk (*Accipiter velox*)	1
Venezuelan hawk	1
Caracara (*Polyborus cheriway*)	3
Lammergeyer (*Gypaëtus barbatus*)	1
South American condor (*Sarcorhamphus gryphus*)	2
California condor (*Gymnogyps californianus*)	3
Griffon vulture (*Gyps fulvus*)	2
Egyptian vulture (*Neophron percnopterus*)	1
Pileated vulture (*Neophron pileatus*)	1
Turkey vulture (*Cathartes aura*)	5
Black vulture (*Catharista urubu*)	1
King vulture (*Gypagus papa*)	1
Ring dove (*Columba palumbus*)	17
Red-billed pigeon (*Columba flavirostris*)	4
Mourning dove (*Zenaidura macroura*)	9
Peaceful dove (*Geopelia tranquilla*)	2
Cape dove (*Œna capensis*)	2
Crested pigeon (*Ocyphaps lophotes*)	1
Chachalaca (*Ortalis vetula*)	3
Purplish guan (*Penelope purpurascens*)	1
Mexican curassow (*Crax globicera*)	2
Chapman's curassow (*Crax chapmani*)	1
Daubenton's curassow (*Crax daubentoni*)	1
Wild turkey (*Meleagris gallopavo silvestris*)	18
Peafowl (*Pavo cristata*)	37
Jungle fowl (*Gallus bankiva*)	1
Reeves's pheasant (*Phasianus reevesi*)	1
Golden pheasant (*Thaumalea picta*)	1
Silver pheasant (*Euplocamus nycthemerus*)	2
Black cock (*Lyrurus tetrix*)	1
European quail (*Coturnix communis*)	1
Hungarian partridge (*Perdix perdix*)	3
Bobwhite (*Colinus virginianus*)	1
Mountain quail (*Oreortyx picta*)	4
Scaled quail (*Callipepla squamata*)	2
California quail (*Lophortyx californica*)	1
Massena quail (*Cyrtonyx montezumæ*)	10
Purple gallinule (*Porphyrio cærulea*)	1
Black-backed gallinule (*Porphyrio melanotus*)	2
American coot (*Fulica americana*)	11
Flightless rail (*Ocydromus australis*)	2
Common cariama (*Cariama cristata*)	1
Demoiselle crane (*Anthropoides virgo*)	5
Crowned crane (*Balearica pavonina*)	2
Sandhill crane (*Grus mexicana*)	2
Australian crane (*Grus australasiana*)	1
Indian white crane (*Grus leucogeranus*)	2
Thick-knee (*Œdicnemus grallarius*)	1
Ruff (*Machetes pugnax*)	4
Black-crowned night heron (*Nycticorax nycticorax nævius*)	81
Little blue heron (*Florida cærulea*)	1
Louisiana heron (*Hydranassa tricolor ruficollis*)	1

Reddish egret (*Dichromanassa rufescens*)	3
Snowy egret (*Egretta candidissima*)	4
Great white heron (*Herodias egretta*)	1
Great blue heron (*Ardea herodias*)	4
Boat-bill (*Cancroma cochlearia*)	2
Black stork (*Ciconia nigra*)	1
White stork (*Ciconia ciconia*)	2
Marabou stork (*Leptoptilus dubius*)	1
Wood ibis (*Mycteria americana*)	2
Sacred ibis (*Ibis æthiopica*)	4
White ibis (*Guara alba*)	21
Roseate spoonbill (*Ajaja ajaja*)	3
European flamingo (*Phœnicopterus antiquorum*)	6
Trumpeter swan (*Olor buccinator*)	2
Whistling swan (*Olor columbianus*)	2
Mute swan (*Cygnus gibbus*)	2
Muscovy duck (*Cairina moschata*)	2
White muscovy duck (*Cairina moschata*)	3
Wandering tree-duck (*Dendrocygna arcuata*)	7
Fulvous tree-duck (*Dendrocygna bicolor*)	2
Australian wood-duck (*Chenonetta jubata*)	1
Egyptian goose (*Chenalopex ægyptiacus*)	1
Brant (*Branta bernicla glaucogastra*)	1
Canada goose (*Branta canadensis*)	8
Hutchins's goose (*Branta canadensis hutchinsii*)	4
Lesser snow goose (*Chen hyperboreus*)	2
Greater snow goose (*Chen hyperboreus nivalis*)	1
American white-fronted goose (*Anser albifrons gambeli*)	6
Chinese goose (*Anser cygnoides*)	3
Red-headed duck (*Marila americana*)	2
Wood duck (*Aix sponsa*)	12
Mandarin duck (*Dendronessa galericulata*)	8
Pintail (*Dafila acuta*)	6
Shoveler duck (*Spatula clypeata*)	3
Blue-winged teal (*Querquedula discors*)	1
Green-winged teal (*Nettion carolinense*)	1
Black duck (*Anas rubripes*)	2
Mallard (*Anas platyrhynchos*)	13
American white pelican (*Pelecanus erythrorhynchos*)	4
European white pelican (*Pelecanus onocrotalus*)	2
Roseate pelican (*Pelecanus roseus*)	1
Brown pelican (*Pelecanus occidentalis*)	4
Black-backed gull (*Larus marinus*)	1
Herring gull (*Larus argentatus*)	1
American herring gull (*Larus argentatus smithsonianus*)	6
Laughing gull (*Larus atricilla*)	3
Gannet (*Sula bassana*)	1
Florida cormorant (*Phalacrocorax auritus floridanus*)	8
Mexican cormorant (*Phalacrocorax vigua mexicanus*)	1
Water turkey (*Anhinga anhinga*)	6
Somali ostrich (*Struthio molybdophanes*)	1
Common cassowary (*Casuarius galeatus*)	1
Common rhea (*Rhea americana*)	3
Emu (*Dromæus novæ hollandiæ*)	1

REPTILES.

Alligator (*Alligator mississippiensis*)	16
Painted turtle (*Chrysemys picta*)	4
Diamond-back terrapin (*Malacoclemys palustris*)	1
Three-toed box-tortoise (*Cistudo triunguis*)	6
Painted box-tortoise (*Cistudo ornata*)	5
Gopher turtle (*Xerobates polyphemus*)	1
Duncan Island tortoise (*Testudo ephippium*)	2
Albemarle Island tortoise (*Testudo vicina*)	2
Comb lizard (*Ctenosaura* sp.)	1
Alligator lizard (*Sceloporus undulatus*)	2
Horned lizard (*Phrynosoma cornutum*)	1
Gila monster (*Heloderma suspectum*)	4
Green lizard (*Lacerta viridis*)	1
Anaconda (*Eunectes murinus*)	2
Common boa (*Boa constrictor*)	1
Antillean boa (*Boa diviniloqua*)	1
Cuban tree-boa (*Epicrates angulifer*)	3
Spreading adder (*Heterodon platyrhinus*)	2
Green snake (*Cyclophis æstivus*)	1
Black snake (*Zamenis constrictor*)	3
Coach-whip snake (*Zamenis flagellum*)	2
Corn snake (*Coluber guttatus*)	1
Common chicken snake (*Coluber quadrivittatus*)	2
Gopher snake (*Compsosoma corais couperii*)	1
Pine snake (*Pityophis melanoleucus*)	11
Bull snake (*Pityophis sayi*)	2
Texas chicken snake (*Ophibolus calligaster*)	2
King snake (*Ophibolus getulus*)	2
Texas garter snake (*Eutænia proxima*)	1
Water moccasin (*Ancistrodon piscivorus*)	1
Copperhead (*Ancistrodon contortrix*)	3
Diamond rattlesnake (*Crotalus adamanteus*)	4
Banded rattlesnake (*Crotalus horridus*)	2

GIFTS.

Mr. and Mrs. Franklin Adams, Pan American Union, two Haitian solenodons.
Miss M. Alexander, Moorefield, W. Va., a brown Capuchin monkey.

Dr. Paul Bartsch, Washington, D. C., two common crows.
Frederick Carl, jr., Washington, D. C., two screech owls.
Miss Catharine Carroll, Washington, D. C., a barn owl.
E. S. Case, Takoma Park, D. C., three blue jays.
Miss M. B. Cole, Washington, D. C., an alligator.
Mrs. Mary F. Crown, Washington, D. C., a yellow-headed Amazon parrot.
Mrs. R. S. Day, Washington, D. C., a common canary.
Boris de Street, Washington, D. C., an alligator.
J. R. Eddy, Lamedeer, Mont., an American badger.
Mr. Eustis, Leesburg, Va., a red-tailed hawk.
Dr. Cecil French, Washington, D. C., four Hungarian quail.
Guy M. Gribble, Buckhannon, W. Va., a red-tailed hawk.
Jesse Hand, jr., Belleplain, N. J., two king snakes.
Mr. C. A. Holland, Fenwick, Va., a bittern.
Clarence Howard, Washington, D. C., a copperhead snake.
E. C. Howe, Washington, D. C., two alligators.
W. H. Kelly, Sandusky, Ohio, two bald eagles.
Mr. Lansdale, Washington, D. C., two common opossums.
Carvel Leary, Washington, D. C., a guinea pig.
Miss Frances McMullen, Largo, Fla., an alligator snapping turtle.
C. W. Marks, Berryville, Va., a black snake.
S. S. Paschals, Chevy Chase, Md., two zebra finches.
L. E. Perry, Gorgona, Canal Zone, a spider monkey.
F. W. Pilling, Washington, D. C., 10 common canaries, a red-crested cardinal and 2 white Java sparrows.
Mrs. J. E. Pleitner, Washington, D. C., a green Amazon parrot.
N. Schutz, Washington, D. C., a screech owl.
John B. Smith, Renovo, Pa., a banded rattlesnake.
Mrs. H. Clay Stewart, Washington, D. C., two common canaries.
J. P. Taylor, Washington, D. C., a copperhead snake and a black snake.
Dr. James R. Tubman, Washington, D. C., a great horned owl.
United States Bureau of Fisheries, two northern fur seals.
James Worcester, Washington, D. C., an alligator.
Unknown donors, a hawk, a parrakeet, and a woodchuck.

LOSSES OF ANIMALS.

The most important losses during the year were a pair of clouded leopards, a lion, and a young Alaskan brown bear from parasitism; a leucoryx, a water buck, and a nilgai, from tuberculosis; a female American bison and a caribou, in the collection for 10 years, from peritonitis; two solenodons from septicemia, and two young fur seals from enteritis and heat stroke.

Dead animals, to the number of 142, were transferred to the United States National Museum. Autopsies were made, as usual, by the Pathological Division of the Bureau of Animal Industry, United States Department of Agriculture.[1]

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[1] The causes of death were as follows: Pneumonia, 10; tuberculosis, 8; pulmonary edema, 1; aspergillosis, 7; pseudomembranous tracheitis, 1; enteritis, 9; gastritis, 1; gastroenteritis, 7; pneumoenteritis, 1; intestinal coccidiosis, 7; peritonitis, 6; nephritis, 2; fatty degeneration of liver, 1; parasitism, 3; stomatitis, 2; strangulated hernia, 1; rupture of gizzard, 1; internal hemorrhage, 1; abscess of scrotum, 1; abscess of head, 1; unable to deliver young, 1; duodenitis, 1; colitis, 1; echinococcosis, 1; necrobacillosis, 1; pyocianeusbacillosis, 1; porocephalosis, 1; septicemia, 3; enterotoxism, 1; cystitis, 1; endocarditis, 1; visceral gout, 1; sarcomatosis, 2; cancer of pouch, 1; leukemia, 1; icterus, 1; impaction, 3; duodenal obstruction, 1; starvation, 2; accidents and injuries, 13; killed because unfit for exhibition, 4; result of autopsy indeterminate, 3; no cause found, 4

Statement of the collection.

ACCESSIONS DURING THE YEAR.

Presented	65
Received from Yellowstone National Park	1
Received in exchange	13
Lent	11
Purchased	130
Born and hatched in National Zoological Park	115
Total	335

SUMMARY.

Animals on hand July 1, 1910	1,424
Accessions during the year	335
Total	1,759
Deduct loss (by exchange, death, and returning of animals)	345
On hand June 30, 1911	1,414

Class.	Species.	Individuals.
Mammals	157	636
Birds	186	685
Reptiles	33	93
Total	376	1,414

VISITORS.

The number of visitors to the park during the year was 521,440, a daily average of 1,428. The largest number in any one month was 95,535, in April, 1911, a daily average for the month of 3,184.

During the year there visited the park 169 schools, Sunday schools, classes, etc., with 4,966 pupils, a monthly average of 414 pupils. This number is an increase over the previous year of 14 schools, 1,083 pupils, and an increase in the monthly average of 90 pupils. While most of the classes were from the District of Columbia, 47 of them were from neighboring States, and classes came from Meriden, Hopedale, Norton, North Attleboro, Clinton, Hudson, and Whitman, Massachusetts; Dover, Peterboro, Lancaster, and Exeter, New Hampshire; Bath, Augusta, Biddeford, Gardiner, and Sanford, Maine; Bellows Falls, Vermont; Raleigh, North Carolina; Middleport (two) and Penn Yan, New York; Waynesburg, Pennsylvania; and Hartford, Connecticut.

IMPROVEMENTS.

A house for zebras, a frame building 35 feet square, was constructed, providing four good-sized stalls with yards attached. This is now occupied by a male Grant's zebra, the male Grevy's zebra, which was returned from the experiment station of the Bureau of Animal Industry at Bethesda, Maryland, after use there in breeding, and a hybrid from the latter animal and a domestic ass.

The existing yards on the west side of the antelope house were too small, and the fences around them, which were of temporary character, had seriously

deteriorated. The construction of new steel fences was begun, inclosing a considerably larger area than the former yards, and was nearly completed by the close of the year. The yards on the north and east sides of the antelope house, which had been begun during the previous year, were completed.

The temporary bird house, which had been in very bad condition, was extensively repaired. New roof covering was put on, and the wooden floor, some of the walls and cages, and much other interior work were renewed.

Some alterations were made in the large cages in the lion house to permit more convenient handling of the animals during feeding and the cleaning of the cages. The woodwork of this portion of the building was also refinished.

The public comfort room for women, which was in a very dilapidated condition, was removed to make way for the yards of the antelope house, and a new comfort room was constructed beneath the outdoor cages of the small mammal house. A small frame building for the same purpose was erected near the Adams Mill Road entrance, that portion of the park being a much frequented resort for women with young children.

A new public comfort room for men was also constructed in the basement of the antelope house, providing permanent conveniences, which are much better and more adequate than have existed heretofore.

The drainage culvert in the beaver valley was extended to the flying cage, a distance of 800 feet, thus providing sewerage, as well as for the carrying away of surface water without the erosion which had occurred previously.

Foundations were laid for cages on the east side of the small mammal house, and a concrete walk was constructed there.

Various small improvements and repairs were made. A cage was built in the lion house with a pool for the young hippopotamus, which was received in May; a paddock with shelter was built for the chamois; an inclosure and pool for fur seals; the condor cage and cage for horned owls were extensively repaired; an inclosure with shelter was built for kangaroos; an additional watch house was built; new wagon scales were set near the shop and coal vault; and the heating conduit and mains from the central heating plant were extended to the elephant house and zebra house.

The cost of this work was:

House for zebras	$2,500
New yards on west side of antelope house	1,775
Completing yards on north and east sides of antelope house	250
Repairs to temporary bird house	1,000
Alterations and repairs to lion house	600
Cage for hippopotamus	275
Paddock for chamois	300
Inclosure and pool for fur seals	275
Repairing condor and owl cages	350
Inclosure for kangaroos	75
Extending drainage culvert	1,500
New concrete walk and cage foundations at small mammal house, with retaining walls, etc	1,050
Additional watch house	125
Extending heating conduit and mains	400
New wagon scales at shop	250
Accessory comfort room for women	350
Women's comfort room	750
Men's comfort room	750

ROADWAYS AND WALKS.

From the appropriation for reconstructing and repairing roadways and walks 4,770 linear feet, or nine-tenths of a mile of road, was treated, from 10 to 45 feet wide, averaging slightly more than 20 feet, a total of 10,700 square yards. The work varied from merely reshaping and supplying a top layer of stone to furnishing the entire thickness of roadbed material, with considerable excavating and filling in some places where the existing grades were too steep. One thousand six hundred square yards (the "concourse") were finished with tarvia. The work cost from 22 cents to $1 per square yard, and the total amount expended for roads was $7,220.

During the year 9,260 linear feet, or 1¾ miles, of walks were laid or repaired. They were from 6 to 16 feet wide, or an average width of about 9 feet, comprising in all 9,230 square yards. Of this about 6,500 square yards was old macadam walk, the remainder gravel or dirt walks. A considerable amount of excavation and filling had to be done in certain places in order to secure reasonably uniform grades, and steps were constructed at points where the grade had before been too steep. The walks are of stone macadam, the surface treated with tarvia by the penetration method. The cost of laying them was from 35 cents to 85 cents per square yard. A considerable amount of work had to be done also in providing proper drainage. The total expenditure for walks was $7,780.

Respectfully submitted.

Frank Baker, *Superintendent.*

Dr. Charles D. Walcott,
Secretary of the Smithsonian Institution.

APPENDIX V.

REPORT ON THE ASTROPHYSICAL OBSERVATORY.

SIR: I have the honor to present the following report on the operations of the Smithsonian Astrophysical Observatory for the year ending June 30, 1911:

EQUIPMENT.

The equipment of the observatory is as follows:

(*a*) At Washington there is an inclosure of about 16,000 square feet, containing five small frame buildings used for observing and computing purposes, three movable frame shelters covering several out-of-door pieces of apparatus, and also one small brick building containing a storage battery and electrical distribution apparatus.

(*b*) At Mount Wilson, California, upon a leased plat of ground 100 feet square in horizontal projection, are located a one-story cement observing structure, designed especially for solar-constant measurements, and also a little frame cottage, 21 feet by 25 feet, for observer's quarters.

There were no important additions to the instrument equipment of the observatory during the year.

In 1909 the Smithsonian Institution, at the expense of the Hodgkins fund, erected on the summit of Mount Whitney, California (height 14,502 feet), a stone and steel house to shelter observers who might apply to the Institution for the use of the house to promote investigations in any branch of science. While this structure is not the actual property of the Astrophysical Observatory, it affords an excellent opportunity for observations in connection with those taken on Mount Wilson.

WORK OF THE YEAR.

In order to thoroughly confirm the results obtained on the summit of Mount Whitney (4,420 meters or 14,502 feet) in 1909, discussed in my last annual report, an expedition again occupied that place in August, 1910. The personnel consisted of the director and Mr. G. F. Marsh, of Lone Pine, California. Nearly all of the equipment for spectrobolometric work had been left on Mount Whitney through the winter and was found in good condition. Additional apparatus for measuring the brightness of the sky by day and by night was carried up by pack train under the care of Mr. Elder, of Lone Pine. The good fortune which had attended the 1909 expedition failed for a moment in 1910, and one mule, carrying the silver-disk pyrheliometer and other loading, rolled off among the rocks and was killed. The pyrheliometer fortunately received no injury.

Solar-constant measurements were made successfully on Mount Whitney in 1910 on three successive days. Mr. Fowle made solar-constant observations

simultaneously on Mount Wilson. I give below the results obtained at Mount Wilson and Mount Whitney in 1909 and 1910:

	Sept. 3, 1909.	Aug. 12, 1910.	Aug. 13, 1910.	Aug. 14, 1910.
Solar constant:				
Mount Wilson	1.943	1.943	1.924	1.904
Mount Whitney	1.959	1.979	1.933	1.958

Taking the mean of the differences between the results obtained simultaneously at the two stations, it appears that the results obtained on Mount Whitney average 1.4 per cent higher than those obtained on Mount Wilson. But considering that the optical apparatus used on Mount Wilson comprised a silvered glass mirror coelostat, an ultra-violet crown glass prism, and two silvered glass mirrors, while that on Mount Whitney comprised only a quartz prism and two magnalium mirrors, and, furthermore, that the pyrheliometers employed at the two stations were read at very different temperatures, it is probable that the slight difference found between the results may be due wholly to experimental differences and implies no discrepancy due to the difference of altitude between the two stations.

This conclusion seems worth emphasizing. We have now made simultaneously solar-constant determinations at sea level (Washington), at over a mile altitude (Mount Wilson), and again at Mount Wilson, and at nearly 3 miles altitude (Mount Whitney). Although both the quantity and the quality of the solar radiation found at these stations differ very much, neither the "solar constant" nor the distribution of the solar energy in the spectrum outside the atmosphere, as fixed by the wholly independent measurements at these three stations, differs more than would be expected in view of the unavoidable small errors of observation. We seem justified in concluding that we do, in fact, eliminate the effects of atmospheric losses and actually determine the true quantity and quality of the sun's radiation outside the atmosphere as we might do if we could observe in free space with no atmosphere at all to hinder.

Expeditions to Mount Wilson have now been made in 1905, 1906, 1908, 1909, and 1910. The last, like the others, continued from May until November. In the earlier years the observations were not made daily, but in 1908, 1909, and 1910 daily determinations of the solar constant were made when possible. As stated in earlier reports, the results indicate a variability of the sun. In order to show the strength of the argument for this conclusion, I give in the accompanying figure a diagram showing all the "solar constant" values obtained in the first four years of observation (fig. 1).

The "solar constant" results lie between 1.80 and 2.00 calories per square centimeter per minute. I call particular attention to the two later years. It will be noted that successive days' results march step by step regularly from low to high values and the reverse, and that this order of march is not the exception, but almost without exception the rule. This seems to render it highly improbable that the fluctuations are due to accidental error, for such a regularity of fluctuation is incompatible with that supposition. As it has now been shown that the altitude of the observing station is immaterial, at least for altitudes below 3 miles, it seems also reasonable to conclude that the fluctuation is not due to faulty estimates of the losses of radiation in the air. Hence the most probable conclusion is that the sun actually varies from day to

day in its output of radiation within limts of from 5 to 10 per cent in quantity and in irregular periods of from 5 to 10 days. This conclusion I state tentatively. Before it can be accepted without question it must be confirmed by showing that the results obtained day after day at another equally good station, at a great distance, confirm those obtained simultaneously at Mount Wilson. Such a final test, it is now expected, will be made during the coming fiscal year.

Summary of solar-constant values.

	Washington.	Mount Wilson.					Mount Whitney.	
	1902-1907	1905	1906	1908	1909	1910	1909	1910
Times observed......	44	59	62	113	95	[1] 28	1	3
Mean value.........	1.960	1.925	1.921	1.929	1.896	1.914	1.959	1.956

[1] Other days of observation not yet ready.

General mean, 1.922 calories (15° C.) per square centimeter per minute.

Number of determinations, 405.

Other observations made on Mount Whitney.—Although the main purpose of the Mount Whitney expedition of 1910 was served by proving that the determinations of the solar constant of radiation are independent of the altitude of the observing station, advantage was taken of the unusual opportunity to make several other kinds of observations. Kapteyn's sky photometer was employed there on two successive nights to measure the relative brightness of the different regions of the night sky and to estimate the total quantity of sky illumination per square degree compared with that of a first-magnitude star. Yntema had employed similar apparatus in Holland. He found the average brightness of the Milky Way about two or three times that of nongalactic regions of the sky, such as the north polar region, but that the sky near the horizon was of about the same brightness as the Milky Way. He concluded that the sky at night is illuminated more by some terrestrial sources of light than by the stars.

The results obtained on Mount Whitney at nearly 3 miles elevation agreed in general with those of Yntema. The following is a summary of the principal points. Mean values are given:

Brightness of night sky.

[Polar brightness=1. Mount Whitney, 1909-1910.]

	Galactic latitude.				Near horizon.
	0° to ±5°	±15° to ±30°	±45° to ±60°	±60° to ±75°	
Relative brightness......................	2.10	1.25	1.19	1.17	1.40

The total illumination from 1 square degree of polar sky was found to be 0.0746 that of one first-magnitude star in the zenith. It is possible that the fraction just given may be a little too small, owing to a source of error discovered after the observations were ended.

Computations from the Mount Whitney results confirm Yntema's conclusion that the great increase of brightness toward the horizon can not be due to any arrangement of starlight, but must be caused by some terrestrial source of light, perhaps a continuous faint aurora.

Bolometric measurements were made on Mount Whitney to determine the relative radiation of the sky by day in all directions, as compared with the

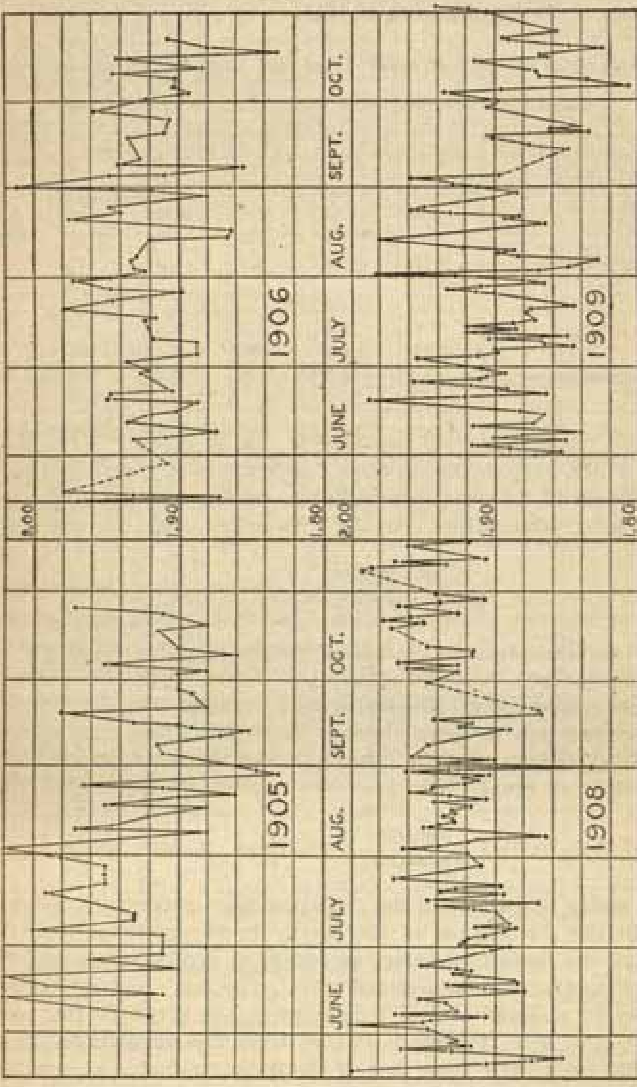

FIG. 1.—Solar-constant values.

sun. These measurements were numerous and seem to have been successful, but are not yet reduced.

The sun's energy spectrum.—A summary has been prepared showing the mean result of determinations of the distribution of the sun's energy in the spectrum, as it would be found outside the atmosphere. The measurements on which it is based include Washington, Mount Wilson, and Mount Whitney work of 1903

to 1910, and have been made with many different optical systems. There is great difficulty in getting an accurate estimate of the relative losses suffered by rays of different wave lengths in traversing the spectroscope. Especially is this the case for the violet and ultra-violet rays, where these losses are greatest. The summary has shown that further determinations are needed to fix the distribution in the extreme ultra violet, and observations for this purpose were made in June, 1911, on Mount Wilson, but are not yet reduced. I give below the summary, excluding the work of 1911.

Intensities in normal solar spectrum, outside the atmosphere.

[Observed at Washington, Mount Wilson, Mount Whitney, 1903-1910.]

	μ	μ	μ	μ	μ	μ	μ
Wave length	0.30	0.35	0.40	0.45	0.47	0.50	0.60
Intensity	440	2,700	4,345	6,047	6,253	6,064	5,047
Probable error (percentage)	50 (?)	7.3	1.5	1.4	1.8	1.9	2.1
Wave length	0.80	1.0	1.3	1.6	2.0	2.5	3.0
Intensity	2,672	1,664	897	526	245	43	12
Probable error (percentage)	1.2	0.7	0.7	1.4	2.4	4.8	45(?)

The sun's temperature.—If we employ the so-called "Wien displacement formula," which connects the absolute temperature of a perfect radiation with the wave length of its maximum radiation, we may proceed as follows, to estimate the solar temperature, on the assumption that the sun is a perfect radiator:

$$\lambda_{max}T=2930.$$

$$\text{If } \lambda_{max}=0.470\ \mu \text{ then } T=6230^\circ \text{ abs. C.}$$

Another radiation formula is that of Stefan, which connects the total quantity of radiation of a perfect radiator per square centimeter per minute with the absolute temperature. Employing this formula, still assuming the sun to be a perfect radiator, its mean distance 149,560,000 kilometers, its mean diameter 696,000 kilometers, and the mean value of the solar constant of radiation 1.922 calories per square centimeter per minute, we proceed as follows:

$$76.8\times10^{-12}\times\left(\frac{696,000}{149,560,000}\right)^2 T^4=1.922 \quad T=5830^\circ \text{ abs. C.}$$

A third means of estimating the sun's probable temperature comes from comparisons of the distribution of the energy in its spectrum with that in the spectrum of the perfect radiator, as computed according to the Wien-Planck formula of spectrum energy distribution. The sun's energy curve and that of the perfect radiator at two temperatures are given in the accompanying illustration (fig. 2). It appears at once from this comparison that the sun's radiation differs greatly from that of the perfect radiator at any temperature. The solar radiation is greater in the infra-red spectrum, and much less in the ultra-violet spectrum, than that of perfect radiators giving approximately the same relative spectral distribution as the sun for visible rays. Taking everything in consideration, the solar energy spectrum seems most comparable with that of a perfect radiator between 6,000° and 7,000° in absolute temperature.

The causes of the discrepancies we have noted may be several. First, there is the influence of the selective absorption of rays in the Fraunhofer lines.

These lines are much crowded toward and within the ultra-violet spectrum, so that perhaps this indicates a principal reason for the weakness of the sun's spectrum in that region. Second, it seems probable that we are dealing with a mixture of rays from sources at different temperatures. The cause and

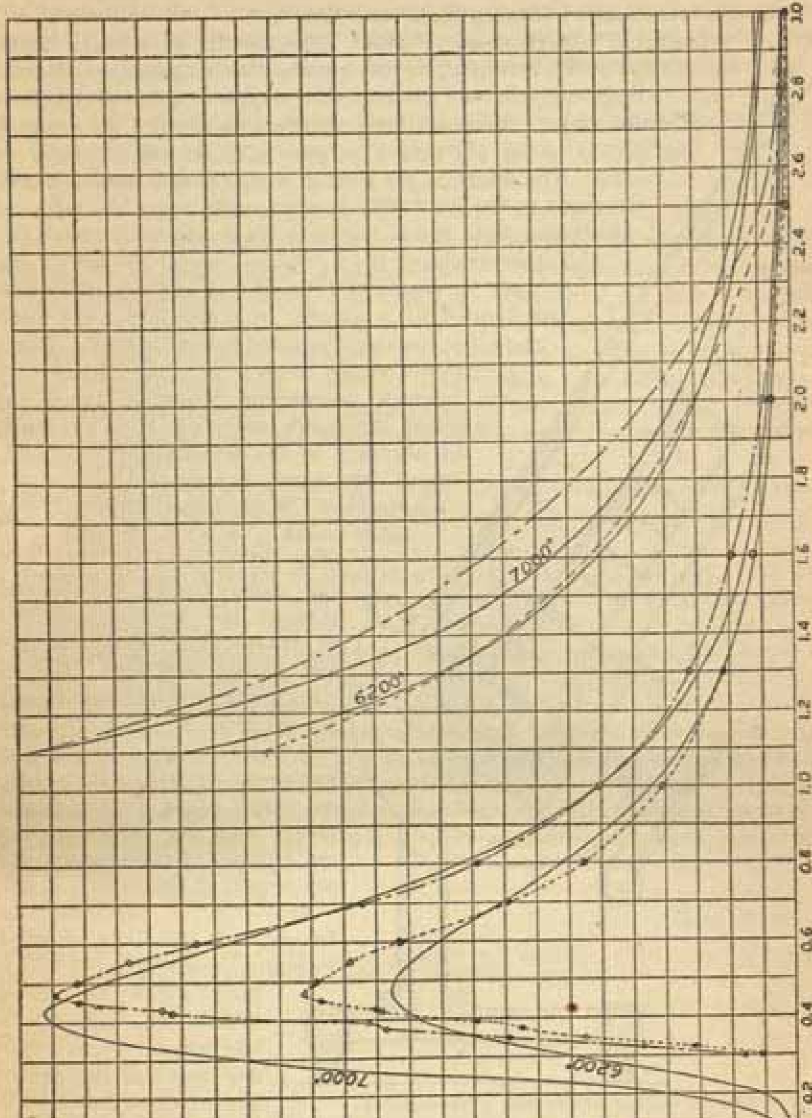

FIG. 2.—Energy spectrum of sun compared with black body.

effect of this difference may each be twofold: For, firstly, at the center of the sun's visible disk we look probably to deeper-lying and hence hotter layers than at the sun's edge, where the line of sight is oblique; and, secondly, since the transmission of the sun's atmosphere is probably like the earth's,

much less for violet and ultra-violet rays than for red and infra-red ones, we probably get infra-red rays from deeper-lying and hence hotter layers in the sun than we do ultra-violet ones.

We conclude that the solar radiation comes from sources ranging in temperature perhaps between the limits 5,000° and 7,000° absolute centigrade, but mostly from sources between 6,000° and 7,000°.

Washington observations.—Further experiments have been made, under Mr. Fowle's direction, on the transmission of radiation of great wave lengths through long columns of air containing known qualities of water vapor. Many of these observations are not yet reduced, so that it is not yet proper to give a numerical summary of results. The length of the column experimented upon has been increased to 800 feet. The measurements cover the infra-red spectrum, from the A line to a wave length of about 17μ. The observations of the water contents of the air column are made by means of pairs of wet and dry thermometers located at a number of points along the path. The air is thoroughly stirred before readings. Check experiments by Mr. Aldrich, in which he drew the air through phosphorus pentoxide tubes and weighed the water absorbed, have confirmed the accuracy of the water-vapor determinations. Mr. Fowle has made a preliminary comparison of the upper infra-red spectrum bands ρ, σ, τ, Φ, Ψ, and Ω, as observed through the tube with the same bands as observed through the whole atmosphere at Washington, Mount Wilson, and Mount Whitney. The results are most interesting, though not yet ripe for publication, and will probably lead to more exact knowledge of the total quantity of water vapor in the atmosphere, and its variation with the altitude of the observer and the season of the year.

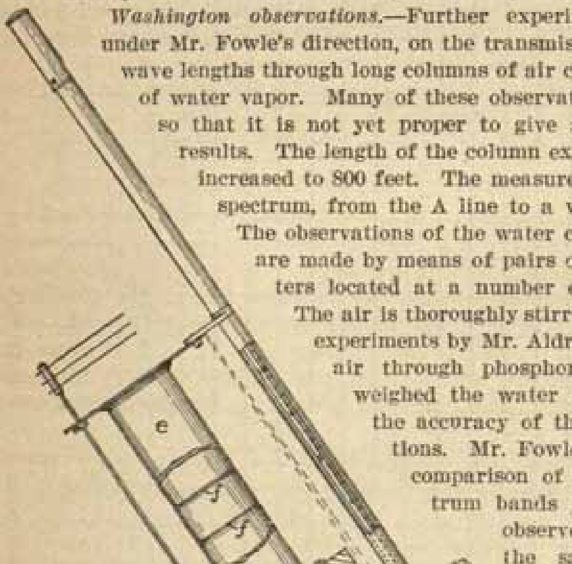

Fig. 3.—Abbot silver disk pyrheliometer.

Reduction of observations.—Upward of 100 days of solar-constant measurements have been made on Mount Wilson on each of the last several years. Each day requires the equivalent of three full days of computation. This work is being done at Washington by Messrs. Fowle and Aldrich and Miss Graves and certain graphical parts of it by minor clerk Segal. The solar-constant reductions are computed as far as the middle of the observing season of 1910.

Pyrheliometry.—Additional comparisons of the Mount Wilson secondary pyrheliometers have been made with primary standard pyrheliometer No. 3. These are not yet all reduced, but such as have been finished confirm the results of the previous fiscal year, so that we may regard the scale of absolute pyrheli-

ometry as now satisfactorily established, and with it the mean value of the solar constant of radiation for the epoch 1905–1910 as fixed at 1.922 calories per square centimeter per minute.

Additional copies of the secondary silver-disk pyrheliometer shown in the accompanying illustration (fig. 3) have been standardized and sent abroad by the Institution as loans or purchases. There have now been sent copies to Russia, Germany, France, Italy, England, Peru, Argentina, and several within the United States, making in all 10 copies now in other hands than ours, besides several now being made to order. The Institution has undertaken the business relating to furnishing these pyrheliometers, which are standardized at the Astrophysical Observatory, to promote exact knowledge of the sun and its possible variability.

SUMMARY.

The year has been distinguished by a successful expedition to Mount Whitney. The results obtained there confirm the view that determinations of the intensity of the solar radiation outside the earth's atmosphere by the spectrobolometric method of high and low sun observation are not dependent on the observer's altitude above sea level, provided the conditions are otherwise good. The Mount Whitney expedition furnished opportunities also for measurements of the brightness of the sky by day and by night, the influence of water vapor on the sun's spectrum, and the distribution of the sun's energy spectrum outside the atmosphere.

Solar-constant observations and closely related researches were continued daily at Mount Wilson until November, 1910, and were taken up again in June, 1911.

Further research tends to confirm the conclusion that the sun's output of radiation varies from day to day in a manner irregular in period and quantity, but roughly running its courses within periods of 5 to 10 days in time and 3 to 10 per cent in amplitude. Assurance seems now complete that this result will be tested in the next fiscal year by long-continued daily observations made simultaneously at two widely separated stations.

Many copies of the silver-disk secondary pyrheliometer have been standardized and sent out to observers in this and foreign countries to promote exactly comparable observations of the sun's radiation.

Measurements of the transparency, for long-wave radiation, of columns of air containing known quantities of water vapor have been continued, and promise highly interesting results.

Respectfully submitted.

C. G. Abbot, *Director.*

Dr. Charles D. Walcott,
Secretary of the Smithsonian Institution.

Appendix VI.

REPORT ON THE LIBRARY.

Sir: I have the honor to present the following report on the operations of the Library of the Smithsonian Institution for the fiscal year ending June 30, 1911, which was prepared by Mr. Paul Brockett, assistant librarian, who had charge until June 1, 1911.

The following improved methods and consolidation of work have been adopted during the past five years by the Library, in the interest of economy and efficiency:

The catalogue has been modified so as to include the author and donor cards and all previous records, thus making it necessary to consult only one file of cards for any information relating to the contents of the Library. The accession record is typewritten on sheets in accordance with the loose-leaf binding system, thus saving the time of copying titles by hand. The annuals have been transferred from the periodical record to the author catalogue, thus avoiding the making of two entries.

A new system of filing letters in numbered folders, with a card index, has been introduced, making easily accessible the correspondence which, in conjunction with the author and donor catalogue, forms a permanent record of the exchanges for the Smithsonian publications. The old files are gradually being rearranged and incorporated with the new system.

The lending of books in the reference room and periodical reading room has been placed in charge of one person, in connection with other duties.

The titles of purchased books are now entered on cards which are filed alphabetically. These card entries take the place of entries on sheets in book form, with card index.

With a thoroughly modern equipment in the way of furniture and fixtures greater improvements could be made than is possible at present.

Extension of space occupied by library.—Tentative plans have been prepared and submitted for fireproof bookstacks and bookcases for the large hall on the main floor of the Smithsonian Building to contain the libraries of the Government bureaus under the Smithsonian Institution. More definite plans are now in preparation.

International Congress of Archivists and Librarians and the International Congress of Bibliography and Documentation.—The Institution was represented by the assistant librarian, Mr. Paul Brockett, who presented a paper giving the views of the Smithsonian Institution in the matter of international exchange. At the same time he made observations on the methods and arrangement of European libraries. A separate report on this matter has been submitted by him.

ACCESSIONS.

For the Smithsonian deposit, Library of Congress, the accessions recorded numbered 3,136 volumes, 1,277 parts of volumes, 3,137 pamphlets, and 489 charts, making a total of 8,039 publications. The accession numbers run from 500,001 to 504,149.

The parts of serial publications entered on the card catalogue numbered 24,426, and 1,100 slips for completed volumes were made, and 100 cards for new periodicals and annuals.

These publications were forwarded to the Library of Congress immediately upon their receipt and entry. In their transmission 230 boxes were required, containing approximately the equivalent of 9,200 volumes. The actual number of pieces sent, including parts of periodicals, pamphlets, and volumes, was 26,286. This statement does not, however, include about 3,200 parts of serial publications secured in exchange to complete sets and transmitted separately.

Inaugural dissertations and academic publications were received from universities at the following places:

Basel.	Halle-an-der-Saale.	Paris.
Bonn.	Heidelberg.	Prague.
Berlin.	Kiel.	Rostock.
Breslau.	Leipzig.	St. Petersburg.
Cuzco.	Liege.	Tübingen.
Dorpat.	London.	Utrecht.
Freiburg i. B.	Lund.	Würzburg.
Giessen.	Marburg.	Zürich.
Graz.	New Haven.	
Greifswald.	Oviedo.	

Similar publications have been received from the technical high schools at Berlin, Braunschweig, Karlsruhe, and Munich.

The office library received 440 volumes and pamphlets, and 77 parts of volumes and charts, making a total of 517 publications. Thirteen volumes were purchased for the employees' library and one received by donation.

As already mentioned, an author catalogue, combining author and donor entries on cards of standard size was established this year and has taken the place of the previous "donor" record. Catalogue cards made for the author-donor catalogue numbered 3,199. In addition, a new finding list of 320 entries was made for the periodicals in the reading room, making a total of 3,519 cards. The recataloguing of scientific serials and annuals was commenced. The volumes recatalogued numbered 1,008.

The policy of sending foreign public documents presented to the Institution to the Library of Congress without stamping or entering has been continued, and the number of publications given above does not include these, nor does it include other publications for the Library of Congress received through the International Exchange Service.

The work of checking up and completing the Smithsonian deposit sets of publications of scientific societies and learned institutions of the world has been continued, and those of France have received special consideration.

DUPLICATES.

For a number of years about 10,000 duplicate Government documents returned by the Library of Congress, principally relating to statistics, were stored in the south tower of the Smithsonian Building. With the assistance of the International Exchanges during the previous year these publications were arranged and listed and later the larger part was turned over to the New York Public Library to complete its sets. Public documents of the United States were returned to the Superintendent of Documents.

EXCHANGES.

The establishing of new exchanges and the securing of missing parts to complete sets of publications in the Smithsonian Library required the writing of 2,600 letters, resulting in the addition of about 100 periodicals and in the receipt of about 3,200 missing parts.

The mail receipts numbered 32,647 packages, and 3,500 packages were received through the International Exchange Service. The publications contained therein were stamped and distributed for entry from the mail desk.

About 4,453 acknowledgments were made on the regular forms in addition to the letters which were written in acknowledgment of publications received in response to the requests of the Institution for exchange.

New exchanges of the annual reports of the American Historical Association from the allotment agreed upon for that purpose resulted in the acquisition of a number of publications of historical societies throughout the world, which were added to the Smithsonian deposit in the Library of Congress.

READING ROOM.

The periodical bins in the reading room were rearranged and, as already mentioned, a new finding list was made out on cards which were arranged alphabetically. Publications no longer consulted were transferred to the permanent sets, either in the Smithsonian deposit or in some one of the libraries of the Government branches of the Institution to which they belong. This gives the Institution and its branches a thoroughly useful periodical reading room.

As many of the publications kept in this room are not to be found in other American libraries, they are consulted not only by Washington investigators, but by some from other centers. During the year the scientific staff of the Institution and its branches made use of 131 bound volumes of periodicals, and 2,949 parts of scientific periodicals and popular magazines. In addition, the various bureaus of the Government continue to avail themselves of the opportunity to use these publications, as well as those in the sectional libraries of the branches of the institution, and the library is frequently visited by investigators from all parts of the world.

ART ROOM.

No additions were made to the art objects or engravings in this room during the past year. With the additional space available for the use of the Division of Graphic Arts in the National Museum, it is expected that some of the engravings will be exhibited there.

THE EMPLOYEES' LIBRARY.

The books added to this library by purchase numbered 13, and one publication was presented. By binding, 415 volumes of periodicals were made available for circulation. The total number of books borrowed was 1,876. A number of books selected especially for the purpose were sent to the National Zoological Park, as in previous years.

LIBRARIES OF THE SMITHSONIAN BRANCHES.

United States National Museum.—The congestion in the museum library reported last year has been relieved to a certain extent by the temporary employment of four cataloguers and the assignment of space on two of the

galleries in the old Museum building for sorting and arranging all the duplicate material. The duplicates were arranged, placed on temporary shelving, and roughly catalogued, and the question of disposing of such part of them as are not required in the general library or by the scientific staff will be taken up during the early part of the coming fiscal year.

Many important gifts were received during the year, and the following members of the staff have presented publications: Dr. Theodore N. Gill, Mr. J. H. Riley, Dr. C. W. Richmond, Mr. Robert Ridgway, Dr. W. H. Dall, Dr. Paul Bartsch, Mr. W. H. Holmes, Dr. Walter Hough, Dr. F. H. Knowlton, Mr. J. C. Crawford, and the late Mr. D. W. Coquillett.

The Museum library now contains 40,211 volumes, 66,674 unbound papers, and 110 manuscrips. The accessions during the year consisted of 1,911 books, 4,014 pamphlets, and 202 parts of volumes; 878 books, 1,033 complete volumes of periodicals, and 4,181 pamphlets were catalogued.

Attention has been given to the preparation of volumes for binding, with the result that 809 books were sent to the Government bindery.

The number of books, periodicals, and pamphlets borrowed from the general library amounted to 28,028, among which were 5,582 obtained from the Library of Congress and other libraries, and 4,142 assigned to the sectional libraries of the Museum.

One sectional library has been added to those already established, and the complete list now stands as follows:

Administration
Administrative assistant's office
Anthropology
Biology
Birds
Botany
Comparative anatomy
Editor's office
Ethnology
Fishes
Geology
History
Insects
Invertebrate paleontology
Mammals
Marine invertebrates
Materia medica
Mesozoic fossils
Mineralogy
Mollusks
Oriental archeology
Paleobotany
Parasites
Physical anthropology
Prehistoric archeology
Reptiles and batrachians
Superintendent's office
Taxidermy
Technology
Vertebrate paleontology

The records of the Museum library consist of an authors' catalogue, an accession book, a periodical record on standard cards, and a lending record. This lending record is on cards and includes the books borrowed from the Library of Congress and other libraries for the use of the scientific staff. No changes were made either in the arrangement or in the methods of carrying on this work.

Letters requesting new exchanges and for the purpose of completing the sets already in the Museum library have been given every consideration, and a number of titles have been added in this way.

Owing to the crowded condition of the general library, it has been necessary to use the reading room as a place for receiving and distributing publications for the Museum library. The transfer and arranging of the duplicates on the galleries will relieve this condition to some extent and make it possible for that work to be done elsewhere.

Bureau of American Ethnology.—The report of this library will be made by the ethnologist in charge and incorporated in his general report.

Astrophysical Observatory.—A thorough overhauling of this library and the removal of duplicates and such other material as is not needed was undertaken during the year. As a result, the observatory now has for reference a very efficient working library relating to astrophysics and allied subjects. During

the year 93 volumes and 11 parts of volumes were added, making a total addition of 104 publications.

National Zoological Park.—A small reference library of zoological books is maintained at the park, to which 15 volumes were added during the year.

Summary of accessions.—The following statement summarizes all the accessions during the year, except for the Bureau of American Ethnology, which is separately administered:

Smithsonian deposit in Library of Congress, including parts to complete sets	11,239
Smithsonian office, Astrophysical Observatory, National Zoological Park, and International Exchanges	676
United States National Museum Library	6,127
Total	18,042

Respectfully submitted.

F. W. True,
Assistant Secretary in charge of Library and Exchanges.

Dr. Charles D. Walcott,
Secretary of the Smithsonian Institution.

Appendix VII.

REPORT ON THE INTERNATIONAL CATALOGUE OF SCIENTIFIC LITERATURE.

Sir: I have the honor to submit the following report on the operations of the United States Bureau of the International Catalogue of Scientific Literature for the year ending June 30, 1911, together with a report of the proceedings at the Second International Convention of the International Catalogue of Scientific Literature held in London July 12 and 13, 1910, outlining the general condition of the whole enterprise:

The appropriation made by Congress for the maintenance of the bureau during the year was $7,500, an increase of $1,500 over the appropriation for the previous year.

Five persons are regularly employed in the bureau, and the services of temporary clerical assistants occasionally engaged.

In order to properly analyze and classify the many scientific works now being published in the United States it is not only desirable but necessary to obtain the advice and assistance of scientific men who are specialists in the several sciences included in the scope of the catalogue, and the increase of $1,500 in the appropriation for the catalogue this year has made it possible to have some of the more technical papers referred to such specialists.

It is a matter of gratification to report that the utmost interest has been shown by all the scientific men who have been approached for aid, and that for a nominal sum classification citations are prepared and furnished to the bureau, thus rendering it possible for the scientific publications of the United States to be not only indexed in a thorough bibliographical manner, but also, when necessary, classified by specialists. The classification numbers used in the subject-catalogue refer to the subject-contents of the papers cited, and furnish the equivalent of an abstract of each paper indexed.

During the year 26,020 cards were sent from this bureau, as follows:

Literature of—	
1901	3
1902	26
1903	28
1904	218
1905	129
1906	374
1907	423
1908	1,301
1909	8,836
1910	14,682
Total	26,020

Thirty-two regional bureaus are now cooperating in the preparation and publication of the International Catalogue of Scientific Literature. The catalogue consists of 17 annual volumes published by a central bureau in London. The regional bureaus are maintained by the countries they represent, usually

by direct governmental grants; the central bureau is maintained by funds derived from subscriptions to the work. Supreme control of the enterprise is vested in a body known as an international convention which met in London in 1905 and again in July, 1910, thereafter to meet every 10 years. Each country maintaining a regional bureau has the right to send delegates to this convention. The assistant in charge of the regional bureau for the United States was appointed by the Secretary of the Smithsonian Institution to represent the United States at the second international convention. The principal countries of the world sent delegates to the convention as follows: Austria, Belgium, Denmark, France, Germany, Netherlands, India, Italy, Japan, New South Wales, Russia, South Australia, Sweden, the United Kingdom, and the United States.

At the opening meeting held in the rooms of the Royal Society on July 12, 1910, Sir Archibald Geikie, president of the Royal Society, was elected chairman, and Prof. Henry E. Armstrong, F. R. S., vice chairman. The report of the executive committee was then laid before the convention. This report stated that the seven annual issues of the catalogue already published, comprising 117 volumes, had cost the London central bureau to edit, print, and publish, \$257,980, for which \$246,410 had been received from the subscribers to the catalogue. Each annual issue of 17 volumes had averaged 9,117 pages. From estimates made it appeared that when the first 10 annual issues were published the receipts and expenditures of the central bureau would probably balance, and it was thought that taking into account the extent and difficulty of the enterprise this result would not be unsatisfactory.

While the gross annual income received from subscriptions has exceeded the estimate originally made by an average of over \$8,000, the cost of editing and printing has been much greater than was originally estimated. This is due mainly to the fact that the size of each issue of the catalogue has greatly exceeded the original estimate, and also, in a lesser degree, to the fact that an edition of 1,000 copies, instead of 500, was printed. The working capital needed was also larger than originally estimated, it being necessary for the Royal Society to advance to the central bureau \$37,500, on which interest is paid.

Although the International Catalogue is understood to be a permanent organization it is one of the duties of each convention to authorize the continuation of the publication for definite periods. The following motion, therefore, was made and it was resolved:

> That in view of the success already achieved by the International Catalogue of Scientific Literature and the great importance of the objects promoted by it, it is imperative to continue the publication of the catalogue at least during the period 1911–1915, and, on recommendation of the international council, during the subsequent five years 1916–1920.

After several motions concerning details of organization, it was unanimously voted "that it is most desirable that a capital fund should be obtained for the catalogue." It is now apparent that a capital fund to be at the disposal of the central bureau has been urgently needed since the beginning of the undertaking. Lacking a capital fund, it has been necessary for the central bureau to borrow money on which interest has to be paid, and on account of lack of funds it has been impossible to carry out several plans looking to the general improvement of the work. Had a capital fund been available in the beginning of the enterprise, it would not have been necessary for the subscription price to be placed at such a high figure. Consequently, a larger edition could have been disposed of and at a lower rate to each subscriber. At the session of the convention on July 13, methods of administration were discussed and the following resolution passed:

That each regional bureau be requested to prepare a list of journals in each science which the catalogue will completely index in the annual issue following the year of publication, and that the central bureau be authorized to publish the lists thus prepared.

The new List of Journals will consist of titles of publications devoted almost exclusively to scientific matters, and these journals will be given precedence in the work of the regional bureaus, though references to scientific papers published in other than regular scientific journals will eventually find a place in the catalogue. Some such action was necessary on account of the impossibility of dealing promptly with the vast number of semiscientific journals now published throughout the world, and, as promptness of publication is one of the most desirable features in an index-catalogue, it was necessary to find some means whereby an index to the more important papers could be prepared practically as soon as the papers themselves were published.

To render it possible to promptly publish future volumes of the catalogue the following resolution was adopted:

That the resolution of the year 1900 authorizing the central bureau to close these volumes at different stated dates, each volume to correspond to the literature of a period of 12 months, be confirmed.

The effect of this resolution will be that the separate volumes of the catalogue will not necessarily cover the whole calendar year but will cover a period of 12 months. A number of discussions then followed, pertaining to plans for improvements in the organization and general work of the regional bureaus. It was then resolved:

That in view of the resolution adopted unanimously by the representatives of the various countries constituting the convention, desiring the Royal Society to continue its responsibility for the publication of the International Catalogue for a further period, the committee appointed be instructed: (1) To take all possible steps to prevent reduplication by the publication of several annual and similar catalogues and indexes on the same subject, by making arrangements such as those now in force with the Zoological Society of London. (2) To obtain further assistance and cooperation in the preparation of the material of the catalogue from the principal scientific societies and academies and the organizations which collect materials for indexing scientific literature.

The idea now seems to prevail that the organization of the International Catalogue of Scientific Literature will gradually be able to cooperate with the present editors and publishers of the various scientific indexes and yearbooks, so that the annual volumes of the International Catalogue will eventually entirely supersede and take the place of all similar publications. This will not only be of common benefit to the International Catalogue and to the societies and private individuals now doing such work, but will greatly assist scientific investigators and librarians in whose interest the International Catalogue is prepared.

The question of publishing a decennial index was then discussed and it was decided that on account of the great expense necessarily involved the work could not for the present be undertaken. The matter was left for the action of the next international council, which will be held within the next two years.

During the meeting of the convention the foreign delegates were the recipients of numerous and gracious hospitalities from the Royal Society, the Royal Society Club, and individually from the English members of the convention.

Very respectfully, yours,

LEONARD C. GUNNELL,
Assistant in Charge.

DR. CHARLES D. WALCOTT,
Secretary of the Smithsonian Institution.

Appendix VIII.

REPORT ON THE PUBLICATIONS.

Sir: I have the honor to submit the following report on the publications of the Smithsonian Institution and its branches during the fiscal year ending June 30, 1911:

The total number of copies of publications of the Smithsonian Institution and its branches distributed during the year was 197,206. This aggregate included 643 volumes and separates of Smithsonian Contributions to Knowledge, 35,935 of Smithsonian Miscellaneous Collections, 19,622 special publications, including 2,743 volumes on the Harriman Alaska expedition; 518 publications not included in the Smithsonian series; 22,482 annual reports and bulletins of the Bureau of American Ethnology, and 110,000 copies of the various publications of the National Museum.

I. SMITHSONIAN CONTRIBUTIONS TO KNOWLEDGE.

The Langley Memoir on Mechanical Flight which was begun by the late Secretary Langley in 1904, and continued by Mr. Charles M. Manly, assistant in charge of experiments, was in type and nearly ready for distribution at the close of the year. This work forms a part of volume 27 of the Contributions to Knowledge.

II. SMITHSONIAN MISCELLANEOUS COLLECTIONS.

In the series of Smithsonian Miscellaneous Collections were published (1) cover and preliminary pages for volume 51; (2) two papers of volume 53, with cover, preliminary pages, and index, completing that volume; (3) thirteen papers of volume 56; (4) four papers of volume 57; (5) and the Smithsonian Physical Tables, by F. E. Fowle, forming part of volume 58.

The issues of the Smithsonian Miscellaneous Collections during the year were as follows:

1928. Smithsonian Miscellaneous Collections. Cover and preliminary pages for volume 54. Octavo. Pages v.

1934. Cambrian Geology and Paleontology. No. 6: Olenellus and other Genera of the Mesonacidæ. By Charles D. Walcott. Published August 12, 1910. Octavo. Pages 231–422 (unpaged index), with Plates 23–44. Volume 53, No. 6.

1939. Cambrian Geology and Paleontology. No. 7: Pre-Cambrian Rocks of the Bow River Valley, Alberta, Canada. By Charles D. Walcott. Published August, 1910. Octavo. Pages 423–431, with Plates 45–47. Volume 53. No. 7.

1940. Cambrian Geology and Paleontology. II. Abrupt Appearance of the Cambrian Fauna on the North American Continent. By Charles D. Walcott. Published August 18, 1910. Octavo. Pages 1–16. Volume 57, No. 1.

1941. Notes on a Horn-feeding Lepidopterous Larva from Africa. By August Busck. Published July, 1910. Octavo. Pages 2, with 2 plates. Volume 56, No. 8.

1942. Description of Seven New Species of East African Mammals. By Edmund Heller. Published July 22, 1910. Octavo. Pages 5, with three plates. Volume 56, No. 9.

1943. Smithsonian Miscellaneous Collections. Cover and preliminary pages for volume 51. Octavo.

1944. Smithsonian Physical Tables. Fifth Revised Edition. By F. E. Fowle, aid, Smithsonian Astrophysical Observatory. Published May 17, 1911. Octavo. Pages xxxiv, 318. Volume 58, No. 1.

1945. New Landshells from the Smithsonian African Expedition. By William Healey Dall. Published July 22, 1910. Octavo. Pages 3. Volume 56, No. 10.

1946. Development of the Digestive Canal of the American Alligator. By Albert M. Reese, Professor of Zoology, West Virginia University. Published October 29, 1910. Octavo. Pages 25, with 15 plates. Volume 56, No. 11.

1947. The Flying Apparatus of the Blow-Fly. By Dr. Wolfgang Ritter. Hodgkins Fund. Published May 11, 1911. Octavo. Pages 76, with 20 plates. Volume 56, No. 12.

1949. Cambrian Geology and Paleontology. By Charles D. Walcott. Cover, preliminary pages, and index for papers 1 to 7. Published June 1, 1911. Octavo. Pages ix, 433–498. Volume 53.

1988. Two New African Ratels. By N. Hollister. Published October 10, 1910. Octavo. Pages 3. Volume 56, No. 13.

2003. Descriptions of Ten New African Birds. By Edgar A. Mearns. Published December 23, 1910. Octavo. Pages 7. Volume 56, No. 14.

2004. New Species of Insectivores from British East Africa, Uganda, and the Sudan. By Edmund Heller. Published December 23, 1910. Octavo. Pages 8, with one plate. Volume 56, No. 15.

2005. Some Results of Recent Anthropological Exploration in Peru. By Aleš Hrdlička. Published April 26, 1911. Octavo. Pages 16, with four plates. Volume 56, No. 16.

2006. New Species of Rodents and Carnivores from Equatorial Africa. Published February 28, 1911. Octavo. Pages 16. Volume 56, No. 17.

2007. Bibliography of the Scientific Writings of R. E. C. Stearns. By Miss Mary R. Stearns. With Biographical Sketch by William H. Dall. Published April 12, 1911. Octavo. Pages 15, with one plate. Volume 56, No. 18.

2008. The Silver Disk Pyrheliometer. By. C. G. Abbot. Published March 31, 1911. Octavo. Pages 10, with one plate. Volume 56, No. 19.

2009. Cambrian Geology and Paleontology. II. No. 2. Middle Cambrian Merostomata. By Charles D. Walcott. Published April 8, 1911. Octavo. Pages 17–40, with six plates. Volume 57, No. 2.

2010. Descriptions of Fifteen New African Birds. By Edgar A. Mearns. Published April 17, 1911. Octavo. Pages 11. Volume 56, No. 20.

2011. Cambrian Geology and Paleontology. II. No. 3: Middle Cambrian Holothurians and Medusæ. By Charles D. Walcott. Published June 13, 1911. Octavo. Pages 41–68, with Plates 8–13. Volume 57, No. 3.

2012. Cambrian Geology and Paleontology. II. No. 4: Cambrian Faunas of China. By Charles D. Walcott. Published June 17, 1911. Octavo. Pages 69–108, with Plates 14–17. Volume 57, No. 4.

The following papers of Smithsonian Miscellaneous Collections were in press at the close of the year:

2014. Cambrian Geology and Paleontology. II. No. 5: Middle Cambrian Annelids. By Charles D. Walcott. Pages 109–144, with Plates 18–23. Volume 57, No. 5.

2015. Description of a New Genus and Species of Hummingbird from Panama. By E. W. Nelson. Volume 56, No. 21.

III. SMITHSONIAN ANNUAL REPORTS.

The annual report for 1909 was published in January, 1911.

1986. Annual Report of the Board of Regents of the Smithsonian Institution, showing Operations, Expenditures, and Conditions of the Institution for the year ending June 30, 1909. Octavo. Pages x, 751, with 73 plates and 4 maps. Containing publications 1915, 1916, and 1950–1985.

Small editions of the following papers, forming the general appendix of the Annual Report of the Board of Regents for 1909, were issued in pamphlet form:

1950. The Future of Mathematics. By Henri Poincaré. Pages 123–140.

1951. What Constitutes Superiority in an Airship. By Paul Renard. Pages 141–156.

1952. Researches in Radiotelegraphy. By J. A. Fleming. Pages 157–183, with two plates.

1953. Recent Progress in Physics. By Sir J. J. Thomson. Pages 185–205.

1954. Production of Low Temperatures, and Refrigeration. By L. Marchis. Pages 207–224.

1955. The Nitrogen Question from the Military Standpoint. By Charles E. Munroe. Pages 225–236.

1956. Simon Newcomb. By Ormond Stone. Pages 237–242, with one plate.

1957. Solar-radiation Researches, by Jules César Janssen. By H. de le Baume Pluvinel. Pages 243–251, with one plate.

1958. The Return of Halley's Comet. By W. W. Campbell. Pages 253–259, with four plates.

1959. The Upper Air. By E. Gold and W. A. Harwood. Pages 261–269.

1960. The Formation, Growth, and Habit of Crystals. By Paul Gaubert. Pages 271–278.

1961. The Distribution of Elements in Igneous Rocks. By Henry S. Washington. Pages 279–304.

1962. The Mechanism of Volcanic Action. By H. J. Jonston-Lavis. Pages 305–315, with 3 plates.

1963. Conservation of Natural Resources. By James Douglas. Pages 317–329.

1964. The Antarctic Land of Victoria. By Maurice Zimmermann. Pages 331–353.

1965. Some Results of the British Antarctic Expedition, 1907–9. By E. H. Shackleton. Pages 355–368, with 6 plates and 3 maps.

1966. The Oceanography of the Sea of Greenland. By D. Damas. Pages 369–383, with 2 plates.

1967. From the Niger, by Lake Chad, to the Nile. By Lieut. Boyd Alexander. Pages 385–400, with 3 plates.

1968. Mesopotamia: Past, Present, and Future. By Sir William Willcocks. Pages 401–416, with 4 plates and 1 map.

1969. Albert Gaudry and the Evolution of the Animal Kingdom. By Ph. Glangeaud. Pages 417–429.

1970. Charles Darwin. By August Weismann. Pages 431–452.

1971. Present Problems in Plant Ecology: Problems of Local Distribution in Arid Regions. By Volney M. Spalding. Pages 453–463.

1972. The Instinct of Self-concealment and the Choice of Colors in the Crustacea. By Romuald Minkiewicz. Pages 465–485.

1973. The Origin and Development of the Parasitical Habits in the Cuculidæ. By C. L. Barrett. Pages 487–492, with 2 plates.

1974. Some Remarks on the Protective Resemblance of South African Birds. By Alwin Haagner. Pages 493–504, with 2 plates.

1975. An inquiry into the History of the Current English Names of North American Land Birds. By Spencer Trotter. Pages 505–519.

1976. Condition of Wild Life in Alaska. By Madison Grant. Pages 521–529, with 1 plate.

1977. Recent Discoveries Bearing on the Antiquity of Man in Europe. By George Grant MacCurdy. Pages 531–583, with 18 plates.

1978. European Population of the United States. By W. Z. Ripley. Pages 585–606.

1979. The Republic of Panama and its People. By Eleanor Yorke Bell. Pages 607–637, with 14 plates.

1980. Ceramic Decoration: Its Evolution and Applications. By Louis Franchet. Pages 639–650.

1981. Some Notes on Roman Architecture. By F. T. Baggallay. Pages 651–667, with 4 plates.

1982. The Relation of Science to Human Life. By Adam Sedgwick. Pages 669–682.

1983. Intellectual Work among the Blind. By Pierre Villey. Pages 683–702.

1984. The Relation of Mosquitoes, Flies, Ticks, Fleas, and other Arthropods to Pathology. By G. Marotel. Pages 703–722.

1985. Natural Resistance to Infectious Disease and its Reinforcement. By Simon Flexner. Pages 723–738.

The report of the executive committee and Proceedings of the Board of Regents of the Institution, as well as the report of the Secretary, for the fiscal year ending June 30, 1910, both forming part of the annual report of the Board of Regents to Congress, were published in pamphlet form in December, 1910, as follows:

2001. Report of the Executive Committee and Proceedings of the Board of Regents for the year ending June 30, 1910. Pages 21, with 1 plate.

2002. Report of the Secretary of the Smithsonian Institution for the year ending June 30, 1910. Pages 89.

The general appendix to the Smithsonian Report for 1910 was in type, but actual presswork could not be completed before the close of the fiscal year. In the general appendix are the following papers:

Melville Weston Fuller, 1833–1910, by Charles D. Walcott.

Ornamentation of Rugs and Carpets, by Alan S. Cole.

Recent Progress in Aviation, by Octave Chanute.

Progress in Reclamation of Arid Lands in the Western United States, by F. H. Newell.

Electric Power from the Mississippi River, by Chester M. Clark.

Safety Provisions in the United States Steel Corporation, by David S. Beyer.

The isolation of an Ion, a Precision Measurement of its Charge, and the Correction of Stokes's Law, by R. A. Millikan.

The Telegraphy of Photographs, Wireless and by Wire, by T. Thorne Baker.

Modern Ideas on the Constitution of Matter, by Jean Becquerel.

Some Modern Developments in Methods of Testing Explosives, by Charles E. Munroe.

Sir William Huggins, by W. W. Campbell.

The Solar Constant of Radiation, by C. G. Abbot.

Astronomical Problems of the Southern Hemisphere, by Heber D. Curtis.

The Progressive Disclosure of the Entire Atmosphere of the Sun, by Dr. H. Deslandres.

Recent Progress in Astrophysics in the United States, by J. Bosler.

The Future Habitability of the Earth, by Thomas Chrowder Chamberlin.

What Is Terra Firma? A review of current research in isostasy, by Bailey Willis.

Transpiration and the Ascent of Sap, by Henry H. Dixon.

The Sacred Ear-Flower of the Aztecs, by William Edwin Safford.

Forest Preservation, by Henry S. Graves.

Alexander Agassiz, 1835–1910, by Alfred Goldsborough Mayer.

Recent Work on the Determination of Sex, by Leonard Doncaster.

The Significance of the Pulse Rate in Vertebrate Animals, by Florence Buchanan.

The Natural History of the Solitary Wasps of the Genus Synagris, by E. Roubaud.

A Contribution to the Ecology of the Adult Hoatzin, by C. William Beebe.

Migration of the Pacific Plover to and from the Hawaiian Islands, by Henry W. Henshaw.

The Plumages of the Ostrich, by Prof. J. E. Duerden.

Manifested Life of Tissues Outside of the Organism, by Alexis Carrel and Montrose T. Burrows.

The Origin of Druidism, by Julius Pokorny.

Geographical and Statistical View of the Contemporary Slav Peoples, by Lubor Niederle.

The Cave Dwellings of the Old and New Worlds, by J. Walter Fewkes.

The Origin of West African Crossbows, by Henry Balfour.

Sanitation on Farms, by Allen W. Freeman.

Epidemiology of Tuberculosis, by Robert Koch.

IV. SPECIAL PUBLICATIONS.

The following special publications were issued during the year:

1871. A Reprint of Smithsonian Mathematical Tables: Hyperbolic Functions. By George F. Becker and C. E. Van Orstrand. Published June, 1911. Octavo. Pages ll, 321.

1932. Classified list of Publications available for distribution May, 1910. Octavo. Pages 37. July, 1910.

1938. Opinions Rendered by the International Commission on Zoological Nomenclature. Opinions 1 to 25. Octavo. Pages 62. July, 1910.

1989. Opinions Rendered by the International Commission on Zoological Nomenclature. Opinions 26 to 29. Octavo. Pages 63–68. October, 1910.

The following special publication was in type but had not been issued at the close of the year.

2013. Opinions Rendered by the International Commission on Zoological Nomenclature. Opinions 30–37.

HARRIMAN ALASKA SERIES.

The Institution received from Mrs. Edward H. Harriman several thousand copies of volumes descriptive of the Harriman expedition to Alaska in 1899. Special Smithsonian title pages were added to the volumes before distribution by the Institution. The subjects were as follows:

1990. Volume I: Narrative, Glaciers, Natives. By John Burroughs, John Muir, and George Bird Grinnell. Pages 184, with 60 plates and 4 maps.

1991. Volume II: History, Geography, Resources. By William H. Dall, Charles Keeler, B. E. Fernow, Henry Gannett, William H. Brewer, C. Hart Merriam, George Bird Grinnell, and M. L. Washburn. Pages 200, with 64 plates and 1 map.

1992. Volume III: Glaciers and Glaciation. By Grove Karl Gilbert. Pages 231, with 17 plates and 1 map.

1993. Volume IV: Geology and Paleontology. By B. K. Emerson, Charles Palache, William H. Dall, E. O. Ulrich, and F. H. Knowlton. Pages 173, with 33 plates and 1 map.

1994. Volume V: Cryptogamic Botany. By J. Cardot, Clara E. Cummings, Alexander W. Evans, C. H. Peck, P. A. Saccardo, De Alton Saunders, I. Theriot, and William Trelease. Pages 424, with 44 plates.

1995. Volume VIII[1]: Insects. Part I. By William H. Ashmead, Nathan Banks, A. W. Caudell, O. F. Cook, Rolla P. Currie, Harrian G. Dyar, Justus Watson Folsom, O. Heidemann, Trevor Kincaid, Theo. Pergande, and E. A. Schwarz. Pages 238, with 17 plates.

1996. Volume IX: Insects. Part II. By William H. Ashmead, D. W. Coquillett, Trevor Kincaid, and Theo. Pergande. Pages 284, with 4 plates.

1997. Volume X: Crustaceans. By Mary J. Rathbun, Harriet Richardson, S. J. Holmes, and Leon J. Cole. Pages 337, with 26 plates.

1998. Volume XI: Nemerteans. By Wesley R. Coe. Bryozoans. By Alice Robertson. Pages 251, with 25 plates.

1999. Volume XII: Enchytræids. By Gustav Eisen. Tubicolous Annelids. By Katherine J. Bush. Pages 355, with 44 plates.

2000. Volume XIII: Land and Freshwater Mollusks. By William H. Dall. Hydroids. By C. C. Nutting. Pages 250, with 15 plates.

V. PUBLICATIONS OF THE UNITED STATES NATIONAL MUSEUM.

The publications of the National Museum are: (a) The annual report to Congress; (b) the Proceedings of the United States National Museum; and (c) the Bulletin of the United States National Museum, which includes the Contributions from the United States National Herbarium. The editorship of these publications is in charge of Dr. Marcus Benjamin.

The publications issued during the year comprised the annual report for 1910; papers 1750 to 1771 of volume 38, proceedings; papers 1772 to 1845 of volumes 39 and 40, proceedings; papers 1846, 1847, 1849–1852, 1854, and 1855 of volume 41, proceedings; five bulletins and seven parts of volumes of Contributions from the National Herbarium.

The bulletins were as follows:

No. 71. A Monograph of the Foraminifera of the North Pacific Ocean. Part II, Textulariidæ. By Joseph Augustine Cushman.

No. 73. An account of the Beaked Whales of the Family Ziphiidæ in the Collection of the United States National Museum, with Remarks on some Specimens in other American Museums. By Frederick W. True.

No. 74. One some West Indian Echinoids. By Theodor Mortensen.

No. 75. North Pacific Ophiurans in the Collection of the United States National Museum. By Hubert Lyman Clark.

No. 76. Asteroidea of the North Pacific and Adjacent Waters. By Walter Kendrick Fisher.

In the series of Contributions from the National Herbarium there appeared:

Volume 15. The North American Species of Panicum. By A. S. Hitchcock and Agnes Chase.

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[1] Volumes VI and VII have not yet been prepared for publication.

Volume 14, Part 2. History of the Coconut Palm in America. By O. F. Cook.

Volume 13, Part 6. The Type Localities of Plants First Described from New Mexico. A Bibliography of New Mexican Botany. By Paul C. Standley.

Volume 13, Part 7. A Preliminary Treatment of the Genus Castilla. By Henry Pittier.

Volume 13, Part 8. The Genus Talinum in Mexico, by J. N. Rose and Paul C. Standley; and Two new Species of Harperella, by J. N. Rose.

Volume 13, Part 9. Studies of Mexican and Central American Plants. No. 7. By J. N. Rose.

Volume 13, Part 10. Miscellaneous Papers. By Albert W. C. T. Herre, William H. Brown, Joseph H. Painter, Paul C. Standley, Edward S. Steele, and E. A. Goldman.

VI. PUBLICATIONS OF THE BUREAU OF AMERICAN ETHNOLOGY.

The publications of the bureau are discussed in detail in another appendix of the Secretary's report. The editorial work is in charge of Mr. J. G. Gurley.

The following eight bulletins were published by the bureau during the year:

Bulletin 30. Handbook of American Indians North of Mexico. Edited by Frederick Webb Hodge. Part 2. Published 1911. Octavo. Pages iv, 1221, with many figures.

Bulletin 37. Antiquities of Central and Southeastern Missouri. By Gerard Fowke. (Report on explorations made in 1906–1907 under the auspices of the Archæological Institute of America.) Published 1910. Octavo. Pages vii, 116, with 19 plates and 20 figures.

Bulletin 40. Handbook of American Indian Languages. By Franz Boas. Part 1. With illustrative sketches by Roland B. Dixon (Maidu), P. E. Goddard (Athapascan: Hupa), William Jones, revised by Truman Michelson (Algonquian), John R. Swanton (Tlingit, Haida), William Thalbitzer (Eskimo); (Franz Boas: Introduction, Chinook, Kwakiutl, Tsimshian; John R. Swanton and Franz Boas, Siouan). Published 1911. Octavo. Pages vii, 1069.

Bulletin 43. Indian Tribes of the Lower Mississippi Valley and Adjacent Coast of the Gulf of Mexico. By John R. Swanton. Published 1911. Octavo. Pages vii, 387, with 32 plates (including 1 map) and 2 figures.

Bulletin 44. Indian Languages of Mexico and Central America, and their Geographical Distribution. By Cyrus Thomas, assisted by John R. Swanton. Accompanied with a linguistic map. Published 1911. Octavo. Pages vii, 108, and 1 map.

Bulletin 45. Chippewa Music. By Frances Densmore. Published 1910. Octavo. Pages xix, 216, with 12 plates, 8 figures, and many musical pieces.

Bulletin 50. Preliminary Report on a Visit to the Navaho National Monument, Arizona. By Jesse Walter Fewkes. Published 1911. Octavo. Pages vii, 35, with 22 plates and 3 figures.

Bulletin 51. Antiquities of the Mesa Verde National Park: Cliff Palace. By Jesse Walter Fewkes. Published 1911. Octavo. Pages 82, with 35 plates and 4 figures.

VII. PUBLICATIONS OF THE SMITHSONIAN ASTROPHYSICAL OBSERVATORY.

There were no new publications issued by the Astrophysical Observatory during the year.

VIII. AMERICAN HISTORICAL ASSOCIATION.

The annual reports of the American Historical Association are transmitted by the association to the Secretary of the Smithsonian Institution and are

communicated to Congress under the provisions of the act of incorporation of the association.

Volume I of the report for the year 1908, sent to the printer in June, 1909, was published in July, 1910. Its contents were as follows:

Report of the Proceedings of the Twenty-fourth Annual Meeting of the American Historical Association. By Waldo G. Leland, secretary.

Report of the Proceedings of the Fifth Annual Meeting of the Pacific Coast Branch. By Jacob N. Bowman, secretary of the branch.

Report of Conference on Relations of Geography to History. By Erle Sparks.

Proceedings of Conference on History in Secondary Schools. Edited by Andrew C. McLaughlin.

Report of Conference on Research in English History. By Edward P. Cheyney.

Report of Conference on Research in American Colonial and Revolutionary History. By Herbert L. Osgood.

Report of Conference on Research in Southern History. By Lyon G. Tyler.

Report on Fifth Annual Conference on the Problems of State and Local Historical Societies. By St. George L. Sioussat.

The Viceroy of New Spain in the Eighteenth Century. By Don E. Smith.

Notes Supplementary to any Edition of Lewis and Clark. By Frederick J. Teggart.

The Historical Value of the Census Records. By Joseph A. Hill.

The American Newspapers of the Eighteenth Century as Sources of History. By William Nelson.

The Wilderness Campaign:

1. Grant's Conduct of the Wilderness Campaign. By Gen. Edward P. Alexander, Confederate States Army.
2. Lee's Conduct of the Wilderness Campaign. By Col. William R. Livermore, United States Army.
3. The Wilderness Campaign from Our Present Point of View. By Maj. Eben Swift, United States Army.

Ninth Annual Report of the Public Archives Commission. By Herman V. Ames, chairman.

Appendix A. Report on the Archives of the State of Maine. By Allen Johnson.

Appendix B. Report on the Archives of the State of Missouri. By Jonas Viles.

Appendix C. Report on the Archives of the State of Washington. By Jacob N. Bowman.

Appendix D. List of the Journals of the Councils and Assemblies and the Acts of the 13 Original Colonies in America Preserved in the Public Record Office, London. Edited by Charles M. Andrews.

Volume II of the 1908 report, sent to the printer April 26, 1910, had not been entirely completed June 30, 1911. It will be made up, for convenience, in two parts, pages 1–807, 808–1617, containing Parts II and III of Texas Diplomatic Correspondence. Edited by Prof. George P. Garrison.

The manuscript of the 1909 report, to form one volume, was sent to the printer January 10, 1911, and was practically all in type before June 30, 1911.

The manuscript of the 1910 report was sent to the printer June 3, 1911.

IX. SOCIETY OF THE DAUGHTERS OF THE AMERICAN REVOLUTION.

The manuscript of the Thirteenth Annual Report of the National Society of the Daughters of the American Revolution, for the year ending October 11,

1910, was received from the society February 24, 1911, and was communicated to Congress on February 27, in accordance with the act of incorporation of that organization.

X. SMITHSONIAN ADVISORY COMMITTEE ON PRINTING AND PUBLICATION.

The editor has continued to serve as secretary of the Smithsonian advisory committee on printing and publication. To this committee have been referred the manuscripts proposed for publication by the various branches of the Institution as well as those offered for printing in the Smithsonian Miscellaneous Collections. The committee also considered forms of routine blanks and various matters pertaining to printing and publication, including the qualities of paper suitable for text and plates. Twenty-four meetings were held and 115 manuscripts were acted upon.

Respectfully submitted.

A. Howard Clark, *Editor.*

Dr. Charles W. Walcott,

Secretary of the Smithsonian Institution.

APPENDIX IX.

REPORT ON CONGRESS OF ARCHIVISTS AND LIBRARIANS, AND CONGRESS OF BIBLIOGRAPHY AND DOCUMENTATION.

SIR: I have the honor to present the following report as the representative of the Smithsonian Institution at the International Congress of Archivists and Librarians and the International Congress of Bibliography and Documentation, held at Brussels, Belgium, in August, 1910.

The Congress of Bibliography and Documentation, the first of the two congresses at Brussels, held its meetings from Thursday, August 25, through Saturday, August 27. On the printed list of members there were enrolled 24 associations, bureaus, and other organizations; 34 individual libraries and other institutions; and 160 persons by name, including duplications on lists. Forty-six countries were scheduled as in relation with the congress or with the Institut International de Bibliographie, under whose auspices this congress was held, and there were actually present representatives from at least 16 countries, including, besides the United States, Great Britain, France, Belgium, the Netherlands, Germany, Austria, Russia, Sweden, Switzerland, Spain, Bulgaria, Denmark, Norway, Monaco, and Turkey, about a hundred persons being actually present at most of the meetings.

This congress was officially opened by M. Paul Otlet, one of the secretaries. He spoke of the work of the Institut International de Bibliographie in collecting catalogue cards for every known scientific publication and their arrangement according to the Dewey decimal classification system; also an author's catalogue arranged alphabetically; a collection of picture postal cards of institutions and public buildings from all parts of the world, as well as of prominent persons, and a collection of photographic negatives covering all subjects, from which prints could be made, for persons pursuing a certain line of study. He explained that by documentation was meant the collection and preserving for reference of a series of newspaper and magazine clippings with their illustrations. He referred to the International Exchange Service and mentioned in glowing terms the work of the Smithsonian Institution in organizing and conducting the service in the United States. The congress then proceeded to consider the following subjects:

I. Documents:
   1. Books, reviews, journals;
   2. Illustrations, foreign photographs;
   3. Archives, ancient and administrative.

II. Works and collections:
   1. Editing;
   2. Library cataloguing.
   3. Collections;
   4. Encyclopedic arrangement.

III. Methods:
   1. Cards;
   2. Rules and classification.

IV. Service, loan copies and exchanges:
1. Partial, general, and special;
2. National;
3. International, special;
4. International, scientific.

The subject of "International Exchanges" was briefly reviewed, and the following resolution was passed:

> It is desirable to promote further developments of international exchange service, especially in obtaining frequent dispatch, in increasing the number of countries taking part in the international convention, and in providing for gratuitous transmission of all correspondence relative to request for exchanges, to the receipts for publications and to their return. It is especially desirable to admit free or beneficial associations and institutions to such exchange.
>
> It is desirable that the Smithsonian Institution, the initiator of the service of international exchanges, should itself promote the revision of the international convention of 1885 for the purpose of realizing these improvements.

The congress officially visited the Congo Museum at Tervueren and closed with a banquet on the evening of August 27.

The Congress of Archivists and Librarians, second to assemble, but first in point of numbers and scope, met at Brussels from Sunday, August 28, through Wednesday, August 31, under the auspices of the Association of the Belgian Archivists and Librarians, M. Louis Stainier, administrator-inspector of the Royal Library of Belgium, being the official in charge of the preliminary preparations. The printed list showed 18 countries represented by national commissions (with especial reference to archives), 12 countries represented by official delegates, delegations from 9 Belgian learned societies, 49 libraries and other institutions entered on the registry and 389 individual names, these last, of course, representing the personnel of the representative delegations as well as individual members. These 389 enrolled participants represented 21 different countries, including, besides the United States, England, Canada, Germany, France, Belgium, Holland, Austria, Hungary, Spain, Switzerland, Portugal, Russia, Italy, Brazil, Cuba, Denmark, Sweden Norway, Luxemburg, and Monaco.

This congress was convened on the afternoon of the 28th of August with addresses of welcome, and immediately divided into two sections, the archivists and the librarians, which held separate meetings. My time was largely devoted to the library section, and the discussions relating particularly to library methods included cataloguing, classification, and the placing of books upon the shelves. My paper on the International Exchange Service, having been printed in advance and distributed, was read by title. This paper is as follows:

> There is no more important subject to be discussed at the Congrès International des Archivistes et des Bibliothecaires than that of the international exchanges, as the value of that service to libraries can not be overestimated. The time has come when the scientific and learned institutions, the public, the research workers, and the students of literature demand the scientific and literary publications of the world.
>
> Considering the question "Dans quel sens a-t-il lieu de réorganiser et d'étendre le service des échanges internationaux" from an American point of view, it does not appear that reorganization is what is needed, for a system of international exchanges working with the hearty cooperation of all nations has not yet ever been developed on the lines of the existing conventions.
>
> The present international exchange service is operating under two conventions made between certain powers, and the work is based upon them. One of these, signed at Brussels in 1886 and officially proclaimed in 1889, made provision for the exchange of official documents and scientific and literary publications. The other, which was concluded and proclaimed at the same time, provided for the immediate exchange of the official journal, as well as of the parliamentary annals and documents of the contracting parties. The

conventions were broadly worded and allowed for the adherence of other states than those that became signatories at the time. The signers were the plenipotentiaries of the United States of America, Belgium, Brazil, Italy, Portugal and the Algarves, Servia, Spain, and the Swiss Confederation. Later the Argentine Republic, Paraguay, and Uraguay signified their adherence, while Bolivia, Chile, Colombia, Costa Rica, France, Liberia, the Netherlands, New South Wales, Peru, Queensland, and Russia have established international exchange bureaus without, however, giving their formal adherence to the conventions. From this it will be seen that there are eleven states that have adhered to the conventions and an equal number that have established bureaus without adherence, while Great Britain, Germany, and the other countries contribute no funds toward the organization of this movement.

It is therefore obvious that under the existing conditions it is not reorganization but organization that is needed, and this may readily be accomplished under the conventions now in force, as they form a firm foundation for a great international institution. The provisions in these conventions made twenty years ago may need revision in order to conform to recent international advancement, and it is possible that the powers that have already agreed to the conventions and lent their support might be willing to reopen them, provided that the powers that have not come in are willing to join in the organization of an international exchange service.

The international exchanges as now carried on are of two classes—scientific and literary publications and official Government publications. The first named of these is of the utmost importance to the cause of education, both scholastic and technical, which the present service has materially advanced by enabling individuals and institutions of learning to disseminate knowledge without restriction and practically without cost to themselves. The scientific institutions are appreciating more and more the fact that their endowments are entirely inadequate to provide for the many calls made upon them, and if in addition to printing their own publications they should have to purchase those of foreign institutions and pay the cost of transportation it would mean that some part of their work would have to be abandoned. It is therefore to a system of international exchanges that they must look for relief in this matter.

The Government exchanges are necessary in order that Governments may ascertain what is being accomplished along similar lines in other countries, and as such publications are issued at the expense of the Governments they should also be distributed at their expense.

The International Exchange Service of the United States is under the direction of the Smithsonian Institution, and was originally inaugurated for the purpose of transmitting publications presented by institutions and individuals in the United States to correspondents abroad, in exchange for like contributions from such recipients, as one of the most efficient means for the "diffusion of knowledge among men," and the entire expense, including that for the exchange of documents published by the Government from 1850 to 1881, was paid from the private funds of the Institution.

Through the action of Congress, upon recommendation of the Department of State, the Smithsonian Institution is recognized by the United States Government as the American agency for the international exchange of governmental, scientific, and literary publications. By the congressional resolutions passed in 1867 and 1901 a certain number of United States Government publications are set aside for exchange with those of foreign countries, to be sent regularly to designated depositories. In accordance with those resolutions there are now forwarded abroad 55 full sets of United States official publications and 33 partial sets; the official journal of the proceedings of Congress, the Congressional Record, is transmitted by mail daily to each of the Parliaments that is willing to reciprocate.

During the fiscal year ending June 30, 1909, the number of packages forwarded through the international exchanges of the United States amounted to 228,875. These packages were sent direct from this country to the one for which they were intended, and from long experience this has been found to be the quickest and most satisfactory method. During the last year nearly 2,000 boxes were shipped in this way without the loss of a single consignment. Shipments are made regularly at least once a month, should the sending be but one package, and to the larger countries every week.

A card index is kept of all correspondents, and upon these cards are recorded the packages sent and received by each institution and individual.

There are now in the United States 3,900 institutions and 8,000 individuals recorded in this index, while the foreign institutions number 16,500 and individuals 34,232. A list of the foreign societies and institutions is published from time to time under the title of "International exchange list," the latest issue being that of 1904.

The public documents received from abroad in exchange are placed in the Library of Congress. The publications received from the scientific and learned societies and institutions of the world form an important part of the Library of the Smithsonian Institution, and while these remain the property of the Institution they are in great part deposited in the Library of Congress.

The needs of the international exchanges under present conditions may be summarized as follows: The adherence of all the civilized nations of the world to the present conventions. The members of the Congress of Archivists and Librarians can do much to further the movement by lending their efforts to arouse the interest of the scientific and literary institutions and societies and governmental authorities in their respective countries, to the end that official action may be taken. The scientific institutions and societies of each country should examine the workings of the international exchange system and solicit exchange of publications from like societies abroad, using the service as a medium of transmission.

Governments should provide a sufficient number of sets of their official publications for exchange purposes in order that each country may have a full set if desired, and in addition there should be copies of the official journals of the Parliaments, or similar bodies, for the interparliamentary exchanges.

Bureaus already established, as well as those to be established, should be granted an appropriation that will allow the carrying out in full of the stipulations of the conventions. A well-paid and energetic staff with a well-equipped office would insure expeditious work and prompt delivery. The present facilities for rapid transportation would be greatly increased by each international exchange office having the franking privilege, such as is allowed in the United States, and the granting of special concessions by the postal authorities, through the International Postal Union, which could possibly be arranged should every nation become a party to the present conventions.

The international exchanges should be extended to every quarter of the globe, and efforts should be made to bring the powers to realize the necessity of perfecting an institution already established which has for its object the "increase and diffusion of knowledge among men."

I gave a résumé of the contents of the above paper and was asked for some resolution which could be passed by the congress incorporating a suggestion contained in the paper "that the members of the Congress of Archivists and Librarians could do much to further the movement by lending their efforts to arouse the interest of the scientific and literary institutions and societies and governmental authorities in their respective countries, to the end that official action may be taken."

The resolution was presented in English, translated into French, and again translated into English, and appears as follows in the Library Journal:

That the scientific and literary institutions, as well as the governmental authorities of all countries, should unite their efforts to obtain the official provision for international exchanges.—VI. Q. 7. International Exchanges (Paul Brockett, Washington).

Regarding the use of the exchange service by private institutions, M. Langlois, Bibliothécaire-en-chef de l'Institut Catholique, of Paris, having experienced some difficulty in sending packages from France, presented the following resolution:

That the international exchanges should be accorded, liberally and in the interest of all workers, to establishments of private initiative (libraries of free institutions and learned societies), which conform to the general regulations and provide reciprocity.—VII. Q. 7. (M. Langlois, Paris, as amended by M. Grosjean, Bruxelles.)

I had with me a copy of Article VII of the conventions of 1886, in both English and French, which was read:

ART. VII. The bureaus of exchange will serve, in an official capacity, as intermediaries between the learned bodies and literary and scientific societies, etc., of the contracting States for the reception and transmission of their publications.

It remains, however, well understood that, in such case, the duty of the bureaus of exchange will be confined to the free transmission of the works exchanged, and that these bureaus will not in any manner take the initiative to bring about the establishment of such relations.

One more resolution was presented:

That the service of international exchanges should be developed in the most complete manner in the participating countries, and that like organizations should be created in the other States.—VIII, Q. 7. (M. Sury, Bruxelles.)

In connection with attending this congress permission was given me to visit the principal libraries of London, Paris, and Berlin, and observations were made and are contained in a series of notes taken down at the time for reference in the Smithsonian Library. When the libraries were closed, I occupied my time in visiting the museums, taking notes of methods, etc.

Respectfully submitted.

PAUL BROCKETT,
Assistant Librarian.

DR. CHARLES D. WALCOTT,
Secretary of the Smithsonian Institution.

REPORT OF THE EXECUTIVE COMMITTEE OF THE BOARD OF REGENTS OF THE SMITHSONIAN INSTITUTION FOR THE YEAR ENDING JUNE 30, 1911.

To the Board of Regents of the Smithsonian Institution:

Your executive committee respectfully submits the following report in relation to the funds, receipts, and disbursements of the Institution, and a statement of the appropriations by Congress for the National Museum, the International Exchanges, the Bureau of American Ethnology, the National Zoological Park, the Astrophysical Observatory, and the International Catalogue of Scientific Literature for the year ending June 30, 1911, together with balances of previous appropriations.

SMITHSONIAN INSTITUTION.

Condition of the fund July 1, 1911.

The permanent fund of the Institution and the sources from which it has been derived are as follows:

DEPOSITED IN THE TREASURY OF THE UNITED STATES.

Bequest of Smithson, 1846		$515,169.00
Residuary legacy of Smithson, 1867		26,210.63
Deposit from savings of income, 1867		108,620.37
Bequest of James Hamilton, 1875	$1,000.00	
Accumulated interest on Hamilton fund, 1895	1,000.00	
		2,000.00
Bequest of Simeon Habel, 1880		500.00
Deposits from proceeds of sale of bonds, 1881		51,500.00
Gift of Thomas G. Hodgkins, 1891		200,000.00
Part of residuary legacy of Thomas G. Hodgkins, 1894		8,000.00
Deposit from savings of income, 1903		25,000.00
Residuary legacy of Thomas G. Hodgkins		7,918.69
Total amount of fund in the United States Treasury		944,918.69

OTHER RESOURCES.

Registered and guaranteed bonds of the West Shore Railroad Co., part of legacy of Thomas G. Hodgkins (par value)	42,000.00
Total permanent fund	986,918.69

Also four small pieces of real estate bequeathed by Robert Stanton Avery, of Washington, D. C.

That part of the fund deposited in the Treasury of the United States bears interest at 6 per cent per annum, under the provisions of the act of Congress of August 10, 1846, organizing the Institution, and the act approved March 12, 1894. The rate of interest on the West Shore Railroad bonds is 4 per cent per annum. The real estate received from Robert Stanton Avery is exempt from taxation and yields only a nominal revenue from rentals.

Statement of receipts and disbursements from July 1, 1910, to June 30, 1911.

RECEIPTS.

Cash on deposit July 1, 1910		$35,364.88
Interest on fund deposited in United States Treasury due July 1, 1910, and Jan. 1, 1911	$56,695.12	
Interest on West Shore Railroad bonds due July 1, 1910, and Jan. 1, 1911	1,680.00	
Repayments, rentals, publications, etc	10,541.75	
Contributions from various sources for specific purposes	14,518.43	
		83,435.30
		118,800.18

DISBURSEMENTS.

Buildings, care and repairs		5,675.55
Furniture and fixtures		943.09
General expenses:		
Salaries	$16,453.13	
Meetings	230.00	
Stationery	916.40	
Postage, telegraph, and telephone	738.45	
Freight	105.35	
Incidentals	787.35	
Garage	5,578.75	
Fuel and lights	213.94	
		25,023.37
Library		2,847.14
Publications and their distribution:		
Miscellaneous collections	5,295.95	
Contributions to knowledge	230.00	
Reports	640.10	
Special publications	381.16	
Publication supplies	261.88	
Salaries	6,079.31	
Alaska Series	3,149.87	
		16,038.27
Explorations, researches, and collections		19,169.17
Hodgkins specific fund, researches and publications		6,127.16
International Exchanges		4,868.41
Legal expenses		1,000.00

Gallery of Art	$31.60
Advances for field expenses	4,450.76
Apparatus	200.00
	86,374.52
Balance June 30, 1911, deposited with the Treasurer of the United States	32,425.66
	118,800.18

By authority, your executive committee again employed Mr. William L. Yaeger, a public accountant of this city, to audit the receipts and disbursements of the Smithsonian Institution during the period covered by this report. The following certificate of examination supports the foregoing statement, and is hereby approved:

WASHINGTON, D. C., *August 5, 1911.*

EXECUTIVE COMMITTEE, BOARD OF REGENTS,
Smithsonian Institution.

SIRS: I have examined the accounts and vouchers of the Smithsonian Institution for the fiscal year ending June 30, 1911, and certify the following to be a correct statement:

Total receipts	$83,435.30
Total disbursements	86,374.52
Excess of disbursements over receipts	2,939.22
Amount from July 1, 1910	35,364.88
Balance on hand June 30, 1911	32,425.66
Balance shown by Treasury statement June 30, 1911	34,445.95
Less outstanding checks	2,020.29
True balance June 30, 1911	32,425.66

The vouchers representing payments from the Smithsonian income during the year, each of which bears the approval of the secretary, or, in his absence, of the acting secretary, and a certificate that the materials and services charged were applied to the purposes of the Institution, have been examined in connection with the books of the Institution and agree with them.

(Signed) WILLIAM L. YAEGER,
Public Accountant and Auditor.

All moneys received by the Smithsonian Institution from interest, sales, refunding of moneys temporarily advanced, or otherwise, are deposited with the Treasurer of the United States to the credit of the Institution, and all payments are made by checks signed by the secretary.

The expenditures made by the disbursing agent of the Institution and audited by the Auditor for the State and Other Departments are reported in detail to Congress and will be found in the printed document.

Your committee also presents the following summary of appropriations for the fiscal year 1911 intrusted by Congress to the care of the Smithsonian Institution, balances of previous appropriations at the

beginning of the fiscal year, and amounts unexpended on June 30, 1911:

	Available after July 1, 1910.	Balance June 30, 1911.
Appropriations committed by Congress to the care of the Institution:		
International Exchanges, 1909	$0.34	[1] $0.34
International Exchanges, 1910	5,506.23	11.47
International Exchanges, 1911	32,000.00	2,323.68
American Ethnology, 1909	1.15	[1] 1.15
American Ethnology, 1910	3,890.50	237.06
American Ethnology, 1911	42,000.00	2,644.69
Astrophysical Observatory, 1909	314.50	[1] 306.50
Astrophysical Observatory, 1910	609.01	119.42
Astrophysical Observatory, 1911	13,000.00	1,063.22
International Catalogue, 1909	2.97	[1] 2.97
International Catalogue, 1910	212.51	1.71
International Catalogue, 1911	7,500.00	437.12
Elevators, Smithsonian Building	10,000.00	946.06
National Museum—		
Furniture and fixtures, 1909	66.61	[1] 66.61
Furniture and fixtures, 1910	87,885.97	60.29
Furniture and fixtures, 1911	125,000.00	34,166.16
Heating and lighting, 1909	137.16	[1] 137.16
Heating and lighting, 1910	14,526.90	3,592.42
Heating and lighting, 1911	50,000.00	9,658.11
Preservation of collections, 1909	222.30	[1] 253.68
Preservation of collections, 1910	23,790.15	8,461.84
Preservation of collections, 1911	300,000.00	20,623.80
Books, 1909	77.05	[1] 1.75
Books, 1910	1,302.08	19.56
Books, 1911	2,000.00	668.05
Postage, 1911	500.00	
Building repairs, 1909	26.62	[1] 26.62
Building repairs, 1910	6,486.30	20.30
Building repairs, 1911	15,000.00	3,513.87
Rent of workshops, 1909	.08	[1] .08
Temporary occupancy of Government buildings for tuberculosis congress	15,678.92	[1] 15,678.92
Transfer of Greenough statue of Washington	409.74	[1] 409.74
Moving collections to new building	24.73	[1] 24.73
Building, National Museum	77,000.00	22,902.78
National Zoological Park, 1909	13.25	[1] 13.25
National Zoological Park, 1910	5,276.60	4.56
National Zoological Park, 1911	115,000.00	6,598.53

[1] Carried to credit of surplus fund.

Statement of income from the Smithsonian fund and other revenues, accrued and prospective, available during the fiscal year ending June 30, 1912.

Balance June 30, 1911		$32,425.66
Interest on fund deposited in United States Treasury, due July 1, 1911, and Jan. 1, 1912	$56,695.00	
Interest on West Shore R. R. bonds, due July 1, 1911, and Jan. 1, 1912	1,680.00	
Exchange repayments, sale of publications, rentals, etc	8,562.48	
Deposits for specific purposes	12,000.00	
		78,937.48
Total available for year ending June 30, 1912		111,363.14

Respectfully submitted.

A. O. Bacon,
Alexander Graham Bell,
John Dalzell,
Executive Committee.

Washington, D. C., *December 5, 1911.*

PROCEEDINGS OF THE BOARD OF REGENTS OF THE SMITHSONIAN INSTITUTION FOR THE YEAR ENDING JUNE 30, 1911.

At a meeting of the Board of Regents held December 14, 1909, the following resolution was adopted:

Resolved, That hereafter the Board of Regents of the Smithsonian Institution shall hold their annual meeting on the second Thursday in December and a supplementary meeting on the second Thursday in February.

In accordance with this resolution the board met at 10 o'clock a. m., on December 8, 1910, and on February 9, 1911.

ANNUAL MEETING, DECEMBER 8, 1910.

Present: The Hon. James S. Sherman, Vice President of the United States; the Hon. John M. Harlan, presiding Justice of the United States Supreme Court; Senator S. M. Cullom; Senator Henry Cabot Lodge; Senator A. O. Bacon; Representative John Dalzell; Representative James R. Mann; Representative William M. Howard; Dr. Andrew D. White; the Hon. John B. Henderson; Mr. Charles F. Choate, jr.; and the secretary, Mr. Charles D. Walcott.

The meeting was called to order by the Vice President.

DEATH OF THE CHANCELLOR.

The secretary announced the death of the chancellor of the Smithsonian Institution, Melville Weston Fuller, Chief Justice of the United States, which occurred at Sorrento, Maine, on July 4, 1910.

The intelligence of this sad event was received at the Institution in the absence of the secretary, and Mr. Richard Rathbun, the acting secretary, sent a telegram of condolence, both official and personal, to Mrs. Nathaniel Francis, who was with her father at the time of his death. Mr. Rathbun attended the obsequies at Sorrento as the representative of the Institution, and accompanied the funeral party to Chicago, where interment took place on July 8.

The secretary stated that the advice and suggestions of the chancellor in relation to matters affecting the Institution that were brought to his attention had always been most helpful. He added that he had enjoyed a personal acquaintance with the chancellor that had extended over 20 years, and that it was with a deep sense of the

loss sustained by the Institution as well as by himself personally that he formally announced his death to the Board of Regents.

Senator Bacon then presented the following resolutions, which on motion, were adopted:

Whereas the Board of Regents of the Smithsonian Institution have received the sad intelligence of the death, on July 4, 1910, of Melville Weston Fuller, Chief Justice of the United States, and for 22 years chancellor of the Institution; therefore be it

Resolved, That we desire here to record our profound sorrow at the severing of the tie that has bound us to him for so long a period of honored service; that we feel keenly the loss of a wise presiding officer, whose vast store of learning and gracious dignity have proved so invaluable in the deliberations of this board, and whose loyal interest in the Smithsonian Institution has been a source of inspiration to his colleagues.

Resolved, That we share in the grief of the nation at the passing away of one who was at once a distinguished leader of the greatest legal tribunal of our land, an eminent jurist, a patriotic citizen, a shining example of Christian gentleness, and who also possessed so charming a personality as a man and as a friend.

Resolved, That we respectfully tender to the members of the family of our late associate our sincerest sympathy in their great bereavement.

Resolved, That an engrossed copy of these resolutions be transmitted to the family of the late chancellor.

ELECTION OF CHANCELLOR.

The chairman announced as the next business in order the election of a chancellor to succeed the late Chief Justice Fuller.

Senator Lodge moved—

That the Vice President of the United States be elected chancellor of the Smithsonian Institution.

Senator Lodge put the question, and, there being a unanimous vote in the affirmative, announced that the Vice President was duly elected.

RESOLUTION RELATIVE TO INCOME AND EXPENDITURE.

Senator Henderson, chairman of the executive committee, presented the following customary resolution, which was adopted:

Resolved, That the income of the Institution for the fiscal year ending June 30, 1912, be appropriated for the service of the Institution, to be expended by the secretary, with the advice of the executive committee, with full discretion on the part of the secretary as to items.

ANNUAL REPORT OF THE EXECUTIVE COMMITTEE.

Senator Henderson submitted the report of the executive committee for the fiscal year ending June 30, 1910, stating that the members of the board had already been supplied with copies in printed form.

On motion the report was adopted.

ANNUAL REPORT OF THE PERMANENT COMMITTEE.

Senator Henderson presented the following report:

To the Board of Regents of the Smithsonian Institution:

GENTLEMEN: The only matter of unfinished business in the hands of this committee is the Andrews will case. A report upon the case was made to the board at the meeting of February 10, 1910, which after discussion was referred back to the committee with power to act.

As a result of a very thorough consideration of the matter, it is recommended by the committee that all proceedings in the Andrews will case be dropped.

JOHN B. HENDERSON, *Chairman.*

On motion the report of the permanent committee was adopted.

ANNUAL REPORT OF THE SECRETARY.

The secretary stated that his report for the year ending June 30, 1910, had been printed and sent to the members of the board.

Delay in formal opening of the new building for the National Museum.—The secretary said that on account of the nondelivery of cases it had been impossible to install the exhibition series in time for the opening of the building before the present Congress adjourned. In view of this and of the great desirability of first having the complete exhibition series thoroughly installed and the entire building in condition for critical inspection he had thought it best to postpone the formal opening until later. In the meantime the collections in cases were so arranged as to be viewed by visitors.

Additions to art collections.—The secretary remarked further that Mr. William T. Evans had presented 32 more paintings to the collections illustrating the work of American artists, and that he understood that Mr. Evans contemplated assembling also a collection illustrative of wood engraving, an art which, because of the development of the various photo-engraving processes, had practically fallen into disuse.

He added that Mr. Charles L. Freer had returned to China for the purpose of enlarging his great collection illustrating the early development of Chinese art, all of which it was expected would come to the Institution. Many of these articles were exceedingly rare and very difficult to obtain, and the Institution would be most fortunate in securing them.

Smithsonian African expedition.—The secretary stated that Col. Roosevelt's final account of the expedition would be found in the secretary's report to the board. This, however, gave the scientific results of the expedition in general terms only. He would state that the total amount subscribed for the expedition was $51,700, and that the expenditures to date amounted to $48,353.09, leaving a balance of $3,346.91, which was being held for expenditures necessary to the

completion of the final reports on the expedition being prepared by the Smithsonian members of the party.

The secretary added that the collections were being permanently arranged by the experts of the National Museum. It was intended to mount certain of the animals in groups, with accessories, so as to show their environment and habits.

On motion the secretary's report was accepted.

LANGLEY MEMORIAL TABLET.

Senator Lodge, chairman of the committee on the Langley memorial tablet, reported that the desire of the board that this tablet should commemorate the work of Mr. Langley in aerial navigation had been carried out in a design representing him as seated, engaged in a profound study of the great problem. The committee had entered into an arrangement with a New York sculptor to design a tablet 4 feet 6 inches high by 2 feet 5 inches wide. It had been expected that the model could be exhibited at this meeting, but a letter had been received from the artist stating that an accident to the model necessitated the working over of a large portion of it, and therefore it could not be submitted at this meeting.

BIOLOGICAL SURVEY OF THE PANAMA ZONE.

The secretary stated that the plan for a biological survey of the Panama Canal Zone, under the direction of the Smithsonian Institution, was described in his annual report, which had already been distributed to the Regents.

Since the preparation of the report, a letter had been written to the President outlining the plan, and asking if it would meet his approval if cooperation were asked of the Isthmian Canal Commission of the War Department, the Bureau of Fisheries of the Department of Commerce and Labor, and the Biological Survey and Bureaus of Entomology and Plant Industry of the Department of Agriculture. The President gave his approval and authorized the secretary to communicate with the departments mentioned, which was done. All have signified their desire to cooperate and have assigned experts to aid in the work. The estimated cost of the survey which would have to be met by the Institution is $11,000, of which $5,750 has been subscribed.

For several years American and foreign naturalists have been asking that a biological survey of the Canal Zone be undertaken, and various attempts have been made to arrange for such a work. The only plan that had materialized was one by the Field Museum of Natural History, Chicago, for the collection and study of the fishes of the Canal Zone. By agreement, this work will now be carried on in conjunction with that of the Smithsonian Expedition,

In answer to Senator Bacon's inquiry as to the scope of the work intended, the secretary said it was to cover studies of the animal and plant life of the land and waters of the Canal Zone. Such a survey is necessary before the canal is completed, as it is believed that conditions will be changed after the canal is opened to commerce and the waters of the Atlantic Ocean are joined with those of the Pacific. The organisms of the various watersheds would then be offered a ready means of mingling together, the natural barriers would be obliterated, and the data for a true understanding of the fauna and flora placed beyond reach.

THE HARRIMAN TRUST AND GIFT.

The secretary stated that he was desirous of establishing at the Institution a number of research associateships. He wished to give exceptionally strong men an opportunity to do research work without the care and burden of administrative duties, and with full knowledge that as long as their work was properly conducted it would be continued and that in the event of incapacity for active work, provision would be made for them.

As an illustration, he cited the case of Dr. C. Hart Merriam, who has been provided for through the liberality of Mrs. Edward H. Harriman. He also mentioned that the Carnegie Institution of Washington has a number of men engaged in special fields of work, but added that there would be no probability of duplication of work. The Carnegie Institution does not undertake exploratory work such as that of the African expedition or the biological survey of the Panama Canal Zone. The field for scientific investigation is extensive and there are numerous worthy projects that can not be undertaken because of lack of means.

In this connection the secretary announced that Dr. Merriam's splendid collection of American mammals had been purchased by Mrs. Harriman for $10,000 and presented to the Institution.

HODGKINS GOLD MEDAL.

The secretary called the attention of the board to the establishment some years ago of a gold medal under the name of "The Hodgkins Medal of the Smithsonian Institution." This was in honor of Mr. Thomas George Hodgkins, the donor of the Hodgkins fund, and was to be awarded for exceptional contributions to our knowledge of the nature and properties of atmospheric air, or for original and practical applications of existing knowledge of the air to the welfare of mankind.

The first Hodgkins medal was awarded in 1898 to Prof. James Dewar for his researches on the liquefaction and solidification of

atmospheric air and for his discovery of the extraordinary magnetic properties of liquid oxygen. The second award of the medal was to Prof. J. J. Thomson in 1902 for his investigations on the conductivity of gases, especially on the gases that compose atmospheric air.

It is now proposed to award a third Hodgkins medal, provided it is determined that sufficiently meritorious discoveries or investigations of the character mentioned have been made, and in order to pass upon the matter an advisory committee on award has been appointed.

PUBLICATION FUND FOR THE INSTITUTION.

The secretary stated that under the general appropriation for public printing and binding, the Institution is allotted $10,000 for the printing of its annual reports, but that its other publications were paid for from private funds of the Institution.

He exhibited a set of the publications issued by the Institution and its branches during the past two years, many of which had been published at the cost of the Institution.

Mr. Mann inquired if the secretary would like to have a larger edition of the annual report, to which the secretary replied that it would be desirable. Mr. Mann responded that this might be possible by a special resolution for any one year.

There was some further discussion, during which it was suggested that it would be proper for the secretary to speak of the matter of an appropriation for the publications of Smithsonian works when he was before the Committee on Appropriations.

DEATH OF OCTAVE CHANUTE.

The secretary recalled to the board that when the committee on award of the Langley medal was appointed, Mr. Octave Chanute was designated its chairman. Mr. Chanute died on November 23 last. His eminence as an engineer and his own important work in the science of aeronautics peculiarly fitted him for the duties of chairman of this committee, and his death will be a severe blow to the new science.

The secretary added that it seemed best to defer the selection of his successor as chairman of the committee for the present.

FULLER MEMORIAL SERVICE.

Senator Cullom said that he thought some more formal action should be taken in regard to the death of Chief Justice Fuller than had been adopted at this meeting, and inquired whether the matter was being considered.

The secretary replied that it had been his intention to request certain members of the board to prepare sketches of Chief Justice Fuller's life, which might later be printed in the annual report.

Senator Cullom added that he would like very much to have an address delivered before the Regents by Justice Harlan, who above all others was the most competent to prepare it.

After further discussion, Senator Cullom moved—

That Mr. Justice Harlan be requested to deliver, under the auspices of the Board of Regents, and at such time as will best suit his convenience, an address upon the life and work of the late Chief Justice Melville W. Fuller.

The motion was carried, and Justice Harlan said that he would be glad to deliver the address and that he would confer with the secretary on the subject.

ADJOURNMENT.

There being no further business to come before the board, on motion the meeting adjourned and the Regents inspected the exhibit of skins and mounted specimens from the African expedition collection.

REGULAR MEETING, FEBRUARY 9, 1911.

Present: The Hon. James S. Sherman, Vice President of the United States (chancellor), in the chair; the Hon. Edward Douglass White, Chief Justice of the United States; Senator S. M. Cullom, Senator A. O. Bacon, Representative John Dalzell, Representative James R. Mann, Dr. James B. Angell, the Hon. John B. Henderson, the Hon. George Gray, and the secretary, Mr. Charles D. Walcott.

ORDER OF BUSINESS.

In accordance with the previously adopted order of business, the following matters were next reported on by the secretary:

Appointment of Regents.—Section 5580 of the Revised Statutes provides that the Chief Justice of the United States shall be a Regent of the Smithsonian Institution. The vacancy in the office of Chief Justice caused by the death of Chief Justice Fuller has been filled by the appointment by the President of Mr. Justice Edward Douglass White, who therefore, under the operation of the section named, becomes a Regent ex officio.

Dr. James B. Angell has been reappointed for a term of six years by joint resolution of Congress.

Closing up of Andrews will case.—At the annual meeting held December 8, 1910, the board adopted a recommendation of the permanent committee that all further proceedings in the Andrews will case be dropped. The instructions of the board have been complied with.

Fuller memorial meeting.—It having appeared to be the wish of the board at its annual meeting on December 8 last that a formal meeting in memory of the late Chief Justice Fuller should be held by the Regents, a resolution was then adopted inviting Justice Harlan to deliver such an address on a suitable occasion, the time of which was to be left entirely to his convenience. The secretary regrets to report that Justice Harlan has written him to say that he finds himself unable in the near future to comply with the wishes of the board.

After discussion, in which it was suggested that the proposed tribute to the late chancellor take the form of a memorial to be published in the annual report, the following resolution was adopted:

> *Resolved*, That the secretary be requested to prepare a suitable memorial of the life and work of the late Chief Justice Melville Weston Fuller, chancellor of the Smithsonian Institution from 1888 to 1910, which memorial is hereby declared approved for inclusion in the next annual report of the Board of Regents.

Langley memorial tablet.—At the last meeting of the board it was reported that the Langley memorial tablet had met with an accident and would have to be remodeled. This work of repair has been going on, but no photograph showing the present condition of the tablet has been submitted by the sculptor.

Hodgkins gold medal of the Institution.—The committee appointed by the secretary to consider whether sufficiently important investigations into the phenomena of atmospheric air in relation to the welfare of mankind had been made to merit the award of the third Hodgkins gold medal have reported their findings with a recommendation, which report is now being considered.

Biological survey of the Panama Canal Zone.—The secretary stated that the board would recall that at the late annual meeting he had spoken of the organization of a biological survey of the Panama Canal Zone to include studies of the life of the land and waters of that region, and had explained the necessity for immediate action, as the opening of the canal would mingle the waters of the Atlantic and Pacific Oceans, which might permanently destroy the possibility of a true understanding of the fauna and flora now existing there.

Since that meeting a party of naturalists designated to carry on the work has reached the zone, and the collections resulting from their work are already arriving. Those engaged in the survey are the following:

Prof. S. E. Meek, of the Field Museum of Natural History; Prof. Henry Pittier, of the United States Bureau of Plant Industry; Mr. E. A. Goldman, of the United States Biological Survey; Mr. S. F. Hildebrand, of the United States Bureau of Fisheries; Mr. E. A. Schwarz and Mr. August Busck, of the United States Bureau of

Entomology; and Mr. William R. Maxon, of the United States National Museum.

Much interest is being manifested in this survey both here and in the zone. The Republic of Panama is so impressed with the importance of the work that it has invited the Institution to extend the survey into that country.

The Institution is indebted to the Departments of State, Agriculture, Commerce and Labor, the War Department, and the Panama Railroad & Steamship Co. for courtesies which have insured the success of the enterprise.

As previously stated, a very considerable part of the funds necessary for the survey has been received by subscription.

Appointment of an additional assistant secretary.—The secretary called attention to the large increase in the work of the Institution and its branches, brought about by the natural growth of their activities and the addition of new interests, and stated that there was need for the appointment of an additional assistant secretary.

He desired the permission of the board to appoint to that position before the close of the present fiscal year Dr. Frederick William True, who entered the service of the Institution in 1878, who was a zoologist of established reputation, and who was now head curator of the Department of Biology in the United States National Museum. After discussion, the following resolution was adopted:

Resolved, That the proposed appointment by the secretary of Dr. Frederick William True as assistant secretary of the Smithsonian Institution be approved.

Bequest of George W. Poore.—The secretary announced that since the annual meeting notice had been received that the Institution had been made the residual legatee of the late George W. Poore, of Lowell, Mass., who left an estate estimated to be $40,000, under the condition that the income from this sum should be added to the principal until a total of $250,000 should have been reached, and that then the income only was to be used for the purposes for which the Institution was created. The portions of the will relating to the bequest are as follows:

ITEM 7. The large and small photographs of myself I desire given to the Smithsonian Institute hereinafter mentioned; to be given a place in their Institute where they may be seen, as one of the conditions of the gift to them herein made by me.

ITEM 8. All the rest, residue, and remainder of my estate, real, personal, and mixed, of whatever name or nature and wherever found or situate, of which I shall die seized, possessed, or entitled, whether at law or in equity, I give, devise, and bequeath to the Smithsonian Institute, at Washington, D. C., but in trust nevertheless and upon the condition, in addition to the condition as to photographs of myself as above, that the fund realized from my estate and from turning the real and personal estate into money shall be held forever by said Smithsonian Institute as a fund to be called the Lucy T., and George W. Poore fund, and upon condition that the income only of said fund

shall be used for the purposes only for which said Smithsonian Institute was created, said Lucy T. and George W. Poore fund to be kept separate from all other funds, and the income from the same not to be used until the principal, by accumulation of the income to be added to the principal from year to year, shall have reached the sum of two hundred and fifty thousand dollars. I make this gift not so much because of its amount as because I hope it will prove an example for other Americans to follow, by supporting and encouraging so wise and beneficent an institution as I believe the Smithsonian Institute to be, and yet it has been neglected and overlooked by American citizens.

The secretary said: "At my request the Institution's interests in the matter are being looked after by Mr. Choate, of the Board of Regents, who has assured me that he will be glad to act as agent or attorney for the Institution without charge."

The Paul J. Rainey expedition to Africa.—The secretary said that Mr. Paul J. Rainey, of New York City, recently called at the Institution and stated that it was his intention to make a hunting and collecting trip in Africa, and asked if a man could be sent with him to prepare the specimens which he wished to present to the Institution. The route of travel was to be north of that of the recent Smithsonian expedition, through the country lying between the northern portion of British East Africa and the southern part of Abyssinia. Mr. Rainey agreed to bear all expenses in connection with the trip.

It was thought desirable to accept this offer, as it was hoped to add new material to the present collections; and Mr. Edmund Heller, who was one of the field naturalists on the Smithsonian expedition, and who was now engaged in working up that collection, had been authorized to suspend work upon it temporarily, and detailed to accompany Mr. Rainey. He expected to sail on February 18, and to be absent about eight months.

Portrait of Washington.—The secretary called attention to a portrait of Gen. Washington, which was hanging in the room in which the board was then meeting.

This portrait was part of the Lewis collection of Washington relics purchased by the Government in 1878 and stored for a time at the Patent Office. When the collection was transmitted to the National Museum in 1883, the Commissioner of Patents retained this picture, and it is only recently that the matter came up, with the result that the portrait was sent to the Institution by the Secretary of the Interior, Mr. Ballinger.

The picture has been attributed to Gilbert Stuart, but a careful investigation fails to reveal anything to substantiate the claim, and it is now recorded as having been painted by an unknown artist. By some it is regarded as a copy of an original painting. Mrs. Lewis had said that there was a tradition in the family that this was considered the best likeness of Washington ever painted.

American Indian memorial and museum building.—It was stated by the secretary that a request to Congress to erect in Washington an American Indian memorial and museum building, under the control of the Secretary of the Interior, had been embodied in two identical bills designated as follows: House joint resolution 274 and Senate bill 9830.

This subject is one which, by direction of Congress, has long been fostered by the Smithsonian Institution through the National Museum and the Bureau of American Ethnology, all material objects being deposited in the former, and all records of investigations in the latter. The Museum collection is the richest in the world as regards the Indians of North America, to which the proposed new building is intended to be devoted. In extent and variety the collections of the National Museum are not what they might and should be, but this is due to the fact that appropriations sufficient to perfect these collections have never been obtainable.

The founding of a new museum, especially under the proposed auspices, could only result in the partial duplication of objects and records and in an increase in the cost of bringing together a proper representation of the North American Indians. Should Congress take any action in this matter, it would seem desirable that it be directed toward giving increased funds for the use of the Institution and Museum. If the movement is one tending to bring individual help from different parts of the country, such cooperation could best be turned toward increasing the present collections, which are already extensive and important.

Commercial museum.—The subject of establishing at the National Capital a trade or commercial museum to be maintained at the expense of the Government has been recently agitated in connection with the Board of Trade of Washington. While no bill in support of such a measure has been submitted to Congress as yet, it is apparently the intention to request congressional action in connection with any celebration which may be held here in commemoration of the completion of the Panama Canal.

While such a museum would follow lines in large part not included in the plan of the National Museum, yet in some respects the tendency would be to duplicate its collections.

It would, furthermore, appear to those who have given the matter consideration that Washington is not the proper place for the location of a museum of this kind. It should be established and conducted in a large commercial center like New York City.

Prehistoric ruins.—The secretary exhibited a number of photographs showing the excavations among prehistoric cliff dwellings and pueblo ruins in New Mexico resulting from the joint work of the Bureau of American Ethnology and the Archeological Institute

of America. In one canyon in which these excavations were conducted the cliff dwellings extend along the wall of the canyon for about 2 miles, while in another locality in the same general region one of the many pueblo ruins covers an area of about 600 feet square. Other photographs were presented showing the excavation and repair of the celebrated Balcony House in southern Colorado, conducted under the joint auspices of the Smithsonian Institution and the Colorado Cliff Dwellers Association. Excavations were made also in newly discovered cliff dwellings and other archeological remains in northwestern Arizona.

Field work has been conducted by the Bureau of American Ethnology among the tribes which composed the Creek Confederacy of the Southern States; the Tewa Indians of the Rio Grande Valley, New Mexico; the Winnebago Indians of Wisconsin and Nebraska; the Piegan, Blackfeet, Cheyenne, and Menominee Indians of the Algonquian family; the Chippewa Indians, especially with reference to their music; the Osage Indians, now in Oklahoma, and the Iroquois in New York. A study of the past and present population of the Indians, with the various causes of their decrease, is being conducted, and a bibliography of the Hawaiian Islands is in preparation.

Resignation of Senator Henderson.—Senator Henderson stated that he had served the Institution as a Regent for 19 years, but that he had now reluctantly come to the conclusion that it was necessary to relieve himself of all possible work, as the condition of his health would not permit him to continue his duties with satisfaction to himself and justice to the Institution. He therefore desired to tender his resignation as a Regent to take effect at such time as would best suit the board's convenience.

After discussion, the Senator first submitted his resignation as a member of the executive committee to take effect at once, and on motion it was carried—

That the resignation of the Hon. John B. Henderson, chairman of the executive committee, as a member of that committee, be accepted with regret.

The Senator then presented his resignation as a Regent to take effect March 1, 1911.

Judge Gray offered the following resolution, which was unanimously adopted:

Whereas the board of Regents of the Smithsonian Institution having learned that the Hon. John B. Henderson has tendered his resignation as a Regent, a position he has filled with signal ability for 19 years;

Resolved, That the Regents desire here to express to him their high appreciation of his services as a member of the board, their sincere regret at the termination of his official connection with the institution, and their cordial good wishes for his future health and happiness.

Mr. Mann then offered the following resolution, which was adopted:

Resolved, That the resolution in relation to the resignation of the Hon. John B. Henderson as a Regent of the Smithsonian Institution be engrossed and transmitted to him.

The chancellor stated that the secretary would communicate to Congress the announcement of Senator Henderson's resignation.

Executive committee vacancy filled.—The matter of the vacancy in the membership of the executive committee was brought up, and Senator Bacon was nominated for the position. After discussion, the following resolution was adopted:

Resolved, That the vacancy in the membership of the executive committee, caused by the resignation of the Hon. John B. Henderson, be filled by the election of the Hon. A. O. Bacon.

Models of patents.—Mr. Mann said that there were pending in Congress bills providing for the destruction of the old models that had been on deposit in the Patent Office for many years, and asked if the Smithsonian Institution could make any use of them.

The secretary explained that this matter had been brought to the Institution's attention two or three years since, and that about 12,000 of the models had been selected for the use of the industrial exhibit in the Museum. Those left were not suited to museum purposes.

Adjournment.—There being no further business to be transacted, on motion the board adjourned.

GENERAL APPENDIX

TO THE

SMITHSONIAN REPORT FOR 1911

ADVERTISEMENT.

The object of the General Appendix to the Annual Report of the Smithsonian Institution is to furnish brief accounts of scientific discovery in particular directions; reports of investigations made by collaborators of the Institution; and memoirs of a general character or on special topics that are of interest or value to the numerous correspondents of the Institution.

It has been a prominent object of the Board of Regents of the Smithsonian Institution, from a very early date, to enrich the annual report required of them by law with memoirs illustrating the more remarkable and important developments in physical and biological discovery, as well as showing the general character of the operations of the Institution; and this purpose has, during the greater part of its history, been carried out largely by the publication of such papers as would possess an interest to all attracted by scientific progress.

In 1880 the secretary, induced in part by the discontinuance of an annual summary of progress which for 30 years previous had been issued by well-known private publishing firms, had prepared by competent collaborators a series of abstracts, showing concisely the prominent features of recent scientific progress in astronomy, geology, meteorology, physics, chemistry, mineralogy, botany, zoology, and anthropology. This latter plan was continued, though not altogether satisfactorily, down to and including the year 1888.

In the report for 1889 a return was made to the earlier method of presenting a miscellaneous selection of papers (some of them original) embracing a considerable range of scientific investigation and discussion. This method has been continued in the present report for 1911.

THE GYROSTATIC COMPASS.[1]

[With 3 plates.]

By H. Marchand.

The gyrostatic compass may be looked upon as one of the most interesting inventions made during recent years.

The gyroscope is familiar to all. Nor are we ignorant to-day of the fundamental laws which govern it. The great physicist Foucault first completely formulated them as the result of his profound researches on the subject.

The first of these laws is that a gyroscope with perfect freedom of movement—that is, the power to move in any direction, and free from the action of gravity—will tend to maintain the initial position given to it. The second law is that if a gyroscope has only two degrees of freedom, in such a way that it can undergo displacement in two planes only, it must, if subject to the action of gravity, and provided that it is not at the poles of the earth, tend to place itself so that its axis is parallel to that of the earth and accordingly will indicate the direction of true north.

A system of this kind is free from the errors which affect the magnetic compass, and therefore the idea of taking advantage of it for navigation must have early attracted the attention of investigators, especially as the general use of steel in the construction of vessels entails grave difficulties in the use of magnetic instruments.

Formerly the means at hand were insufficient for constructing a satisfactory, practical instrument, and so, during the time of Foucault, and even much later, the numerous scientists who approached the problem did not meet with much success.

A German investigator, Dr. Anschütz, has recently succeeded in constructing an instrument on gyrostatic principles which is practical. In 1900 he commenced the study of a gyroscope with perfect freedom of movement. Later, however, in 1906, he abandoned that for one having only two degrees of freedom.

Even with the latter conditions the problem required great nicety. A grave difficulty comes from the fact that such a device is affected, under ordinary circumstances, not only by the rotation of the earth but also by all the forces to which it is subjected because of the rolling

[1] Translated by permission from Cosmos, Paris, New Series No. 1385, Aug. 12, 1911, pp. 181-184.

of the ship. Therefore, in order to get a good result, it was necessary for the compass to have a very great gyrostatic resistance, so termed, opposing energetically any force tending to change the direction of its axis of rotation, and that the friction of its bearings should be made as small as possible. A consequence of the latter condition, however, would be that the gyrostat would come to its normal position only after a relatively long time, oscillating to and fro about that normal position. Meanwhile it would be subject to new perturbations.

Accordingly one great desideratum was to provide some device for lessening these oscillations; at first, Anschütz tried for this purpose a second gyrostat; later he developed a much more simple and efficient method. His gyrostatic compass was tried on the steamer *Deutschland* in 1908 and has since been used in the German Navy. It has just been adopted by the English Navy, and other navies are also trying it.

Let us consider its principles: We know that a gyroscope once started tends to maintain its axis in an invariable direction, and that if any force is applied tending to change this direction, precessional movement takes place, which displaces the axis perpendicular to the direction of the disturbing force. Such being the case, let us imagine a gyroscope, inclosed in an appropriate box, suspended from a float which rests in a liquid bath in such a manner that the gyroscope is perfectly free to swing in any direction like a pendulum which is at rest; the center of gravity of the system is below the metacenter; the gyroscope is mounted at the lowest point possible. Because of its weight the axis of the gyroscope tends to maintain itself, as well as the whole attached mechanism, in a horizontal position.

Let us set the gyroscope disk rotating. In the past such rotation could be effected only by rough and very unsatisfactory means; now we have a much more advantageous method at our disposal. We may, for instance, drive it by a little three-phase motor fed by means of fine conducting wires so that the rotation may be kept up indefinitely.

As soon as the gyroscope disk is in rapid rotation with its axis horizontal, then if this axis is not in the plane of the terrestrial meridian, the rotation of the earth will tend to alter the axis from its original position. The gyroscope tends to respond, but, restricted by its weight, which forces the axis to remain horizontal, it will undergo only a horizontal displacement.

This leads it to take a north and south direction, because as long as its axis is not parallel to that of the earth, the cause of this movement is still effective, so that if it is sufficiently free to move, it will indicate true north.

Plate 1 shows a model designed to show experimentally this action. It consists of a small gyroscope, driven by a small three-phase elec-

tric motor, and entirely free to turn in any direction were it not for two small springs, which serve to represent the attraction due to gravity and tend to keep the gyroscope's axis tangent to the surface of the sphere upon which it is mounted. This apparatus may be slipped along a large movable metallic circle representing a meridian.

When the springs are detached the axis of the gyroscope tends to take an invariable direction and to depart from it only because of the inevitable friction which is present at the pivots.

However, once these springs are attached, if the meridian circle is moved to another place on the globe, then the axis will change so as to come into the plane of the circle, one of its extremities being directed toward the upper pole of the circle. According to the direction of the gyroscope and that of the circle, one or the other end of the axis moves so as to point to this upper pole.

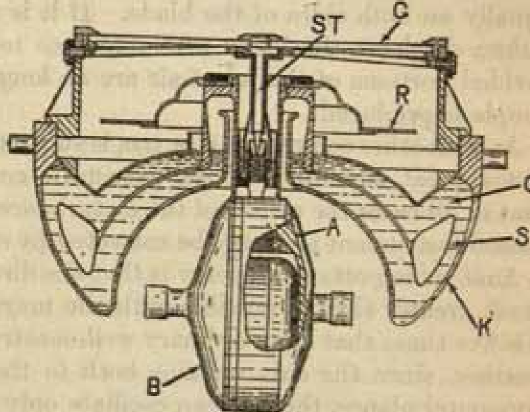


FIG. 1.—Anschütz gyrostatic compass. Vertical section. A, three-phase alternating-current motor in box B (the rotor of the motor serves as the gyrostat); R, compass card; S, hollow annular steel float, floating in the mercury Q and counterbalancing the weight of the moving system; K, compass box, suspended as usual by gymbals; S, T, special suspension, made of two insulated conductors for leading in two branches of the three-phase current, the third circuit being made through the floating ring and the surrounding mercury.

In the Anschütz compass, of which figure 1 is a sectional and plate 2 a perspective view, the gyrostat is similarly driven by a three-phase electric motor; the float from which the gyroscope is suspended is a hollow bowl of steel partially immersed in a mercury bath contained in an annular box, also of steel. To the top of this float is fixed the compass card. The north-south line of the card coincides exactly with the direction of the axis of the gyrostat.

The small motor which rotates the gyrostat disk is so constructed that its stationary part is built on the box of the gyrostat. The electrical connections to the exterior are made for two of the circuits through small cups of mercury. The third circuit passes through the mercury bath containing the float and then through the case itself. The rotor is rigidly built on the gyrostat disk. It is of one piece, spindle and all, and made of nickel steel. It is provided with ball bearings of extra-hard steel and makes 20,000 revolutions per minute. The axle is of the Laval type or "flexible axle." Its great

velocity of rotation frees it from any danger of deformation due to shocks.

A small level is attached to the compass card to assure that the instrument is horizontal. The whole system is mounted on gymbals and attached to the binnacle with springs after the usual manner with marine magnetic compasses.

The damping of the oscillations of the compass is effected in a very ingenious manner. Near the center and on both sides of the gyrostat box are bored small holes. A third hole is bored in the surrounding case. The rotation of the gyrostat produces a current of air within and a pressure toward the exterior.

The jet of air at its exit is cut by a small blade attached to a pendulum. When the compass is exactly horizontal, the jet is divided equally on both sides of the blade. If it is not horizontal, the pendulum displaces the blade with reference to the aperture; then the divided portions of the jet of air are no longer equal and a damping couple is produced.

As with other compasses, this, too, is subject to disturbing influences. But a great advantage of the gyrostatic compasses lies in the fact that in all cases the causes of the disturbances are independent of the special instrument and may be corrected by specially prepared tables.

Another important property is that the directing force can be made much greater than is possible with the magnetic needle. Generally it is five times that of an ordinary well-constructed magnetic compass. Further, since the axis remains both in the meridional and in the horizontal planes, the dial can oscillate only slightly about the north and south direction. This renders it easy to fix contact points at the extremities of the east and west line for the electrical transmission elsewhere of the indications of the compass.

A gyrostatic compass equipment consists of a master compass, provided with a transmitter, and secondary compasses connected electrically with the master. The master compass, together with the transmitter, is placed in a convenient, well-protected place, and the secondary ones placed wherever they are needed; or two master compasses may be used with two systems of secondary ones.

The master compass, with its transmitter, of which a photograph is shown in plate 3, figure 1, differs from the others in that the binnacle is moved by a reversible electric motor controlled by contacts under the gyrostat itself, so that it turns rapidly when necessary and follows at all times the motions of the axis of the gyrostat.

It is this moving binnacle which sends the currents controlling the secondary compasses and keeps them in synchronism with the master compass. The latter carries on its axis the necessary commutator.

Special secondary compasses are employed, as shown in the illustration (pl. 3, fig. 2). It may be noted that it has at its center a

second limb, which makes one complete rotation for each 10 degrees of deviation and thus renders visible very small deviations. The current for the motors of the gyrostat and of the transmitter is furnished at 120 volts, 333 periods per second by a 16-pole motor generator working on an ordinary direct-current lighting circuit. It runs at a speed of 2,500 turns per minute. The motor of the gyrostat is bipolar. An Anschütz compass uses normally 700 watts. Besides the apparatus already described, there is furnished a short description, with the necessary directions for starting the compass and regulating it. Ammeters are placed in each of the three circuits, and a voltmeter may be connected between any two of them. For each wire there is a pair of fuses so contrived that, by means of a quick-working switch, if one of the fuses fails the other may be quickly inserted.

DEMONSTRATION MODEL OF GYROSTATIC COMPASS.

GYROSTATIC COMPASS.

1. COMPASS AND TRANSMITTER. MASTER COMPASS.

2. RECEIVER. SECONDARY COMPASS.

RADIOTELEGRAPHY.[1]

[With 1 plate.]

By Commendatore G. Marconi, LL.D., D.Sc.

The practical application of electric waves to the purposes of wireless telegraphic transmission over long distances has continued to extend to a remarkable degree during the last few years, and many of the difficulties, which at the outset appeared almost insurmountable, have been gradually overcome, chiefly through the improved knowledge which we have obtained in regard to the subject generally and to the principles involved.

The experiments which I have been fortunate enough to be able to carry out, on a much larger scale than can be done in ordinary laboratories, have made possible the investigation of phenomena often novel and certainly unexpected.

Although we have—or believe we have—all the data necessary for the satisfactory production and reception of electric waves, we are yet far from possessing any very exact knowledge concerning the conditions governing the transmission of these waves through space, especially over what may be termed long distances. Although it is now perfectly easy to design, construct, and operate stations capable of satisfactory commercial working over distances up to 2,500 miles, no really clear explanation has yet been given of many absolutely authenticated facts concerning these waves. Some of these hitherto apparent anomalies I shall mention briefly in passing.

Why is it that when using short waves the distances covered at night are usually enormously greater than those traversed in the day time, while when using much longer waves the range of transmission by day and night is about equal and sometimes even greater by day?

What explanation has been given of the fact that the night distances obtainable in a north-southerly direction are so much greater than those which can be effected in an east-westerly one?

Why is it that mountains and land generally should greatly obstruct the propagation of short waves when sunlight is present and not during the hours of darkness?

[1] Reprinted by permission from author's separate of Proceedings of the Royal Institution. Read before Royal Institution of Great Britain at weekly evening meeting, Friday, June 2, 1911.

The general principles on which practical radiotelegraphy is based are now so well known that I need only refer to them in the briefest possible manner.

Wireless telegraphy, which was made possible by the fields of research thrown open by the work of Faraday, Maxwell, and Hertz, is operated by electric waves, which are created by alternating currents of very high frequency, induced in suitably placed elevated wires or capacity areas. These waves are received or picked up at a distant station on other elevated conductors tuned to the period of the waves, and the latter are revealed to our senses by means of appropriate detectors.

My original system as used in 1896 consisted of the arrangement shown diagrammatically in figure 1, where an elevated or vertical wire was employed. This wire sometimes terminated in a capacity or was connected to earth through a spark gap.

By using an induction coil or other source of sufficiently high tension electricity sparks were made to jump across the gap; this gave rise to oscillations of high frequency in the elevated conductor and earth, with the result that energy in the form of electric waves was radiated through space.

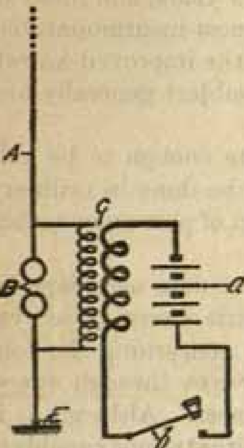


FIG. 1.

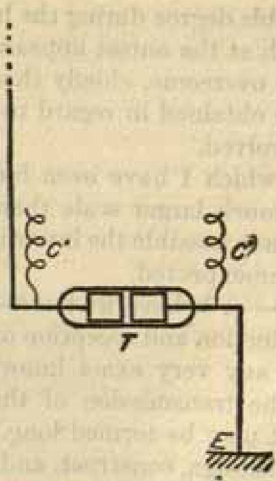


FIG. 2.

At the receiving station (fig. 2) these waves induced oscillatory currents in a conductor containing a detector, in the form of a coherer, which was usually placed between the elevated conductor and earth.

Although this arrangement was extraordinarily efficient in regard to the radiation of electrical energy, it had numerous drawbacks.

The electrical capacity of the system was very small, with the result that the small amount of energy in the aerial was thrown into space in an exceedingly short period of time. In other words, the energy, instead of giving rise to a train of waves, was all dissipated after only a few oscillations, and, consequently, anything approaching good tuning between the transmitter and receiver was found to be unobtainable in practice.

Many mechanical analogies could be quoted which show that in order to obtain syntony the operating energy must be supplied in the form of a sufficient number of small oscillations or impulses properly timed. Acoustics furnish us with numerous examples of this fact, such as the resonance produced by the well-known tuning fork experiment.

Other illustrations of this principle may be given; e. g., if we have to set a heavy pendulum in motion by means of small thrusts or impulses, the latter must be timed to the period of the pendulum, as otherwise its oscillations would not acquire any appreciable amplitude.

In 1900 I first adopted the arrangement which is now in general use, and which consists (as shown in fig. 3) of the inductive association of the elevated radiating wire with a condenser circuit which may be used to store up a considerable amount of electrical energy and impart it at a slow rate to the radiating wire.

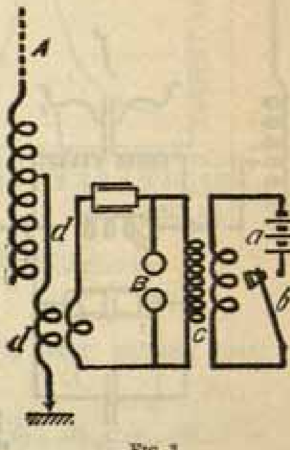


FIG. 3.

As is now well known, the oscillations in a condenser circuit can be made to persist for what is electrically a long period of time, and it can be arranged moreover that by means of suitable aerials or antennæ these oscillations are radiated into space in the form of a series of waves, which through their cumulative effect are eminently suitable for enabling good tuning and syntony to be obtained between the transmitter and receiver.

The circuits, consisting of the condenser circuit and the elevated aerial or radiating circuit, were more or less closely coupled to each other. By adjusting the inductance in the elevated conductor, and by the employment of the right value of capacity or inductance required in the condenser circuit, the two circuits were brought into electrical resonance, a condition which I first pointed out as being essential in order to obtain efficient radiation and good tuning.

The receiver (as shown in fig. 4) also consists of an elevated conductor or aerial connected to earth or capacity through an oscillating transformer. The latter also contains the condenser and detector, the circuits being made to have approximately the same electrical time period as that of the transmitter circuits.

At the long distance station situated at Clifden, in Ireland, the arrangement which has given the best results is based substantially upon my syntonic system of 1900, to which have been added numerous improvements.

An important innovation from a practical point of view was the adoption at Clifden and Glace Bay of air condensers, composed of insulated metallic plates suspended in air at ordinary pressure. In this manner we greatly reduce the loss of energy which would take place in consequence of dielectric hysteresis were a glass or solid dielectric employed. A very considerable economy in working also results from the absence of dielectric breakages, for, should the potential be so raised as to even produce a discharge from plate to plate across the condenser, this does not permanently affect the value of the dielectric, as air is self-healing and one of the few commodities which can be replaced at a minimum of cost.

Various arrangements have been tried and tested for obtaining continuous or very prolonged trains of waves, but it has been my experience that, when utilizing the best receivers at present available, it is neither economical nor efficient to attempt to make the waves too continuous. Much better results are obtained when groups of waves (fig. 5) are emitted at regular intervals in such manner that their cumulative effect produces a clear musical note in the receiver, which is tuned not only to the periodicity of the electric waves transmitted but also to their group frequency.

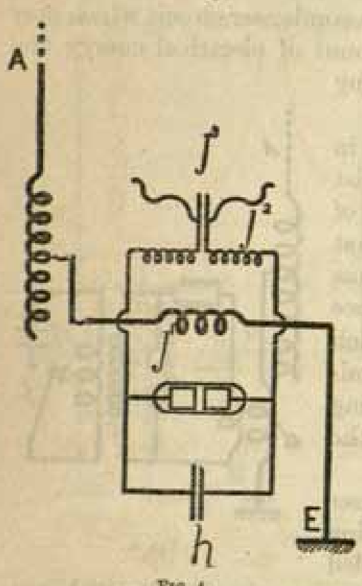


FIG. 4.

In this manner the receiver may be doubly tuned, with the result that a far greater selectivity can be obtained than by the employment of wave tuning alone.

In fact, it is quite easy to pick up simultaneously different messages transmitted on the same wave length, but syntonized to different group frequencies.

As far as wave tuning goes, very good results—almost as good as are obtainable by means of continuous oscillations—can be achieved with groups of waves, the decrement of which is in each group 0.03 or 0.04, which means that about 30 or 40 useful oscillations are radiated before their amplitude has become too small to perceptibly affect the receiver.

The condenser circuit at Clifden has a decrement of from 0.015 to 0.03 for fairly long waves.

This persistency of the oscillations has been obtained by the employment of the system shown in figure 6, which I first described in a patent taken out in September, 1907. This method eliminates

almost completely the spark gap and its consequent resistance, which, as is well known, is the principal cause of the damping or decay of the waves in the usual transmitting circuit.

The apparatus shown in figure 6 consists of a metal disk *a*, having copper studs firmly fixed at regular intervals in its periphery and placed transversely to its plane. This disk is caused to rotate very rapidly between two other disks, *b*, by means of a rapidly revolving electric motor or steam turbine. These side disks are also made to slowly turn round in a plane at right angles to that of the middle disk. The connections are as illustrated in the figure. The studs are of such length as to just touch the side disks in passing, and thereby bridge the gap between the latter.

With the frequency employed at Clifden, namely, 45,000, when a potential of 15,000 volts is used on the condenser, the spark gap is practically closed during the time in which one complete oscillation only is taking place, when the peripherical speed of the disk is about 600 feet a second. The result is that the primary circuit can continue oscillating without material loss by resistance in the spark gap. Of course the number of oscillations which can take place is governed by the breadth or thickness of the side disks, the primary circuit being abruptly opened as soon as the studs attached to the middle disk leave the side disks.

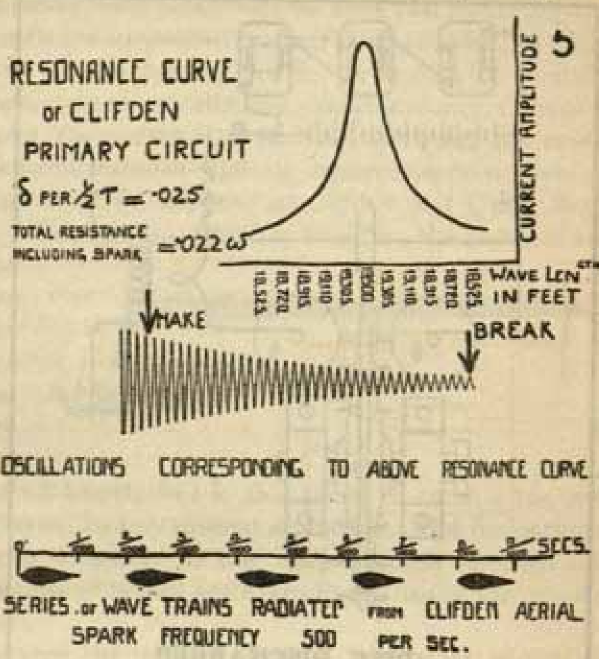


FIG. 5.

This sudden opening of the primary circuit tends to immediately quench any oscillations which may still persist in the condenser circuit; and this fact carries with it a further and not inconsiderable advantage, for if the coupling of the condenser circuit to the aerial is of a suitable value the energy of the primary will have practically all passed to the aerial circuit during the period of time in which the

primary condenser circuit is closed by the stud filling the gap between the side disks; but after this the opening of the gap at the disks prevents the energy returning to the condenser circuit from the aerial, as would happen were the ordinary spark gap employed. In this manner the usual reaction which would take place between the aerial and the condenser circuit can be obviated, with the result that with this type of discharger and with a suitable degree of coupling the energy is radiated from the aerial in the form of a pure wave, the loss from the spark gap resistance being reduced to a minimum.

I am able to show a resonance curve taken at Clifden which was obtained from the oscillations in the primary alone (fig. 5).

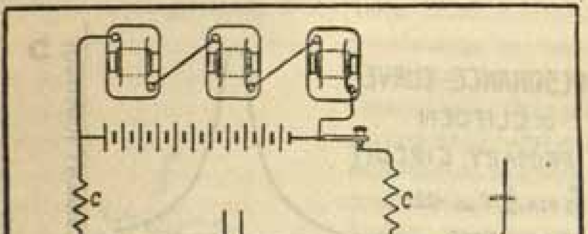


FIG. 6.

An interesting feature of the Clifden plant, especially from a practical and engineering point of view, is the regular employment of high-tension direct current for charging the condenser. Continuous current at a potential which is capable of being raised to 20,000 volts is obtained by means of special direct-current generators; these machines charge a storage battery consisting of 6,000 cells, all connected in series, and it may be pointed out that this battery is the largest of its kind in existence. The capacity of each cell is 40 ampere-hours. When employing the cells alone the working voltage is from 11,000 to 12,000 volts, and when both the direct-current generators and the battery are used together the potential may be raised to 15,000 volts through utilizing the gassing voltage of the storage cells.

For a considerable portion of the day the storage battery alone is employed, with a result that for 16 hours out of the 24 no running

machinery need be used for operating the station, with the single exception of the small motor revolving the disk.

The potential to which the condenser is charged reaches 18,000 volts when that of the battery or generators is 12,000. This potential is obtained in consequence of the rise of potential at the condenser plates, brought about by the rush of current through the choking or inductance coils at each charge. These coils are placed between the battery or generator and the condenser *c*, figure 6.

No practical difficulty has been encountered either at Clifden or Glace Bay in regard to the insulation and maintenance of these high-tension storage batteries. Satisfactory insulation has been obtained by dividing the battery into small sets of cells placed on separate stands. These stands are suspended on insulators attached to girders fixed in the ceiling of the battery room. A system of switches, which can all be operated electrically and simultaneously, divides the battery into sections, the potential of each section being low enough to enable the cells to be handled without inconvenience or risk.

The arrangement of aerial adopted at Clifden and Glace Bay is shown in figure 7. This system, which is based on the result of tests which I first described before the Royal Society in June, 1906,[1] not only makes it possible to efficiently radiate and receive waves of any desired length, but it also tends to confine the main portion of the radiation to any desired direction. The limitation of transmission to one direction is not very sharply defined, but nevertheless the results obtained are exceedingly useful for practical working.

FIG. 7.

In a similar manner, by means of these horizontal wires, it is possible to define the bearing or direction of a sending station, and also limit the receptivity of the receiver to waves arriving from a given direction.

The commercial working of radiotelegraphy and the widespread application of the system on shore and afloat in nearly all parts of the world has greatly facilitated the marshaling of facts and the observation of effects. Many of these, as I have already stated, still await a satisfactory explanation.

A curious result which I first noticed over nine years ago in long-distance tests carried out on the steamship *Philadelphia*, and which still remains an important feature in long-distance space telegraphy,

[1] "On methods whereby the radiation of electric waves may be mainly confined, etc." Proc. Roy. Soc., A, vol. 77, p. 413.

is the detrimental effect produced by daylight on the propagation of electric waves over great distances.

The generally accepted hypothesis of the cause of this absorption of electric waves in sunlight is founded on the belief that the absorption is due to the ionization of the gaseous molecules of the air affected by the ultra violet light, and as the ultra violet rays which emanate from the sun are largely absorbed in the upper atmosphere of the earth, it is probable that that portion of the earth's atmosphere which is facing the sun will contain more ions or electrons than that which is in darkness, and therefore, as Sir J. J. Thomson has shown,[1] this illuminated or ionized air will absorb some of the energy of the electric waves.

The wave length of the oscillations employed has much to do with this interesting phenomenon, long waves being subject to the effect of daylight to a very much lesser degree than are short waves.

Although certain physicists thought some years ago that the daylight effect should be more marked on long waves than on short, the reverse has been my experience; indeed, in some transatlantic experiments, in which waves about 8,000 meters long were used, the energy received by day at the distant receiving station was usually greater than that obtained at night.

Recent observation, however, reveals the interesting fact that the effects vary greatly with the direction in which transmission is taking place, the results obtained when transmitting in a northerly and southerly direction being often altogether different from those observed in the easterly and westerly one.

Research in regard to the changes in the strength of the received radiations which are employed for telegraphy across the Atlantic has been recently greatly facilitated by the use of sensitive galvanometers, by means of which the strength of the received signals can be measured with a fair degree of accuracy.

In regard to moderate power stations such as are employed on ships, and which, in compliance with the international convention, use wave lengths of 300 and 600 meters, the distance over which communication can be effected during daytime is generally about the same, whatever the bearing of the ships to each other or to the land stations —whilst at night interesting and apparently curious results are obtained. Ships over 1,000 miles away, off the south of Spain or round the coast of Italy, can almost always communicate during the hours of darkness with the post-office stations situated on the coasts of England and Ireland, whilst the same ships, when at a similar distance on the Atlantic to the westward of these islands and on the usual track between England and America, can hardly ever communi-

[1] Philosophical Magazine, ser. 6, vol. 4, p. 253.

cate with these shore stations unless by means of specially powerful instruments.

It is also to be noticed that in order to reach ships in the Mediterranean the electric waves have to pass over a large portion of Europe and, in many cases, over the Alps. Such long stretches of land, especially when including very high mountains, constitute, as is well known, an insurmountable barrier to the propagation of short waves during the daytime. Although no such obstacles lie between the English and Irish stations and ships in the North Atlantic en route for North America, a night transmission of 1,000 miles is there of exceptionally rare occurrence. The same effects generally are noticeable when ships are communicating with stations situated on the Atlantic coast of America.

Although high power stations are now used for communicating across the Atlantic Ocean, and messages can be sent by day as well as by night, there still exist periods of fairly regular daily occurrence during which the strength of the received signals is at a minimum.

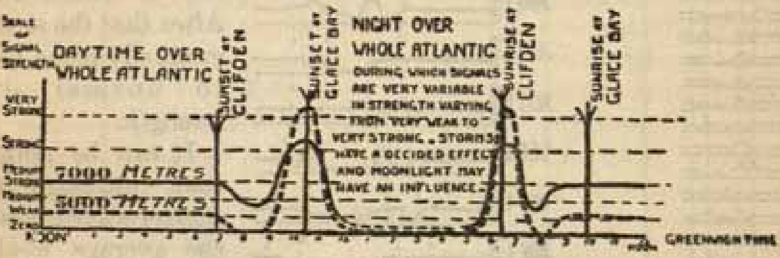


FIG. 8.

Thus in the morning and the evening, when, in consequence of the difference in longitude, daylight or darkness extends only part of the way across the ocean, the received signals are at their weakest. It would almost appear as if electric waves, in passing from dark space to illuminated space and vice versa, were reflected and refracted in such a manner as to be diverted from the normal path.

Later results, however, seem to indicate that it is unlikely that this difficulty would be experienced in telegraphing over equal distances north and south on about the same meridian, as, in this case, the passage from daylight to darkness would occur more rapidly over the whole distance between the two stations.

I have here some diagrams which have been carefully prepared by Mr. H. J. Round. These show the average daily variation of the signals received at Clifden from Glace Bay.

The curves traced on the diagram (fig. 8) show the usual variation in the strength of these transatlantic signals on two wave lengths —one of 7,000 meters and the other of 5,000 meters.

The strength of the received waves remains as a rule steady during daytime.

Shortly after sunset at Clifden they become gradually weaker, and about two hours later they are at their weakest. They then begin to strengthen again, and reach a very high maximum at about the time of sunset at Glace Bay.

They then gradually return to about normal strength, but through the night they are very variable. Shortly before sunrise at Clifden the signals commence to strengthen steadily, and reach another high maximum shortly after sunrise at Clifden. The received energy then steadily decreases again until it reaches a very marked minimum, a short time before sunrise at Glace Bay. After that the signals gradually come back to normal day strength.

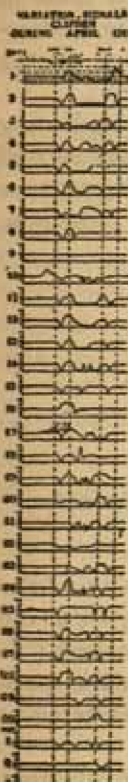


FIG. 9.

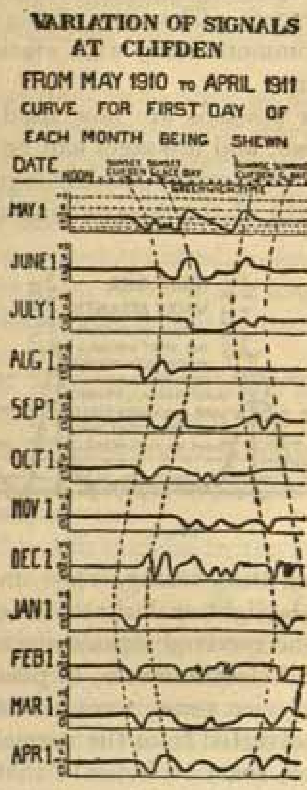


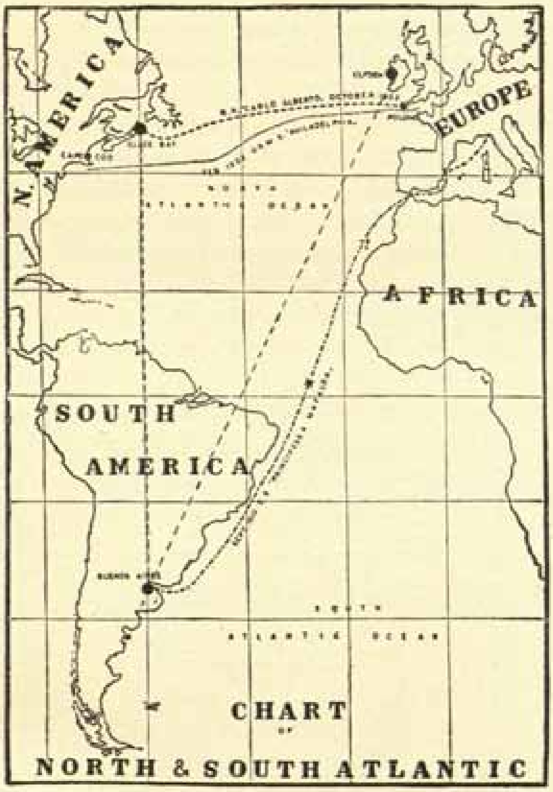
FIG. 10.

It can be noticed that, although the shorter wave gives on the average weaker signals, its maximum and minimum variations of strength very sensibly exceed that of the longer waves.

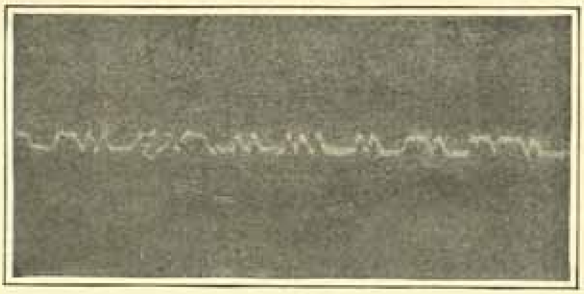
Figure 9 shows the variations at Clifden during periods of 24 hours, commencing at 12 noon throughout the month of April, 1911, the vertical dotted lines representing sunset and sunrise at Glace Bay and Clifden.

Figure 10 shows the curve for the first day of each month for one year, from May, 1910, to April, 1911.

I carried out a series of tests over longer distances than had ever been previously attempted, in September and October of last year, between the stations of Clifden and Glace Bay, and a receiving station placed on the Italian Steamship *Principessa Mafalda*, in the course of a voyage from Italy to Argentina (pl. 1, fig. 1).



1. Long Distance Wireless Tests in 1910.



2. Record of Wireless Signals.

During these tests the receiving wire was supported by means of a kite, as was done in my early transatlantic tests of 1901, the height of the kite varying from about 1,000 to 3,000 feet. Signals and messages were obtained without difficulty, by day as well as by night, up to a distance of 4,000 statute miles from Clifden.

Beyond that distance reception could only be carried out during nighttime. At Buenos Aires, over 6,000 miles from Clifden, the night signals from both Clifden and Glace Bay were generally good, but their strength suffered some variations.

It is rather remarkable that the radiations from Clifden should have been detected at Buenos Aires so clearly at nighttime and not at all during the day, whilst in Canada the signals coming from Clifden (2,400 miles distant) are no stronger during the night than they are by day.

Further tests have been carried out recently for the Italian Government between a station situated at Massaua in East Africa and Coltano in Italy. Considerable interest attached to these experiments, in view of the fact that the line connecting the two stations passes over exceedingly dry country and across vast stretches of desert, including parts of Abyssinia, the Soudan, and the Libyan Desert. The distance between the two stations is about 2,600 miles.

The wave length of the sending station in Africa was too small to allow of transmission being effected during daytime, but the results obtained during the hours of darkness were exceedingly good, the received signals being quite steady and readable.

The improvements introduced at Clifden and Glace Bay have had the result of greatly minimizing the interference to which wireless transmission over long distances was particularly exposed in the early days.

The signals arriving at Clifden from Canada are as a rule easily read through any ordinary electrical atmospheric disturbance. This strengthening of the received signals has moreover made possible the use of recording instruments, which will not only give a fixed record of the received messages, but are also capable of being operated at a much higher rate of speed than could ever be obtained by means of an operator reading by sound or sight. The record of the signals is obtained by means of photography in the following manner: A sensitive Einthoven string galvanometer is connected to the magnetic detector or valve receiver, and the deflections of its filament caused by the incoming signals are projected and photographically fixed on a sensitive strip, which is moved along at a suitable speed (pl. 1, fig. 2). On some of these records, which I am able to show, it is interesting to note the characteristic marks and signs produced amongst the signals by natural electric waves or other electrical disturbances of

the atmosphere, which, on account of their doubtful origin, have been called "X's."

Although the mathematical theory of electric wave propagation through space was worked out by Clerk Maxwell more than 50 years ago, and notwithstanding all the experimental evidence obtained in laboratories concerning the nature of these waves, yet so far we understand but incompletely the true fundamental principles concerning the manner of propagation of the waves on which wireless telegraph transmission is based. For example, in the early days of wireless telegraphy it was generally believed that the curvature of the earth would constitute an insurmountable obstacle to the transmission of electric waves between widely separated points. For a considerable time not sufficient account was taken of the probable effect of the earth connection, especially in regard to the transmission of oscillations over long distances.

Physicists seemed to consider for a long time that wireless telegraphy was solely dependent on the effects of free Hertzian radiation through space, and it was years before the probable effect of the conductivity of the earth was considered and discussed.

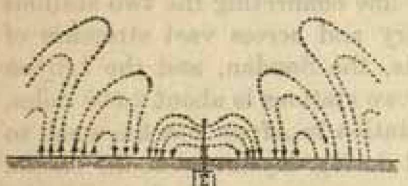


FIG. 11.

Lord Rayleigh, in referring to transatlantic radiotelegraphy, stated in a paper read before the Royal Society in May, 1903, that the results which I had obtained in signaling across the Atlantic suggested "a more decided bending or diffraction of the waves round the protuberant earth than had been expected," and further said that it imparted a great interest to the theoretical problem.[1] Prof. Fleming, in his book on electric wave telegraphy, gives diagrams showing what may be taken to be a diagrammatic representation of the detachment of semiloops of electric strain from a simple vertical wire (fig. 11).

As will be seen, these waves do not propagate in the same manner as does free radiation from a classical Hertzian oscillator, but instead glide along the surface of the earth.

Prof. Zenneck[2] has carefully examined the effect of earthed receiving and transmitting aerials, and has endeavored to show mathematically that when the lines of electrical force, constituting a wave front, pass along a surface of low specific inductive capacity—such as the earth—they become inclined forward, their lower ends being retarded by the resistance of the conductor, to which they are

[1] Proc. Roy. Soc., vol. 72, p. 40.

[2] "Annalen der Physik," vol. 23, p. 846, "Physikalische Zeitschrift," 1908, pp. 50, 553.

attached. It therefore would seem that wireless telegraphy as at present practiced is, to some extent at least, dependent on the conductivity of the earth, and that the difference in operation across long distances of sea compared to over land is sufficiently explained by the fact that sea water is a much better conductor than is land.

The importance or utility of the earth connection has been sometimes questioned, but in my opinion no practical system of wireless telegraphy exists where the instruments are not in some manner connected to earth. By connection to earth I do not necessarily mean an ordinary metallic connection as used for wire telegraphs. The earth wire may have a condenser in series with it, or it may be connected to what is really equivalent, a capacity area placed close to the surface of the ground. It is now perfectly well known that a condenser, if large enough, does not prevent the passage of high-frequency oscillations, and therefore in this case, when a so-called balancing capacity is used, the antenna is for all practical purposes connected to earth.

I am also of opinion that there is absolutely no foundation in the statement which has recently been repeated to the effect that an earth connection is detrimental to good tuning, provided of course that the earth is good.

Certainly, in consequence of its resistance, what electricians call a bad earth will damp out the oscillations, and in that way make tuning difficult; but no such effect is noticed when employing an efficient earth connection.

In conclusion, I believe that I am not any too bold when I say that wireless telegraphy is tending to revolutionize our means of communication from place to place on the earth's surface. For example, commercial messages containing a total of 812,200 words were sent and received between Clifden and Glace Bay from May 1, 1910, to the end of April, 1911; wireless telegraphy has already furnished means of communication between ships and the shore where communication was before practically impossible. The fact that a system of imperial wireless telegraphy is to be discussed by the imperial conference, now holding its meetings in London, shows the supremely important position which radiotelegraphy over long distances has assumed in the short space of one decade. Its importance from a commercial, naval, and military point of view has increased very greatly during the last few years as a consequence of the innumerable stations which have been erected, or are now in course of construction, on various coasts, in inland regions, and on board ships in all parts of the world. Notwithstanding this multiplicity of stations and their almost constant operation, I can say from practical experience that mutual interference between properly equipped and efficiently tuned instru-

ments has so far been almost entirely absent. Some interference does without doubt take place between ships, in consequence of the fact that the two wave lengths adopted in accordance with the rules laid down by the international convention, are not sufficient for the proper handling of the very large amount of messages transmitted from the ever increasing number of ships fitted with wireless telegraphy. A considerable advantage would be obtained by the utilization of a third and longer wave to be employed exclusively for communication over long distances.

In regard to the high-power transatlantic stations, the facility with which interference has been prevented has to some extent exceeded my expectations. At the receiving station situated at a distance of only 8 miles from the powerful sender at Clifden, during a recent demonstration arranged for the Admiralty, messages could be received from Glace Bay without any interference from Clifden when this latter station was transmitting at full power on a wave length differing only 25 per cent from the wave radiated from Glace Bay, the ratio between the maximum recorded range of Clifden and 8 miles being in the proportion of 750 to 1.

Arrangements are being made to permanently send and receive simultaneously at these stations, which, when completed, will constitute in effect the duplexing of radiotelegraphic communication between Ireland and Canada.

The result which I have last referred to also goes to show that it would be practicable to operate at one time, on slightly different wave lengths, a great number of long-distance stations situated in England and Ireland without danger of mutual interference.

The extended use of wireless telegraphy is principally dependent on the ease with which a number of stations can be efficiently worked in the vicinity of each other.

Considering that the wave lengths at present in use range from 200 to 23,000 feet, and moreover that wave group tuning and directive systems are now available, it is not difficult to foresee that this comparatively new method of communication is destined to fill a position of the greatest importance in facilitating communication throughout the world.

Apart from long-distance work, the practical value of wireless telegraphy may perhaps be divided into two parts, (1) when used for transmission over sea and (2) when used over land.

Many countries, including Italy, Canada, and Spain, have already supplemented their ordinary telegraph systems by wireless-telegraphy installations, but some time must pass before this method of communication will be very largely used for inland purposes in Europe generally, owing to the efficient network of land lines already existing which render further means of communication unnecessary; and

therefore it is probable that, at any rate for the present, the main use of radiotelegraphy will be confined to extra-European countries, in some of which climatic conditions and other causes absolutely prohibit the efficient maintenance of land-line telegraphy. A proof of this has been afforded by the success which has attended the working of the stations recently erected in Brazil on the upper Amazon.

By the majority of people the most marvelous side of wireless telegraphy is perhaps considered to be its use at sea. Up to the time of its introduction, ships at any appreciable distance from land had no means of getting in touch with the shore throughout the whole duration of their voyage. But those who now make long sea journeys are no longer cut off from the rest of the world; business men can continue to correspond at reasonable rates with their offices in America or Europe; ordinary social messages can be exchanged between passengers and their friends on shore; a daily newspaper is published on board most of the principal liners, giving the chief news of the day. Wireless telegraphy has on more than one occasion proved an invaluable aid to the course of justice—a well-known instance of which is the arrest, which took place recently through its agency, of a notorious criminal when about to land in Canada.

The chief benefit, however, of radiotelegraphy lies in the facility which it affords to ships in distress of communicating their plight to neighboring vessels or coast stations; that it is now considered indispensable for this reason is shown by the fact that several governments have passed a law making a wireless-telegraph installation a compulsory part of the equipment of all passenger boats entering their ports.

Therefore it is probable that, at any rate for the present, the sphere of wireless telegraphy will be confined to [illegible] [illegible] [illegible] cases of [illegible] [illegible] with [illegible] and other means [illegible] [illegible] the efficient maintenance of land [illegible] [illegible]. A [illegible] of this has been afforded by the success which has attended the working of the [illegible] recently erected in [illegible] on the [illegible] [illegible].

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MULTIPLEX TELEPHONY AND TELEGRAPHY BY MEANS OF ELECTRIC WAVES GUIDED BY WIRES.[1]

[With 1 plate.]

DR. GEORGE O. SQUIER,

Major Signal Corps, United States Army.

I.—INTRODUCTION.

Electrical transmission of intelligence, so vital to the progress of civilization, has taken a development at present into telephony and telegraphy over metallic wires; and telegraphy, and, to a limited extent, telephony, through the medium of the ether by means of electric waves.

During the past 12 years the achievements of wireless telegraphy have been truly marvelous. From an engineering viewpoint, the wonder of it all is, that, with the transmitting energy being radiated out over the surface of the earth in all directions, enough of this energy is delivered at a single point on the circumference of a circle, of which the transmitting antenna is approximately the center, to operate successfully suitable receiving devices by which the electromagnetic waves are translated into intelligence.

The "plant efficiency" for electrical energy in the best types of wireless stations yet produced is so low that there can be no comparison between it and the least efficient transmission of energy by conducting wires.

The limits of audibility, being physiological functions, are well known to vary considerably, but they may be taken to be in the neighborhood of 16 complete cycles per second as the lower limit and 15,000 to 20,000 cycles per second as the upper limit. If, therefore, there are impressed upon a wire circuit for transmitting intelligence harmonic electromotive forces of frequencies between 0 and 16 cycles per second, or, again, above 15,000 to 20,000 cycles per second, it would seem certain that whatever effects such electric-wave frequencies produced upon metallic lines, the present apparatus employed in operating them could not translate these effects into audible signals.

[1] A paper presented at the twenty-eighth annual convention of the American Institute of Electrical Engineers, Chicago, Ill., June 26-30, 1911. Copyright, 1911, by A. I. E. E. Reprinted by permission from Proceedings of the Institute for May, 1911, pp. 857-905.

There are, therefore, two possible solutions to the problem of multiplex telephony and telegraphy upon this principle by electric waves, based upon the unalterable characteristics of the human ear, viz, by employing (1) electric waves of infra sound frequencies, and (2) those of ultra sound frequencies. One great difficulty in designing generators of infra sound frequencies is in securing a pure sine wave, as otherwise any harmonic of the fundamental would appear within the range of audition. Furthermore, the range of frequencies is restricted, and the physical dimensions of the tuning elements for such low frequencies would have a tendency to become unwieldy.

The electromagnetic spectrum at present extends from about four to eight periods per second, such as are employed upon ocean cables, to the shortest waves of ultra-violet light. In this whole range of frequencies there are two distinct intervals which have not as yet been used, viz, frequencies from about 3×10^{12} of the extreme infra-red to 5×10^{10}, which is the freqeuncy of the shortest electric waves yet produced by electrical apparatus, and from about 80,000 to 100,000 cycles per second to about 15,000 to 20,000 cycles per second. The upper limit of this latter interval represents about the lowest frequencies yet employed for long-distance wireless telegraphy.

Within the past few years generators have been developed in the United States giving an output of 2 kilowatts and above at a frequency of 100,000 cycles per second, and also capable of being operated satisfactorily at as low a frequency as 20,000 cycles per second. Furthermore, these machines give a practically pure sine wave.

The necessary conditions for telephony by electric waves guided by wires are an uninterrupted source of sustained oscillations and some form of receiving device which is quantitative in its action. In the experiments described in multiplex telephony and telegraphy it has been necessary and sufficient to combine the present engineering practice of wire telephony and telegraphy with the engineering practice of wireless telephony and telegraphy.

The frequencies involved in telephony over wires do not exceed 1,800 to 2,000, and for such frequencies the telephonic currents are fairly well distributed throughout the cross section of the conductor. As the frequency is increased the so-called "skin effect" becomes noticeable, and the energy is more and more transmitted in the ether surrounding the conductor.

It has been found possible to superimpose, upon the ordinary telephonic wire circuits now commercially used, electric waves of ultra sound frequencies without producing any harmful effects upon the operation of the existing telephonic service. Fortunately, therefore, the experiments described below are constructive and additive, rather than destructive and supplantive.

Electric waves of ultra sound frequencies are guided by means of wires of an existing commercial installation and are made the vehicle for the transmission of additional telephonic and telegraphic messages.

APPARATUS AND EQUIPMENT.

Under a special appropriation granted to the Signal Corps by Congress in the army appropriation act of 1909, a small research laboratory has been established at the Bureau of Standards, in the suburbs of the city of Washington. This laboratory is equipped with the latest forms of apparatus now employed in the wireless telephone and telegraph art, and also with the standard types of telephone and telegraph apparatus now used upon wire circuits. The small construction laboratory of the United States Signal Corps is located at 1710 Pennsylvanue Avenue and is also equipped with the usual types and forms of apparatus used in transmitting intelligence by electrical means. Each of these laboratories is supplied with a wireless telephone and telegraph installation with suitable antennæ. In addition, these two laboratories are connected by a standard telephone cable line about 7 miles in length, which was employed in the experiments described below.

THE 100,000-CYCLE GENERATOR.[1]

The high-frequency alternator, which is shown complete with driving motor and switchboard in the accompanying illustrations, is a special form of the inductor type designed for a frequency of 100,000 cycles with an output of 2 kilowatts, making it adapted for use in wireless telephony or telegraphy (pl. 1).

Driving motor.—The motor is a shunt-wound 10-horsepower machine with a normal speed of 1,250 revolutions per minute. It is connected by a chain drive to an intermediate shaft which runs at a speed of 2,000 revolutions per minute. The intermediate shaft drives the flexible shaft of the alternator through a De Laval turbine gearing, having a ratio of 10 to 1. The flexible shaft and inductor thus revolve at a speed of 20,000 revolutions per minute.

Field coils.—The field coils, mounted on the stationary iron frame of the alternator, surround the periphery of the inductor. The magnetic flux produced by these coils passes through the laminated armature and armature coils, the air gap, and the inductor. This flux is periodically decreased by the nonmagnetic sections of phosphor-bronze embedded radially in the inductor at its periphery.

Armature coils.—The armature or stators are ring-shaped and are made of laminated iron. Six hundred slots are cut on the radial face of each; a quadruple silk-covered copper wire, 0.016 inch (0.4

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[1] Alexanderson, Trans. Amer. Inst. Electr. Eng., vol. 28, p. 399, 1909.

millimeter) in diameter, is wound in a continuous wave up and down the successive slots. The peripheries of the armature frames are threaded to screw into the iron frame of the alternator. By means of a graduated scale on the alternator frame, the armatures can be readily adjusted for any desired air gap.

Inductor.—The inductor or rotor has 300 teeth on each side of its periphery, spaced 0.125 inch (3.17 millimeters) between centers. The spaces between the teeth are filled with U-shaped phosphor-bronze wires, securely anchored, so as to withstand the centrifugal force of 80 pounds (36.3 kilograms) exerted by each. Since each tooth of the inductor gives a complete cycle, 100,000 cycles per second are developed at 20,000 revolutions per minute. The diameter of the disk being 1 foot (0.30 meter), the peripheral speed is 1,047 feet (319 meters) per second, or 700 miles (1,127 kilometers) per hour, at which rate it would roll from the United States to Europe in four hours. By careful design and selection of material, a factor of safety of 6.7 is obtained in the disk, although the centrifugal force at its periphery is 68,000 times the weight of the metal there.

Bearings.—The generator has two sets of bearings, as shown in the illustrations, the outer set being the main bearings which support the weight of the revolving parts. These bearings are self-aligning and are fitted with special sleeves, which are ground to coincide with longitudinal corrugations of the shaft, thus taking up the end thrust. A pump maintains a continuous stream of oil through these bearings, thus allowing the machine to be run continuously at full speed without troublesome heating.

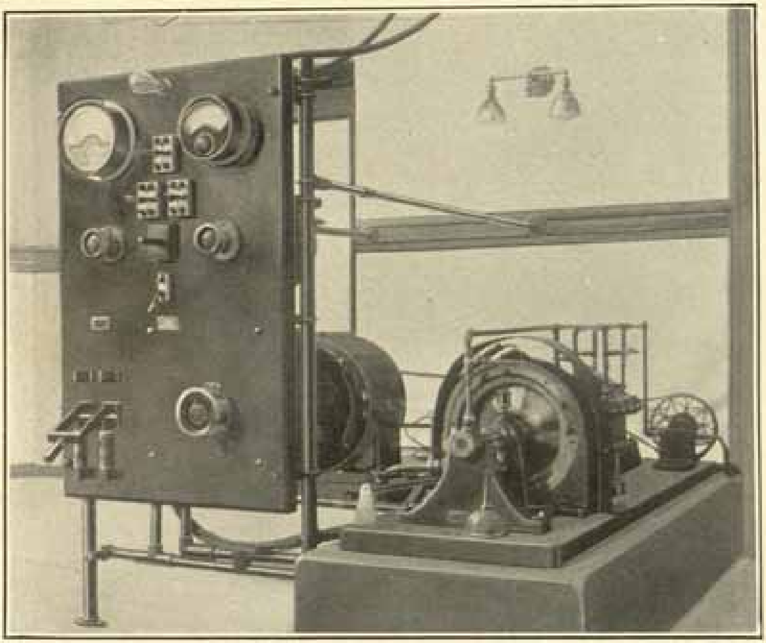
The middle bearings normally do not touch the shaft, but take up excessive end thrust and prevent excessive radial vibration of the flexible shaft.

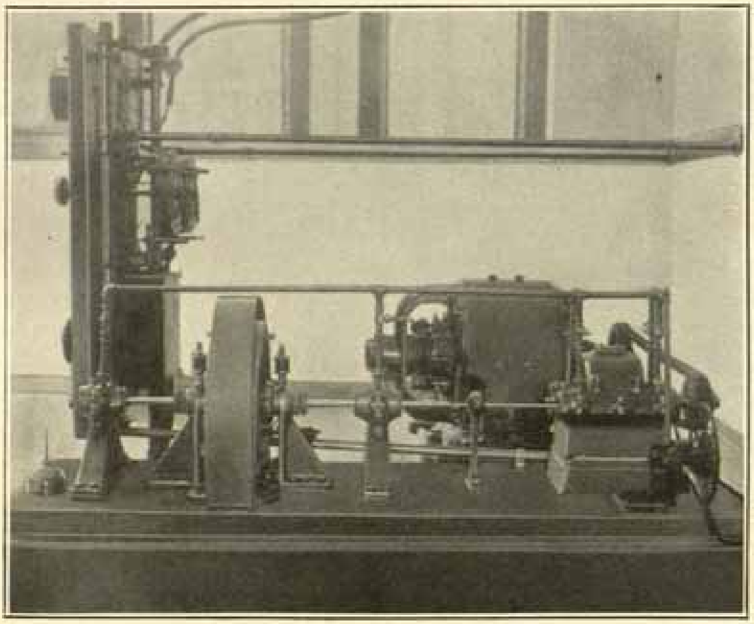
An auxiliary bearing or guide is placed midway between the gear box and the end bearing. Its function is to limit the vibration of that portion of the shaft.

Critical periods.—In starting the machine, severe vibration occurs at two distinct critical speeds, one at about 1,700 and the other at about 9,000 revolutions per minute. The middle bearings prevent this vibration from becoming dangerous.

Voltage.—With the normal air gap between the armatures and revolving disk of 0.015 inch (0.38 millimeter), the potential developed is 150 volts with the armatures connected in series. It is possible, however, to decrease the air gap to 0.004 inch (0.10 millimeter) for short runs, which gives a corresponding increase in voltage up to nearly 300 volts. It is considered inadvisable, however, to run with this small air gap for any considerable length of time.

The machine is intended to be used with a condenser, the capacity reactance of which balances the armature induction reactance, which





FRONT AND REAR VIEW OF HIGH-FREQUENCY ALTERNATOR, DRIVING MOTOR, AND SWITCHBOARD.

is 5.4 ohms at 100,000 cycles. This would require a capacity of about 0.3 microfarad for resonance at this frequency, but in the experiments conducted at 100,000 cycles it was found necessary to decrease this amount on account of the fixed auxiliary inductance of the leads.

CONSTANTS OF THE TELEPHONE LINE.

The telephone line used in these experiments extends from the Signal Corps laboratory at 1710 Pennsylvania Avenue to the Signal Corps research laboratory at the Bureau of Standards.

This line is made up of the regular standard commercial equipment and consists of paper-insulated, twisted pairs in lead-covered cable, placed in conduit in the usual manner employed for city installation. For the sake of convenience, one of the pair is designated as No. 1 wire and the other as No. 2 wire.

The air-line distance between the two laboratories is a little over 3 miles (4.8 kilometers), but the telephone line, by passing through three exchanges, covers about 7 miles (11.27 kilometers). The course of the line, with the size and type of conductor, is as follows:

Laboratory to main exchange, underground cable, No. 22 B. & S.
Main exchange to west exchange, underground cable, No. 19 B. & S.
West exchange to Cleveland exchange, underground cable, No. 19 B. & S.
Cleveland exchange to Bureau of Standards, underground cable, No. 19 B. & S.
All underground cable except from Bureau of Standards to Wisconsin Avenue and Pierce Mill Road, about 3,400 feet, which is aerial cable.

This line is equipped with protective heat coils of a standard type, one in each wire of the metallic circuit, at the Cleveland exchange and the main exchange, but none at the west exchange. The constants of each of these coils are as follows:

Direct current resistance of 65° F....ohms..	3.8
Size of wire, No. 30 B. & S.	
Length of wire....cm..	40
Number of turns in each coil, about....	38
Measured inductance at 70,000 cycles....cm..	4,400
Or 4.4×10^{-6} henry.	

The above constants were measured from a sample of one of these coils selected at random.

Resistance of metallic circuit....ohms..	776
Capacity measured (one minute electrification) between No. 1 and No. 2 wires ....microfarad..	0.69
Insulation resistance:	
Between No. 1 wire and earth....megohms..	0.9
Between No. 2 wire and earth....do....	1.3
Between No. 1 and No. 2 wires in parallel and earth....do....	0.8
Between No. 1 and No. 2 wires....do....	2.1

The line included the usual house-wiring at each station, which was undisturbed in taking the measurements.

II.—DUPLEX-DIPLEX TELEPHONY OVER WIRE CIRCUITS.

Such has been the development of telephone engineering that at present any proposal which requires for its success the supplanting of the present low-frequency battery system would be most radical. It would surely be admitted that any plan which permits the present engineering telephone system to remain intact and superimpose thereon additional telephone circuits would possess cardinal advantages. Accordingly, the first preliminary experiments were directed to the inquiry as to whether or not it is possible to superimpose upon the minute telephonic currents now employed in telephony over wires, electric waves of ultra-sound frequencies without causing prohibitive interference with the battery telephone currents. Manifestly, this fundamental point can best be determined by experiments, at the generator itself, with the most sensitive part of the telephone equipment, viz, the telephone receiver. Accordingly, experiments were first conducted with various forms and types of telephone receivers in connection with local circuits at the generator. Such is the sensibility of the telephone receiver that it was thought possible that, although currents of frequencies entirely above audition were applied to the receiver from a dynamo as a source, there might be some frequency or frequencies from the operation of the apparatus which would be within the range of audition. Such was found, in fact, to be the case at certain critical frequencies of the machine, but they were of no practical importance, as will be shown later.

With a collection of telephone receivers ranging from about 50 to over 8,000 ohms and of a variety of designs, a series of tests was made under severe conditions to determine the above point. It was found, in general, that alternating currents of frequencies ranging from 30,000 to 100,000 cycles per second, when coupled conductively, inductively, or electrostatically to local circuits from the generator produced absolutely no perceptible physiological effects in the receivers, excepting only that at certain of the lower frequencies a distinct audible note could be faintly heard in one of the receivers of about 250 ohms resistance.

A search for the cause of this note showed that it is due to a slight variation of the amplitude of the high-frequency current of the generator, since no evidence of it could be detected on the battery telephone side of the circuit. It appears to be caused by a very slight vibration of the rotor as a whole in the magnetic field of the generator. It was almost entirely removed by the simple device of opening out the stators, which increases the clearance and materially cuts down the flux of the machine. In practice it is a distinct advantage, however, to have a trace of this note still left on the high-frequency side of the circuit, otherwise there is no ready means of determining at the

receiving end of the cable line whether or not the high-frequency current is present on the line, whereas this note, which has to be searched for in tuning and which was entirely tuned out when speech was best, gave a very convenient method of testing for the presence of high-frequency current.

Having determined the general nature of this disturbance and its comparative unimportance, no further investigation of it was considered necessary at that time.

The next fundamental point to determine was whether or not at these frequencies a telephone can receive enough energy to make it operative for producing sound waves in air.

Since the self-induction of a standard telephone receiver is high, energy at these frequencies is effectively barred from it. In the wireless telegraph art, where the frequencies involved are from one hundred thousand to several million per second, this problem has been uniformly solved by the introduction of some form of detector for electromagnetic waves, whose function is to transform the energy of the high-frequency oscillations into other forms suitable to a type of instrument such as a telephone receiver.

The next step, therefore, consisted in introducing various forms of detectors, such as are now used in wireless telegraphy, between the telephone receiver itself and the energizing circuit. Since the frequencies being here considered are entirely above audition it was necessary, in order to produce a physiological effect, to introduce another element in this transformation, viz, some method of modifying the continuous train of sustained oscillations from the generator into groups or trains, the period of which falls within the limits of audition. This was accomplished by employing the regular forms of automatic interrupters, such as are now used in wireless telegraphy, with the expected result that with these two additional and essential pieces of apparatus operatively connected between the telephone receiver and the generator, the energy of the generator was delivered to the ear in a form well suited for physiological effects. Since it is well known that the human ear is most sensitive at a period of about 500 cycles per second, or 1,000 alternations, interrupters giving this frequency were employed.

The presence of the detectors in this chain of transformations is necessitated by the use of the telephone receiver as a translating device.

Although some of the detectors for electric waves are very sensitive to electrical energy they are here employed not because they are more sensitive to electrical energy than is the telephone receiver itself, which is not the case, but because the telephone receiver is not adapted, for the reasons stated above, to translate electrical energy of these frequencies into movements of its diaphragm.

The elements of the apparatus thus far include a generator of sustained high-frequency oscillations, an interrupter to modify the amplitude of these oscillations into groups of a period within the range of audition, some form of detector to rectify these oscillations, and a telephone receiver. Manifestly here are all of the elements that are necessary for telegraphy, using the telephone receiver to interpret the signals.

If in the above mentioned chain of apparatus the interrupter is replaced by some form of telephone transmitter, such as the microphone, this is all that is necessary for the transmission of speech.

Experiments were made over local circuits with apparatus arranged in this order over a range of frequencies from 20,000 to 100,000 per second, with the result that speech was transmitted very satisfactorily. Upon removing the detector from the above arrangement all perceptible effect in the telephone receiver ceased; in fact no arrangement of connections of a telephone receiver to such a high frequency circuit which did not include some form of detector was found to be operative for telephony, unless certain low resistance telephones were used in which case the speech was so much weaker as to be of an entirely different order of magnitude.

The presence of a detector in this chain of operations, is not absolutely necessary in the case of telegraphy, since if the interrupter automatically produces a definite number of wave-trains per second, each train consisting of at least several complete oscillations, an effect may be produced upon a telephone receiver directly without a detector. The physiological effect, however, is quite different, the clear fundamental note corresponding to the frequency of the interrupter being no longer audible, but, instead, a peculiar dull hissing sound. If, however, a telephone receiver was used, which, instead of having a permanent magnet as a core, had one of soft iron, no effect without the detector was produced with the energy used.

As stated above in the case of telephony, the energy required for telegraphy without a detector is of a different order of magnitude.

Having determined the necessary and sufficient conditions for the accomplishment of telegraphy and telephony by means of electric waves guided by wires upon local circuits, the next step was to apply these means and conditions to an actual commercial telephone cable line, the constants of which have been given above.

The machine was run at a frequency of 100,000 cycles per second with the circuit arrangements as shown in figure 1, where one wire of the telephone cable was connected to one terminal of the secondary of an air-core transformer, the other terminal being connected to earth.

At the receiving end of the line, which was the Signal Corps construction laboratory, at 1710 Pennsylvania Avenue, Washington,

D. C., this wire was connected directly to earth through a "perikon" crystal detector, such as is well known in wireless telegraphy, and a high resistance telephone receiver of about 8,000 ohms was shunted around the crystal. In this preliminary experiment no attempt was made at tuning, either at the transmitting end or at the receiving end of the line.

In the primary circuit of the generator, arrangements were made by which either an interrupter and telegraph key or a telephone transmitter could be inserted by throwing a switch.

In the line circuit a hot wire milliammeter was inserted in a convenient position so that the effect of the operation of either the telegraph key or of the human voice upon the transmitter could be observed by watching the fluctuations of the needle of the milliammeter.

A loose coupling was employed between the two circuits at the transmitting end, and the line circuit adjusted by varying the coupling until the current in the line was 20 to 30 milliamperes. With this arrangement (1) telegraphic signals were sent and easily received, and (2) speech was transmitted and received successfully over this single wire with ground return.

The ammeter showed marked fluctuations from the human voice and enabled the operator at the transmitting station to be certain that modified electric waves were being transmitted over the line.

The actual ohmic resistance of the line apparently played an unimportant part for telegraphy at 100,000 cycles, since with one of the wires of the pair and a ground return, the effect of doubling the conductivity of the wire by joining both wires in parallel, although this arrangement increased the capacity of the wires, could not be detected with certainty by an operator listening to the signals and unaware of which arrangement was being used.

Inserting in the line wire a noninductive carbon rod resistance of 750 ohms, which is practically the resistance of the line itself, could not be detected by any change in the intensity of the received signals.

The next experiment was to determine what effect, if any, such sustained electrical oscillations would have upon the minute telephonic currents employed in battery telephony.

DUPLEX TELEPHONY, USING ONE GROUNDED CIRCUIT.

To determine the fact that electric waves of ultra sound frequency produce no perceptible effect when superimposed on the same circuit over which telephonic conversation is being transmitted, the next step was to use such a train of sustained oscillations as the vehicle for transmitting additional speech over the same circuit. For this

purpose the twisted-pair telephone line was equipped with a complete standard local battery telephone set, as installed for commercial practice, and in addition one of the wires of the pair was equipped as in figure 1, the circuit being shown diagrammatically in figure 2. This particular arrangement was employed in this experiment for the reason that it was desired to have the battery telephone operate on its usual circuit with the introduction of ground connections at the ends of the line for the superposition of the high-frequency circuit. When such ground connections were introduced directly without tuning elements therein the metallic circuit experienced the usual disturbances found under city conditions, but the metallic circuit could be reduced to silence again by introducing in the ground connections the necessary tuning elements of magnitudes suited to wireless telegraphy.

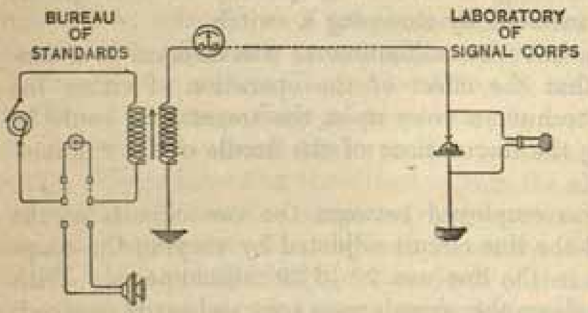


FIG. 1.

Next, the twisted-pair telephone line was equipped with a complete standard local battery telephone set, as installed for commercial practice, with the exception that the local battery circuit of the transmitter telephone set was opened and a few turns of coarse wire inserted in series with the two dry cells which are normally used, as shown in figure 3. Inductively connected with this coil was the armature circuit of the generator. A hot wire milliammeter was placed in the line circuit to indicate the magnitude of the high-frequency current which was flowing on the line. With this arrangement tests were made to determine whether or not there were any effects upon the transmission of speech, due to superimposing high-frequency currents upon the battery telephone sets. With an operator at each end of the line, using the equipment in the regular commercial way, the direct-current voltage and the alternating-current voltage in series with it in the

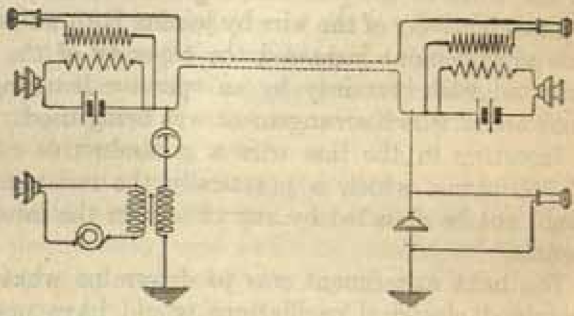


FIG. 2.

primary circuit of the transmitter were varied individually and relatively in a variety of ways, with the striking result that just at the point where the direct-current voltage was decreased, so that no sounds were received, the line became absolutely silent, although the alternating voltage in the circuit was at its largest value, or, again, speech would reappear at the receiving station at the moment when sufficient direct-current voltage was introduced to produce it, and the simultaneous presence of both the maximum direct voltage and maximum high-frequency voltage in a circuit produced exactly the same result as the maximum direct-current voltage did alone. When, however, the high-frequency current in the local circuit was forced to a point which caused "burning" in the transmitter itself, then, and then only, did the high-frequency current in any way interfere with the transmission.

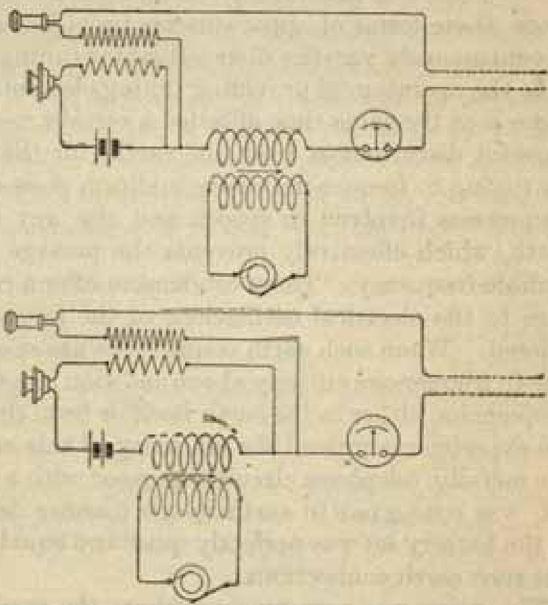


Fig. 3.

By transferring this coil from the local circuit of the telephone set directly into the line itself, so that the high-frequency oscillations would be superimposed upon the line beyond the iron-cored induction coil of the telephone transmitter, it was not possible to detect the presence or absence of high-frequency currents.

As a test under severest conditions the effect was noted upon speech received at the same station at which the high-frequency current is being impressed, for here are the attenuated telephonic currents at the receiving end of the telephone line, on which is superimposed a high-frequency current of vastly greater magnitude at the same point. No effects of any kind could be detected under these conditions. From the above experiments it appears that in any attempt at multiplex telephony by means of electric waves of ultra sound frequencies superimposed upon the minute telephonic currents employed in battery transmission there is nothing to fear from disturbances of such currents upon the operation of the ordinary battery equipment.

SILENT EARTH CIRCUITS.

The electromagnetic constants of the apparatus employed in telegraphy and telephony over wire circuits are of the order of magnitude of microfarads and henrys, and since no attempt is made at tuning, these are constructed at present with no provision for continuously varying the units.

In wireless telegraphy and telephony these electromagnetic constants are of the order of magnitude one thousand times smaller, or are expressed in thousandths of microfarads and of henrys; furthermore, these forms of apparatus are provided with convenient means of continuously varying their values for tuning.

In the operation of providing tuning elements for earth connections there is at the same time afforded a certain means of eliminating any harmful disturbances from the earth, for the condensers employed for tuning to frequencies above audition possess an impedance to the frequencies involved in speech and also any disturbances from the earth, which effectively prevents the passage of any disturbance of audible frequency. These condensers offer a comparatively free passage to the electrical oscillations of the frequencies here being considered. When such earth connections are selectively tuned with the line to frequencies entirely above audition it is evident that no audible frequencies, either in the earth itself or from the line, can pass. Simple experiments proved the efficiency of this arrangement, and when the metallic telephone circuit, equipped with a standard local battery set, was connected to earth in the manner described, the operation of the battery set was perfectly quiet and equally good with and without such earth connections.

The point was now reached where the road was clear for duplex telephony, and for this purpose the apparatus and methods employed in wireless telephony were applied to one of the wires of the metallic circuit as though it were an antenna. The actual arrangement of this circuit is shown in figure 4, in which G is the source of sustained high frequency oscillations; C′ is the tuning condenser of the oscillatory circuit; L′ is the tuning inductance of the oscillatory circuit; P is the primary of the oscillation transformer; A is the ammeter; M is the transmitter microphone; S is the secondary of the ocsillation transformer in the line circuit; C is the tuning condenser in the line circuit; L is the tuning inductance in the line circuit; A′ is the ammeter in the line. At the receiving end of the line C_1 is the line tuning condenser; L_1 is the line tuning inductance; P_1 is the primary of the oscillation transformer; S_1 is the secondary of the oscillation transformer; L_1' is the tuning inductance in the oscillatory circuit; e_1' is the tuning condenser in the oscillatory circuit, between which and the tele-

phone F′ the detector D is operatively connected; E is the earth connection.

The local battery telephone sets are connected across the two line wires in the usual manner. In both sets 1 is the microphone transmitter; 2 is the local battery; 3 is the induction coil; 4 is the ringing system, including the bell and hand generator; 5 is the switch hook; 6 is the telephone receiver.

It was found that cross-talk was heard in the detector circuit from the battery transmitter at the transmitting end when the detector circuit alone was connected directly to earth from the line without any tuning coil or condenser. If, however, the tuning condenser was inserted, this cross-talk entirely disappeared, even though the tuning coil was not inserted. This is because the impedance of the small tuning condenser is large for telephonic frequencies, while the tuning coil impedance admits these telephonic frequencies. Both elements of tuning are required for selective absorption of energy, so that the high-frequency circuit is available as an additional telephonic circuit. With this arrangement talking in the transmitter of the high-frequency side of the system was heard only in the detector and there was no cross-talk from the ordinary local battery circuit. Similarly, there was no effect of the high-frequency transmission on the local battery transmission, and the two telephonic messages were completely separated. Both circuits were entirely free from earth disturbances.

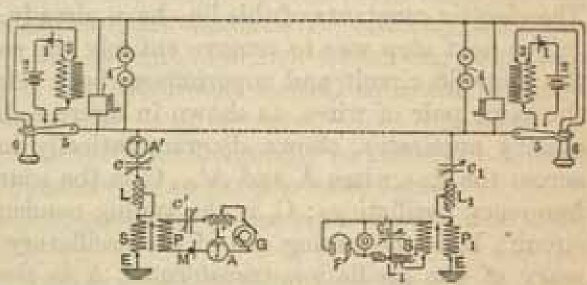


FIG. 4.

The volume of speech at the receiving end of the cable is greatly increased by simply inserting the transmitter in the dynamo circuit and operating this circuit at or near resonance. In addition, the coupling at both transmitting and receiving stations should be so designed as to permit adjustment for optimum.

The frequency used in this experiment was about 100,000 cycles per second. The talk on the regular battery circuit was of the usual high standard both ways, so that the only reason at this point why complete duplex-diplex telephony was not obtained was the fact that there was no high-frequency dynamo available at the laboratory. There is, however, available at this laboratory one of the latest forms of the high-frequency arc, and accordingly this was arranged with suitable electromagnetic constants to give a period of about 71,000

cycles per second, as measured by a standard wave meter such as is now commonly used in wireless telephony and telegraphy. This source of high-frequency electromotive force was induced upon the high-frequency line wire in a similar manner to that described in the station at the Bureau of Standards, with the result that one of the wires of the twisted pair was made to carry simultaneously the battery telephonic currents from the two transmitters, the high-frequency oscillations of about 100,000 cycles per second, applied at the Bureau of Standards, and the high-frequency oscillations of about 71,000 cycles per second, applied at the laboratory. No influence from these conditions was perceptible upon the excellence of the battery transmission and reception of speech either way.

DUPLEX TELEPHONY, USING METALLIC CIRCUIT.

(A) BRIDGING ARRANGEMENT.

The next experiments pertained to the standard metallic circuit as universally used on telephone toll lines in congested districts. The electric constants of this line have already been given.

The next step was to remove entirely the earth connections from the metallic circuit and superimpose both telephonic circuits upon the same pair of wires, as shown in figure 6, in which the high-frequency apparatus, shown diagrammatically in figure 5, is bridged across the line wires A and A′. G is the source of sustained high-frequency oscillations; C_1 is the tuning condenser of the oscillatory circuit; L_1 is the tuning coil of the oscillatory circuit; P is the primary of the oscillation transformer; A is the ammeter; M is the transmitter microphone; S is the secondary of the oscillation transformer in the line circuit; C is the tuning condenser in the line circuit; L is the tuning inductance in the line circuit; A_1 is the ammeter in the line. At the receiving end of the line, C′ is the line tuning condenser; L′ is the line tuning inductance; P′ is the primary of the oscillation transformer; S′ is the secondary of the oscillation transformer; L″ is the tuning inductance in the oscillatory circuit; C″ is the tuning condenser in the oscillatory circuit, between which and the telephone F the detector D is operatively connected.

The local battery telephone sets are connected across the line wires in the usual manner. In both sets, 1 is the microphone transmitter; 2 is the local battery; 3 is the induction coil; 4 is the ringing system, including the bell and hand generator; 5 is the switch hook; 6 is the telephone receiver.

Since the high-frequency apparatus as commercially developed in the wireless telegraph art was used, each of the units was variable and had been previously carefully calibrated by reference to the standards of the Bureau of Standards. The coupling coils were of

the design adapted for wireless telephony, the coefficient of coupling being adjustable between wide limits. It was therefore a matter of hours to run through a large number of experiments in which various combinations were tried.

The transmitters first tried were those of the microphone type inserted in the armature circuit of the dynamo and provided with water cooling when currents of several amperes were to be used.

It was soon found, however, that the efficiency of transmission of this cable line was so good for electric waves of these frequencies that a very small current, in the neighborhood of 2 milliamperes, sent into the line was amply sufficient for good speech at the receiving end about 7 miles distant. No attempt was made to determine to what lower limit the transmission current could reach in this respect, but such small currents enabled the ordinary telephone transmitter to be used without any provision for cooling, especially when it was inserted in the line circuit instead of in the armature circuit of the dynamo.

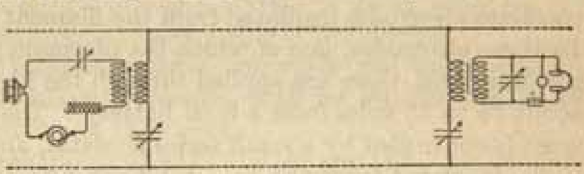


FIG. 5.

The telephone receivers were those regularly furnished for wireless telephony, ranging in resistance from 2,000 to 8,000 ohms.

Resonance.—As was expected, the phenomena of resonance under

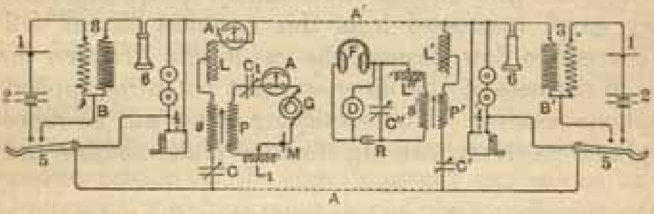


FIG. 6.

the conditions which here obtained were very pronounced and highly consistent, since there is here a definite circuit free from the disturbances and variations inherent in radio telegraphy and telephony. In wireless telegraphy and telephony it is well known that within a few minutes transmission will drop off many fold from causes not entirely understood, and from diurnal variations and electrostatic disturbances, effective transmission is often prevented.

In general, the different circuits were tuned to resonance in the same manner, for the same purpose, and with the same effect as in wireless telephony and telegraphy.

The line circuit itself was readily tuned to resonance for the particular frequency of the dynamo by noting the maximum reading of the hot wire ammeter A_1 in the line itself. This maximum is readily found by varying either the capacity C or the inductance L, or both.

At the receiving end of the line, coil L′ and the condenser C′, as well as the coil L″ and the condenser C″, were tuned to give a maximum intensity of signals in the receiving telephone of the audion.

The audion, a detector of the so-called vacuum type, consists of an exhausted bulb containing (*a*) a tungsten filament maintained at incandescence by a current from a local battery of 6 volts and (*b*) two platinum electrodes insulated from the filament and from each other. To these electrodes, one of which is a platinum plate and the other a platinum grid, there are applied through the high resistance receivers about 35 to 45 volts from a local battery. The brilliancy of the filament is controlled by a small series rheostat, and the voltage applied to the insulated terminals by a local potentiometer.

The gases in the bulb, becoming ionized by contact with the glowing electrode, serve as a conductor of electricity, having a high unilateral conductivity. If the platinum wire grid is close to the hot filament and the plate at some greater distance, the direction of greater conductivity is from the plate through the gas by the ionic path to the grid, so that if the positive terminal of the telephone battery is applied at the plate terminal and the negative at the grid terminal, a sufficient current to operate the telephone will flow.

If the terminals of the condenser of a resonant receiving circuit are connected to the grid and to one terminal of the filament the high frequency e.m.f. impressed from this resonant circuit will cause a greater current to flow through the gas in one direction than in the other, as in the case of the direct-current potential applied through the telephone receiver. This rectifying effect will be reproduced in the telephone receivers, causing them to make audible the received signals.

By changing the coefficient of coupling or the potential across the audion, which is adjustable, or the amount of ionization of the gases in the tube by adjusting the current through the filament, or any combination of these, it was found that the receiving operator could bring out the speech to suit his particular fancy.

As stated above, the dynamo operated regularly at ranges from 100,000 cycles per second down to 20,000 cycles per second. It was therefore possible to try the effect of a comparatively wide range of frequencies in these experiments, covering three octaves, the inductances and capacities being chosen to correspond to each particular frequency. It was found that more energy was delivered over this particular type and length of circuit by using the lower frequencies of

this range than the higher ones, although efficient results were easily obtained at any point.

The battery telephone side of the equipment was left absolutely intact, as it would be commercially used, and severe tests were made, employing four operators, to determine the efficiency of two simultaneous conversations over this same pair of wires.

The ringing circuit was operative both ways with no apparent effect on the high frequency telephone transmission. This ringing circuit develops a comparatively large alternating current flowing in the wire at about 30 cycles per second and at a voltage of many times that of either the high frequency or the battery side of the circuit.

Articulation tests, including music, numerals and other difficult combinations, gave satisfactory results, with no interference whatever between the two sides of the circuit.

By holding one telephone receiver to one ear and the other receiver to the other ear the receiving operator could hear two entirely different conversations simultaneously over the same pair of wires.

(B) SERIES ARRANGEMENT.

A circuit was next made up with high-frequency apparatus inserted directly in the line in series, instead of in the bridging arrangement shown in figure 5. The circuit used is shown diagrammatically in figure 7, in which L and L′ are the secondary coils of the transmitter and receiver, respectively. C and C′ represent variable condensers of the order of magnitude used in wireless telegraphy and serve as low impedance paths for the high-frequency oscillations, and at the same time prevent the short circuiting of the low-frequency battery telephone current. It was found that this arrangement gave apparently as good results as the bridging arrangement of the circuit.

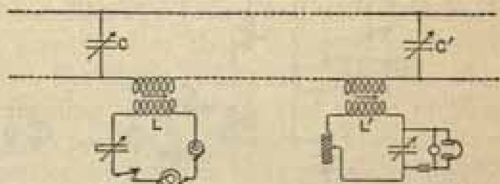


FIG. 7.

III.—DUPLEX-DIPLEX TELEGRAPHY.

Having described in detail the experiments for obtaining the simultaneous transmission of two telephonic messages over a single circuit, it will be apparent that the problem of transmitting two telegraphic messages over the same circuit may be solved by methods and apparatus as far as the high-frequency side of the circuit is concerned, which are practically identical with those described above.

In this connection the metallic circuit referred to was equipped with a standard Morse set for manual operation, and upon this cir-

cuit was superimposed an equipment for transmitting in one direction telegraphic messages by means of sustained high-frequency oscillations, employing the telephone as the means for receiving the signals. The circuit used is shown diagrammatically in figure 8, in which, in the Morse set, there are shown between the line wire and the ground G, the line relay S, the key K, and the line battery B; and the local battery *b* and the sounder *s;* and in which, in the high-frequency set, are similarly shown between the line wire and the ground G the tuning elements C and L; and at the transmitting end the oscillation transformer T, the primary of which is in circuit with the dynamo as a source of sustained oscillations, the telegraph key K′, the interrupter I and the tuning elements C′ and L′, and at the receiving end the oscillation transformer R in the secondary circuit of which are included the usual tuning elements and operatively connected to them the detector and its telephone as a means of receiving the signals.

As noted in the case of the preliminary local circuit tests, it was found that over this particular line it was not necessary to use a

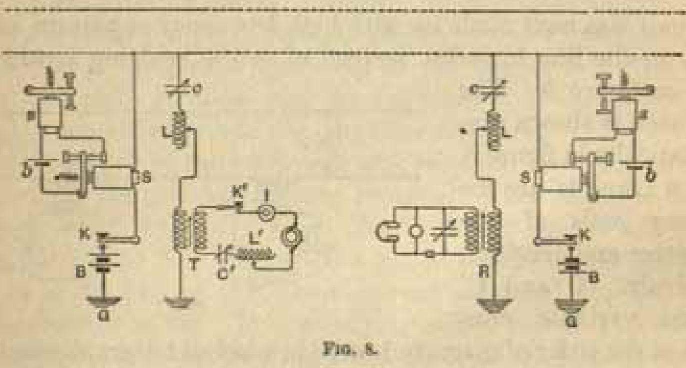


FIG. 8.

detector for electromagnetic waves, since enough energy was delivered to operate the telephone receiver by connecting it directly between the line and the earth.

The sound produced, however, was characteristically different in the two cases. With the detector the individual signals had the characteristic tone corresponding to the interrupter at the transmitting end of the line, whereas without the detector this tone was entirely absent, and a general dull sound, due to the resultant action of the wave-trains was heard. If, however, a telephone receiver was employed with a soft iron core, instead of a permanent magnet, no result was obtained with the limited power used on this line.

Although little mention of telegraphy by high-frequency electric waves has been made thus far, as a matter of fact it was found convenient during the experiments upon telephony actually to

employ telegraphy as a quick and ready means of determining resonance between the circuits in each particular case.

When any particular arrangement was being employed the first steps were invariably to send simple Morse signals over the circuit until the operator at the distant end of the line reported maximum loudness in the receiving telephone, which indicated that the terminal apparatus with the line circuit was properly tuned. This being accomplished, it was necessary only to throw a switch to substitute for the automatic interrupter and telegraph key the telephone transmitter, and the experiments could then proceed on telephony without any material change being made at the receiving station. Telephony and telegraphy thus proceeded hand in hand as a mere matter of convenience, and one of the practical advantages in the use of electric waves for transmitting intelligence is that the whole set-up of apparatus is practically the same for each and they can be used interchangeably over the same circuit.

Considering the Morse equipment, indicated in figure 8, the electromagnetic units involved are of the order of magnitude of microfarads and henrys, and the period of the interrupted direct current for Morse sending is not more than the equivalent of about 10 complete cycles per second, whereas in the high-frequency side of the circuit the electromagnetic units are of the order of magnitude of thousandths of a microfarad and of thousandths of a henry and with frequencies not less than 2,000 times greater than those involved in manual Morse sending. Furthermore, the ohmic resistance of the line which plays a prominent part in limiting the distance and speed of Morse working, is comparatively unimportant in the case of electric waves guided by wires. The operation of the line equipped as in figure 8 was perfectly satisfactory, there being no perceptible interference between the two messages in either direction.

Since the standard telegraph circuits of the world use a ground return, this same equipment was arranged to operate on one of the wires of the twisted-pair in the telephone cable as such a circuit with earth connections at each end, and its operation was equally successful.

Since it is a well-known characteristic of high-frequency apparatus used in tuned circuits that there shall be no iron involved in the circuit, it is evident that in cases where such a high-frequency current is to be superimposed upon a line comprising way stations, where line relays are inserted directly in the circuit, it will be necessary and sufficient to shunt such way stations by condensers of the order of magnitude of thousandths of a microfarad. Such condensers offer a comparatively free path for the high-frequency electric waves, but interpose a practical barrier to the Morse frequencies.

The same general statement can be made relative to any of the standard forms of low-frequency telegraphy over wires as now practiced, such as the polar duplex, the differential duplex, and the duplex-diplex, employing alternating currents of low frequency and standard keys, relays, and sounders.

Inserting a regular 150-ohm telegraph relay in series in the line cuts down the high-frequency current to a small percentage of its original value, which indicates the marked influence of the presence of iron in such a circuit. Furthermore, it was noted that at 100,000 cycles the hysteresis of the iron core was so great that it became heated very perceptibly in a few moments.

Since a portion of the telegraph lines now used is still composed of iron wires, it would be expected that electric waves would be propagated over such wires less efficiently than over copper wires, although it is well known that electric waves penetrate only about one-thirteenth as deeply into soft iron for a given frequency as into copper, but this is modified by the fact that the iron in telegraph wires is not soft iron and in addition is galvanized.

[Section 4 of this paper, giving details of measurements of electric waves of frequencies from 20,000 to 100,000 cycles per second on a standard telephone cable line, is omitted from the present reprint by the Smithsonian Institution.]

SUMMARY.

Radiotelegraphy has no competitor as a means of transmitting intelligence between ships at sea and between ships and shore stations, and on land it is also unique in its usefulness in reaching isolated districts and otherwise inaccessible points. To what extent it may be also developed to furnish practical intercommunication according to the high standard now enjoyed in thickly populated districts it is not attempted to predict.

The foregoing experiments indicate that either the existing wire system, or additional wires for the purpose may be utilized for the efficient transmission of telephonic and telegraphic messages, and the former without interfering with the existing telephone traffic on these wires.

The fact that each of the circuits created by the use of superimposed high-frequency methods is both a telephone and a telegraph circuit interchangeably, makes it possible to offer to the public a new type of service, which it is believed will offer many advantages to the commercial world. This type of circuit should be particularly applicable to press association service, railroad service, and leased wire service of all kinds.

The experiments described should not be interpreted as in any way indicating limitations to radio telegraphy and telephony in the future, for their present rapid development gives justification for great pros-

pect for the future. It is rather considered that the whole system of intercommunication, including both wire methods and wireless methods, will grow apace, and as each advance is made in either of these it will create new demands and standards for still further development. We need more wireless telegraphy everywhere, and not less do we need more wire telegraphy and telephony everywhere and, again, more submarine cables. The number of submarine cables connecting Europe with America could be increased many times and all of them kept fully occupied, provided the traffic were properly classified to enable some of the enormous business which is now carried on by mail to be transferred to the quicker and more efficient cablegram letter. That time will surely come when the methods of electrical intercommunication will have been so developed and multiplied that the people of the different countries of the world may become real neighbors.

Accustomed to the methods of transmitting energy for power purposes by means of wire, it is a matter of wonder that enough energy can be delivered at a receiving antenna from a transmitting point thousands of miles distant to operate successfully receiving devices. The value of a metallic wire guide for the energy of the electric waves is strikingly shown in the above experiments, and it furnishes an efficient directive wireless system which confines the ether disturbances to closely bounded regions and thus offers a ready solution to the serious problems of interferences between messages which of necessity have to be met in wireless operations through space.

The distortion of speech, which is an inherent feature of telephony over wires, should be much less, if not practically absent, when we more and more withdraw the phenomena from the metal of the wire and confine them to a longitudinal strip of the ether which forms the region between the two wires of a metallic circuit.

The ohmic resistance of the wire as shown can be made to play a comparatively unimportant part in the transmission of speech, and the more the phenomena are of the ether, instead of metallic conduction, the more perfectly will the modified electric waves, which are the vehicle for transmitting the speech, be delivered at the receiving point without distortion.

It has been shown that the phenomena of resonance, which are met with in so many different branches of physics, exhibit very striking and orderly results when applied to electric waves propagated by means of wires. By utilizing this principle it has been shown that the receiving current at the end of the line may be built up and amplified many times over what it would be with untuned circuits.

The tuned electrical circuit at the receiving end readily admits electromagnetic waves of a certain definite frequency, and bars from entrance electromagnetic waves of other frequencies. This permits the possibility of utilizing a single circuit for multiplex telephony and telegraphy.

[illegible]

We proceed to the question of [illegible]

[illegible]

It has been shown that the phenomena of [illegible]

[illegible] methods and instruments.

RECENT EXPERIMENTS WITH INVISIBLE LIGHT.[1]

[With 6 plates.]

By R. W. Wood, LL. D.,

Professor of Experimental Physics, Johns Hopkins University.

By far the greater proportion of the discoveries which have been made in natural science up to the present time depend upon observations made with the eye, either with or without the aid of optical instruments. The eye is, however, sensitive to only a very small part of the total radiation which reaches it, and it seems not unlikely that, if its range could be extended, many new phenomena would immediately come to light. By the employment of photography and of instruments which detect and measure the intensity of the infra-red or heat rays, much new information has been gathered, especially in the science of spectroscopy; but usually these methods have been applied only in cases where the invisible radiations were known to be present. It seemed quite probable that if photographic methods were applied to various physical phenomena which excluded the action of any but invisible rays, new facts would probably be discovered. I can illustrate what I mean by taking two striking cases which were found at the very outset of the investigation, and which will be more fully discussed presently.

If the finger be dipped into powdered zinc oxide and rubbed over a sheet of white paper, eye observation is absolutely unable to detect the presence of the streaks made by the white powder, unless it has been very thickly applied. If, however, we photograph the paper with ultra-violet light we obtain a picture in which the streaks are as black as if made with powdered charcoal. This suggests that if we apply the process to the photography of the moon and planets, we have some reason to suspect that substances which can not be detected visually may come out in the photographs, a surmise which has been justified in one case at least. This and other similar cases will be taken up in detail presently.

As an illustration of how the method may be applied to the investigation of various physical phenomena, we may take another interesting case, in which a new radiant emission from the electric spark has been discovered. It was suspected that the very short

[1] Lecture before the Royal Institution of Great Britain, Friday, May 19, 1911. Reprinted by permission from author's separate of Proceedings of the Royal Institution.

waves discovered by Schumann, which are powerfully absorbed by air, might possibly render the air fluorescent, the emitted light being invisible, however, on account of its short wave length. A heavy spark discharge was accordingly placed behind a small disk of metal, which cut off all the direct light, and the surrounding region photographed with a quartz lens, which is transparent to the ultra-violet rays. It was found that the air in the neighborhood of the spark actually did give off actinic invisible rays, the photograph giving the impression of a luminous fog surrounding the metal disk.

I will now show you an experiment which illustrates that two objects which can not be distinguished under ordinary illumination may appear quite different when the light which illuminates them is restricted to certain regions of the spectrum. I have here two pieces of scarlet silk which can not be distinguished the one from the other in the light of the incandescent electric lamps which illuminate this room. I now extinguish the lamps and place the two pieces of silk under this Cooper-Hewitt mercury arc lamp, and as you see, one of them still appears scarlet as before, while the other appears very dark blue, almost black, in fact. The peculiarity of the mercury lamp lies in the fact that it gives out little or no red light, consequently red objects in general appear almost black. The peculiarity of this particular piece of silk, by virtue of which it appears quite as red as in ordinary lights, lies in the fact that the red dye with which it is colored is fluorescent under the action of the green rays from the lamp; the red light is manufactured, so to speak, from the green light by the coloring matter of the silk. If I place the arc lamp and the piece of silk behind this large sheet of red glass, you will observe that the fabric is actually brighter than the lamp itself, probably eight or ten times as bright. We can form an image of the lamp on the silk with a lens, and the image will be many times brighter than the lamp, which might be taken as a refutation of the old and well-known theorem in optics that no optical system can yield an image brighter than the source (!) Here is another piece of white silk upon which I have made some red spots with this same dye. By the ordinary illumination of the room it is seen to be white, with large pink polka dots, something quite suitable for a young lady's summer gown. I now place it behind the red screen under the mercury arc and it at once becomes quite diabolical in appearance, bluish-black with flaming spots of scarlet, entirely unsuitable for the aforementioned purpose. The dye which was used for coloring these fluorescent fabrics was rhodamin. The conditions of illumination and observation are, of course, rather special in these cases, and I have introduced them merely to illustrate how the eye may be deceived under certain conditions.

Practically all sources of light in ordinary use give out more or less ultra-violet light which plays no part in vision, but which can be rendered apparent in various ways. I have on the table a new arrangement by which these rays can be separated from the visible ones. The apparatus is practically identical with the device quite recently used by Prof. Rubens and myself for isolating the longest heat waves that have been discovered up to the present time. It can be used as well for the isolation of the ultra-violet, since its action depends upon the high refractive index which quartz has for these two types of radiation. The source is, in this case, an electric spark contained in this box, and the ultra-violet rays are brought to a focus upon a small circular aperture in a cardboard screen. The focal length of the lens is so much greater for visible light that these rays do not come to a focus at all, but are spread over a circular area of a diameter nearly half that of the lens.

A penny has been fastened to the center of the lens with wax, and this shields the aperture from the cone of visible rays coming from the central portions of the lens. If I hold a sheet of white paper above the aperture you observe that it remains dark—that is, no visible rays pass through to the paper; if, however, I substitute for the paper this mass of uranium nitrate crystals, the presence of the ultra-violet rays is made manifest, the crystals shining with a brilliant green light.

Certain vapors shine with a brilliant light when exposed to these invisible rays. One of the most striking is the vapor of metallic mercury, which I can show you by boiling the metal in this flask of fused quartz placed above the aperture. The metal is boiling now, and you can all see the brilliant cone of green light which marks the path of the ultra-violet rays through the metallic vapor. If I hold a thin sheet of glass between the aperture and the flask, you will observe that the vapor instantly becomes dark, for the glass stops completely the rays in question.

The vapor of mercury exhibits an absorption band in the ultra-violet region which resembles the band at wave-length 5893 shown by dense sodium vapor. So powerful is this absorption that I have detected it in the vapor of mercury at room temperature. It occurred to me that this light instead of being absorbed might possibly be reemitted by the vapor laterally in all directions. To test this point I sealed up a drop of mercury in an exhausted flask of quartz, and focused the light of the mercury arc (burning in a silica tube) at the center of the bulb, which was not heated. The bulb was then photographed with a quartz lens, and the picture clearly showed the cone of focused rays precisely as if the bulb were filled with smoke. This is another very good example of how new discoveries may be made by ultra-violet photography.

If the object to be photographed gives off visible rays in addition to the invisible ones, it is necessary to remove these by a suitable screen or ray filter. We will begin by considering some remarkable effects which are obtained when sunlit landscapes are photographed by means of the obscure rays at the extreme red end of the spectrum. A screen can be prepared which transmits these rays, and is at the same time opaque to all other radiations, by combining a sheet of the densest blue cobalt glass with a solution of bichromate of potash or some suitable orange dye.

Such a screen transmits a region of the spectrum comprised between wave lengths 6900 and 7500. Though this region is visible to the eye if all other rays are cut off, it is so feeble in its action that it plays no part in ordinary vision, being overpowered by the other radiations. We may thence, for convenience, call photographs made through such a screen infra-red pictures, though the infra-red region is usually considered as beginning at the point where all action upon the human retina ceases.

The photographs which I am now going to show you were taken through such a screen, with the spectrum plates made by Wratten and Wainwright. The time of exposure was about three minutes in full sunlight, with the lens stop set at *f*/8. The views were, for the most part, made in Sicily and Italy, and have a very curious appearance, for while the sky comes out in all of them almost as black as midnight, the foliage of the trees and the grass come out snow white. This peculiar effect results from the failure of the atmosphere to scatter these long rays. The green leaves, however, reflect them very powerfully, or, more correctly, transmit them, since we are dealing with pigment or transmission color. If we look at a landscape through the screen, carefully protecting the eye from all extraneous light with a black cloth, we shall find that the trees shine with a beautiful rich red light against a black sky. This condition obtains only on very clear days, for the presence of the least haze in the air enables it to scatter the long rays, and you will notice that in those pictures which show the sky down to the horizon there is a progressive increase in its luminosity as we pass from the zenith downward, as a result of the greater thickness of the mass of air sending the scattered rays to the camera.

Another point to be noticed is the intense blackness of the shadows in the infra-red pictures, due to the fact that most of the light comes directly from the sun and little or none from the sky, which reminds one forcibly of the conditions which obtain on the moon, where there is no atmosphere at all to form a luminous sky.

When we come to the subject of photographs made with ultra-violet light, we shall find that we have the conditions reversed, for

practically all of these very short waves are scattered by the atmosphere, and we have no shadows even in full sunlight.

We will now run through the series of infra-red pictures as rapidly as possible, for I have a considerable number of them. The one which is on the screen is one of the finest in the collection (pl. 1). It was made in the park at Florence, and shows the long drive, overshadowed by trees, the one in the foreground being particularly fine in appearance. The next one (pl. 2) was made at the bottom of one of the old quarries or latomiæ at Syracuse, the view looking out through a cavelike formation at a group of almond trees, with which the quarry is overgrown.

Here is a fine row of cypresses growing by an old gate, taken on a somewhat hazy day, with the sky appearing a little lighter than usual. Some of the pictures show the advantage gained in bringing out the detail of distant objects seen through the atmospheric haze, and it does not seem impossible that photographs of the brighter planets made through an infra-red screen might prove interesting if the planets are surrounded by a light scattering atmosphere, for we must bear in mind that the surface of the earth, as seen from a neighboring planet, would be seen through a luminous haze, equal in brilliance to the blue sky on a clear day; that is, it would present much the same appearance as is presented by the moon when seen at noonday.

We will now look into the question of how things would appear if our eyes were sensitive only to ultra-violet light. In applying the same method which we have used for the infra-red, we require a screen which is opaque to all visible light, but which transmits the ultra-violet.

Glass is opaque to these rays, cutting them off almost completely, and for this reason we can not employ glass lenses. Quartz, on the other hand, is exceedingly transparent to these invisible rays, but it is a little difficult to find a medium which is transparent to them and at the same time quite opaque to visible light. Indeed, there is only one substance known which completely fulfills such a condition, namely, metallic silver. If we deposit chemically a thin film of metallic silver on the surface of a quartz lens, a certain amount of ultra-violet radiation between 3000 and 3200 is able to struggle through and form an image on the plate.

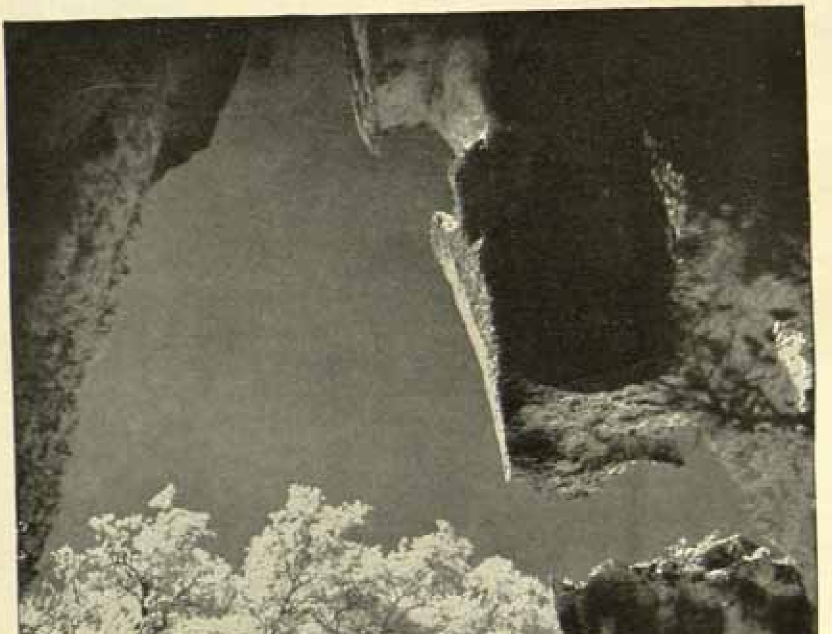
I have used silver films through which the filament of a tungsten lamp is invisible. The best thickness is that at which the tungsten lamp is just barely discernible. If the objects to be photographed are illuminated with the light of an electric spark, or some other source, rich in ultra-violet rays, much thinner films of silver can be employed, but in the case of sunlight, which has passed through the earth's atmosphere, the ultra-violet in the region for which silver has

its lowest reflecting power and greatest transparency has been so tremendously weakened by atmospheric absorption, that it is necessary to employ thick films and long exposures, otherwise the action upon the photographic plate results chiefly from the violet and ultra-violet rays, which are capable of traversing glass.

As an illustration of the behavior of silver films of different thicknesses, used as ray filters, we may take some pictures which were made for the purpose of studying the reflecting power of various metals, suitable for telescope mirrors, for ultra-violet photography. As silver reflects only about 4 per cent of the ultra-violet in the spectrum range for which it is transparent, a silvered glass reflecting telescope for this purpose is obviously out of the question. Speculum metal is fairly suitable, but speculum mirrors of large size are troublesome, and difficult to procure. I accordingly worked out a method of depositing nickel on glass. The glass is first silvered, and then electro-plated with nickel, by a process which I have described recently in the Astrophysical Journal (Dec., 1911). The double sulphate of nickel and ammonia is used with one or two dry cells. The solution must be very dilute (10 grams or less to the liter), otherwise the nickel strips the silver from the glass. We have here four pictures of a silvered glass dish, partially plated with nickel (pl. 3, fig. 1). The silvered portion is marked Ag, the nickel Ni, while at G we have a spot of clear glass from which the metal has been removed. The dish stands against a flat plate of polished speculum metal Sp, and the metal surfaces reflect the light of the sky to the camera. The first picture was made by blue and violet light without any ray filter, and as you see the glass surface G is quite black, while the silver reflects much more powerfully than the nickel. The following three pictures were made with a quartz lens, coated with silver films of increasing thickness. The silver and nickel reflect to about the same degree in the second picture, in the third the silver is much darker than the nickel, while in the fourth the silver is seen to reflect no more than the spot of clear glass G. This last was made through a film, through which a tungsten lamp was invisible. If these ultra-violet rays were visible to us, metallic silver would appear to have about the same reflecting power and appearance as anthracite coal.

We will next take up the action of our atmosphere on these ultra-violet rays. I have taken two photographs of a man standing in the road in full sunshine, in the one case by ordinary light and in the other by ultra-violet radiation. In the latter the shadow is completely absent. Ultra-violet behaves in exactly the opposite way to the infra-red. The infra-red rays are enabled to drive through the atmosphere without being scattered laterally by the molecules of the air or the dust particles. The short or ultra-violet rays, on the other

PARK IN FLORENCE. PHOTOGRAPHED BY INFRA-RED RAYS.



QUARRY IN SYRACUSE. PHOTOGRAPHED BY INFRA-RED RAYS.

hand, are completely scattered, so that the greater part of the ultra-violet light which reaches the surface of the earth comes from the sky and not directly from the sun. If our eyes were sensitive only to ultra-violet we should find the world appearing not greatly different from the aspect which obtains at the time of light fog. We should, indeed, see the sun, but it would be very dull, and there would be no shadows, just as there are none on a foggy day. We should walk the earth like Peter Schlemeil, the shadowless man of the German fable.

The next picture (pl. 3, fig. 2) illustrates the opacity of ordinary window glass to ultra-violet radiation. It will be noticed that there is no trace of the landscape seen through the glass window, although it is clearly rendered in the companion picture taken with visible light. Another difference to be noted in these pictures is that the flowers in the garden, which are white in the picture taken with visible light, disappear entirely in the picture taken by means of the ultra-violet radiation. The white garden flowers become almost black, as is shown in plate 4, figure 1, which shows white phlox photographed by visible and ultra-violet light. It occurred to me that this ability of the white flowers to absorb the ultra-violet rays might play some economic part in the growth of the plant. I therefore experimented with some flowers which had been grown under glass, and had thus been deprived of ultra-violet, but I was unable to find any marked difference between those which had been grown in the open and others which had been deprived of their full quota of this radiation. It is possible that if the experiments were carried on through the course of a number of generations, we should find a difference. I have found, however, that all white flowers are not equally dark when photographed with ultra-violet light. White geraniums, for example, come out much lighter than common white phlox, which is practically black when photographed through the silvered quartz lens.

In order to demonstrate the difference in the appearance of one of the common pigments when viewed respectively with visible light and with ultra-violet radiation, some letters were painted in Chinese white on a page of a magazine. In the photograph (pl. 4, fig. 2) taken with visible light the Chinese white appears as white as the paper itself, if not indeed whiter; but, photographed with the ultra-violet radiation, it comes out absolutely black. One may say that what is Chinese white in visible light becomes Japan black in ultra-violet. Under this radiation also black printer's ink becomes lighter than in visible light. This failure in the reflecting capacity of Chinese white is a source of some annoyance in reproducing drawings executed in part in this medium, as has been pointed out by Mr. A. J. Newton. In working with my Chinese white I made a mistake in one letter in the word "appears," and carefully wiped it out, leaving no trace of the

correction discernable in visible light; but when the photograph was made with the ultra-violet, the erasure, otherwise invisible, showed as a black smudge. The ultra-violet camera is evidently very much more sensitive than the eye to the presence of traces of Chinese white on the printed page, for so far as I could see every particle of the pigment had been removed. Whether this has any bearing upon the detection of forgeries has yet to be discovered.

Another class of work in which this comparative study is likely to be of service is the photography of celestial bodies. For the full moon the exposure through the silver screen was two minutes with ultra-violet light belonging to the region 3000 to 3200. This length of exposure necessitated an equatorial telescope with some means of driving it to compensate for the moon's movement. The support for my telescope was the framework of an old bicycle minus the wheels. This carried a 4-inch refractor and a quartz-silver telescope, and by the operation of a little screw it was possible to follow the moon accurately for half an hour. It will be seen at once (pl. 5) that there is very little difference between the ordinary image of the moon and the one which is shown us by the ultra-violet radiation. Nevertheless in the neighborhood of Aristarchus, which is the brightest crater on the lunar surface, the photograph taken with the ultra-violet rays shows a dark patch which is absent on the one taken with visible light. I made an enlargement of the region in which this crater appears, and it is evident that there is in its neighborhood a large deposit of some material which can only be brought out by means of the ultra-violet. These photographs of the moon make it appear extremely probable that by carrying on experiments of this nature on a larger scale we might get a good deal of new information as to the materials of which the moon is composed. It is possible to examine the igneous rocks of the earth under the different radiations, and then compare them with the pictures of celestial objects obtained at the same wave-lengths. I have found that some rocks, which when illuminated by ultra-violet rays appear darker than others, are lighter than the others in visible light.

[Note added October, 1911.]

[I have had constructed a 16-inch mirror of 26-feet focus which I have coated with nickel, for extending the study of the ultra-violet photography of the moon and planets. This is now being used in combination with a plate of the new ultra-violet glass, 12 centimeters square and 1 millimeter thick, heavily silvered. The plate was made by Zeiss, and I find that it is quite as transparent as quartz for the rays transmitted by the silver filter. This reflector was mounted on the 23-inch equatorial of Princeton University, and some very fair pictures have been obtained, though the moon's motion

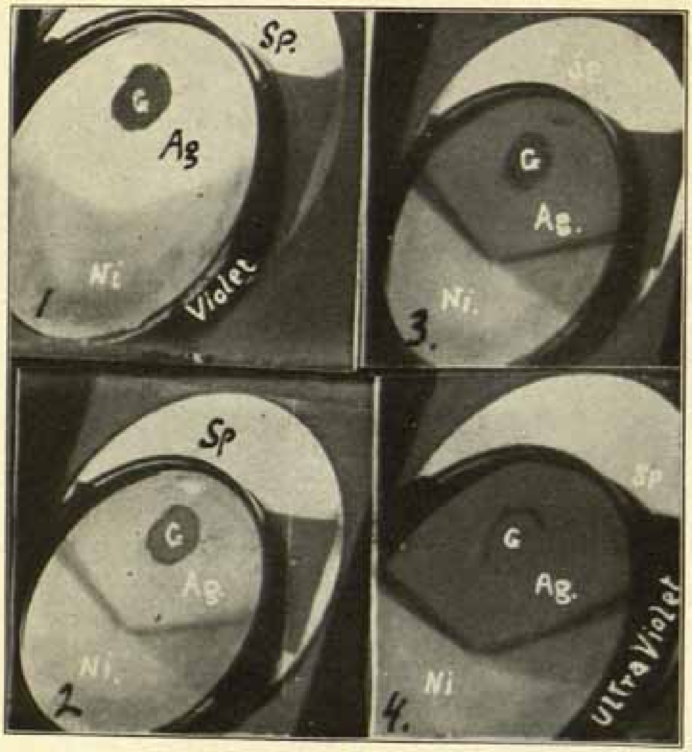
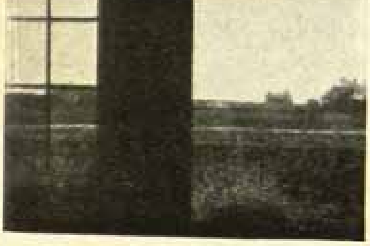
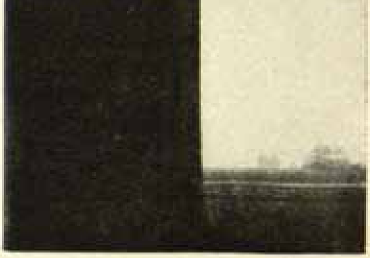


FIG. 1.



VISIBLE LIGHT.



ULTRA-VIOLET LIGHT.

FIG. 2.

VISIBLE LIGHT.

ULTRA-VIOLET LIGHT.

FIG. 1.

VISIBLE LIGHT.

ULTRA-VIOLET LIGHT.

FIG. 2.

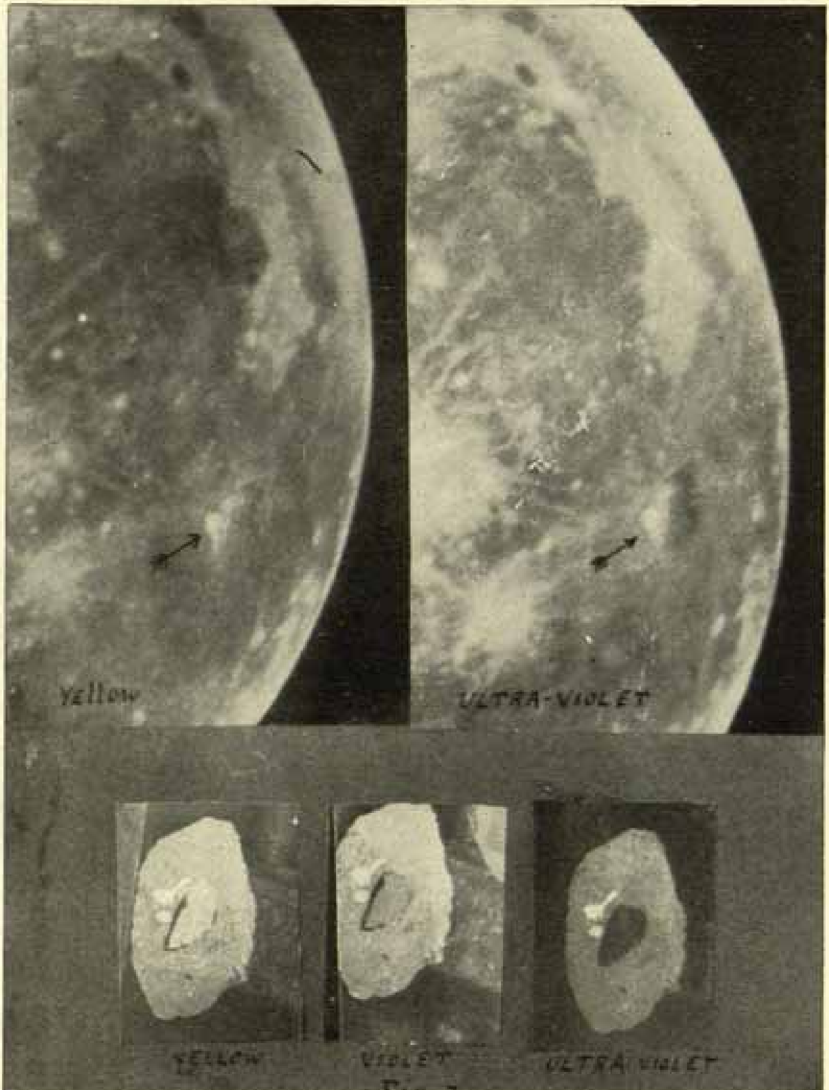
in declination could not be followed with sufficient accuracy to secure the best results. Figure 7 (pl. 5) shows two views of the region around Aristarchus (indicated by an arrow), one made with yellow, the other with ultra-violet light. The dark deposit to the right of the bright crater comes out very clearly in the latter. The markings to the right of this region are quite different in the two pictures. Immediately below the pictures of the moon are three photographs made of two samples of volcanic "tuff" arranged one upon the other, with the crater Aristarchus marked with white chalk (as a check upon the exposure). The left-hand picture was made with yellow light, and the central specimen is lighter than the one surrounding it. The right-hand one was made with ultra-violet, and shows the central specimen distinctly darker. The middle picture was taken with violet light, which shows the two specimens of very nearly the same luminosity. I made an analysis of the fragment of tuff which photographed dark in ultra-violet light, and found that it contained iron and traces of sulphur. Photographs of rocks stained with iron oxide did not show the required peculiarity, and I accordingly attributed the result to the sulphur. A light deposit of sulphur was formed on the surface of a piece of light-gray rock by directing a fine jet of sulphur vapor against it. The deposit was so slight that absolutely no trace of it could be detected by the eye. The specimen was then photographed with yellow, violet, and ultra-violet light, and it was found that the deposit was quite invisible in the first picture, faintly visible in the second, and quite black in the third—precisely the peculiarity shown by the deposit surrounding the crater Aristarchus. Plate 6, *a*, *b*, *c*, show the gradual appearance of the deposit, which is an oval spot in the center of the specimen. I feel inclined, therefore, to attribute this spot to an extensive deposit of sulphur, resulting from vapor ejected from the crater. The shape and vast extent of the deposit has always suggested to me that it resulted from material driven out in a volcanic blast.]

Returning now from the moon to the physical laboratory, we will consider a further phenomenon which has been discovered and studied by means of photography in the ultra-violet region. The vapor of mercury has an absorption band in this region at wave length 2536, which I have made the subject of a somewhat extended investigation. At low pressures the line is very narrow, resembling one of the D lines of sodium, and I have detected its presence in mercury vapor at room temperature by employing a tube 3 meters long closed with quartz plates. It occurred to me that this vapor might prove to be the substance which I have long sought for the study of what I have named resonance radiation, i. e., a re-emission of light by absorping molecules, of precisely the same wave length as that of the light absorbed. Sodium vapor was found to exhibit the phenomenon,

but the experimental difficulties were so great that very little was accomplished. A small box was made of brass and square plates of quartz. The inside was varnished and blackened with soot, a drop of mercury introduced, and the box exhausted. The camera with its quartz objective was now trained on the box, and a beam of light from a mercury lamp (quartz) focused at the center of the box. Though the eye could see no trace of the cone of rays, the photograph brought it out as distinctly as if the box was full of smoke. An exposure of only 1 second was necessary, and with a 10-second exposure the spectrum of the light scattered by the vapor was secured. It was found to consist of a single line only (the 2536 line), though the light entering the box was the total radiation of the mercury arc, the spectrum of which contained hundreds of lines. The pressure of the mercury vapor was about 0.001 millimeter, in other words, $\frac{1}{1000000}$ of the pressure of the air in the room. It seems most extraordinary that a vapor at such a very low pressure and at the temperature of the room should glow so brilliantly with invisible light. A little further experimenting resulted in a further discovery. It was found that if the box was filled with air at atmospheric pressure, the cone of rays glowed feebly in the mercury vapor with which the air was saturated. As the pressure was reduced the glow increased in brilliancy, reaching its maximum at a pressure of about 5 millimeters. As the exhaustion was pushed further the mercury vapor outside of the cone became luminous, and at the highest vacuum attainable the glow filled the entire box. This is secondary resonance radiation excited by the primary radiation of the mercury vapor, which is excited by the cone of focused rays. The brilliancy of the cone remained about the same, so that we can not attribute the bursting out of this secondary fluorescence to a mere increase in the brilliancy of the directly excited vapor.

Experiments are now in progress to determine why the presence of a few millimeters of air destroys all trace of the secondary radiation. Photographs of the glowing vapor in air at pressures of 5 millimeters, 1 millimeter, and 0 are reproduced in plate 6, *d*, *e*, *f*.

If we put the drop of mercury in a small flask with very thick walls, exhaust the air, and seal the neck of the flask with the oxyhydrogen flame, we are in a position to study this interesting type of radiation in mercury vapor at high pressures. I found that as the temperature of the flask was raised the radiation came from a region nearer and nearer the front surface, which was illuminated by tht rays from the lamp, and that when the pressure was about 10 atmospheres the ray from the lamp, which had a wave length of 2536, was selectively reflected from the surface of the vapor, precisely as if the inner surface of the bulb were plated with silver. The other rays passed through the bulb with their usual facility. I am



THE MOON PHOTOGRAPHED WITH INVISIBLE LIGHT.

a

b

c

d

e

f

g

EXPERIMENTS WITH INVISIBLE LIGHT.

at the present time engaged in the study of just how the change from the resonance radiation (which is scattered in all directions) to the regular reflection takes place, a matter of great interest in connection with the theory of absorption and reflection. As a matter of fact, I expect it to turn out that the mercury light does not absorb the light at all, for experiments indicate that the lateral emission of the ultra-violet light is about as bright as when white paper is used to scatter the light.

Another interesting line of investigation which I have recently carried out illustrates how new discoveries may be made by the aid of ultra-violet photography. It occurred to me that the air surrounding an electric spark might possibly be rendered fluorescent by the absorption of the very short ultra-violet waves discovered by Schumann, but that the flourescence might be made up wholly of ultra-violet light and consequently invisible. I therefore photographed the region surrounding a powerful spark discharge with a quartz lens, shielded from the direct light of the spark by a circular disk. The photograph, when developed, showed a highly luminous aureole surrounding the spark and extending out in all directions to a distance of nearly 2 centimeters. It was now necessary to prove that this was not light scattered by the dust particles in the air. To do this we have only to protograph the spectrum of the aureole. If it is similar to the spectrum of the spark we are safe in attributing it to scattered light. It it differs we know that it must be fluorescence, or the genesis of waves of different wave length from any present in the light of the spark. A photograph of the region surrounding the spark was made with a quartz spectrograph, and it was at once found that the spectrum was wholly different from that of the spark; in fact, it was almost identical with that of the oxy-hydrogen flame. For the further study of the phenomenon, a piece of apparatus was devised by which the light of the spark could be more effectually shut off. A small hole was bored through a plate of aluminum fastened to the end of a short vertical brass tube. This plate formed one electrode, the spark passing between an aluminum rod lying along the axis of the tube and the underside of the plate at the point perforated by the hole.

In a perfectly dark room, if the eye was held a little below the plane of the plate, no luminosity could be seen in the air above the hole, if it was reasonably free from dust, yet a photograph taken with a quartz lens showed a bright beam, or squirt, of light issuing from the hole. A photograph of the phenomenon is here shown, and you will notice the strong resemblance which it bears to a comet (pl. 6, *g*).

Many weeks have been spent in an attempt to determine the exact origin of this radiation, and the question has proved to be the most baffling one which I have ever attempted to solve. The work

is still in progress, and many remarkable observations have been made, each one leaving us more in the dark than before. As an illustration I may mention a circumstance discovered by Dr. Hemsalech and myself last winter in Paris. We found that if a jet of air was blown through the squirt of light, the luminosity was destroyed in the region traversed by the moving current of air, but was of undiminished intensity both above and below this region. This makes it seem as if the emanation which comes from the spark, and which causes the luminosity of the air, must act for a brief time upon the air in order to cause the luminosity. It also shows that the emanation, whatever may be its nature, is not swept aside by the air current. We have also found that other gases become luminous when subjected to the spark emanations, the spectrum in each case being different and peculiar to the gas used, electrolytic hydrogen, for example, giving a strong luminosity.

It is thus apparent that by employing this "photographic eye" of quartz many new phenomena may be brought to light which have previously hidden themselves behind the limitations of the human eye. A study of the absorption by the candle-flame of ultra-violet has also been made. In this case the light emitted by the candle falls out of the problem, for its flame emits little or no ultra-violet. I can show you a photograph of the shadow cast by a flame of this description, and you will observe that the shadow is blackest at the point where the flame is brightest, that is, at the point where the minute carbon particles, which, by their incandescence, cause the luminosity, are being set free from the hydrocarbon vapor.

There are other questions which can doubtless be investigated to advantage by means of ultra-violet photography. It is well known, for example, that the amount of ultra-violet light emitted by a body increases with the temperature. By photographing groups of stars through the quartz silver filter, and comparing the photometric intensities of the images obtained in this way with the intensities as shown on a plate made by means of yellow light, valuable data might be obtained. This method is merely an extension of one already in use at the Harvard Observatory.

WHAT ELECTROCHEMISTRY IS ACCOMPLISHING.[1]

By Joseph W. Richards,
Professor of Metallurgy, Lehigh University.

My theme is to depict for you, as clearly as I may be able, the part which electrochemistry is playing in modern industrial processes. I have no exhaustive catalogue of electrochemical processes to present, nor columns of statistics of these industries; but my object will be to classify the various activities of electrochemists and to analyze the scope of the electrochemical industries.

SCOPE OF ELECTROCHEMISTRY AND ELECTROMETALLURGY.

Chemistry is the science which investigates the composition of substances and studies changes of composition and reactions of substances upon each other. As an applied science, it deals chiefly with the working over of crude natural material, and its conversion into more valuable and more useful substances.

Some common examples, to illustrate this statement, are the conversion of native sulphur into sulphuric acid, the manufacture of soda and hydrochloric acid from common salt, the conversion of phosphate rock into superphosphate fertilizer, etc. Several pages would not suffice to merely catalogue the great variety of chemical industries; immense amounts of capital are invested in them and they are some of the most fundamental industries in their relation to supplying the needs of a rapidly advancing civilization.

Metallurgy is the art of extracting metals from their ores, and of purifying or refining them to the quality required by the metal-working industries. It is a branch of applied chemistry. The metallurgical industries form a highly important part of our national resources; on them we depend for iron, steel, copper, brass, gold, silver, lead, zinc, aluminum, etc., in fact for all the supply of metals used in arts and industry.

Electrochemistry is the art of applying electrical energy to facilitating the work of the chemist. It is chemistry helped by electricity. It is the use of a new agency in accomplishing chemical operations, and it has not only succeeded in facilitating many of the most difficult

[1] An address delivered at the seventeenth general meeting of the American Electrochemical Society, in Pittsburgh, Pa., May 7, 1910, President L. H. Baekeland in the chair. Reprinted by permission from the Transactions of the American Electrochemical Society, vol. 17, 1910, being the transactions of the seventeenth general meeting, at Pittsburgh, Pa., May 4-7, 1910. In the presentation of this paper Prof. Richards showed a large number of lantern slides illustrating electrochemical works in operation.

and costly of chemical reactions, but it has in many cases supplanted them by quick, simple, and direct methods; it has even, in many cases, developed new reactions and produced new materials which are not otherwise capable of being made. A few examples will illustrate these points: Caustic soda and bleaching powder are made from common salt by a series of operations, but the electrical method does this neatly and cheaply in practically one operation; lime and carbon do not react by ordinary chemical processes, but in the electric furnace they react at once to form the valuable and familiar calcium carbide; carbon stays carbon except when the intense heat of the electric furnace converts it into artificial graphite. The list of such operations is a long one, and it may be said that the chemist has become a much more highly efficient and accomplished chemist since he became an electrochemist, and he is becoming more of an electrochemist daily.

Electrometallurgy applies electric energy to facilitating the solution of the problems confronting the metallurgist. Its birth is but recent, yet it has rendered invaluable service; it has made easy some of the most difficult extractions, has produced several of the metals at a small fraction of their former cost, and has put at our disposal in commercial quantities and at practicable prices metals which were formerly unknown or else mere chemical curiosities. It has, further, refined many metals to a degree of purity not previously known. The metallurgist is rapidly appreciating the possibilities of electrometallurgical methods and they already form a considerable proportion of present metallurgical practice.

Applied electrochemistry, covering in general all of the field just described, is therefore an important part of chemistry and metallurgy, and is rapidly increasing in importance. It is a new art, people are really only beginning to understand its principles and to appreciate its possibilities; it is an art pursued by the most energetic and enterprising chemists, with the assistance of the most skilled electricians. Some of its most prominent exponents are electrical engineers who have been attracted by the vast possibilities opened up by these applications of electricity. The chemists have worked with electricity like children with a new toy, or a boy with a new machine; they have had the novel experience of seeing what wonders their newly applied agency could accomplish, and it is no exaggeration to say that they have astonished the world—and themselves.

THE AGENTS OF ELECTROCHEMISTRY.

The operating agent in electrochemistry is, of course, electric energy, which may be used in three classes of apparatus, viz:

I. Electrolytic apparatus.
II. Electric arcs and discharges in gases.
III. Electric furnaces.

I.

Electrolytic apparatus and processes use or utilize the separating or decomposing power of the electric current. Whenever an electric current is sent through a liquid material which is compound in its nature, i. e., a chemical compound, the current tends to decompose the compound into two constituents, appearing respectively at the two points of contact of the electric-conducting circuit with the liquid in question, i. e., at the surface or face of contact of the undecomposable conducting part of the circuit with the decomposable part. If the current has a definite direction the constituents appear at definite electrodes. The action is simply the result of the current extracting (or tending to extract) from the electrolyte one of its constituents at each of the two electrode surfaces. All subsequent changes following upon this primary tendency of the current are called secondary reactions, and are practically simultaneous with the primary. These may even be regarded as truly primary reactions also, the primitive decomposing or separating power of the current passing being regarded only as a tendency or a determining cause which practically results in the reactions actually taking place.

This agency is an extremely vigorous and potent force for producing chemical transformations. It enables us, for instance, to split up some of the strongest chemical compounds into their elementary constituents, to convert cheap materials into much more valuable derivatives, to purify impure materials, in short, to perform easily some very difficult chemical operations and in some cases to perform chemical operations otherwise impossible. A description of all these various processes would take a volume, but a short explanation of a few of them will make the principles clear and suffice for my present purpose.

Electrolysis of water.—As a raw material, water may be said to cost nothing. Apply an electric current to it in the proper way, and it is resolved into its constituent gases, hydrogen and oxygen, as cleanly and perfectly as anyone could desire. These gases have many and various uses, and are valued each at several cents per pound. A whole industry has thus grown up, based on the simple electrolysis of water, to supply these two gases for various industrial uses. Europe possesses many of these plants; there are a few in the United States. The speaker has translated from the German a small treatise on this industry.

Electrolysis of salt.—Common salt, sodium chloride, is one of the cheapest of natural chemicals. It has some uses of its own, but centuries ago chemists and even alchemists devised chemical processes for transforming it into other sodium salts, such as caustic

soda or soda lye for use in soap, soda ash or carbonate, for washing or glassmaking, and into chlorine bleaching materials. Chemical works operating these rather complicated chemical processes exist on an immense scale in all civilized countries; it is estimated that $50,000,000 is thus invested in Great Britain alone. The electrolytic alkali industry is barely 20 years old, yet it is already more than holding its own with the older chemical process, and advancing rapidly; 20 years more will probably see the older processes entirely superseded—they are at present fighting for their existence. As for the electrolytic process, the salt is simply dissolved in water and by the action of the current converted into caustic soda at one electrode and chlorine gas at the other. By some special devices these are kept separate and collected by themselves, and the work is done. The principles involved are simplicity itself as compared with the older chemical processes, the only agent consumed is electric energy, and the products are clean and pure.

Chlorates.—These are salts used on matches and in gunpowder. Chlorate of potassium is a valuable salt with important uses. It is made from common cheap potassium chloride, in solution in water, by simply electrolyzing the solution without trying to separate the products forming at the electrodes. It is a simpler operation than the production of electrolytic alkali. Chlorate thus forms in the warm solution, and is obtained by letting the solution cool and the chlorate crystallize out. The ordinary chemical manufacture of this salt was tedious and dangerous; the electrolytic method has practically entirely superseded it.

Perchlorates.—These salts have more limited uses, but are made by expensive chemical methods. The electrolysis of a chlorate solution at a low temperature, without separating the products formed at the two electrodes, results in the direct and easy production of perchlorates. I cite this more to illustrate what I might call the versatility of the electrochemical methods, rather than because of its commercial importance.

Metallic sodium.—The caustic soda produced from salt can itself be electrolytically decomposed; this is the easiest way of producing metallic sodium. Sir Humphry Davy discovered sodium by electrolyzing melted caustic soda, and at this moment several large works are working his method on an immense scale. The caustic contains sodium, hydrogen, and oxygen, and the current simply liberates the sodium as a molten metal and frees the other two as gases which escape into the air. The process is simplicity itself—when the exact conditions are known and rigidly adhered to. Metallic sodium is a very useful material to the chemist, and the electrolytic method produces it at probably one-fourth the cost of making it in any purely chemical way.

Magnesium.—This is a wonderfully light metal, whose chief use is in flashlight powders. Its compounds are abundant in nature, but its manufacture by any other than the electrolytic method is almost impracticable. The operation consists in simply passing the decomposing current through a fused magnesium salt—a chloride of magnesium and potassium found in abundance in Germany.

Aluminium.—The most useful of the light metals; an element more abundant in nature than iron, yet which costs by chemical methods at least $1 per pound to produce; electrochemistry enables the makers to sell it at a profit at $0.25 per pound. This is probably the most useful metal given to the world by electrochemistry. Although the French chemist Deville obtained it by an electrolytic method in 1855, yet he had only the battery as a source of electric current, and the process was too costly. This very city of Pittsburgh was the real cradle of the electrolytic manufacture of aluminium, when in 1889 Mr. Charles M. Hall, with the financial assistance of the Mellons and the business assistance of Capt. A. E. Hunt, commenced to work his process up at Thirty-third Street on the West Side. The principle of the process is here again one of beautiful simplicity—when it is once made known. Aluminium oxide, abundant in nature, is infusible in ordinary furnaces, but easily melts and dissolves, like sugar in water, in certain very stable and liquid fused salts—double flourides of aluminium and the alkali metals. On passing the electric current through this bath, the dissolved aluminium oxide is decomposed, appearing at the two electrodes as aluminium and oxygen, respectively. When all the oxide is thus broken up, more is added, and the operation continues. One of the most difficult problems of ordinary chemistry is thus simply, neatly, and effectively solved by electrochemistry. The lower cost of power at Niagara Falls drew the industry away from Pittsburgh in 1893, and it is now run on an immense scale at several places where water power is cheap and abundant. Mechanical power is, however, being produced cheaper every year; gas engines have halved the cost of such power, steam turbines on exhaust steam may even do better; there is no inherent impossibility in the return of the aluminium industry to the Pittsburgh district. Many other factors besides cost of power bear on the question—cost of labor, abundance of labor, cost of carbon, coal for heating, various supplies, railroad freights, nearness to the consumers, and many other considerations must be taken into account. Aluminium is certainly destined to become the most important metal next to iron and steel, and, as far as one can now foresee, will always be produced electrochemically. To have accomplished the establishment of this one single industry would of itself have proved the usefulness of electrical methods and their importance to chemistry and metallurgy.

Refining of metals.—Unless metals are of high purity they are usually of very little usefulness. Electrolytic methods enable almost perfect purity to be easily attained, and in addition permit the separation at the same time of the valuable gold and silver contained in small amounts in the baser metals. Over $100,000,000 worth of copper is electrically refined every year in the United States; the metal produced is purer than can be otherwise obtained, giving the electrical engineer the highest grade of conducting metal, while several million dollars' worth of gold and silver are recovered which would otherwise have to be allowed to remain in the copper. Again, the method is so simple that but a few words are necessary to set it forth in principle. The impure copper is used as one electrode—the anode—in a solution of copper sulphate containing some sulphuric acid; the receiving electrode—the cathode—is a thin sheet of pure copper, or of lead, greased. The electric action causes pure copper only to deposit upon the cathode, if a properly regulated current is used, while a corresponding amount of metal is dissolved from the anode. Silver, gold, and platinum are undissolved, and remain as mud or sediment in the bottom of the bath; other impurities may go into the solution, but are not deposited on the cathode if the current is kept low. The cost of this operation is small, and the results are so highly satisfactory that 90 per cent of all the copper produced is thus refined. Similar methods are in use for refining other metals, silver, gold, and lead are thus refined on a large scale; antimony, bismuth, tin, platinum, zinc, and even iron can be thus refined; the field is very inviting to the experimenter and to the technologist, and is rapidly increasing in industrial importance.

Metal plating.—All electroplating is done by the use of electrolytic methods similar to those just described. If we imagine the impure metal anode replaced by pure metal, and the receiving cathode to be the object to be electroplated, we have before us the electroplating bath ready for action. Everybody knows the value and use of gold, silver, and nickel plating; less well known are platinum, cadmium, chromium, zinc, brass, and bronze plating. These are among the oldest of the electrochemical industries. Electrotyping is only a variation of this work; also the electrolytic reproduction of medals, engravings, cuts, etc., and even the production of metallic articles of various and complicated forms, such as tubes, needles, mirrors, vases, statues, etc. The speaker has translated from the German a monograph concerning these last-named uses of the electric current. There is opportunity here to hardly more than catalogue these various branches of electrometallurgical activity. Pittsburgh people will be interested, however, in knowing that many of the newer buildings in this city contain thousands of feet of electrical conduits zinc plated in splendid fashion by electrolysis, at a works within a few miles of

this city. At McKeesport tubes are coated on an immense scale, by dipping into melted zinc, but the electrolytic method is gaining a foothold, and we may live to see all galvanizing in reality practiced as it is spelled. The removing of metallic tin from waste tin scrap is also accomplished on a large scale by the application of similar principles. It is being operated at a distance from Pittsburgh, but your open-hearth furnaces use up annually thousands of tons of the scrap steel thus cleaned and saved for remanufacture into useful shape.

Without having mentioned or described more than a fraction of the electrolytic methods in actual industrial use, I hope that I have made clear the importance and extent of this kind of electrochemical processes. Assuming this, we will pass to the consideration of another entirely different and yet important class of apparatus and processes.

II.

Electric arcs and high-tension discharges through gases are capable of producing some chemical compositions and decompositions which are very useful and profitable to operate. This is a branch of electrochemistry which has not been as thoroughly studied as some others, its phenomena are not as thoroughly under control as electrolysis and electrothermal reactions, and its possibilities are not as thoroughly understood or utilized.

Ozone is being made from air by the silent discharge of high-tension electric current. The apparatus is so far simplified as to be made in small units suitable for household use, ready to attach to a low-tension alternating current supply. The uses for the ozone thus produced are particularly for purifying water and air. It makes very impure water perfectly safe to drink and purifies the air of assembly halls and sick rooms, acting as an antiseptic. According to all appearances, this electrochemical doubling up of oxygen into a more efficient oxidizing form is developing into a simple and highly efficient aid to healthy living.

Nitric acid is an expensive acid made from the natural alkaline nitrate salts, such as Chili saltpeter. These nitrates are the salvation of the agriculturist, for they furnish the ground with the necessary nitrogen which plants can assimilate. The Chili "nitrate kings" have gained many millions of dollars, even hundreds of millions, in thus supplying the world's demand for fertilizer. But electrochemistry has another solution to this problem, which is rapidly rendering every country which adopts it independent of the foreign fertilizer. The air we breathe contains uncombined nitrogen and oxygen gases, which, if combined and brought into contact with water, furnish the exact constituents of nitric acid. The way to do this has been laboriously worked out, and the electric arc is the agent which does it. Air is simply blown into the electric arc, where it for

an instant partakes of the enormous temperature, and on leaving the arc is cooled as quickly as possible. In the arc the combination of nitrogen and oxygen is effected to a certain extent, and the mixture is cooled so suddenly that it does not find time to disunite. The nitrogen oxides thus obtained are drawn through water, and this solution of nitric acid is run upon soda to produce sodium nitrate or on lime to produce calcium nitrate, the latter called nitrolime or "Norwegian saltpeter." These salts entirely replace the South American natural salt.

The materials used in this industry are air and lime, and to these is added electrical energy. Air is universal, lime cheap almost everywhere, and electrical energy is cheapest where water powers are most abundant. In Norway water power can be developed and electrical energy supplied from it at a total cost of $4 to $8 per horsepower year. Some other countries can do nearly as well. Under these conditions, almost every country can afford to make its own nitrates and so be independent of other countries for the fertilizer needed in peace and the gunpowder used in war. Norway felicitates itself already on being thus independent. Nearly 200,000 horsepower is being utilized there by a $15,000,000 syndicate, and the industry is spreading rapidly over Europe. The study of this problem, its solution, and the rapid development of this vigorous industry, is one of the most remarkable chapters in the history of recent industrial development. In this accomplishment electrochemistry has signally aided the agriculturist and demonstrably multiplied the food-supply resources of all civilized and highly populated countries.

Boron is an element which has until recently defied the best efforts of chemists to isolate in a pure state. It is an element which may have important application in the manufacture of a high-class special steel—boron steel. Dr. Weintraub, one of our fellow members, has recently solved the problem of its production by an adaptation of the "oxygen-nitrogen" arc apparatus and utilizing the same principle of introducing the material into the arc and very rapidly cooling the products obtained. We mention this not because of its great commercial importance at present, but because it shows how the "arc method" may be of wide application in solving other difficult chemical problems. It has opened before us a new method in chemical science, and may give birth to many and various new chemical industries.

III.

Electric furnaces are furnaces in which the necessary heat or degree of temperature is produced or attained by means of electrical energy. The electric current is used in these furnaces solely for its heating or thermal effect, and either alternating or direct current may

be used, but alternating is preferred because of its easier generation and management, capability of being stepped up or down by transformers, and absence of electrolytic effects.

Electric furnaces render remarkable and highly valuable service to the chemist and metallurgist, for two distinct and unique capabilities; they can generate heat within themselves without the use of combustion and the consequent products of combustion to complicate the working of the furnace, and they can besides, if desirable, produce temperatures absolutely unapproachable in furnaces using fuel, and thereby enable the carrying out of operations only possible at these extremely high temperatures. The upper limit of electric furnace temperature is simply the volatilizing point of carbon, the temperature at which the material of which the lining of the furnace is made is boiled away. This is about 3,700° C. or 6,700° F. The simple statement that this is three times as high as the melting point of cast iron may give some notion of the enormous temperature here at one's command. Besides intense temperature, the efficiency of application of electrical heat to the useful purpose is usually high; in many cases 50 to 75 per cent of all the heat developed can be usefully applied, as against 5 to 50 per cent utilized in fuel-fired furnaces. The heating value or thermal equivalent of the electric current is perfectly definitely known; 1 kilowatt-hour will furnish 860 calories (3,400 B. t. u.), which if applied usefully at 100 per cent efficiency would bring to boiling and convert into steam 1.35 kilograms (3 pounds) of water, or bring to melting and melt about 3 kilograms (7.5 pounds) of cast iron, or 2.5 kilograms (5.5 pounds) of steel.

Artificial graphite is a product particularly electrochemical in its manufacture. Your fellow townsman, Dr. E. G. Acheson, has practically created this industry and his name sticks to the product—Acheson graphite. No temperature but that of the electric furnace can convert the ordinary amorphous carbon, containing small amounts of foreign substances, into pure, soft, homogeneous, unctuous graphite. The purity of the product and its quality has even surpassed the artifice of mother nature herself. Whereas, before, graphite in small scales was laboriously gathered from Ceylon and Siberia, and with great pains worked up into graphite articles, now the articles are simply molded in ordinary impure amorphous carbon, and converted through and through, retaining their shape, into finished and complete graphite articles. What this highly pure product is going to do for lubrication, for annihilating the friction of the world's machinery, perhaps only a few suspect and only Mr. Acheson knows. You will all know more about this soon, and everyone of you who uses machinery will profit by it. Meanwhile, in another direction, probably half the electrochemical industries now operating are bene-

ficiaries of this invention, using artificial graphite anodes in electrolytic operations or as electrodes in electric furnaces. The electrochemical industry in general has been most wonderfully helped by this one electrochemical process.

Carborundum stands for a large industry, centered at Niagara Falls, and founded also by Mr. Acheson. Twenty years ago the name was not in the dictionary; now it is known all over the world as the most efficient abrasive material in use. First produced just across the Monongahela, in a little furnace as large as a cigar box, and sold for polishing diamonds at many dollars per ounce, it is now made by tons in electric furnaces of 2,000 horsepower capacity, and competes successfully with such common natural abrasives as emery and common sand. And in fact, common silica sand, the most abundant material on earth, with common carbon, like coke, furnish all the ingredients necessary for the furnace to work upon to produce SiC (silicon carbide). Mr. Acheson not merely founded another new industry, but he discovered a new chemical compound; he has enriched science, promoted industry, and created new instruments of service; no wonder that his scientific friends have showered on him honors—the Rumford Medal, the Perkin Medal, and two years ago the presidency of this Electrochemical Society.

Silicon is the metal whose oxide is silica sand, and is by far the most abundant metallic element on earth. Up until very recently it was to be seen only in chemical museums, costly and useless—a chemical curiosity. Now Mr. F. J. Tone, one of Mr. Acheson's former lieutenants, is producing it by the ton and selling it by the carload at a few cents per pound. The chemical world has found uses for it, large uses, such as in solidifying steel, making good copper castings, reducing other metals from their oxides, chemical "pots and pans," etc. This illustrates again the variety of the achievements of electrochemistry. Here is a new material furnished the world at a low price and all sorts of workers are finding all sorts of advantageous uses for it. The electric furnace makes it from simply sand and carbon, with electric energy plus considerable "brains."

Calcium carbide is the product of another American invention. The name was scarcely in the chemical books, and the purveyors of the rarest chemicals did not have it on their lists, when Mr. Thomas Willson, trying to make something else in the electric furnace, made this compound from ordinary lime and carbon, and started an electrochemical industry which has spread all over the civilized world. I am almost tempted to say that there is a calcium carbide works everywhere but in Pittsburgh, but that would really be an exaggeration, and I will not say it. The best thing about calcium carbide is that it is easy to make; the raw materials may be found almost

everywhere, and wherever power is cheap a flourishing calcium carbide industry may be built up. The curious thing about it is that its chief use is based on destroying it, acting upon it by water and forming acetylene gas. How great a boon acetylene gas has been to the bicyclist, automobilist, for lighting trains, isolated houses, stations, and towns needs no recital before this audience, but the value of acetylene as a means of welding with the blowpipe is only commencing to be appreciated. Acetylene welding is a convenience which owes its existence entirely to the electrochemical production of calcium carbide, and the iron and steel and other metal industries are being greatly helped by its use.

Titanium carbide is not as familiar as calcium carbide. It is made in a manner similar to the production of carborundum, using titanium oxide (rutile) and carbon. It has no uses similar to calcium carbide, nor any like silicon carbide. But electrical engineers have discovered that as arc-light tips or electrodes it gives the most efficient arc light yet discovered, with a light efficiency running up to 3 candle-power per watt of electrical energy. This is probably 50 per cent of the theoretically possible conversion of electrical energy into light energy, and is doubly as efficient as has ever before been attained. What this means for street lighting everywhere is difficult to realize; perhaps the best and most easily understood comparison is to say that the titanium carbide arc lamp is to the ordinary arc as the tungsten filament incandescent lamp is to the carbon filament lamp; you will all grasp the scope of that statement. With acetylene lighting on one hand and titanium arc lighting on the other we need say no more about the influence of electrochemistry on modern illumination.

Phosphorus.—I stated before that the potassium chlorate on safety matches was all being made electrochemically. We can say practically the same of phosphorus. The electric furnace enables us to distill phosphorus much more easily and safely from the natural phosphates than the older chemical methods. Calcium carbide gives us acetylene gas, and another electrochemical furnace gives us the phosphorus to "strike the light."

Ferroalloys are alloys of iron with the more expensive metals, used in manufacturing steels of various kinds. Ferromanganese is used in practically all steel, ferrosilicon is used in almost all. Ferrochromium, nickel, tungsten, molybdenum, boron, uranium, vanadium are some of the alloys used to make the special alloy steels, such as find great use in rapid tool steel, automobile axles, armor plate, gun steel, etc. These alloys are of great importance to the steel industry, and are made almost exclusively in electric furnaces. The industry has flourished most in countries having cheap power,

such as among the French Alps, and the importations into this country have been on a large scale. Fortunately, we are commencing at Niagara Falls, in Virginia, and in Canada to supply ourselves with these necessities of the steel industry, and we may look forward to a steady and large domestic development of this industry. Within a few miles of this hall a small electric furnace is now at work making ferrotungsten to go into expensive high-class steel. Pittsburgh is going to take its share in the running of this particular electrometallurgical industry.

Pig iron would seem to be about the last item to find a place in an address upon the electrochemical industries. But the truth must "out"—electric-furnace pig iron is now being made, and made and sold at a profit. We will hasten to admit that the furnaces are small, that they are in California and Sweden, where fuel is expensive and power is cheap, that a great deal of money has been sunk in bringing them to their present condition; but after all has been admitted, the fact remains that electric furnace production of pig iron is not a chimera, but an accomplished fact. Pittsburgh has been able to boast that she "could manufacture a ton of pig iron and put it down anywhere in the world cheaper than it could be there produced." That may be still true of the kind of pig iron which Pittsburgh is able to make, but there are grades and qualities of pig iron (Swedish charcoal pig iron, for instance) which are still imported into this country and sold at double the price of our domestic pig iron. And, in the country where that charcoal pig is slowly, laboriously, and skillfully made, the electric shaft furnace is able to compete with the charcoal blast furnace in producing this high quality pig iron. Dr. Haanel, of the Canadian department of mines, has in a recent report given us the most reliable information about the running of this furnace. The construction is peculiar, and still somewhat experimental, the full power for which the furnace was designed has not yet been available for running it, the workmen are new to their tasks, the overseers are still learning, the irregularities in the running are not yet all overcome, and many of the minor details are yet being adjusted. The furnace is still, in brief, decidedly in the formative or experimental stage. Yet, notwithstanding, Prof. Odelstjerna, one of the most expert of Swedish metallurgists, states that the cost of production is \$1.50 per ton less than in the Swedish blast furnaces. If that is true now, it needs little gift of prophecy to figure out at least \$2.50 per ton saving when the furnace is properly run. Three similar furnaces of greater capacity, 2,500 kilowatts each, are to be erected in Norway; three similar ones are to be put up at Sault Ste. Marie, Canada. These are only the forerunners, we may be sure, of dozens or perhaps even hundreds which will be built and operated within the

lifetime of most of this audience. The time at our disposal forbids my describing these interesting furnaces; I can only refer you to Dr. Haanel's interesting reports and to the transactions of this society, particularly to our Volume XV. One surmise of my own I will, however, take time to mention: I have predicted that this electric-furnace pig iron, made without the admittance or use of air blast, will be far superior to ordinary pig iron for conversion into steel, because of the absence of oxygen or, particularly, of nitrogen. Time will test this prediction, too.

Electric steel is at present a topic of absorbing interest and great potentialities. It was primarily a competitor of the most expensive kind of steel—crucible steel. It was first made commercially in 1900, by Mr. F. A. Kjellin, of Sweden, by melting together in an electric furnace the same high-grade materials which are usually melted down in crucibles to form crucible steel. The product was made equal in quality to crucible steel, it was produced in lots of a ton or more at a melt, of very satisfactory uniformity, and with cheap water power to furnish electricity the cost was considerably below that of crucible steel.

The steel melting pot or crucible is a siliceous vessel, holding about 100 pounds of steel, lasting only a few heats, and lifted in and out of the furnace by manual labor. The consumption of fuel to get the required melting heat is wickedly wasteful; not over 5 per cent of the heat-developing power of the fuel used is efficiently utilized as heat in the melted steel, and the actual proportion is usually less than half that much. The cost of labor, crucibles, and fuel is excessive, and to this must be added the high cost of the pure material which must be used—practically the purest iron which can be made.

The electric furnace is changing all this, rapidly in continental Europe, slower in Sheffield, and still slower in America; but the change is spreading surely and inevitably. Real crucible steel will soon be a thing of the past, supplanted entirely by electric furnace steel of equal quality, made and sold much more cheaply.

The electric furnaces used are of almost all types. The induction furnace was developed commercially by Kjellin in Sweden, improved, enlarged, and greatly developed by his associates in Germany, combined with the Colby pattern in America, and still further modified by Hiorth in Norway. Thirty-six of these furnaces, the maximum capacity being one at Krupp's works at Essen, 8½ tons at a charge, are now built or building. The American Electric Furnace Co. is organized to push their building and operation in America. The arc radiation furnace was developed by Maj. Stassano, an Italian artillery officer. It melts by heat radiated from powerful electric arcs. Several of these are in operation in Europe, and a

gentleman managing one of the large American steel companies, who has just returned from an inspection of the different electric steel furnaces operating in Europe, tells me that he considered the Stassano furnace as doing the best work, all around, of all the furnaces he saw in operation. I have seen this furnace operating smoothly and regularly in Turin, producing steel for castings which were being sold in competition with open-hearth and Bessemer steel castings in the open market. The single arc furnace is best illustrated by the Girod furnace, which is built like the body of an open-hearth furnace with the electric current entering the bath by carbon electrodes suspended above it, and springing arcs to it, while the current leaves the bath through metallic conductors passing through the saucer-shaped hearth below the level of the metallic surface. These furnaces work with great regularity, and a large number are operating in Europe, in capacities up to 12 tons each. I am informed that the Krupp Works at Essen has just contracted to put in five of these of the 12-ton size, which would confirm statements made to me by my European friends that this furnace is working the best of all the electric steel furnaces now operating in Europe. The double-arc furnace, of which the Heroult furnace is the most familiar type, works with two arcs in series, the current entering the bath and leaving it also through electrodes suspended above it. The general style is that of an open-hearth furnace with electrodes passing through the roof. The current used is roughly 100 kilowatts per ton of steel capacity, and the largest so far operated is 15 tons. A 3-ton furnace of this type was seen by you at the Firth-Stirling Steel Works at Demmler, yesterday, producing crucible-quality steel. The United States Steel Corporation has acquired licenses to operate the Heroult furnace, and has already two 15-ton furnaces in operation. Without doubt, the Heroult furnace is at the present time the most popular and successful electric steel furnace in the United States. I have not time to more than name the Keller, the Hiorth, the Harmet, the Frick—all of which are operating at this present moment in Europe.

There are other ways of making steel than the crucible method. Bessemer steel is the cheapest, and open-hearth steel is next best. These two varieties grade into each other in quality, but between open-hearth and crucible steel there is an enormous gap in price and in quality which is destined to be bridged over by intermediate qualities of electric steel as it becomes cheaper and is manufactured on a larger scale. This will soon become one of the large uses of the electric method, occupying a field peculiarly its own. It will enable steel manufacturers to supply steel better than the best open-hearth product at less than the price of crucible steel. I need not enlarge upon the advantages of this to a Pittsburgh audience.

There are also varieties of methods of manufacture of steel, aside from the melting together of highly pure materials as in the crucible method, which are equally available in most types of the electric furnace. The Bessemer converter takes liquid pig iron as it comes from the blast furnace and by rapid oxidation by air blast converts it into steel. Mr. Heroult has tried to combine the Bessemer converter with the electric furnace in one apparatus the idea being to first oxidize the metal by air blast and then to finish it while electric current supplied the necessary heat. I have no information that this combination furnace is anywhere in successful operation, but the equivalent of the same operation performed first in the Bessemer converter and then on the blown metal transferred into an electric furnace for finishing is already in regular commercial operation at the South Chicago Works of the United States Steel Corporation. I have had the privilege and pleasure, thanks to Mr. Heroult, of studying that operation, in company with Mr. Heroult and the editor of Metallurgical and Chemical Engineering. You may find a description of the process in the April number of that journal, so I will not repeat it here—except so far as to say that 15 tons of the product of the Bessemer blow, oxidized to the extent usual in the Bessemer converter, was kept melted less than two hours on the basic hearth of the electric furnace, treated with two different slags to refine it from phosphorus and sulphur, deoxidized or "dead-melted," and then poured into ingots of steel intended for axles. The steel produced was of better quality than the usual corresponding open-hearth metal, and was produced at slightly less total cost. This combination process bids fair to give a new lease of life to the declining Bessemer steel industry; its economic importance will appeal particularly to this audience.

The open-hearth steel furnace is at present the most important of the methods of manufacturing steel—"tonnage steel." It makes steel from pig iron and scrap of proper quality, or from pig iron and iron ore (mill scale), or from pig, scrap, and ore. It makes its best steel on silica hearths from high-grade material low in sulphur and phosphorus, and its cheapest steel on basic hearths from almost anything. The electric furnace can do any or all of these things, and, as a general proposition, produce better steel from given materials than the open-hearth furnace. Under what circumstances it will pay to use the electric furnace instead of the open-hearth furnace would take at least one lecture to discuss; we will not go deeply into it here. In Europe, countries which have very cheap water power, around $10 per horsepower year, and fuel costing $4 to $6 per ton, are finding the electric furnace the cheaper; with power costing $20 and coal $5, the two are about on equal terms; in Pittsburgh, with power at $30 and coal at $1, the open-hearth furnace is by far the cheaper for produc-

ing such steel as it can produce. However, even here the combination of Bessemer and electric furnace is possibly cheaper than the all open-hearth process; the combination of open-hearth and electric-furnace processes is quite possible and practicable to produce crucible-quality steel on a large (tonnage) scale, and the combination of the open-hearth and electric furnace into one furnace is not only a possible combination, but is actually being "tried out." The latter idea is to take an open-hearth furnace and to place electrodes in the roof. The furnace is run as an ordinary open-hearth furnace, with the electrodes withdrawn, and at the close of the open-hearth heat gas and air are shut off entirely, the electrodes lowered into proximity to the bath, and the heat finished as an electric-furnace heat. The idea is sound and practicable and will result in the production of better steel than can be obtained from any open-hearth furnace at but a slight advance on the cost of the open-hearth steel, say $2 to $3 per ton.

As to the capacity for enlargement of electric steel furnaces, they started out to duplicate the crucible-steel process, producing 100 pounds of melted steel at a heat, and in eight years have risen to 15 tons' capacity. In Europe an electric calcium-carbide furnace of 18,000 kilowatts, capable of producing 200 tons of carbide daily, is in practical operation. A furnace of like power capacity could be built to make steel, and would be a 200-ton steel furnace or larger. We can therefore say with assurance that with a little more experience and experiment electrometallurgists will be able to furnish the steel maker with electric steel furnaces as large as are wanted—up to 200 tons' capacity, if desired.

ANCIENT AND MODERN VIEWS REGARDING THE CHEMICAL ELEMENTS.[1]

By Prof. Sir William Ramsay, K.C.B., Ph.D., LL.D., D.Sc., M.D., F.R.S.

It has been the usual custom of my predecessors in office either to give a summary of the progress of science within the past year or to attempt to present in intelligible language some aspect of the science in which they have themselves been engaged. I possess no qualifications for the former course, and I therefore ask you to bear with me while I devote some minutes to the consideration of ancient and modern views regarding the chemical elements. To many in my audience part of my story will prove an oft-told tale; but I must ask those to excuse me, in order that it may be in some wise complete.

In the days of the early Greeks the word "element" was applied rather to denote a property of matter than one of its constituents. Thus, when a substance was said to contain fire, air, water, and earth (of which terms a childish game doubtless once played by all of us is a relic), it probably meant that they partook of the nature of the so-called elements. Inflammability showed the presence of concealed fire; the escape of "airs" when some substances are heated or when vegetable or animal matter is distilled no doubt led to the idea that these airs were imprisoned in the matters from which they escaped; hardness and permanence were ascribed to the presence of earth, while liquidity and fusibility were properties conveyed by the presence of concealed water. At a later date the Spagyrics added three hypostatical principles to the quadrilateral; these were salt, sulphur, and mercury. The first conveyed solubility, and fixedness in fire; the second, inflammability; and the third, the power which some substances manifest of producing a liquid, generally termed "phlegm," on application of heat, or of themselves being converted into the liquid state by fusion.

It was Robert Boyle, in his Skeptical Chymist, who first controverted these ancient and medieval notions, and who gave to the word

[1] Presidential address by Prof. Ramsay at the Portsmouth meeting of the British Association for the Advancement of Science, 1911. Reprinted by permission from author's separate, omitting introductory matter on work of the association.

element the meaning that it now possesses—the constituent of a compound. But in the middle of the seventeenth century chemistry had not advanced far enough to make his definition useful; for he was unable to suggest any particular substance as elementary. And, indeed, the main tenet of the doctrine of phlogiston, promulgated by Stahl in the eighteenth century, and widely accepted, was that all bodies capable of burning or of being converted into a calx, or earthy powder, did so in virtue of the escape of a subtle fluid from their pores; this fluid could be restored to the calces by heating them with other substances rich in phlogiston, such as charcoal, oil, flour, and the like. Stahl, however false his theory, had at least the merit of having constructed a reversible chemical equation:

$$\text{Metal} - \text{phlogiston} = \text{Calx}; \ \text{Calx} + \text{phlogiston} = \text{Metal}.$$

It is difficult to say when the first element was known to be an element. After Lavoisier's overthrow of the phlogistic hypothesis, the part played by oxygen, then recently discovered by Priestley and Scheele, came prominently forward. Loss of phlogiston was identified with oxidation; gain of phlogiston with loss of oxygen. The scheme of nomenclature (Méthode de Nomenclature chimique), published by Lavoisier in conjunction with Guyton de Morveau, Berthollet, and Fourcroy, created a system of chemistry out of a wilderness of isolated facts and descriptions. Shortly after, in 1789, Lavoisier published his Traité de Chimie, and in the preface the words occur: "If we mean by elements the simple and indivisible molecules of which bodies consist, it is probable that we do not know them; if, on the other hand, we mean the last term in analysis, then every substance which we have not been able to decompose is for us an element; not that we can be certain that bodies which we regard as simple are not themselves composed of two or even a larger number of elements, but because these elements can never be separated, or rather because we have no means of separating them, they act, so far as we can judge, as elements, and we can not call them simple until experiment and observation shall have furnished a proof that they are so."

The close connection between crocus of Mars and metallic iron, the former named by Lavoisier oxyde de fer, and similar relations between metals and their oxides, made it likely that bodies which reacted as oxides in dissolving in acids and forming salts must also possess a metallic substratum. In October, 1807, Sir Humphry Davy proved the correctness of this view for soda and potash by his famous experiment of splitting these bodies by a powerful electric current into oxygen and hydrogen, on the one hand, and the metals sodium and potassium, on the other. Calcium, barium, strontium, and magnesium were added to the list as constituents of the oxides,

lime, barytes, strontia, and magnesia. Some years later Scheele's dephlogisticated marine acid, obtained by heating pyrolusite with spirit of salt, was identified by Davy as in all likelihood elementary. His words are: "All the conclusions which I have ventured to make respecting the undecompounded nature of oxymuriatic gas are, I conceive, entirely confirmed by these new facts. * * * It has been judged most proper to suggest a name founded upon one of its obvious and characteristic properties, its color, and to call it chlorine." The subsequent discovery of iodine by Courtois in 1812 and of bromine by Balard in 1826 led to the inevitable conclusion that fluorine, if isolated, should resemble the other halogens in propreties, and much later, in the able hands of Moissan, this was shown to be true.

The modern conception of the elements was much strengthened by Dalton's revival of the Greek hypothesis of the atomic constitution of matter and the assigning to each atom a definite weight. This momentous step for the progress of chemistry was taken in 1803; the first account of the theory was given to the public with Dalton's consent in the third edition of Thomas Thomson's System of Chemistry in 1807; it was subsequently elaborated in the first volume of Dalton's own System of Chemical Philosophy, published in 1808. The notion that compounds consisted of aggregations of atoms of elements united in definite or multiple proportions familiarized the world with the conception of elements as the bricks of which the universe is built. Yet the more daring spirits of that day were not without hope that the elements themselves might prove decomposable. Davy, indeed, went so far as to write in 1811: "It is the duty of the chemist to be bold in pursuit; he must recollect how contrary knowledge is to what appears to be experience. * * * To inquire whether the elements be capable of being composed and decomposed is a grand object of true philosophy." And Faraday, his great pupil and successor, at a later date, 1815, was not behind Davy in his aspirations when he wrote: "To decompose the metals, to re-form them, and to realize the once absurd notion of transformation—these are the problems now given to the chemist for solution."

Indeed, the ancient idea of the unitary nature of matter was in those days held to be highly probable. For attempts were soon made to demonstrate that the atomic weights were themselves multiples of that of one of the elements. At first the suggestion was that oxygen was the common basis; and later, when this supposition turned out to be untenable, the claims of hydrogen were brought forward by Prout. The hypothesis was revived in 1842 when Liebig and Redtenbacher, and subsequently Dumas carried out a revision of the atomic weights of some of the commoner elements and showed that Berzelius was in error in attributing to carbon the atomic

weight 12.25 instead of 12.00. Of recent years a great advance in the accuracy of the determinations of atomic weights has been made, chiefly owing to the work of Richards and his pupils, of Gray, and of Guye and his collaborators, and every year an international committee publishes a table in which the most probable numbers are given on the basis of the atomic weight of oxygen being taken as 16. In the table for 1911, of 81 elements no fewer than 43 have recorded atomic weights within one-tenth of a unit above or below an integral number. My mathematical colleague, Karl Pearson, assures me that the probability against such a condition being fortuitous is 20,000 millions to one.

The relation between the elements has, however, been approached from another point of view. After preliminary suggestions by Döbereiner, Dumas, and others, John Newlands in 1862 and the following years arranged the elements in the numerical order of their atomic weights and published in the Chemical News of 1863 what he termed his law of octaves—that every eighth element, like the octave of a musical note, is in some measure a repetition of its forerunner. Thus, just as C on the third space is the octave of C below the line, so potassium, in 1863 the eighth known element numerically above sodium, repeats the characters of sodium, not only in its physical properties—color, softness, ductility, malleability, etc.—but also in the properties of its compounds, which indeed resemble each other very closely. The same fundamental notion was reproduced at a later date and independently by Lothar Meyer and Dmitri Mendeléeff; and to accentuate the recurrence of such similar elements in periods, the expression "the periodic system of arranging the elements" was applied to Newlands's arrangement in octaves. As everyone knows, by help of this arrangement Mendeléeff predicted the existence of then unknown elements under the names of eka-boron, eka-aluminium, and eka-silicon, since named scandium, gallium, and germanium by their discoverers, Cleve, Lecoq de Boisbaudran, and Winckler.

It might have been supposed that our knowledge of the elements was practically complete; that perhaps a few more might be discovered to fill the outstanding gaps in the periodic table. True, a puzzle existed and still exists in the classification of the rare earths, oxides of metals occurring in certain minerals; these metals have atomic weights between 139 and 180, and their properties preclude their arrangement in the columns of the periodic table. Besides these, the discovery of the inert gases of the atmosphere, of the existence of which Johnstone Stoney's spiral curve, published in 1888, pointed a forecast, joined the elements like sodium and potassium, strongly electro-negative, to those like fluorine and chlorine, highly electro-positive, by a series of bodies electrically as well as

chemically inert, and neon, argon, krypton, and xenon formed links between fluorine and sodium, chlorine and potassium, bromine and rubidium, and iodine and cæsium.

Including the inactive gases, and adding the more recently discovered elements of the rare earths, and radium, of which I shall have more to say presently, there are 84 definite elements, all of which find places in the periodic table, if merely numerical values be considered. Between lanthanum, with atomic weight 139, and tantalum, 181, there are in the periodic table 17 spaces; and although it is impossible to admit, on account of their properties, that the elements of the rare earths can be distributed in successive columns (for they all resemble lanthanum in properties), yet there are now 14 such elements; and it is not improbable that other 3 will be separated from the complex mixture of their oxides by further work. Assuming that the metals of the rare earths fill these 17 spaces, how many still remain to be filled? We will take for granted that the atomic weight of uranium, 238.5, which is the highest known, forms an upper limit not likely to be surpassed. It is easy to count the gaps; there are 11.

But we are confronted by an embarras de richesse. The discovery of radioactivity by Henri Becquerel, of radium by the Curies, and the theory of the disintegration of the radioactive elements, which we owe to Rutherford and Soddy, have indicated the existence of no fewer than 26 elements hitherto unknown. To what places in the periodic table can they be assigned?

But what proof have we that these substances are elementary? Let us take them in order.

Beginning with radium, its salts were first studied by Madame Curie; they closely resemble those of barium—sulphate, carbonate, and chromate insoluble; chloride and bromide similar in crystalline form to chloride and bromide of barium; metal, recently prepared by Madame Curie, white, attacked by water, and evidently of the type of barium. The atomic weight, too, falls into its place; as determined by Madame Curie and by Thorpe, it is 89.5 units higher than that of barium; in short, there can be no doubt that radium fits the periodic table, with an atomic weight of about 226.5. It is an undoubted element.

But it is a very curious one, for it is unstable. Now, stability was believed to be the essential characteristic of an element. Radium, however, disintegrates—that is, changes into other bodies, and at a constant rate. If 1 gram of radium is kept for 1,760 years, only half a gram will be left at the end of that time; half of it will have given other products. What are they? We can answer that question. Rutherford and Soddy found that it gives a condensable gas, which they named radium-emanation; and Soddy and I in 1903 discovered

that, in addition, it evolves helium, one of the inactive series of gases, like argon. Helium is an undoubted element, with a well-defined spectrum; it belongs to a well-defined series. And radium-emanation, which was shown by Rutherford and Soddy to be incapable of chemical union, has been liquefied and solidified in the laboratory of University College, London; its spectrum has been measured and its density determined. From the density the atomic weight can be calculated, and it corresponds with that of a congener of argon, the whole series being, helium, 4; neon, 20; argon, 40; krypton, 83; xenon, 130; unknown, about 178; and niton (the name proposed for the emanation to recall its connection with its congeners, and its phosphorescent properties), about 222.4. The formation of niton from radium would therefore be represented by the equation, radium (226.4) = helium (4) + niton (222.4).

Niton, in its turn, disintegrates, or decomposes, and at a rate much more rapid than the rate of radium; half of it has changed in about four days. Its investigation, therefore, had to be carried out very rapidly, in order that its decomposition might not be appreciable while its properties were being determined. Its product of change was named by Rutherford radium A, and it is undoubtedly deposited from niton as a metal, with simultaneous evolution of helium; the equation would therefore be, niton (222.4) = helium (4) + radium A (218.4). But it is impossible to investigate radium A chemically, for in 3 minutes it has half changed into another solid substance, radium B, again giving off helium. This change would be represented by the equation, radium A (218.4) = helium (4) + radium B (214.4). Radium B, again, can hardly be examined chemically, for in 27 minutes it has half changed into radium C^1. In this case, however, no helium is evolved, only atoms of negative electricity, to which the name electrons has been given by Dr. Stoney, and these have minute weight which, although approximately ascertainable, at present has defied direct measurement. Radium C^1 has a half-life of 19.5 minutes, too short, again, for chemical investigation; but it changes into radium C^2, and in doing so each atom parts with a helium atom; hence the equation, radium C^1 (214.4) = helium (4) + radium C^2 (210.4). In 2.5 minutes radium C^2 is half gone, parting with electrons, forming radium D. Radium D gives the chemist a chance, for its half-life is no less than 16½ years. Without parting with anything detectable, radium D passes into radium E, of which the half-life period is 5 days; and, lastly, radium E changes spontaneously into radium F, the substance to which Madame Curie gave the name polonium in allusion to her native country, Poland. Polonium, in its turn, is half changed in 140 days with loss of an atom of helium into an unknown metal, supposed to be possibly lead. If that be the case, the equation would run, polonium (210.4) = helium (4) + lead (206.4). But the

atomic weight of lead is 207.1, and not 206.4; however, it is possible that the atomic weight of radium is 227.1, and not 226.4.

We have another method of approaching the same subject. It is practically certain that the progenitor of radium is uranium, and that the transformation of uranium into radium involves the loss of 3 alpha particles; that is, of 3 atoms of helium. The atomic weight of helium may be taken as one of the most certain; it is 3.994, as determined by Mr. Watson, in my laboratories. Three atoms would therefore weigh 11.98, practically 12. There is, however, still some uncertainty in the atomic weight of uranium; Richards and Merigold make it 239.4; but the general mean, calculated by Clarke, is 239. Subtracting 12 from these numbers, we have the values 227, and 227.4 for the atomic weight of radium. It is as yet impossible to draw any certain conclusion.

The importance of the work which will enable a definite and sure conclusion to be drawn is this: For the first time, we have accurate knowledge as to the descent of some of the elements. Supposing the atomic weight of uranium to be certainly 239, it may be taken as proved that in losing 3 atoms of helium, radium is produced, and, if the change consists solely in the loss of the 3 atoms of helium, the atomic weight of radium must necessarily be 227. But it is known that β-rays, or electrons, are also parted with during this change; and electrons have weight. How many electrons are lost is unknown; therefore, although the weight of an electron is approximately known, it is impossible to say how much to allow for in estimating the atomic weight of radium. But it is possible to solve this question indirectly, by determining exactly the atomic weights of radium and of uranium; the difference between the atomic weight of radium plus 12, i. e., plus the weight of 3 atoms of helium, and that of uranium, will give the weight of the number of electrons which escape. Taking the most probable numbers available, viz, 239.4 for uranium, and 226.8 for radium, and adding 12 to the latter, the weight of the escaping electrons would be 0.6.

The correct solution of this problem would in great measure clear up the mystery of the irregularities in the periodic table, and would account for the deviations from Prout's Law, that the atomic weights are multiples of some common factor or factors. I also venture to suggest that it would throw light on allotropy, which in some cases at least may very well be due to the loss or gain of electrons, accompanied by a positive or negative heat-change. Incidentally, this suggestion would afford places in the periodic table for the somewhat overwhelming number of pseudo-elements the existence of which is made practically certain by the disintegration hypothesis. Of the 26 elements derived from uranium, thorium, and actinium, 10, which are formed by the emission of electrons alone, may be regarded as

allotropes or pseudoelements; this leaves 16, for which 16 or 17 gaps would appear to be available in the periodic table, provided the reasonable supposition be made that a second change in the length of the periods has taken place. It is above all things certain that it would be a fatal mistake to regard the existence of such elements as irreconcilable with the periodic arrangement, which has rendered to systematic chemistry such signal service in the past.

Attention has repeatedly been drawn to the enormous quantity of energy stored up in radium and its descendants. That in its emanation, niton, is such that if what it parts with as heat during its disintegration were available, it would be equal to three and a half million times the energy available by the explosion of an equal volume of detonating gas—a mixture of 1 volume of oxygen with 2 volumes of hydrogen. The major part of this energy comes apparently from the expulsion of particles (that is, of atoms of helium) with enormous velocity. It is easy to convey an idea of this magnitude in a form more realizable by giving it a somewhat mechanical turn. Suppose that the energy in a ton of radium could be utilized in 30 years instead of being evolved at its invariable slow rate of 1,760 years for half-disintegration, it would suffice to propel a ship of 15,000 tons, with engines of 15,000 horsepower, at the rate of 15 knots an hour for 30 years, practically the lifetime of a ship. To do this actually requires $1\frac{1}{2}$ million tons of coal.

It is easily seen that the virtue of the energy of the radium consists in the small weight in which it is contained; in other words, the radium-energy is in an enormously concentrated form. I have attempted to apply the energy contained in niton to various purposes; it decomposes water, ammonia, hydrogen chloride, and carbon dioxide, each into its constituents; further experiments on its action on salts of copper appeared to show that the metal copper was converted partially into lithium, a metal of the sodium column; and similar experiments, of which there is not time to speak, indicate that thorium, zirconium, titanium, and silicon are degraded into carbon; for solutions of compounds of these, mixed with niton, invariably generated carbon dioxide; while cerium, silver, mercury, and some other metals gave none. One can imagine the very atoms themselves exposed to bombardment by enormously quickly moving helium atoms failing to withstand the impacts. Indeed, the argument a priori is a strong one; if we know for certain that radium and its descendants decompose spontaneously, evolving energy, why should not other more stable elements decompose when subjected to enormous strains?

This leads to the speculation whether, if elements are capable of disintegration, the world may not have at its disposal a hitherto unsuspected source of energy. If radium were to evolve its stored-up

energy at the same rate that gun-cotton does, we should have an undreamed-of explosive; could we control the rate we should have a useful and potent source of energy, provided always that a sufficient supply of radium were forthcoming. But the supply is certainly a very limited one; and it can be safely affirmed that the production will never surpass half an ounce a year. If, however, the elements which we have been used to consider as permanent are capable of changing with evolution of energy; if some form of catalyser could be discovered which would usefully increase their almost inconceivably slow rate of change, then it is not too much to say that the whole future of our race would be altered.

The whole progress of the human race has indeed been due to individual members discovering means of concentrating energy, and of transforming one form into another. The carnivorous animals strike with their paws and crush with their teeth; the first man who aided his arm with a stick in striking a blow discovered how to concentrate his small supply of kinetic energy; the first man who used a spear found that its sharp point in motion represented a still more concentrated form; the arrow was a further advance, for the spear was then propelled by mechanical means; the bolt of the crossbow, the bullet shot forth by compressed hot gas, first derived from black powder, later, from high explosives; all these represent progress. To take another sequence: The preparation of oxygen by Priestley applied energy to oxide of mercury in the form of heat; Davy improved on this when he concentrated electrical energy into the tip of a thin wire by aid of a powerful battery, and isolated potassium and sodium.

Great progress has been made during the past century in effecting the conversion of one form of energy into others, with as little useless expenditure as possible. Let me illustrate by examples: A good steam engine converts about one-eighth of the potential energy of the fuel into useful work; seven-eighths are lost as unused heat and useless friction. A good gas engine utilizes more than one-third of the total energy in the gaseous fuel; two-thirds are uneconomically expended. This is a universal proposition; in order to effect the conversion from one form of energy into another, some energy must be expended uneconomically. If A is the total energy which it is required to convert; if B is the energy into which it is desired to convert A; then a certain amount of energy, C, must be expended to effect the conversion. In short, $A=B+C$. It is eminently desirable to keep C, the useless expenditure, as small as possible; it can never equal zero, but it can be made small. The ratio of C to B (the economic coefficient) should therefore be as large as is attainable.

The middle of the nineteenth century will always be noted as the beginning of the golden age of science; the epoch when great generali-

zations were made, of the highest importance on all sides, philosophical, economic, and scientific. Carnot, Clausius, Helmholtz, Julius Robert Mayer abroad, and the Thomsons, Lord Kelvin and his brother James, Rankine, Tait, Joule, Clerk Maxwell, and many others at home, laid the foundations on which the splendid structure has been erected. That the latent energy of fuel can be converted into energy of motion by means of the steam engine is what we owe to Newcomen and Watt; that the kinetic energy of the flywheel can be transformed into electrical energy was due to Faraday, and to him, too, we are indebted for the reconversion of electrical energy into mechanical work; and it is this power of work which gives us leisure, and which enables a small country like ours to support the population which inhabits it.

I suppose that it will be generally granted that the Commonwealth of Athens attained a high-water mark in literature and thought which has never yet been surpassed. The reason is not difficult to find; a large proportion of its people had ample leisure, due to ample means; they had time to think and time to discuss what they thought. How was this achieved? The answer is simple: Each Greek freeman had on an average at least 5 helots who did his bidding, who worked his mines, looked after his farm, and, in short, saved him from manual labor. Now, we in Britain are much better off; the population of the British Isles is in round numbers 45 millions; there are consumed in our factories at least 50 million tons of coal annually, and "it is generally agreed that the consumption of coal per indicated horsepower per hour is on an average about 5 pounds." (Royal Commission on Coal Supplies, Part I.) This gives 7 million horsepower per year. How many manpower are equal to a horsepower? I have arrived at an estimate thus: A Bhutanese can carry 230 pounds plus his own weight, in all 400 pounds, up a hill 4,000 feet high in 8 hours; this is equivalent to about one twenty-fifth of a horsepower; 7 million horsepower are therefore about 175 million manpower. Taking a family as consisting on the average of 5 persons, our 45 millions would represent 9 million families; and dividing the total manpower by the number of families, we must conclude that each British family has, on the average, nearly 20 helots doing his bidding, instead of the 5 of the Athenian family. We do not appear, however, to have gained more leisure thereby, but it is this that makes it possible for the British Isles to support the population which it does.

We have in this world of ours only a limited supply of stored-up energy; in the British Isles a very limited one—namely, our coal fields. The rate at which this supply is being exhausted has been increasing very steadily for the last 40 years, as anyone can prove by mapping the data given on page 27, Table D, of the General Report of the Royal Commission on Coal Supplies (1906). In 1870, 110 million tons were mined in Great Britain, and ever since the amount has

increased by 3½ million tons a year. The available quantity of coal in the proved coal fields is very nearly 100,000 million tons; it is easy to calculate that if the rate of working increases as it is doing our coal will be completely exhausted in 175 years. But, it will be replied, the rate of increase will slow down. Why? It has shown no sign whatever of slackening during the last 40 years. Later, of course, it must slow down, when coal grows dearer owing to approaching exhaustion. It may also be said that 175 years is a long time; why, I myself have seen a man whose father fought in 1745 on the Pretender's side, nearly 170 years ago! In the life of a nation 175 years is a span.

This consumption is still proceeding at an accelerated rate. Between 1905 and 1907 the amount of coal raised in the United Kingdom increased from 236 to 268 million tons, equal to 6 tons per head of the population, against 3½ tons in Belgium, 2½ tons in Germany, and 1 ton in France. Our commercial supremacy and our power of competing with other European nations are obviously governed, so far as we can see, by the relative price of coal; and when our prices rise, owing to the approaching exhaustion of our supplies, we may look forward to the near approach of famine and misery.

Having been struck some years ago with the optimism of my nonscientific friends as regards our future, I suggested that a committee of the British Science Guild should be formed to investigate our available sources of energy. This guild is an organization founded by Sir Norman Lockyer, after his tenure of the presidency of this association, for the purpose of endeavoring to impress on our people and their Government the necessity of viewing problems affecting the race and the State from the standpoint of science; and the definition of science in this, as in other connections, is simply the acquisition of knowledge, and orderly reasoning on experience already gained and on experiments capable of being carried out, so as to forecast and control the course of events; and, if possible, to apply this knowledge to the benefit of the human race.

The Science Guild has enlisted the services of a number of men, each eminent in his own department, and each has now reported on the particular source of energy of which he has special knowledge.

Besides considering the uses of coal and its products, and how they may be more economically employed, in which branches the Hon. Sir Charles Parsons, Mr. Dugald Clerk, Sir Boverton Redwood, Dr. Beilby, Dr. Hele-Shaw, Prof. Vivian Lewes, and others have furnished reports, the following sources of energy have been brought under review: The possibility of utilizing the tides; the internal heat of the earth; the winds; solar heat; waterpower; the extension of forests, and the use of wood and peat as fuels; and lastly, the possibility of

controlling the undoubted but almost infinitely slow disintegration of the elements, with the view of utilizing their stored-up energy.

However interesting a detailed discussion of these possible sources of energy might be, time prevents my dwelling on them. Suffice it to say that the Hon. R. J. Strutt has shown that in this country at least it would be impracticable to attempt to utilize terrestrial heat from boreholes; others have deduced that from the tides, the winds, and waterpower small supplies of energy are no doubt obtainable, but that, in comparison with that derived from the combustion of coal, they are negligible; nothing is to be hoped for from the direct utilization of solar heat in this temperate and uncertain climate; and it would be folly to consider seriously a possible supply of energy in a conceivable acceleration of the liberation of energy by atomic change. It looks utterly improbable, too, that we shall ever be able to utilize the energy due to the revolution of the earth on her axis, or to her proper motion round the sun.

Attention should undoubtedly be paid to forestry, and to the utilization of our stores of peat. On the Continent the forests are largely the property of the State; it is unreasonable, especially in these latter days of uncertain tenure of property, to expect any private owner of land to invest money in schemes which would at best only benefit his descendants, but which, under our present trend of legislation, do not promise even that remote return. Our neighbors and rivals, Germany and France, spend annually £2,200,000 on the conservation and utilization of their forests; the net return is £6,000,000. There is no doubt that we could imitate them with advantage. Moreover, an increase in our forests would bring with it an increase in our waterpower; for without forest land rain rapidly reaches the sea, instead of distributing itself, so as to keep the supply of water regular, and so more easily utilized.

Various schemes have been proposed for utilizing our deposits of peat. I believe that in Germany the peat industry is moderately profitable; but our humid climate does not lend itself to natural evaporation of most of the large amount of water contained in peat, without which processes of distillation prove barely remunerative.

We must therefore rely chiefly on our coal reserve for our supply of energy, and for the means of supporting our population, and it is to the more economical use of coal that we must look, in order that our life as a nation may be prolonged. We can economize in many ways: By the substitution of turbine engines for reciprocating engines, thereby reducing the coal required per horsepower from 4 to 5 pounds to 1½ or 2 pounds; by the further replacement of turbines by gas engines, raising the economy to 30 per cent of the total energy available in the coal, that is, lowering the coal consumption per horsepower to 1 or 1¼

pounds; by creating the power at the pit mouth, and distributing it electrically, as is already done in the Tyne district. Economy can also be effected in replacing beehive coke ovens by recovery ovens; this is rapidly being done; and Dr. Beilby calculates that in 1909 nearly 6 million tons of coal, out of a total of 16 to 18 millions, were coked in recovery ovens, thus effecting a saving of 2 to 3 million tons of fuel annually. Progress is also being made in substituting gas for coal or coke in metallurgical, chemical, and other works. But it must be remembered that for economic use, gaseous fuel must not be charged with the heavy costs of piping and distribution.

The domestic fire problem is also one which claims our instant attention. It is best grappled with from the point of view of smoke. Although the actual loss of thermal energy in the form of smoke is small—at most less than a half per cent of the fuel consumed—still the presence of smoke is a sign of waste of fuel and careless stoking. In works mechanical stokers which insure regularity of firing and complete combustion of fuel are more and more widely replacing hand-firing. But we are still utterly wasteful in our consumption of fuel in domestic fires. There is probably no single remedy applicable; but the introduction of central heating, of gas fires, and of grates which permit of better utilization of fuel will all play a part in economizing our coal. It is open to argument whether it might not be wise to hasten the time when smoke is no more by imposing a 6-penny fine for each offense; an instantaneous photograph could easily prove the offense to have been committed; and the imposition of the fine might be delayed until three warnings had been given by the police.

Now, I think that what I wish to convey will be best expressed by an allegory. A man of mature years who has surmounted the troubles of childhood and adolescence without much disturbance to his physical and mental state gradually becomes aware that he is suffereng from loss of blood; his system is being drained of this essential to life and strength. What does he do? If he is sensible, he calls in a doctor, or perhaps several, in consultation; they ascertain the seat of the disease, and diagnose the cause. They point out that while consumption of blood is necessary for healthy life, it will lead to a permature end if the constantly increasing drain is not stopped. They suggest certain precautionary measures; and if he adopts them, he has a good chance of living at least as long as his contemporaries; if he neglects them, his days are numbered.

That is our condition as a nation. We have had our consultation in 1903; the doctors were the members of the coal commission. They showed the gravity of our case, but we have turned a deaf ear.

It is true that the self-interest of coal consumers is slowly leading them to adopt more economical means of turning coal into energy. But I have noticed and frequently publicly announced a fact which

can not but strike even the most unobservant. It is this: When trade is good, as it appears to be at present, manufacturers are making money; they are overwhelmed with orders, and have no inclination to adopt economies which do not appear to them to be essential, and the introduction of which would take thought and time, and which would withdraw the attention of their employees from the chief object of the business—how to make the most of the present opportunities. Hence improvements are postponed. When bad times come, then there is no money to spend on improvements; they are again postponed until better times arrive.

What can be done?

I would answer: Do as other nations have done and are doing; take stock annually. The Americans have a permanent commission initiated by Mr. Roosevelt, consisting of three representatives from each State, the sole object of which is to keep abreast with the diminution of the stores of natural energy, and to take steps to lessen its rate. This is a nonpolitical undertaking, and one worthy of being initiated by the ruler of a great country. If the example is followed here the question will become a national one.

Two courses are open to us; first, the laissez-faire plan of leaving to self-interested competition the combating of waste; or second, initiating legislation which, in the interest of the whole nation, will endeavor to lessen the squandering of our national resources. This legislation may be of two kinds: Penal, that is, imposing a penalty on wasteful expenditure of energy supplies; and helpful, that is, imparting information as to what can be done, advancing loans at an easy rate of interest to enable reforms to be carried out, and insisting on the greater prosperity which would result from the use of more efficient appliances.

This is not the place, nor is there the time, to enter into detail; the subject is a complicated one, and it will demand the combined efforts of experts and legislators for a generation; but if it be not considered with the definite intention of immediate action, we shall be held up to the deserved execration of our not very remote descendants.

The two great principles which I have alluded to in an earlier part of this address must not, however, be lost sight of; they should guide all our efforts to use energy economically. Concentration of energy in the form of electric current at high potential makes it possible to convey it for long distances through thin and therefore comparatively inexpensive wires; and the economic coefficient of the conversion of mechanical into electrical and of electrical into mechanical energy is a high one; the useless expenditure does not much exceed one-twentieth part of the energy which can be utilized. These considerations would point to the conversion at the pit mouth of the energy of the fuel into electrical energy, using as an intermediary turbines, or preferably

gas engines; and distributing the electrical energy to where it is wanted. The use of gas engines may, if desired, be accompanied by the production of half-distilled coal, a fuel which burns nearly without smoke, and one which is suitable for domestic fires, if it is found too difficult to displace them and to induce our population to adopt the more efficient and economical systems of domestic heating which are used in America and on the Continent. The increasing use of gas for factory, metallurgical, and chemical purposes points to the gradual concentration of works near the coal mines, in order that the laying down of expensive piping may be avoided.

An invention which would enable us to convert the energy of coal directly into electrical energy would revolutionize our ideas and methods, yet it is not unthinkable. The nearest practical approach to this is the Mond gas battery, which, however, has not succeeded, owing to the imperfection of the machine.

In conclusion, I would put in a plea for the study of pure science, without regard to its applications. The discovery of radium and similar radioactive substances has widened the bounds of thought. While themselves, in all probability, incapable of industrial application, save in the domain of medicine, their study has shown us to what enormous advances in the concentration of energy it is permissible to look forward, with the hope of applying the knowledge thereby gained to the betterment of the whole human race. As charity begins at home, however, and as I am speaking to the British Association for the Advancement of Science, I would urge that our first duty is to strive for all which makes for the permanence of the British commonweal and which will enable us to transmit to our posterity a heritage not unworthy to be added to that which we have received from those who have gone before.

(FARADAY LECTURE.)

THE FUNDAMENTAL PROPERTIES OF THE ELEMENTS.[1]

By Theodore William Richards,

Professor of Chemistry, Harvard University.

We meet to-night to honor the memory of Michael Faraday. It is fitting that we should come to this historic place, for here were his home and his laboratory, and in this room he lectured. Science is one of the great influences promoting the solidarity of mankind; it is world embracing, and recognizes no bounds of nationality. Faraday's work especially was a message to the whole world, and has grown into a priceless heritage for all humanity. Therefore, from time to time the generous guardians of this famous lectureship have called chemists and physicists from many lands to honor his unique genius. England, Germany, France, Italy, Russia, have all sent eminent representatives; and now from across the sea there comes a pilgrim who is proud indeed to bring the homage of the New World to this shrine of cherished memories. The many ties which bind together our two nations add especial pleasure to the fulfillment of the trust.

The mystery that enshrouds the ultimate nature of the physical universe has always stimulated the curiosity of thinking man. Of old, philosophers sought to solve the cosmic problem by abstract reasoning, but to-day we agree that the only hope of penetrating into the closely guarded secret lies in the precise estimation of that which is tangible and visible. Knowledge of the actual behavior of material and of energy provides the only safe basis for logical inference as to the real essence of things. Faraday was deeply imbued with this conviction, and it is widely recognized as the basis of all modern experimental science. The subject of my lecture to-night concerns the methods and general results of several extended series of investigations, planned with the hope of adding a little to the foundations of human knowledge by means of careful experiment.

[1] Delivered before the Fellows of the Chemical Society in the theater of the Royal Institution, London, on Wednesday, June 14, 1911. Printed in the Journal of the Chemical Society, London, vol. 99, p. 1201, 1911. See also Proceedings of the Chemical Society vol. 27, p. 177, 1911. Printed also in Science, Oct. 27, 1911. Reprinted by permission, after author's revision.

At the outset let me remind you of an old saying of Plato's, for it sounds the keynote of the lecture: "If arithmetic, mensuration and weighing be taken away from any art, that which remains will not be much."[1] In other words, the soundness of all important conclusions of mankind depends on the definiteness of the data on which they are based.

Lord Kelvin said: "Accurate and minute measurement seems to the nonscientific imagination a less lofty and dignified work than looking for something new. But nearly all the grandest discoveries of science have been the rewards of accurate measurement and patient, long-continued labor in the minute sifting of numerical results."[2] The more subtle and complicated the conclusions to be drawn, the more exactly quantitative must be the knowledge of the facts.

Measurement is a means, not an end. Through measurement we obtain data full of precise significance, about which to reason; but indiscriminate measurement will lead nowhere. We must choose wisely the quantities to be measured, or else our time may be wasted.

Among all quantities worthy of exact measurement the properties of the chemical elements are surely some of the most fundamental, because the elements are the vehicles of all the manifold phenomena within the range of our perception.

Weight is clearly one of the most significant of these properties. The eighty or more individual numbers which we call the atomic weights are perhaps the most striking of the physical records nature has given us concerning the earliest stages of the evolution of the universe. They are mute witnesses of the first beginnings of the cosmos out of the chaos, and their significance is one of the first concerns of the chemical philosopher.

Mankind is not yet in a position to predict any single atomic weight with exactness. Therefore the exact determination of atomic weights rests upon precise laboratory work; and in order to arrive at the real values of these fundamental constants, chemical methods must be improved and revised so as to free them from systematic or accidental errors.

What, now, are the most important precautions to be taken in such work? These are worthy of brief notice, because the value of the results inevitably depends upon them. Obvious although they may be, they are often disregarded.

In the first place, each portion of substance to be weighed must be free from the suspicion of containing unheeded impurities; otherwise its weight will mean little. This is an end not easily attained, for liquids often attack their containing vessels and absorb gases, crystals

[1] Plato, Philebus (trans. Jowett), 1875, vol. 4, p. 104.

[2] Sir W. Thomson (Lord Kelvin), Address to British Association, August, 1871, Life, vol. 2, 600.

include and occlude solvents, precipitates carry down polluting impurities, dried substances cling to water, and solids, even at high temperatures, often fail to discharge their imprisoned contaminations.

In the next place, after an analysis has once begun, every trace of each substance to be weighed must be collected and find its way in due course to the scale pan. The trouble here lies in the difficulty in estimating, or even detecting, minute traces of substances remaining in solution, or minute losses by evaporation at high temperatures.

In brief, "the whole truth and nothing but the truth" is the aim. The chemical side of the question is far more intricate and uncertain than the physical operation of weighing. For this reason it is neither necessary nor advisable to use extraordinarily large amounts of material. From 5 to 20 grams in each experiment is usually enough. The exclamation, "What wonderfully fine scales you must have to weigh atoms" indicates lack of knowledge. The real difficulties precede the introduction of the substance into the balance case.[1] Every substance must be assumed to be impure, every reaction must be assumed to be incomplete, every measurement must be assumed to contain error, until proof to the contrary can be obtained. Only by means of the utmost care, applied with ever-watchful judgment, may the unexpected snares which always lurk in complicated processes be detected and rendered powerless for evil.

Among all the possibilities of error, the unsuspected presence of water is perhaps the most frequent and most insidious. Hence, I shall show you a device for overcoming this potent source of confusion, a device which has played a great rôle in the recent researches concerning atomic weights at Harvard, and is in large measure responsible for such value as the results may possess. The instrument[2] enables one to dry, inclose, and weigh an anhydrous substance in such a manner as to preclude the admission of a trace of water from the atmosphere. It might well find applications in every quantitative laboratory. The simple device consists of a quartz ignition tube fitted to a soft-glass tube which has a projection or pocket in one side (fig. 1). A weighing bottle is placed at the end of the latter tube, and its stopper in the pocket. The boat containing the substance to be dried is heated in the quartz tube, surrounded by an atmosphere consisting of any desired mixture of gases. These gases are displaced after partial cooling, first by nitrogen and then by pure dry air, and the boat is pushed past the stopper into the weighing bottle,

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[1] Richards, Methods Used in Precise Chemical Investigation, published by the Carnegie Institution of Washington, 1910, No. 125, p. 97.

[2] Richards, Zeitsch. anorg. Chem., 1895, vol. 8, p. 267; also Richards and Parker, ibid., 1897, vol. 13, p. 86. Two forms of apparatus are shown in this diagram; the upper drawing depicts the earlier form, suitable for a hard glass or porcelain ignition tube, whereas the lower drawing illustrates a form slightly different from the original arrangement, although the main idea is the same. The flat ground joint between quartz and glass allows for their different coefficients of expansion, and makes a quartz tube interchangeable with any other in case of breakage.

the stopper being then forced into place and the substance thus shut up in an entirely dry atmosphere. The weighing bottle may now be removed, placed in an ordinary desiccator and weighed at leisure. The substance is really dry, and its weight has definite significance.

Mention may be made also of another instrument, which likewise has greatly facilitated the recent work at Harvard, namely, the nephelometer.[1] With the nephelometer, minute traces of suspended precipitate may be approximately determined from the brightness of the light they reflect. The construction is very simple. Two test tubes, near together and slightly inclined toward one another, are arranged so as to be partly shielded from a bright source of light by sliding screens. The tubes are observed from above through two thin prisms, which bring their images together and produce an appearance resembling that in the familiar half-shadow polarimeter. The

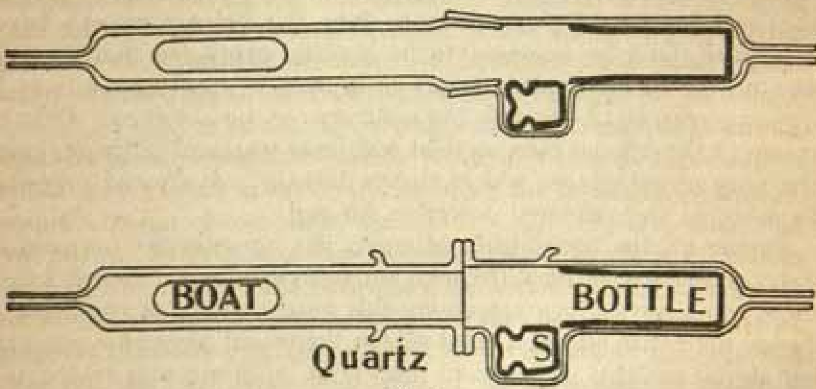

FIG. 1.

unknown quantity of dissolved substance is precipitated as a faint opalescence in one tube by means of suitable reagents, and a known amount, treated in exactly the same way, is prepared in the other. Each precipitate reflects the light; the tubes appear faintly luminous. If the tubes show like tints to the eye when the screens are similarly placed, the precipitates may be presumed to be equal in amount. In case of inequality of appearance, the changed positions of the screens necessary to produce equality of tint give a fairly accurate guide as to the relative quantities of precipitate in the two tubes. Traces of substance, which are too attenuated to be caught on any ordinary filter, may thus be estimated.

The two errors obviated by these simple devices, namely, the presence of residual water and the loss of traces of precipitate, respectively, have perhaps ruined more previous investigations than any

[1] Richards, Zeitsch. anorg. Chem., 1895, vol. 8, p. 269; Richards and Wells, American Chemical Journal, 1904, vol. 31, p. 235; Richards, ibid., 1906, vol. 35, p. 510.

other two causes, unless the inclusion of foreign substances by precipitates may be ranked as an equal vitiating effect. But these are merely details. The scope and method of the recent work on this subject at Harvard (in the course of which 30 atomic weights have been redetermined) may be seen in their full bearing only in the original papers.[1]

That the atomic weights may be connected by precise mathematical equations seems highly probable; but, although many interesting attempts have been made to solve the problem,[2] the exact nature of such relationships has not yet been discovered. No attempt which takes liberties with the more certain of the observed values is worthy of much respect. It seems to me that the discovery of the ultimate generalization is not likely to occur until many atomic weights have been determined with the greatest accuracy. No trouble being too great to attain this end, the Harvard work will be continued indefinitely, and attempts will be made to improve its quality, for the discovery of an exact mathematical relationship between atomic weights would afford us an immeasurably precious insight into the ultimate nature of things.

But weight is only one of the fundamental properties of an element Volume is almost, if not quite, as important in its own way, although far more variable and confusing. All gases, indeed, approach closely to a simple relationship of volumes, defined by the law of Gay Lussac and the rule of Avogadro, and well known to you all. In the liquid and solid state, however, great irregularities are manifest, and very little system as regards volume is generally recognized.

About 12 years ago, the study of such small irregularities as exist among gases led me to the suspicion of a possible cause for the greater irregularities in liquids and solids.[3] On applying van der Waals's well-known equation to several gases, in some tentative and unpublished computations, it seemed clear that the quantity b is not really a constant quantity, but is subject to change under the influence of both pressure and temperature. This conclusion has also been reached independently by van der Waals himself.[4] But if the quantity b (supposed to be dependent upon the space

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[1] An important part in these researches has been taken by G. P. Baxter, and many able students also have assisted the author in the work. A complete bibliography is given in Publications Carnegie Institution of Washington, 1910, No. 125, p. 91. Most of the papers are reprinted in full in a volume entitled, "Experimentelle Untersuchungen über Atomgewichte," by the author and his collaborators (Hamburg, 1909). The Carnegie Institution of Washington has generously subsidized the work in recent years.

[2] See especially Rydberg, Zeitsch. anorg. Chem., 1897, vol. 14, p. 66.

[3] Richards, The Significance of Changing Atomic Volume, Proceedings American Academy, 1901, vol. 37, p. 1; 1902, vol. 37, p. 300; 1902, vol. 38, p. 293; 1904, vol. 39, p. 581; Zeitsch. physikal. Chem., 1902, vol. 40, pp. 169, 597; 1903, vol. 42, p. 129; 1904, vol. 49, p. 15.

[4] Van der Waals, Zeitsch. physikal. Chem., 1901, vol. 38, p. 257. His earlier publication on this topic (Proc. R. Akad. Wetensch. Amsterdam, 1898, vol. 29, p. 138) was unknown to me at that time. See also Lewis, Proceedings American Academy, 1899, vol. 35, p. 21.

actually occupied by the molecules) is changeable, are not the molecules themselves compressible?[1]

The next step in the train of thought is perhaps equally obvious. If changes in the bulk of molecules are to be inferred even from gases, may not the expansion and contraction of solids and liquids afford a much better clue to the relative expansion and contraction of these molecules?

Most physical chemists refer all changes in volume to changes in the extent of the empty space between the molecules. But are there, after all, any such empty spaces in solids and liquids? Solids do not behave as if the atoms were far apart within them; porosity is often conspicuous by its absence. Take, for instance, the case of glass; the careful experiments of Landolt on the conservation of weight[2] show that glass is highly impermeable to oxygen, nitrogen and water for long periods. Such porosity as occurs in rigid, compact solids usually permits the passage only of substances which enter into the chemical structure of the solids themselves. Thus, nitrogen can not free itself from imprisonment within hot cupric oxide, although oxygen can escape;[3] again, water can not evaporate into even the driest of atmospheres from accidental incarceration in crystals lacking water of crystallization.[4] Palladium, on occluding hydrogen, is obliged to expand its bulk in order to make room for even this small addition to its substance. The behavior of platinum, nickel, and iron is probably analogous, although less marked.[5] Fused quartz, impermeable when cold, allows of the passage of helium and hydrogen at high temperatures;[6] but most other gases seem to be refused admission and very many solid substances appear to act as effective barriers to the passage of even hydrogen and helium, especially when cold. In these cases, as in so many others the so-called sphere of influence of the atom is the actual boundary by which we know the atom and measure its behavior.[7] Why not call this the actual bulk of the atom?

From another point of view, the ordinary conception of a solid has always seemed to me little short of an absurdity. A gas may very properly be imagined with moving particles far apart, but

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[1] Van der Waals speaks cautiously, but with some conviction, as to the probable compressibility of the molecules on p. 283 of the paper cited above.

[2] H. Landolt, Ueber die Erhaltung der Masse bei chem. Umwandlungen, Abhandlung der königl. preuss. Akad. der Wissenschaften, 1910.

[3] Richards, Zeitsch. anorg. Chem., 1892, vol. 1, p. 196; Proceedings American Academy, 1893, vol. 28, p. 200; Ibid, 1898, vol. 38, p. 399.

[4] Baker and Adlam, Journal Chemical Society Transactions, 1911, vol. 99, p. 507.

[5] Richards and Behr, Publications Carnegie Institution, 1906, No. 61.

[6] Jacquerod and Perrot, Compt. rend., 1907, vol. 144, p. 135.

[7] Since these ideas were first advanced, Barlow and Pope have brought forward much interesting evidence concerning the significance of the volumes of solids and liquids, which supports the idea that the atoms are closely in contact with one another. (Trans., 1906, vol. 89, p. 1675; 1907, vol. 91, p. 1150; 1908, vol. 93, p. 1528; 1910, vol. 97, p. 2308.)

what could give the rigidity of steel to such an unstable structure? The most reasonable conclusion, from all the evidence taken together, seems to be that the interstices between atoms in solids and liquids must usually be small even in proportion to the size of the atoms themselves, if, indeed, there are any interstices at all.

Very direct and convincing evidence of another sort is at hand. The idea that atoms may be compressible receives striking confirmation from a recent interesting investigation of Grüneisen [1] concerning the small effect of low temperatures on the compressibility of metals. The average compressibility of aluminium, iron, copper, silver, and platinum falls off only 7 per cent between the temperature of the room and that of liquid air. Extrapolation of the curves indicates that at the absolute zero very little further diminution should occur. As far as we can guess, therefore, the hard metals are almost as compressible at the absolute zero as at room temperatures. But at the absolute zero all heat-vibration is supposed to stop; hence this remaining compressibility must needs be ascribed to the atoms themselves.

If the atoms are compressible, all mathematical reasoning which assumes them to be incompressible rests upon a false basis. The kinetic theory of gases remains unmolested by these considerations, except as they indicate the changeability of b in the equation of van der Waals, but the new views affect seriously the application of this equation to solids and liquids.

Let us proceed to trace a few of the outcomes of our hypothesis. If atoms may really be packed closely together, the volumes of solids and liquids should afford valuable knowledge concerning the relative spaces occupied by the atoms themselves under varying conditions. The densities of solids and liquids then assume a significance far more interesting to the chemical philosopher than before, because they have a more definite connection with the fundamental nature of things.

An apparent objection at once suggests itself; if the particles in condensed material are really touching one another, how can we account for heat within the material? Would such closely packed atoms be able to vibrate?

The theory of compressible atoms supplies as one of its own corollaries the immediate answer to this question. If atoms are compressible throughout their whole substance, they may contract and expand, or vibrate within themselves, even when their surfaces are prevented from moving by being closely packed together. It is thus possible to conceive of a vibrational effect, even in contiguous atoms, provided we can conceive of these atoms as being elastic throughout

[1] E. Grüneisen, Ann. Physik, 1910 (iv), vol. 33, p. 1239. The relative values for the compressibilities recorded in this investigation are doubtless trustworthy, although the absolute magnitudes are somewhat uncertain because they depend on the rather inadequate theory of elasticity.

all their substance. Agitation sufficient to produce even the Brownian movement might easily exist in such a system.

Clearly there is nothing impossible or obviously contradictory to experimental knowledge in the notion that atoms are compressible; indeed, the old idea of small, hard particles far apart is really more arbitrary and hypothetical than the new conception. The obvious simplicity of the latter is rather in its favor than otherwise, as in Dalton's atomic theory. In general, the more simply an hypothesis interprets the phenomena of nature, the more useful the hypothesis is likely to be, provided, of course, that the interpretation is adequate. The modern philosophy of pragmatism is a good guide in such matters; a theory not obviously illogical should be judged by its usefulness. Let us then test the new hypothesis by applying it to other aspects of physical chemistry.

If pressure produces a change in the sizes of the atoms and molecules themselves, may not the actual volumes of liquids and solids be used as a guide to the unknown internal pressures within them? Can not we thus discover whether or not chemical affinity exerts pressure in its action? To follow this clue, the simplest possible case was chosen at first, namely, the comparison of the contractions taking place on combining several elements in succession with a single very compressible one. The changes of volume occurring during the formation of oxides were first computed; later, chlorides and bromides were studied. According to the theory of compressible atoms, we should expect to find greater contraction in cases of greater affinity. The diagram (fig. 2), which depicts typical data concerning certain nearly related chlorides, strongly supports this inference.[1] One of these lines shows the total change of volume which occurs when a gram-molecule of chlorine combines with the equivalent weight of metal; the other gives the heat evolved during combination. The lines show distinct parallelism; that is to say, reactions evolving much heat manifest great contraction. In cases of this kind the heat of reaction is usually not very different from the change of free-energy; therefore we may infer that greater affinity is associated with greater contraction; and it is but a small leap in the dark to guess that the change of volume is caused by the pressure of affinity. Since chemical attraction holds two elements firmly together, why should it not exert pressure? And if it exerts pressure, why should not the volume of the system be diminished by this pressure?

This interpretation is not wholly new. Faraday's great teacher, Davy,[2] pointed out for the first time a similar fact, namely, that the contraction which takes place on forming the oxide of potassium is

[1] Richards, Proceedings American Academy, 1902, vol. 37, p. 399; also, especially, Richards and Jones, Journal American Chemical Society, 1909, vol. 31, p. 188.

[2] Humphry Davy, Collected Works, 1840, vol. 5, p. 133 (footnote).

greater than the contraction which takes place on forming several other oxides, and he ascribed this effect to the well-known differences of affinity in these cases; but he did not carry the idea further. Long afterwards, Braun,[1] Mueller-Erzbach,[2] Hagemann,[3] and Traube,[4] independently and apparently without knowledge of each other's work, called attention to other cases of similar relationships.

All of these researches have produced so little effect on the literature of the subject[5] that they were entirely overlooked during the

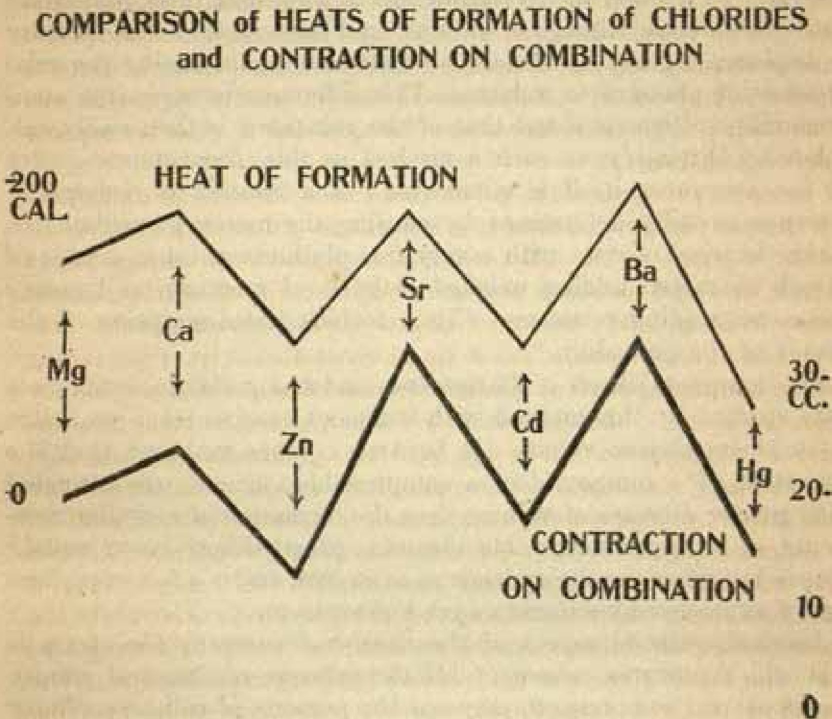

FIG. 2.

earlier part of the present investigation. The oversight mattered little, however, because the whole subject needed a fresh attack. Essential factors in the situation had not been noticed by any of these earlier investigators. Affinities, indeed, had been considered, but the nature of the substances on which the affinities act had been overlooked. Evidently the change of volume in any case must depend not only on the intensity of the pressure exerted by the affinity, but also, among other things, on the compressibility of the sub-

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[1] V. Braun, see Johnson, Journal Chemical Society Transactions, 1877, vol. 31, p. 252.

[2] Mueller-Erzbach, Ber., d. deutsch. Ch. Ges., 1881, vol. 14, pp. 217, 2043.

[3] Hagemann (private publication, Friedländer, Berlin, 1900).

[4] Traube, Ueber den Raum der Atome, Ahrens's Sammlung der chem. und chem.-techn. Vorträge, vol. 4, p. 256.

[5] See, for example, Ostwald's Gundriss der allgemeinen Chemie, 1899, p. 185.

stances concerned. The greater the compressibility, the greater should be the change of volume caused by a given pressure of affinity. Before any definite conclusion can be drawn, the differences in compressibility must be taken into account.

These thoughts led to the measuring of the compressibilities of a large number of elements and simple compounds. The previously employed methods for solids and liquids being unsatisfactory, a new and highly satisfactory method was devised for the work done at Harvard. Pure mercury is compressed in a suitable tube, measuring both pressure and change of volume, and then most of the mercury is displaced by the substance to be studied, again noting the relationship of pressure to volume. The difference between the compressibility of mercury and that of the substance is then easily calculated. Obviously, in such a method as this, the compressibility of the apparatus itself is eliminated. The relation of volume to pressure is easily determined by causing the mercury meniscus to make electrical contact with a very fine platinum point in a tube of narrow diameter, adding weighed globules of mercury, and noting the corresponding pressures.[1] Time forbids the description of the details of the procedure.

The compressibilities of 35 elements and many simple compounds were studied by this method with sufficient care to leave no doubt as to their relative values. It became at once manifest that the formation of a compound of a compressible element was attended with greater decrease of volume than the formation of a similar compound of a less compressible element, other things being equal.[2] This is just what the theory leads us to expect, and is a fact inexplicable by any other hypothesis as yet known to me.

Another essential aspect of the theory of compressible atoms is that which concerns cohesion.[3] If the pressure of chemical affinity causes atomic compression, may not the pressure of cohesive affinity also have the same effect? Traube suggested this possibility, but looked at the whole question from a different point of view.[4] The affinity which prevents solids and liquids from vaporizing is generally admitted to produce great internal pressure; must it not tend to compress the molecules into smaller space? Molecules with high cohesive affinity (those of substances hard to volatilize) should be much com-

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[1] Richards, in collaboration with Stull, Bonnet, Brink, Mathews, Jones, Speyers, Publication Carnegie Institute of Washington, Nos. 7 and 76; Journal American Chemical Society, 1904, vol. 26, p. 399; 1909, vol. 31, p. 154; Zeitsch. physikal. Chem., 1904, vol. 49, p. 1; 1907, vol. 61, p. 77.

[2] Richards, Proceedings American Academy, 1904, vol. 39, p. 581.

[3] Ibid.

[4] See especially, Traube Ann. Physik., 1897, (iii), vol. 61, p. 383; 1901 (iv.), vol. 5, p. 548; 1902, vol. 8, p. 267; 1907, vol. 22, p. 519; Zeitsch. physikal. Chem., 1910, vol. 68, p. 289; also Walden, Zeitsch. physikal. Chem., 1909, vol. 66, p. 385. Their interpretation depends largely on the application of van der Waals's equation and the complicating assumption of a covolume; however, Walden's very recent paper presents a number of interesting and important relations concerning internal pressure, which seem to demand the assumption of atomic compressibility for their explanation.

pressed and possess small volume, whereas molecules with a slight cohesive affinity should be more bulky. Moreover, those molecules already much compressed by their own self-affinity would naturally be but little affected by additional pressure. Thus, as regards two substances otherwise similar, the less volatile one would be less compressible, denser, and possess greater surface tension.[1] These outcomes of the theory agree with the facts in 80 per cent of the cases thus far studied; for example, *o*-xylene is denser, less volatile, less compressible, and possesses a greater surface tension than either *m*-xylene or *p*-xylene.[2] Differences of structure and differences of chemical nature sometimes conceal these relations; the parallelism appears most strikingly among isomeric compounds. In brief, the bulk of evidence strongly indicates that cohesiveness as well as chemical affinity exerts pressure in its action, and hence that each plays a part in determining the volumes occupied by molecules.

Thus the computation of the space occupied by either a solid or a liquid becomes a very complex matter. Not only must the various chemical affinities at work be taken into account, but also the cohesive attraction of both factors and products, and the compressibilities over a very wide range of all the substances concerned. Discoverable parallelism in volume changes is to be expected only when one alone of these tendencies is the chief variable.

The exact mathematical working out of the consequences is very far in the distance, if, indeed, it can ever be attained. This fact does not, however, militate in the least against the plausibility of the idea. Although mankind has not yet been able to devise a method of mathematical analysis which will solve at one stroke the gravitational relations of three bodies, nature is not on that account prevented from causing three or more bodies to act on one another with the force of gravity, or astronomers from calculating as nearly as may be the consequences by a process of approximation.

Carried through to its logical conclusion, the idea that atoms are compressible gives one quite a new conception of the molecular me-

[1] Richards and Mathews, Zeitsch. physikal. Chem., 1908, vol. 61, p. 449.

[2] With the help of C. L. Speyers I have determined these constants with great care. The substances were unusually pure, the *p*-xylene freezing at 13.2°. The details will be published as soon as possible. The results are recorded in the following table:

	Boiling point.	Density 20°/4°	Surface tension mg./mm.; 20°	Compressibility × 10^6 at 20° per megabar.
o-xylene	144.0°	0.8811	3.09	61.1
m-xylene	139.0	.8658	2.96	64.8
p-xylene	138.2	.8611	2.92	66.8

chanics of the universe. The influence of atomic compressibilities may be perceived everywhere, and in most cases each fact seems to fit easily and without constraint into its place in the hypothesis. Even apparent exceptions, such as the abnormal bulk of ice, may be ascribed in a reasonable fashion to superposed effects. A detailed discussion of many applications of the theory is impossible here, but a few may be suggested, in order to make clearer its possibilities.

The satisfying of each valence of an atom would cause a depression on the atomic surface, owing to the pressure exerted by the affinity in that spot. The stronger the affinity, the greater should be this distortion. Evidently this conception gives a new picture of the asymmetric carbon atom, which, combined with four other different atoms, would have upon its surface depressions of four unequal magnitudes, and be twisted into an unsymmetrical tetrahedron. The combining atoms would be held on the faces of the tetrahedron thus formed, instead of impossibly perching upon the several peaks. According to this hypothesis, the carbon atom need not be imagined as a tetrahedron in the first place; it would assume the tetrahedral shape when combined with the other four atoms. One can easily imagine that the development of each new valence would change the affinities previously exercised, somewhat as a second depression in the side of a rubber ball will modify a forcibly caused dimple in some other part. Thus a part of the effect which each new atom has on the affinities of the other atoms already present may be explained.

Many other physico-chemical phenomena assume a new aspect when viewed from the standpoint of this idea. New notions of the mechanism of the critical phenomena, surface tension, ductility, malleability, tenacity, and coefficient of expansion are gained. The peculiar relations of material and light, such as magnetic rotation, fluorescence, partial absorption, and so forth, may be referred to the modified vibrations of distorted atoms. The deviations from the exact fulfillment of many older generalizations concerning volume (such as the equation of van der Waals already cited, the comparative volumes of aqueous solutions, especially of electrolytically dissociated substances,[1] and the variations in the crystal forms of isomorphous substances) are seen to be a foregone conclusion. Moreover, the theory, although not necessarily dependent on the modern belief that atoms are built up of numbers of much smaller corpuscles, is consistent with that belief, for would not such an entity be compressible?

The more closely the actual data are studied, the more plausible the hypothesis of compressible atoms appears. Ten years' experience

[1] Baxter has very recently discussed this matter from the point of view of the theory of compressible atoms. (Journal American Chemical Society, 1911, vol. 33, p. 922.)

with its interpretations leads me to feel that the idea is highly suggestive and helpful in stimulating new search after truth and in correlating and codifying diverse facts. By such fruit are hypotheses justified.

The relation between heat of reaction and change of volume stimulates interest in chemical thermodynamics and curiosity as to the mechanism of the output of energy during chemical change. A search for accurate data wherewith to reason about this question soon revealed the uncertain nature of many of the figures. Here, in the domain of thermochemistry, as in those of atomic weights and compressibilities, new methods were needed in order to attain precise results. Accordingly, a device was adopted which at one stroke annihilates the pernicious "cooling correction"—the worst foe to accuracy—by merely causing the temperature of the jacket around the calorimeter to change in temperature at the same rate as the calorimeter itself. There are several ways in which this may be accomplished; among these ways the following was chosen as the best method for a chemical laboratory. The calorimeter, inclosed in a slightly larger water-tight vessel, with tubes above—a kind of submarine—is immersed under the surface of dilute crude alkali in a pail. Thermometers inside and out enable one to adjust the temperatures at the same point. The reaction is then started in the calorimeter, and at the same moment and at a corresponding rate acid is dropped into the dilute alkali in the pail, so that the two temperatures inside and out keep pace with one another. Thus there is no loss of heat from the inside vessel; the thermochemical reaction is strictly adiabatic. This method has already been used at Harvard with very encouraging outcome in determining a wide variety of thermochemical data, heats of combustion of hydrocarbons, of solutions of metals in acids and of neutralization, specific heats of solutions, and also of the elements at very low temperatures, and finally latent heats of evaporation.[1] It has proved itself especially valuable in the study of slow reactions, where the cooling correction may become a large portion of the total result. The effort is being made to apply to this experimentation concerning chemical energetics the same degree of care which has recently been attempted in the revision of the atomic weights, and although on account of the greater complexity of the problem the percentage accuracy thus far reached has not equaled that in the case of atomic weights, one can not help thinking that the proportional gain over previous investigations is perhaps as great in this case as in the other.

[1] Richards, in collaboration with Henderson, Forbes, Frevert, Mathews, Rowe, Jesse, Burgess, and Jackson, Proceedings American Academy, 1905, vol. 41, p. 3; 1907, vol. 42, p. 573; 1908, vol. 43, p. 475; 1911, vol. 46, p. 363; Journal American Chemical Society, 1909, vol. 31, p. 1275; 1910, vol. 32, pp. 268, 432, 1176; Zeitsch. physikal. Chem., 1905, vol. 52, p. 551; 1907, vol. 59, p. 531; 1909, vol. 70, p. 414.

In thermochemical reasoning particularly, accurate data possess a significance wholly denied to cruder results. The relations between the heat of formation of organic substances, if determined accurately enough, may be hoped to throw light on organic structure and the nature of valence. Approximate values are of no use at all for such a purpose. Enough has been done already to suggest relations of a highly interesting sort between heats of combustion, heats of evaporation, compressibility, and many other properties; and to add support to the theory of compressible atoms.[1] Moreover, taken in connection with more precise knowledge of the free energy of chemical changes, the new results will permit the evaluation of bound energy, and give results which may decide whether or not bound energy is really a simple function of change of heat capacity, as has been more than once intimated.[2] There is time now only to suggest possibilities, each of which would take hours to elucidate.

How can we collate all the varying properties so as to show their many-sided relationships? How can we piece together the scattered evidence so as to synthesize an adequate conception of the ultimate nature of things? These questions may never be adequately answered, but science must ceaselessly endeavor to solve the problem which they present.

A first step is clearly to find the way in which each property varies in relation to every other. With this in mind, let us appeal to the irregular system of the periodic classification, which formed the subject of the Faraday lecture by Mendeléeff 22 years ago. This mysterious index of uncharted tendencies must hide within itself guiding ideas capable of pointing us onward.

Clearly each property must receive, not merely qualitative, but strictly quantitative treatment. With this in mind, let us compare our various facts by plotting atomic weight in one direction, and all the other properties in another. Then by noting the parallelism or antiparallelism of the wavy lines many relationships may be traced. The device is not new. Carnelley compared Lothar Meyer's atomic volume curve with that of melting points, and other similar data have been plotted; but the method has not been used to its full extent.

Let us then turn to the diagram (fig. 3) in which the variations in a number of properties are plotted with relation to the atomic weights. Prominent among the lines is the atomic-volume curve just mentioned. Below it is plotted the almost parallel line depicting the

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[1] Richards, Proceedings American Academy, 1908, vol. 39, p. 581; also Zeitsch. physikal. Chem., 1904, vol. 49, p. 15.

[2] Helmholtz, Lewis, van't Hoff, Nernst, and Haber, as well as the author and many others, have contributed to this discussion. An interesting résumé, with references to many of the original papers, will be found in Haber's Thermodynamics of Technical Gas Reactions (translated by Lamb), London and New York, 1908.

compressibilities of the solid elements as determined at Harvard; these are immediately seen to be, like the atomic volumes, periodic functions of the atomic weights. The parallelism can not but suggest that atomic volume and compressibility are fundamentally connected; and, indeed, the theory of compressible atoms gives a plausible explanation of the connection. We should expect the large atomic volumes to be more compressible, because we might infer from their bulk that they are not under as great pressures as the small volumes, and material under slight pressure is likely to be easily compressible. Moreover, the bulky and easily compressible elements are in most cases more easily melted and volatilized than those possessing small

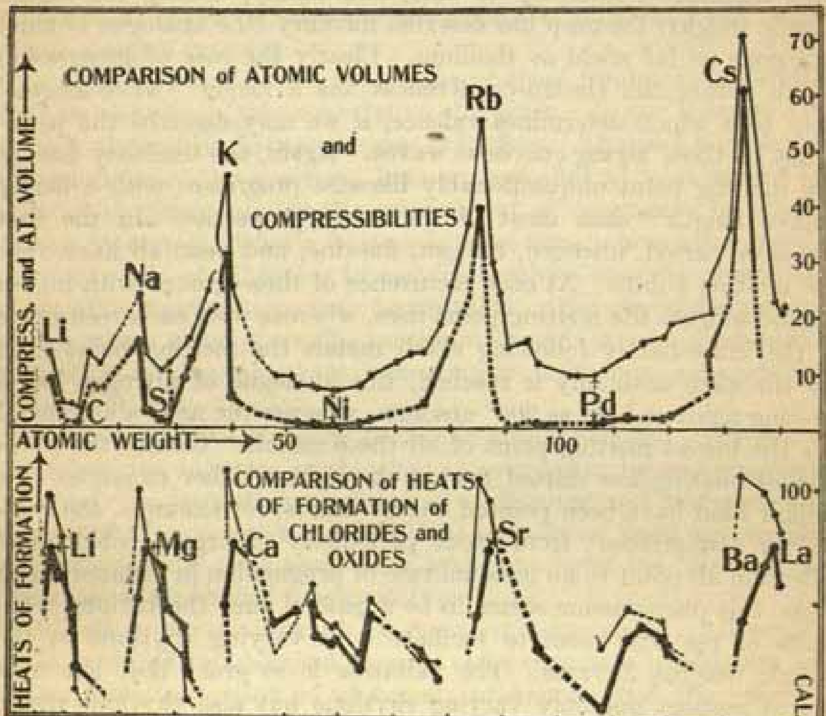

FIG. 3.

volume and slight compressibility. This is just what we might expect; all these properties combine to indicate that the bukly elements have less cohesion than the compact ones.

Next, another set of waves may be considered, representing properties not often depicted in this way. These are the heats of formation of sundry similar compounds, also plotted with relation to the atomic weights. In the third curve are given the heats of combination of chlorine with other elements, and below it a heavy line depicting the heats of the combination of oxygen with these elements, both sets of quantities being expressed in terms of gram-equivalents.

These two run partly parallel with one another; but a deviation in the parallelism appears, which is full of suggestiveness. The peaks of the curves representing oxides shift distinctly to the right of the curve representing chlorides as the atomic weight increases. Lithium marks a maximum with both curves, but the oxygen curve lags greatly at the succeeding peaks, having its maximum with lanthanum at the atomic weight 139,[1] and shifting over as far as lead above 200. This simple fact standing alone would perhaps mean but little, but other similar facts seem to point in the same direction. For example, the property of electro-positiveness, exhibited by the alkali metals, instead of reappearing in copper, has been carried over with diminished intensity to zinc; and finally, among the higher atomic weights the cusp has deserted mercury (the analogue of zinc) and gone as far afield as thallium. Clearly the rate of progression which determines electro-positiveness has a longer "wave-length" than that which determines valence, if we may describe the periodicity of these zigzag curves as waves. Again, the tendency toward low melting point unquestionably likewise progresses with a longer "wave length" than most of the other properties. In the first complete period, nitrogen, oxygen, fluorine, and neon all have very low melting points. At each recurrence of these groups with higher atomic weights the melting point rises, whereas with each recurrence of the immediately following alkali metals the melting point falls. By the time antimony is reached, this analogue of nitrogen has a melting point as high as 900° absolute, whereas the next alkali metal has the lowest melting point of all these metals. Clearly the property of melting has shifted toward the right. Other examples of a similar kind have been pointed out by others, for example, the well-known displacement from strict periodicity of argon, cobalt, and tellurium all point to an unequal rate of progression in isolated cases. Thus, this phenomenon seems to be a general one; the various properties of material seem to oscillate with varying rhythms as the atomic weights increase. The variation is so great that one may almost suspect not only varying rhythms but also rhythms represented by different types of mathematical functions.

These facts suggest a possible reason for the great irregularity of the last part of the periodic table. May it not be that the nature

[1] The essential data for discovering this generalization, namely, the heats of oxidation of the metals having great affinity for oxygen, are as follows: Lithium, 72; sodium, 50; magnesium, 72; potassium, 43; calcium 76; rubidium, 42; strontium, 71; cæsium, 41; barium, 67, and lanthanum, 74. These values correspond with gram-equivalents, that is, combination with 8 grams of oxygen, and are expressed in kilogram-calories. The typical oxide is always meant. The figures rest chiefly upon the recent work of Rengade, de Forcrand and Guntz. References to most of the papers are to be found in Abegg's "Handbuch der anorganischen Chemie." The work of Guntz is published in Compt. rend., 1903, vol. 136, p. 1071; 1905, vol. 140, p. 863; Bull. Soc. chim., 1906 (III), vol. 35, p. 503. The work on lanthanum was done by Matignon, Ann. Chim. Phys., 1906 (viii), vol. 8, p. 426. The heat of oxidation of beryllium is not accurately known, but since the oxide may be decomposed by magnesium at high temperatures, the value is very probably less than 70 calories per gram-equivalent.

of the elements is determined by several fundamental tendencies which may be compared to the Mendelian characters of the modern theory of heredity? If these characters recur at different intervals as the atomic weight increases, a given rhythm occurring at first would necessarily be obliterated toward the end of the system. To change the analogy and borrow a term from the nomenclature of light, we may say that the tendencies which produce the curves in this diagram, might first reënforce and afterwards interfere with one another, because they possess different wave lengths. At first, overlapping might accentuate one set of properties; later the changing relation might annihilate this set of properties and cause another. Thus, all the varieties of material may be functions of some few fundamental characteristics which progress at different rates as the atomic weights increase.

Any attempt to discover the nature of these fundamental tendencies must be of a highly speculative character. In our ignorance we can not distinguish between cause and effect. The well-known definite relations of the spectrum lines suggest that at least one of the essential requirements for the existence of an atom may be susceptibility to certain definite harmonic vibrations; those compressible atoms capable of vibrating in certain rhythms may be permanent, whilst other aggregations may be unstable. The gap in the periodic system where ekaiodine and ekacæsium should be, and the amazing instability of the elements immediately following, supports the notion.

But here we have a cosmic puzzle for future solution. To-day we lack adequate data; we are blocked at every turn by our ignorance; therefore, the immediate problem is to discover and test each step as carefully as possible. When the facts have been ascertained, man will have a solid basis upon which to build his future superstructure of theoretical interpretation.

The quest is not dictated by mere curiosity alone. All organic life is actuated by chemical energy, and exists in a mechanism and environment composed of chemical substances; and the effort to understand these essential conditions of human existence constitutes one of the most important objects of human endeavor. Superficial observation of the complex phenomena of life can do but little; as Faraday well knew, patient study of the fundamental laws of the physical universe alone can help to unravel the interwoven threads. Health, well-being, and a profound philosophic outlook are alike dependent upon the result. No one can predict how far we shall be enabled by means of our limited intelligence to penetrate into the mysteries of a universe immeasurably vast and wonderful; nevertheless, each step in advance is certain to bring new blessing to humanity and new inspiration to greater endeavor.

[illegible]

[illegible] the Mendelian [illegible] theory of heredity [illegible]

[illegible]

[illegible]

[illegible]

THE PRODUCTION AND IDENTIFICATION OF ARTIFICIAL PRECIOUS STONES.[1]

[With 3 plates.]

By Noel Heaton, B. Sc., F. C. S.

During recent years the production of artificial stones on a commercial scale has become an accomplished fact, and a great many misconceptions and misleading statements have been made as to the relation which these productions bear to natural products on the one hand and imitations gems on the other. It may therefore be of some use to make the matter clear by describing as fully as circumstances permit what has been done in this direction and what has not been done; what is practicable and what is impracticable in the present state of our knowledge.

I suppose there are few subjects of interest from so many points of view as that of precious stones. The beauty and rarity of fine specimens has from time immemorial rendered them the most treasured of possessions. With the romance that surrounds this aspect of the question we have nothing whatever to do to-night, except to bear in mind that on account of their great value men have for centuries strained their ingenuity to solve the mystery that surrounds the origin of such stones, and amass wealth by producing them at will instead of by the laborious and highly speculative process of digging for them in the earth.

Until the development of modern science and accurate methods of investigation this problem resisted all attempts at solution, and it is, in fact, only within the last few years that the artificial production of any species of gem on a commercial scale has become practicable.

Of course, one can cut the Gordian knot by preparing a colorable imitation of the real thing, but that is quite another matter, and I want to make it quite clear at this point that I propose to limit the term "artificial" to such productions as possess the same chemical composition and physicial constants as the natural stones, differing from them only in minute details consequent upon their being produced in the labora-

[1] Read before the Royal Society of Arts, Wednesday, April 26, 1911. Reprinted by permission from Journal of the Royal Society of Arts, London, No. 3049, Vol. 59, Apr. 28, 1911.

tory instead of being dug out of the earth; all other makeshifts being properly described as "imitations." The production of imitation gems is by no means a modern invention, as is doubtless well known to you. To go no further back than the time of the Roman Empire, the master glassmakers of the dawn of our era, whose skill and knowledge of glassmaking one appreciates more highly the more one investigates the industrial life of those times, were able to imitate almost any precious stone exactly, as far as outward appearance went, in colored glass—and not only the transparent gems, but the structure of such semiprecious stones as agate, cornelian, lapis, and porphyry. It would be quite out of place to devote any time to-night to this historical aspect of imitation gems, but I can not refrain from alluding to the remarkable examples of such imitations found by Mr. Woolley at Karanog,[1] from which it is difficult to resist the conclusion that in quite early times Nubia was the center of this industry. To judge by the stories one reads about jewels in those times—stories of the Emperor Comnenus, for example—one suspects that the glassmakers turned their skill in this direction to some account and considerable profit on behalf of an ignorant and somewhat credulous aristocracy; for in those days, and, in fact, until quite recently, not only was the nomenclature of gems very vague, but methods of identification were chiefly remarkable for their nonexistence.

The chief criterion of a precious stone was its color, so much so that throughout medieval times blue glass was known as sapphire and green glass as beryl, etc., giving rise to the legend that in the time of Queen Elizabeth windows were glazed with sheets of beryl.[2] As the tendency still lingers to regard all red stones as rubies and green as emeralds, and so on, I would like to make it clear at this point that color is really quite an accidental property of precious stones; the substance of which nearly every species of transparent gem is essentially composed is colorless, and the color is really produced by minute proportions of impurity.

This being the case, we find that on the one hand the same species of gem stone may exist in a large variety of colors, and on the other hand that a color characteristically associated with one gem may often be found in another having essentially different composition and properties. Owing to this confusion it was very difficult to draw the line between a genuine and imitation stone until the various species of gem stone were accurately defined and their names clearly associated with particular composition and properties, the determination of which forms at the present time a means of distinguishing one from another,

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[1] Karanog, by C. L. Woolley and D. Randall. MacIver: Philadelphia Museum, 1910.

[2] This is quoted in Hollingshed. We read in Theophilus (II, cap. xii) of "tabulas saphiri pretiosas ac satis utiles in fenestris." In a previous paper (Journal, Mar. 15, 1907) I have shown how the name jet was variously applied.

and also of deciding whether an alleged gem is genuine or imitation with ease and certainty.

The scientific examination and identification of gems in this manner is a matter of the greatest interest, but it would take far too much time to discuss it in detail, and it is quite unnecessary to do so, because it has already been brought before the society most exhaustively by our chairman, Dr. Miers.[1] I propose, therefore, merely to remind you of the main points by means of the accompanying summary (Table I).

Table I.—*Properties influencing the value of precious stones and used as means of identification.*

Beauty	Color.	
	Structure	Cleavage.
		Lamination.
		Inclusions.
	Optical properties	Refractive power [refractometer].
		Double refraction [polariscope].
		Pleochroism [dichroscope].
		Dispersion.
		Absorption spectrum [spectroscope].
Durability	Hardness [hardness points].	
	Toughness.	
	Chemical composition.	
Additional means of identification	Specific gravity.	
	Thermal conductivity.	
	X rays.	

In order to bring this matter up to date in the records of the society, however, I must refer briefly to one or two particulars in which advance has been made since the time of these lectures.

The most important properties of a precious stone are those depending upon its refractive powers. Until recently the accurate determination of the refractive index of a stone was a matter involving the use of complicated and expensive instruments, and a matter for the skilled mineralogist rather than the practical jeweler. It is true that at the time Dr. Miers published his lectures there existed an instrument known as the reflectometer, but the determination of the refractive index with this was a matter of some difficulty even in skilled hands, and its value for commercial purposes was very small. Since that time, however, thanks to the ingenuity of Dr. Herbert Smith, this instrument has been improved out of all recognition, and in its place we have the Herbert Smith refractometer (pl. 1, fig. 1), by means of which anyone of normal common sense can determine the refractive index of a stone in a few seconds without even removing it from its setting, and which, with a little

[1] Cantor Lectures on Precious Stones, April, 1896.

practice, will also enable one to determine with similar ease the amount and kind of double refraction and the degree of dispersion.

As will be seen from the diagram (pl. 1, fig. 2), the main principle of the instrument is the same as that of the reflectometer, the refractive index being measured against a standard of highly refracting glass by means of the angle of total reflection, which of course diminishes the nearer the index of the stone approaches that of the standard. It is, however, in the details of construction that such a marked advance has been made, and it is these details which make all the difference in practical work. To use this instrument all that has to be done is to place the stone under examination in optical contact with the flat surface of the dense glass, and arrange it so that a good light (preferably monochromatic) enters the instrument through the lower lenticular opening, when the refractive index is read off directly on a scale, without calculation.[1]

Some little advance has also been made in the construction of the dichroscope for determining pleochroism. As will be seen from the illustration (pl. 1, fig. 3), the instrument in use to-day is provided with a revolving holder tipped with wax, to which the stone is readily fixed, leaving both hands free—a detail, but again it is such details that count in practice.

Taking the properties of precious stones as a whole, the great point about them is the remarkable combination of qualities; it is not so much that they have optical properties which make them extraordinarily beautiful, or that they have remarkable hardness and durability, but they have both, and it is the impossibility of reproducing this combination in any other material that renders the detection of imitations a matter of ease in the hands of anyone familiar with the facts.

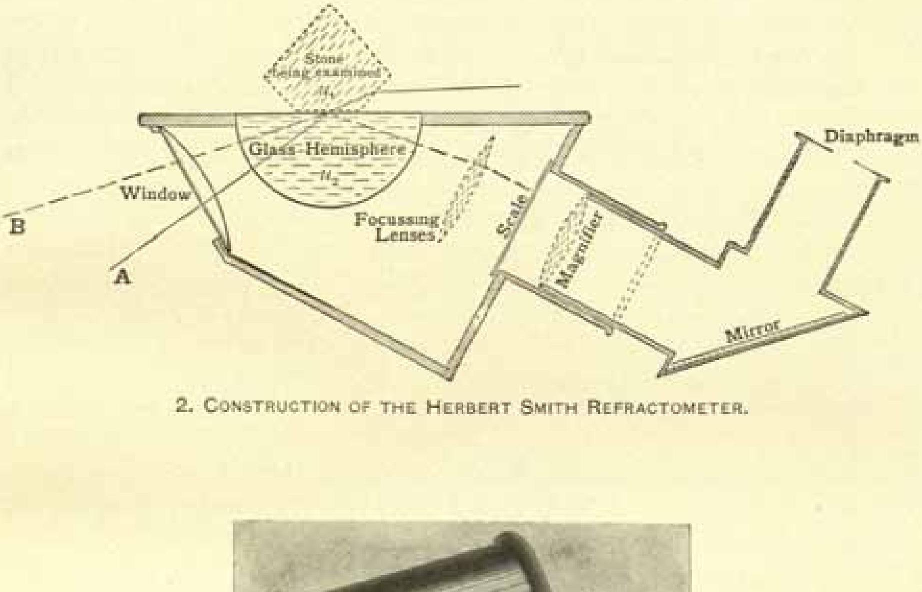
Of course, glass is the obvious material to use in the production of imitation gems, and, as I have indicated, it has been so used from time immemorial. And, in later times, while science was equipping the expert in precious stones with the means of identifying them with certainty, the maker of imitations was also invoking its aid in the production of more successful imitations.

In modern times the manufacture of imitation gems on scientific lines was introduced by Strasser in Vienna; hence the name "strass," although "paste" is the more commonly used term.

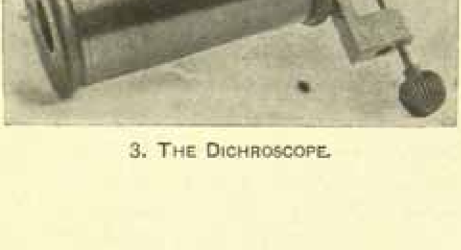
The finest of such modern paste bears little relation to the clumsy imitations of early times; the glass is specially prepared in order to combine, as far as possible, the necessary optical qualities with a fair amount of durability. It is well known that by using lead

[1] It is impossible here to give any detailed account of the construction and use of this instrument. Full particulars will be found in The Herbert Smith Refractometer, published by J. H. Steward, 406 Strand.

1. THE HERBERT SMITH REFRACTOMETER.



2. CONSTRUCTION OF THE HERBERT SMITH REFRACTOMETER.



3. THE DICHROSCOPE.

instead of lime as the basic constituent, the refractive index and dispersive power of glass are much increased, and by replacing the alkaline constituent by thallium oxide in the same manner the refractive index may be raised as high as 1.96 and the dispersion to 0.049.[1] By adjusting the composition in this way, and preparing the glass with the greatest regard to the purity of the materials, manipulating it, moreover, in a similar elaborate manner to that employed in the production of glass for optical instruments, in order to secure the utmost freedom from striation and inclusions, it is possible to imitate any precious stone accurately, as far as outward appearance is concerned.

The trouble is, however, that with glass the more you increase its refractive power in this way the softer and less durable it becomes, until you find that the very "dense" flint used for the refractometer, having a refractive index of 1.8049, is so soft that it has to be handled with great care to avoid scratches, and so little resistant to decay that in a comparatively short time the exposed surface becomes corroded, which is the one weak point of this instrument. It is true that this softness may be counteracted to some extent by further adjustment of the composition, adding a proportion of alumina and zinc, and by careful thermal treatment of the finished stone in some such manner as that originally introduced by Bastie, in which the glass is case-hardened by plunging whilst hot into a bath of oil. In some of the best modern paste I have found a refractive index of over 1.6 combined with a hardness close on that of quartz, but this is the absolute limit, and it is not possible in any way to obtain a paste that can not be scratched with a hardened steel point. Paste can also be readily identified by means of the scientific tests, as indicated in Table II.

TABLE II.—*Identification of imitation precious stones.*

Paste.	Stones.
Index of refraction rarely exceeds 1.65.	Index of refraction ranging up to 2.4.
Single refracting, or false double refracting owing to strain.	Double refracting, with exception of diamond, garnet, and spinel.
Never pleochroic.	Often strongly pleochroic when colored.
Hardness always below 7.	Hardness 7 or over (with a few exceptions).
Specific gravity usually above 4.	Specific gravity usually below 4.
Thermal conductivity low.	Thermal conductivity comparatively high.
Opaque to X rays.	Translucent or transparent to X rays.
Generally show spherical bubbles and curved striæ.	Frequently show lamination or inclusions.

[1] These are the constants given for the Jena glass, No. S. 57; the specific gravity is 6.33. Refractive index of diamond is 2.4, and dispersion 0.057.

TABLE III.—*Composition of the principal precious stones.*

	Species.	Variety.	Composition.
Element	Diamond		Carbon.
Oxides	Corundum	Ruby Sapphire Oriental amethyst, etc.	Oxide of aluminium.
	Quartz	Crystal Amethyst Cairngorm, etc.	Silica.
Aluminates	Spinel	Balas ruby, etc.	Magnesium aluminate.
	Chrysoberyl	Cymophane Alexandrite	Beryllium aluminate.
Silicates	Beryl	Emerald Aquamarine	Beryllium aluminium silicate.
	Garnet	Hessonite	Calcium aluminium silicate.
		Pyrope	Magnesium aluminium silicate.
		Almandine	Iron aluminium silicate.
		Demantoid, etc.	Calcium iron silicate.
	Olivene	(Peridot)	Magnesium iron silicate.
	Sphene		Calcium titanium silicate.
	Spodumene	(Kunzite)	Lithium aluminium silicate.
	Topaz		Aluminium fluo-silicate.
	Tourmaline		Complex alkali-lime-alumina silicate.
	Zircon	Jargoon Hyacinth	Zirconium silicate.
	Turquoise		Hydrous aluminium phosphate.
	Opal		Hydrous silica.
	Pearl		Calcium carbonate.

The most important point to remember about paste, however, is its lack of durability; it is not only too soft to stand much wear, but its composition is so unstable that it rapidly deteriorates and loses its brilliancy on exposure. You will see, therefore, that although there is a certain legitimate scope for such paste imitations they are very unsatisfactory substitutes for the genuine article. This being the case, as scientific knowledge has advanced, attention has been more and more concentrated on the problem of producing by artificial means the actual minerals found in nature, and thus obtaining what I have defined as artificial in contradistinction to imitation jewels, having both the beauty and durability of the natural article without the objectional concomitant of enormous cost.

The first point to be considered in attacking this problem is the composition of the stone, as it is obvious that, other things being equal, the possibilities of success are greater with one of simple than one of comparatively complicated composition. One also has to consider, however, the economic aspect—it is not much use devoting time and ingenuity to the production of an artificial stone when the natural one is so common that the cost of the two would be practically identical.

Taking these two points in conjunction, and confining our attention for the moment to the transparent stones as summarized in Table III, the diamond appears to offer the most promising field for attack and corundum comes next, and we find that the main attempts at artificial production center round these species. From the point of view of composition alone, quartz is the most simple, but it is so common in nature as to render its artificial production scarcely worth while. The aluminate group offers some attraction, but the artificial production of crystalline silicates on a large scale is a very difficult problem, and, with the exception of the emerald, the stones comprised in this group are so freely distributed in nature as to render their artificial production a matter of academic rather than industrial interest.

It is unnecessary to discuss at any length the artificial production of the diamond[1]—the problem has been attacked by numerous scientists, and was solved by Moissan some years ago. Some 15 years ago, on the occasion of a visit to Paris, I had the privilege of witnessing the production of his diamonds, prepared, as all the world knows, by saturating iron with carbon at the temperature of the electric arc and plunging the molten mass into cold water. The mass of iron is then dissolved in acid and the residue subjected to a laborious process of extraction, the diamonds being picked out by aid of the microscope. The largest diamond that has been produced in this way is barely visible to the naked eye, however, and when I say that the problem of their production has been solved, I mean from the scientific point of view.

The artificial production of the diamond is, in fact, far more complicated than it appears at first sight. If it were only a matter of obtaining the necessary high temperature to fuse the carbon to obtain it in the crystalline condition it would be simple—such high temperatures are readily obtained nowadays by means of the electric furnace and the oxy-acetylene flame—but carbon is one of those substances which pass direct from the solid to the gaseous state under ordinary atmospheric conditions, and only assumes the liquid condition under enormous pressure. The combination of high temperature and enormous pressure can be obtained momentarily by Moissan's ingenious process, but to obtain crystals of any size it is necessary to conduct the operation on a very large scale and to maintain the combined temperature and pressure for a sufficient length of time to allow the liquid carbon to separate out from its matrix; moreover, the entire operation must be conducted out of contact with air, for carbon rapidly combines with oxygen at high temperatures.

[1] A complete account is given in "Diamonds," by Sir William Crookes (Harper's Library of Living Thought).

Commercially, we are as far from being able to produce artificial diamonds as in the days of the alchemists. It is, perhaps, a bold thing to say that no such thing as an artificial diamond will ever be placed on the market, but one can safely assert that so far as our knowledge stands at present it is impracticable. In saying this, I am quite aware that statements as to the commercial production of synthetic diamonds being an accomplished fact have quite recently appeared broadcast in the public press, but those who are responsible for such statements are, shall we say, under a misapprehension as to the meaning generally conveyed by the term "synthetic," and are unable to follow the distinction I have drawn between an artificial gem and an imitation.

To pass on to corundum, the problem of its artificial production is very much simplified by the fact that its composition is oxide of aluminium, and alumina—which is, therefore, its amorphous equivalent—fuses to a liquid under ordinary atmospheric pressure at a temperature somewhere about 2,000° C. (the exact point has not as yet been determined), and being the only stable oxide of a strongly basic metal, it can be heated in air without any change.

The chief problem to be faced, therefore, is that of attaining the necessary temperature, and it is not surprising that crystalline alumina was produced as a scientific curiosity as far back as the commencement of the nineteenth century. It is at this time that we first begin to hear of the oxy-hydrogen blowpipe (or the gas blowpipe as it was then called), and in a book published in 1819,[1] describing various experiments with this new apparatus, we read that "two rubies were placed upon charcoal and exposed to the flame of the gas blowpipe * * * after suffering it to become cold * * * the two rubies were melted into one bead." This hint does not appear to have been followed up for some considerable time, however, and the earlier experimenters in the production of artificial gems worked in another direction; they were unable to obtain products of commercial utility, because although they succeeded in obtaining crystalline alumina, it was produced under conditions which resulted in the formation of a mass of small crystals, almost microscopic in size. Moreover, the form of these crystals was that of the hexagonal plate which is the fundamental form of corundum, and such a form would be useless for cutting even when of considerable area, owing to its thinness. Thus Gaudin, who appears to have been one of the first to attain any success in this direction, obtained a mass of such crystals by fusing alum and potassium sulphate in a closed crucible. Ebelman obtained similar results by fusing alumina with borax, and later Deville and Caron used aluminum fluoride and boric acid. All these attempts yielded similar results, as in each

[1] The Gas Blowpipe, by Dr. E. D. Clarke.

case fusion was obtained by the aid of a substance melting at a lower temperature which acted as a solvent. Consequently the alumina crystallized out in much the same manner as a salt crystallizes from a saturated solution, and to obtain sufficiently large crystals to be of practical use it would be necessary to conduct the experiment on a very large scale, and subject the fused mass to very slow and carefully regulated cooling.

In 1877 Fremy and Feil attempted to get over this difficulty by using lead oxide as the flux and employing a crucible composed of highly acid clay. On heating up the mixture in such a crucible the lead oxide melts and combines with the alumina to form lead aluminate, and on further heating this reacts with the silica of the fire clay, forming lead silicate and setting free the alumina, which crystallizes out. But although very much larger crystals were obtained by this ingenious process, they had the same form and were too thin for industrial employment.[1]

Some time earlier than this, however, we hear of the oxy-hydrogen blowpipe again, for Gaudin had noticed (as Clarke did in 1819) that by introducing alumina into the flame of an oxy-hydrogen blowpipe he could obtain globules of fused alumina similar to the borax beads one makes in the ordinary blowpipe. Gaudin appears to have taken it for granted that these beads were amorphous—that is, an alumina glass—and it was not realized until many years later that they were really identical in all their properties with natural crystalline corundum. When this was realized, the commercial production of corundum became only a matter of detail.

Having obtained this further point, the idea immediately suggests itself of converting small and useless stones into valuable gems by fusing them together into one, and, as a matter of fact, "reconstructed rubies"—as stones produced by this method are now generally called—made in this manner were the first artificial gems to be prepared on a commercial scale. These were introduced some quarter of a century ago under the name of "Geneva rubies," and were offered as, and realized the price of, natural stones, until the method of their production became apparent.

It will, of course, be well understood that the experiments I have briefly indicated toward the artificial production of corundum had as their immediate objective the formation of ruby, that being by far the most valuable variety. It had long been known that the color of the ruby was due to a trace of chromium, and by adding a small proportion of potassium or ammonium chromate to their mixture Fremy and Feil reproduced accurately the color of the ruby in their crystalline flakes.

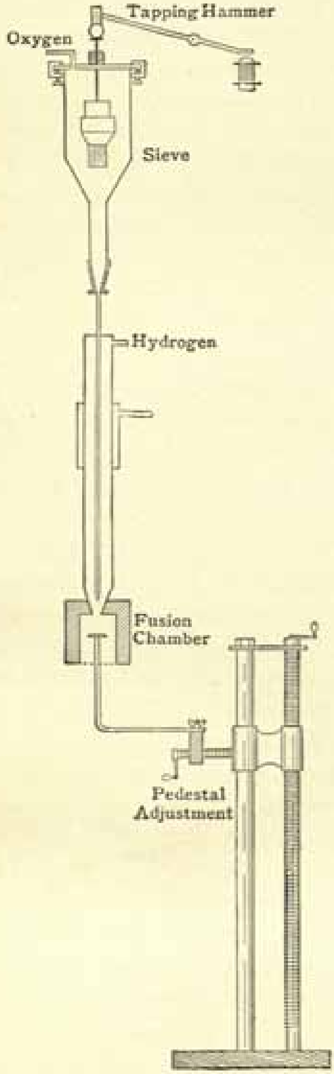
[1] For a full account of the history of these earlier attempts, see La Synthèse du Rubis, by F. Fremy, 1891.

The process of producing reconstructed rubies by means of the oxy-hydrogen blowpipe is, roughly, as follows: The residue from cutting rubies and small worthless stones is broken into coarse sand, a small quantity of which is placed on the center of a disk of platinum; this is then carefully brought to the fusion point, care being taken at this stage not to raise the temperature to such an extent as to melt the platinum support. As soon as this mass is fused it serves to protect the platinum, and the reconstructed ruby can be built up on it by adding the fragments of ruby one at a time by means of small platinum forceps. These pieces have to be dropped on with great care in order to secure incorporation with the mass and prevent as far as possible the formation of air bubbles. It will be readily understood that this process is a tedious and laborious one, and, in fact, the formation of masses of sufficient size to yield large stones on cutting is a matter of such difficulty that the cost of production is very high.

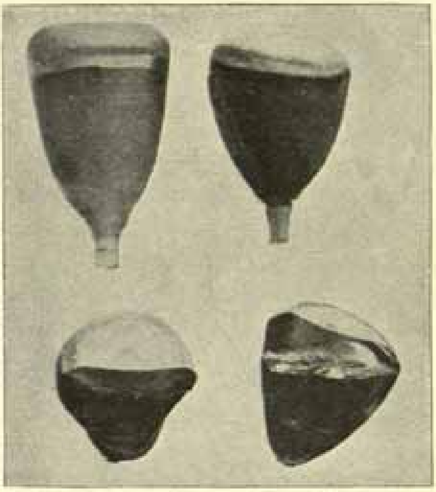
Just about seven years ago, however, Verneuil[1] overcame this restriction when he hit on the extremely ingenious idea of introducing the raw material through the blowpipe, and thus placing it on the support automatically. The diagram (pl. 2, fig. 1) shows the principle of his apparatus. The blowpipe is arranged vertically over a small insulated chamber containing the support on which the mass is to be built up. The oxygen tube communicates at its upper extremity with a funnel-shaped hopper, in which is suspended a small sieve filled with the raw material, which is rhythmically shaken by means of a small hammer actuated by an electromagnet or cam. Each time the hammer taps the support of the sieve, causing it to vibrate, a small quantity of the powder falls through into the tube below, and, carried along by the gas, passes out at its lower extremity into the zone of flame, where it is immediately raised to the fusion point, and falls as a melted globule on to the support below.

As seen in the diagram, this support is arranged with a screw adjustment, so that as the mass of corundum is gradually built up by the constant addition of fresh globules the surface can be kept at a constant level, and the portion already formed removed from the zone of heating so as to allow it to stiffen. When the apparatus is first started the blowpipe is adjusted so as to give a comparatively cool flame, and the powder is admitted slowly. By this means a small "stalk" is formed, which insulates the mass from the support and prevents the fusion of the latter. When this has been formed the full pressure of the blowpipe is put on and the rate of admission increased, with the consequent formation of a "boule," as it is termed, having the shape of a pear, as illustrated in plate 2, figure 2.

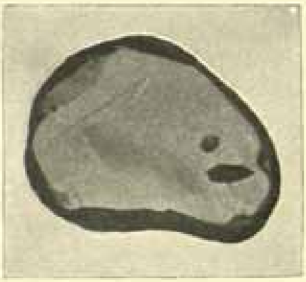
[1] "Mémoire sur la reproduction artificielle du rubis par fusion," M. A. Verneuil, *Annales de Chimie et de Physique*, September, 1904.



1. PRINCIPLE OF VERNEUIL'S APPARATUS FOR PRODUCTION OF ARTIFICIAL CORUNDUM.



2. "BOULES" OF ARTIFICIAL CORUNDUM.



3. SECTION OF NATURAL RUBY, × 10.

With this apparatus a boule weighing some 20 to 30 carats, and capable of yielding two cut stones of about 6 carats each, can be prepared in about half an hour almost automatically, a single operator being able to control several machines. The boules, on cooling, very often split in half in the direction of their growth, as in the lower example seen in figure 2, and this is a convenience rather than otherwise, as the resulting shape can be cut to greater advantage.

In the first instance reconstructed rubies were made in this way after the manner introduced by Gaudin, the material fed into the blowpipe being pulverized rubies and chips, and this method is still employed by some workers. But more commonly nowadays the corundum is produced direct from amorphous alumina by using pure ammonium alum as the raw material. On reaching the flame this decomposes, the ammonia and sulphuric acid volatilizing, leaving the alumina. Stones made by this process are generally known as "synthetic," as distinct from "reconstructed," although, of course, to be pedantic, the process is one of decomposition rather than synthesis.

The "synthetic" corundum produced in this way, if pure ammonium alum is used, is of course colorless, and can be used as artificial white sapphire. If a small proportion of chrome alum is added, the resulting stones are rubies, and other colors may be produced in the same way. For a long time all attempts to reproduce the fine blue of the sapphire failed, because following the apparent analogy of silicates, cobalt was invariably employed as the coloring agent. This, however, does not readily form an aluminate in the same way that it does a silicate, and, in consequence, it is impossible to produce a satisfactory coloration in the corundum by its means; it is possible to get the cobalt in a state of combination by adding a large proportion of magnesia to the alumina, but then the product formed is not a crystalline alumina but magnesium aluminate, and its properties are fundamentally different. Its refractive index is lower, its refraction single, and its hardness lower. In fact, the result is blue spinel instead of sapphire. Moreover, such blue stones have the characteristic absorption of cobalt, and appear purple in a light that does not contain a large proportion of blue rays.

In 1908 Paris attempted to avoid this latter difficulty by preparing a calcium aluminate colored with cobalt, as it is found that in this case the transmission of the red rays is less pronounced. But the calcium aluminate so formed is not crystalline at all, but amorphous. A year or so ago, however, the problem of producing synthetic sapphire was finally solved by the use of titanium oxide, a very unexpected result, considering the chemical position of this element. With this last advance the artificial production of the corundum gem stone may be considered to be completely solved, and cut stones can now be obtained in every variety of color, from pure white to ruby and sap-

phire, at prices ranging from 4 to 10 shillings a carat, according to color, quality, and size.

Whatever may be their economic importance, a very much debated question, there can be no doubt as to the scientific interest of this group of artificial gems. In the first place it is a matter of some interest that a mass of fused material formed in this way should not only be crystalline but possess all the characteristics of a single crystal. Crystallographers are agreed that each boule is a single crystalline individual, with the axis roughly perpendicular to the plane of formation; that is to say, running from the point of attachment of the pedestal to the top of the mass. On the top of the boule one invariably finds a mass of symmetrically arranged facets, which Dr. Herbert Smith has found to correspond with the fundamental rhombohedron of corundum. Judging by analogy with other materials, one would expect at first sight that a fused mass formed in this way would be either a heterogeneous mass of minute crystals or entirely amorphous, possessing the structure characteristic of glass. It is well known, for example, that under similar conditions pure silica yields "quartz glass," which is extensively manufactured at the present time. One is tempted to dwell upon this point, and discuss its bearing on such matters as the devitrification of glass, but it would be entirely out of place to do so in the present paper.

Then, again, there is the matter of coloration. One would like very much to know what is the state of combination of the chromium in a ruby, and whether the color is produced by chromium aluminate in solution or metallic chromium in molecular suspension. In glass, as is now well established, this color is produced by the optical effect of ultramicroscopic spheres of metallic gold or copper, but there seems to be no parallel between the two cases.

A point of more practical interest is the fact that although the artificial corundum is a true crystal it possesses the shape and formation of a congealed liquid or glass. The practical interest of this lies in the fact that it affords the only means of distinction between this artificial corundum and the naturally formed gem stone. Being of exactly the same composition and crystalline structure as the natural mineral, it can not be identified by any of the physical tests I briefly referred to above. For all practical purposes the artificial ruby is a ruby, and one can only deny that it is a "genuine ruby" if this word is held to connote essentially a product found in the earth and not made by man.

And yet, owing to the curious anomaly of its structure, the artificial product can almost invariably be distinguished from the natural with the greatest ease. In the naturally formed stone any foreign matter which may be present is coerced into following the lines of growth of the crystal, and more particularly bubbles of gas which

may be present in the liquid are distorted from their natural shape so as to accord with this symmetrical growth. It is the great exception to find a natural ruby entirely free from such inclusions, which generally form irregular cavities with a decided tendency to geometrical shape.

It is very common also to find the structure technically known as "silk" caused by microscopic bubbles drawn out into a series of parallel canals, all lying in one plane. Any variation of color in different portions of the stone also follows the lines of growth in this manner (pl. 2, fig. 3; pl. 3, fig. 1).

In the artificially produced corundum, on the other hand, although the particles arrange themselves symmetrically, any air bubbles that are entangled in the successive globules remain undisturbed, and appear as naturally spherical bubbles in the finished product; and, moreover, if one globule differs slightly from another in the proportion of chromium, the resulting difference in color follows the form of the mass as a whole, the zones of color being circular (pl. 3, fig. 2).

As some of the air entangled between the fine particles fed into the blowpipe almost invariably fails to make its escape during the brief fusion, the presence and form of the bubbles is in this way sufficient to identify the artificial process of formation.

In the great majority of cases examination of the cut stone with a lens is sufficient to decide the point, but in doubtful cases a more minute examination may be made by placing the stone in a little cell filled with highly refracting liquid, in order to secure regular illumination, and examining it under the microscope by transmitted light, when the minutest trace of structure can be detected (pl. 3, fig. 3). In the case of an absolutely flawless stone it would be impossible to decide whether it were natural or artificial, but such stones are so rare that this case is almost theoretical.

It is claimed in some quarters, it is true, that "experts" can invariably distinguish the artificial product merely by reference to the color, which is said never to be exactly the same as that of the natural stone, much as this latter varies. Personally, however, I am rather skeptical on this point, as one knows that experts claim in a similar manner to distinguish between one species of natural gem stone and another by color alone, and their results are not always in accordance with scientific tests. At any rate such dexterity can only be acquired by a lifetime of specialized experience.

As I have already indicated, spinels may be produced artificially by the same process as corundum, adding the necessary magnesia to the alumina, and the same remarks apply to the production and identification of this species as to corundum, the artificial stone being identical with the natural in all respects except those to which I have just referred.

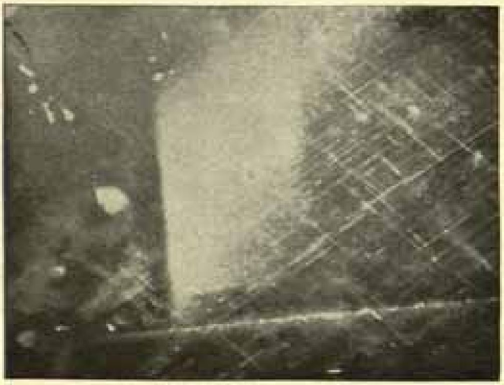
As regards the remaining transparent gem stones, which fall into a group by reason of the fact that they contain silica as an essential component, their artificial production is of little importance. They can not be produced by the same process as corundum, owing to the fact, already alluded to, that under such conditions both pure silica and compound silicates yield an amorphous product, which has not the optical properties of the natural stone. One is constrained, for the artificial production of the crystalline material, to fall back upon methods similar to those employed in the earlier attempts to obtain ruby—obtaining the requisite composition by chemical reaction and maintaining the mass at a temperature just above its fusion point for a sufficient time to allow the silicate to crystallize out.

Topaz, garnets, and zircon have been produced in this way experimentally as a matter of scientific interest, but the small stones produced have no commercial value, and to describe their production in detail would only weary you to no purpose. The majority of these stones are of such common occurrence in nature, and consequently of such little value, that their artificial production in this manner is not a commercial proposition.

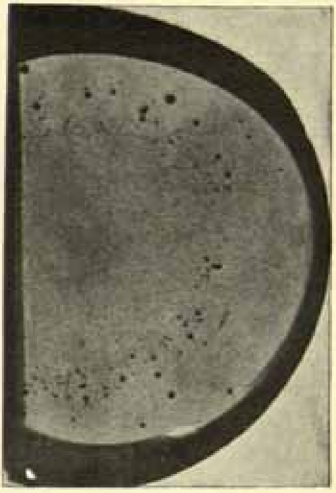
An exception, however, must be made in the case of emerald, which ranks next in value to corundum, and many attempts have been made to produce it artificially. Reconstructed emeralds have been made by the Verneuil process, but these are, of course, amorphous, and do not possess the double refraction and other properties consequent upon the crystalline structure of the natural stone. The problem of producing this stone artificially has not as yet been solved in fact. I am quite aware in saying this that recent newspaper reports lead one to believe otherwise, but, as in the case of the diamond, such reports indicate either remarkable foresight on the part of the writers or show that their imagination is developed at the expense of their powers of accurate observation.

There remain now to be considered those precious stones which are opaque, and owe their beauty entirely to color and structure.

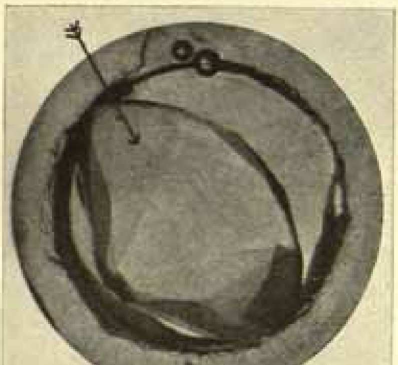
Turquoise is a stone formed under conditions which are easy to reproduce, and its artificial production was successfully accomplished, many years ago, by precipitating hydrated phosphate of aluminium with the requisite proportion of copper phosphate to give it the color and subjecting the precipitate whilst still damp to hydraulic pressure for a considerable time. Prepared in this way the artificial turquoise is so nearly identical with the natural that its identification is a matter of considerable difficulty. There is, however, generally, a slight difference in the specific gravity, hardness, and index of refraction (when this can be measured), which will serve to distinguish it on careful examination. The only point in which there is any decided difference between the two is the behavior on heating, but



1. SECTION OF NATURAL RUBY, × 100.



2. SECTION OF ARTIFICIAL RUBY, × 10.



3. SMALL ARTIFICIAL SAPPHIRE, MOUNTED IN CELL, × 10, SHOWING MINUTE BUBBLES.

4. SECTION OF PEARL, × 50.

as this involves the destruction of the stone it can not be offered as a practical test.

Opal consists essentially of what is known as colloid silica, that is, silica in the amorphous state and combined with water. The play of color one associates with it is entirely an optical effect, due to an accidental structure of the stone, which is permeated by a number of minute fissures between which a thin film of air penetrates, the extreme thinness of this film causing the optical effect known as interference. If a piece of opal is powdered it is no longer colored, as would be the case with a ruby or sapphire, but yields a dirty white powder, and generally a specimen of opal, as found, only shows the structure in parts, the remainder being dull and lusterless like flint.

This peculiar structure is, moreover, by no means confined to opal, but may occur in any mineral deposited under similar conditions. In the mineral known as lumachello, or fire marble, for example, the same effect is seen in a limestone. But opal is the only mineral which combines this structure with sufficient durability for use as a gem stone, and in this connection it should be remembered that, as a matter of fact, it only just possesses sufficient hardness for this purpose, and is one of the softest and least durable of all the precious stones. This fact, combined with the fragility consequent upon its structure, has involved the opal in a mass of superstition and romance from time immemorial.

Although it has this unfortunate drawback, opal is, at any rate in my estimation, the most beautiful of the precious stones, and when one appreciates the reason of its beauty it will be readily understood that its artificial production, or even successful imitation, presents almost insuperable difficulties.

It is true that a somewhat similar play of color can be imparted to glass by rendering it translucent by a slight addition of arsenic or tin in the making, and by etching the surface in various ways, and such iridescent glasses are often found naturally as the result of decomposition, but this is merely a surface effect, and such specimens can not be cut to advantage; moreover, they lack the beauty caused by the fire permeating the entire substance of the gem. The opal ranks with the diamond, therefore, in resisting attempts at artificial production, and is even superior to it in that it can not be really successfully imitated.

I come finally to the pearl. This, of course, differs from all other precious stones in being entirely of organic origin. The peculiar luster of the pearl, like the color of the opal, is due rather to its structure than its composition. It is formed in the oyster by the deposition of successive layers of calcium carbonate round some central object, and consists of an innumerable number of thin overlapping laminæ of the crystalline variety of this substance known as

aragonite. These layers being semitransparent, the light falling on the surface is partially reflected from the surface and partially transmitted into the stone, where it suffers reflection from the surface of lower layers (pl. 3, fig. 4).

To produce this complicated structure artificially is practically impossible, unless one can describe as an artificial pearl that formed by the oyster in response to the deliberate introduction of irritant foreign matter by human agency. But in this case who shall decide where nature ends and human ingenuity begins? Perhaps the well-known Japanese pearl may be correctly described as artificial pearl, although the oyster has a great deal to do with it.

Such pearls are formed by introducing a piece of mother-of-pearl in the shape of a hemisphere between the shell and mantle of the oyster and then leaving the oyster alone for a time to allow it to convert this into a pearl by the deposition of several layers of nacre. The mass is then removed from the shell and converted into the semblance of a true pearl by supplying a back of mother-of-pearl. Such pearls, however, never have the fine orient of those produced under normal conditions, and they can readily be detected by examining the back, when the lusterless mother-of-pearl and the line of junction can be detected.

Of course, wonderful imitations of pearl are made in various ways, which are difficult to distinguish from the natural article by casual examination. One method of preparation is as follows: Small hollow spheres are blown in opalescent glass, coated inside with a preparation of fish scales, and then filled up solid with wax. Such imitations are identified by examination of the hole or by putting a spot of ink on the surface, when the reflection from the inner surface of the glass is seen. These empirical tests are usually sufficient, and it is rarely necessary to resort to testing the specific gravity and hardness, which provide further means of identification. It is worthy of note, however, that such imitation pearls are unique amongst imitation gems in that, in some respects, they are actually superior to the natural article. They are considerably harder, for instance, and their luster is not affected by constant wear.

In conclusion, I would like to refer very briefly to the present position of gems from the economic point of view. It is, perhaps, natural that the considerable influx of artificial gems in recent years, more particularly of the corundum species, has led to a great deal of controversy and difference of opinion as regards their merits. On the one hand the vendors of the artificial stones often publish extravagant statements as to their defying identification, which, as I have shown you, is all nonsense. On the other hand, those interested in maintaining the prestige of the natural article make equally unreasonable statements, to the effect that such artificial productions,

to quote a recently published circular, "are as worthless as the jewelry from a Christmas cracker." I have, I hope, clearly shown you the immense difference that exists between the imitation and the artificial ruby, taking an example; the former, it is true, depreciates rapidly in use and deserves such a description, but the latter has absolutely all the essential qualities of the natural stone, and to place the two on the same plane as worthless trash is unfair to modern science and ingenuity. It must be clearly understood that there is no essential difference discernible between natural and artificial ruby as regards their beauty and their durability, which, as we have seen, are the two great items in the intrinsic value of a stone. But, of course, the price of a stone is chiefly determined by that third factor, which I have not so far taken into account—namely, rarity. Personally I must confess that I have never been able to see why one should value a thing for no other reason than that it is difficult to get, although I suppose here I am in a hopeless minority and that it is and always will be human nature to take this view.

It would serve no useful purpose to enter into that fruitful subject of controversy, the price of an article due to extrinsic causes, but I may say this—that whilst to me personally one is as good as the other, if any man is prepared to pay £100 for a natural stone when he can obtain essentially the same thing, artificially produced, for £5, he is absolutely entitled to get it; and I would not wish you to think that I would defend for a moment the man who attempted to supply artificial as natural. But if this is so, it is still more the case that nobody has any right to supply anyone with paste under the name of artificial (or synthetic, or scientific, if these names are preferred) gem. I do think that the distinction between the two should be clearly recognized and that it should not be permitted to use the term artificial indiscriminately. At present this is being widely practiced; every day one sees offered for sale "rubies, emeralds, sapphires, and pearls artificially produced and having all the properties of the natural stone." Now, as I have indicated, such a thing as an artificial emerald answering this description is unknown and, as a matter of fact, the stones supplied under this title are, as a rule, nothing more nor less than paste imitations, the public being deliberately led to believe otherwise. There is in this case, as I have indicated, a real practical difference between the two articles, not merely a question of opinion.

Again, one must deprecate the custom that has sprung up of arguing that, because "a rose by any other name will smell as sweet," a "scientific" stone will be as good by any other name than its right one. When synthetic yellow sapphire is called "scientific topaz" perhaps no serious fraud is perpetrated, although it is misleading, but when artificial white sapphire is openly and deliberately sold at

a fancy price as "synthetic diamond," with the support of the press, I for one consider that matters are going too far, and that this is being done at the present moment anyone can verify for himself. All these misrepresentations may bring wealth to individuals, but they tend to bring into disrepute the artificially produced stone, and instead of allowing it a place of its own as a distinct achievement, cause it to be looked upon as a spurious make-believe.

However, I did not come here for the purpose of discussing this aspect, and I will not dwell upon it further. I have, as far as possible, given you a résumé of the whole subject and I will detain you no longer, except, if I may add one more word, to acknowledge the fact that my ability to bring this paper before you is very largely due to the assistance I have received in many quarters, and more particularly from Mr. E. Hopkins, whose enthusiasm on the subject of the technology of precious stones is only exceeded by his knowledge and experience. I am indebted to him, not only for much advice and information, but also for the loan of the specimens from which I have prepared the illustrations to this paper.

THE STERILIZATION OF DRINKING WATER BY ULTRA-VIOLET RADIATIONS.[1]

By Dr. Jules Courmont,

Professor of Hygiene in the Faculty of Medicine of Lyon.

That solar light is capable of killing bacteria has been recognized by Downes and Blunt, S. Arloing, Duclaux, and others. This action is due to the ultra-violet portion of sunlight, that is, to the waves of very small length, which are manifested by their chemical action rather than their power of producing heat. Solar light, however, is rather poor in ultra-violet rays, for they are to a great extent absorbed by our atmosphere. Indeed their very limited bactericidal power is scarcely comparable with the very great power possessed by the untra-violet radiation given out by some artificial light sources, notably by the mercury-vapor lamp, whose containing tube is made of quartz. Only such sources as the latter are of practical application to the sterilization of potable water.

THE ULTRA-VIOLET RADIATION—THE QUARTZ MERCURY-VAPOR LAMP.

A few general data will be first stated. The wave lengths (λ) of light rays are generally measured in units which have received the designation of Ångströms (Å. units). The Ångström unit is equal to 0.0000000001 meter. The following table gives the wave lengths of a few different places in the spectrum:

	Å. units.
Spectrum of the Welsbach light:	
Limit of the infra-red	600.000
Solar spectrum:	
Limit of the infra-red	300.000
Limit of the visible red	7.610
Limit of the visible violet	3.970
Limit of the ultra-violet	2.950
Upper limit of the very bactericidal ultra-violet	2.800
Metallic spectra:	
Inferior limit of the mercury spectrum	2.225
Limit of the metallic ultra-violet	1.200
Ordinary gas spectra:	
Limit of the extreme ultra-violet	1.030

[1] Translated by permission from Revue générale des Sciences pures et appliquées, Paris, April 30, 1911, pp. 332-338.

Ultra-violet radiations of solar origin of wave length smaller than 2.950Å. are absorbed by the atmosphere and do not reach us. Therefore in order to obtain light which is truly bactericidal (of wave length less than 2.800Å.) we must have recourse to artificial sources.

The quartz mercury-vapor lamp is the most powerful among these latter. Luminescent mercury vapor is very rich in ultra-violet light. Its ultra-violet spectrum reaches from λ=3.650Å. to λ=2.225Å. Quartz is transparent to all light of greater wave length than 1.500Å., and therefore to all of the rays of the spectrum given out by luminous mercury vapor. Since the ultra-violet rays of smaller wave length than λ=2.800Å. are especially bactericidal, those between 2.800Å. and 2.225Å. render the quartz mercury-vapor lamp very nocuous to all living cells, dangerous to anyone handling it without precaution, as well as useful in the destruction of microbes.

The quartz mercury-vapor lamp is fed by a continuous current. It must be protected by suitable cooling devices. With proper precautions theoretically it will last indefinitely, practically a very long time. The running of the lamp is very easily regulated either by a "sentinel" lamp in the same circuit with the mercury lamp or by simply noting the luminous state of the lamp itself. The lamp is most readily lit by rocking it. As soon as a small thread of mercury connects the two poles, a current of electricity is established and the lamp becomes luminous. The lamp is then turned to its usual position, the thread of mercury broken, but the current continues to pass by means of the luminous vapors from the mercury.

THE STERILIZATION OF DRINKING WATER BY MEANS OF THE QUARTZ MERCURY-VAPOR LAMP.

The most practical application of the bactericidal power of the ultra-violet radiation from the quartz mercury-vapor lamp is for the sterilization of drinking water.

The difficulties met in the sterilization of drinking water are well known. Innumerable are the processes of filtration or of chemical or physical purification which have been advocated and applied. Some are of little value, others are effective but costly and requiring too extensive areas of land and too much manipulation. For a long while a method has been sought which is not only simple and economical, but also absolute in its efficacy for the sterilization of drinking water under such conditions as occur in the great majority of cases where water is collected for a city's use.

Just such a simple, sure, and economical process has been devised by M. Nogier and myself.[1] This process makes use of the bac-

[1] J. Courmont et Th. Nogier, Sur la stérilisation de l'eau potable au moyen de la lampe en quartz à vapeur de mercure. C. R. Acad. des Sciences, 22 février 1909.

tericidal properties of the ultra-violet rays from the quartz mercury-vapor lamp. * * *

Let us state our method of procedure. At first we used the classical lamp of Kromayer. A metallic tube, provided with several test holes, and closed at one end by a quartz window (fig. 1), was placed face to face with a Kromayer lamp. The tube, filled with polluted water, was thus subjected to the radiation from the lamp for various lengths of time. Samples of the water were taken from each test hole by means of sterilized pipettes. Preliminary tests showed us that the water was very rapidly sterilized to about 0.30 meters from the lamp. Water was therefore permeable to the bactericidal rays from the lamp, and especially to those which killed very rapidly the microbes contained in the water. The most important fact for our purpose was therefore established.

We next had constructed some long lamps (0.15 to 0.30 meters) of the form shown in figure 2. These lamps were hung in the axis of a metallic cylindrical box, about 1.20 meters in diameter, and holding 110 liters (fig. 2). This box could be filled through an orifice in the

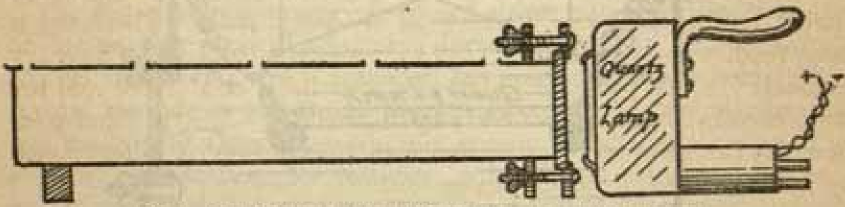


FIG. 1.—Tube for determining to what distance water may be sterilized.

top; a cock was provided at the bottom. Through a large glass window could be safely noted what happened within. The box was mounted on a pivot, so that it could be tilted for lighting the lamp. When we would experiment with thin layers of liquid, a glass basin could be introduced through the window and placed under the lamp.

Finally, a single lamp was placed in the axis of a portion of a tube, 0.60 meter in diameter, so that the walls of the latter were nowhere farther than 0.30 meter from the luminous source. In fact, the distance could have been made much greater; we were convinced of that later.

With this metal box we have made a great number of experiments, which enable us to affirm the rapid and complete sterilization of water, no matter how polluted, provided only that it be transparent. Later my collaborator, Th. Nogier, constructed a set of apparatus for the application of our discovery.

The problem of the sterilization of potable water in private houses and in small public establishments (hotels, barracks, hospitals, etc.)

is solved through the use of such apparatus as we have described using ultra-violet radiations. That of the sterilization of very great quantities of water, as in the case of a city's supply, is now under study but very near solution by the same means.

CAN ALL LIQUIDS BE STERILIZED BY THE ULTRA-VIOLET RAYS?

To this question I must answer, No. With Th. Nogier, I have shown that substances rich in colloidal matter (wine, beer, cider, bouillon, peptonized solutions, etc.) absorb very rapidly the ultra-violet radiation.[1] This radiation will penetrate only a few millimeters or fractions of a millimeter of such liquids, which therefore are not sterilized. Even in the case of the most limpid beer, the clearest

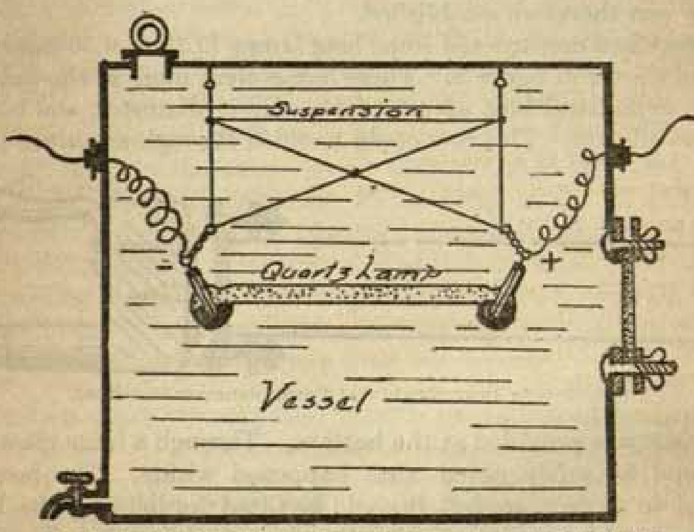


FIG. 2.—Vessel holding 115 liters for experiments on the sterilization of water.

white wine, a peptonized solution as transparent as water, sterilization does not result. Indeed, such liquids may be sterilized in the laboratory either by exposing them in very thin layers or by stirring them so that every portion comes in contact with the lamp. The practical results of such methods are negligible; such sterilization would be too costly.

The water for our method must be clear; a muddy water would not be sterilized. It would have to be filtered before entering our apparatus.

And so clear water is practically the only known liquid permeable to the ultra-violet radiation and easily sterilized by it.

[1] J. Courmont et Th. Nogier, Sur la faible pénétration des rayons ultra-violets à travers les liquids contenant des substances colloïdes. Ac. des Sciences, 2 août 1909.

EXPERIMENTS SHOWING THE STERILIZING OF WATER BY THE ULTRA-VIOLET RADIATIONS.

The sterilization of the water is complete, no matter how polluted it may have been, provided that it is still transparent to the ultra-violet rays. The ultra-violet rays can therefore absolutely free from germs water far more polluted than is ever the case with the natural water which in practice requires purification.

The experiments by means of which Th. Nogier and myself have shown that the sterilization is complete are simple and may be summarized in a few words. We have had built above our laboratory a reservoir holding some 60 liters, filled with city water, but into which we could introduce all the impurities with which we wished to experiment—colon bacilli, typhoid-fever bacilli, solutions of fecal matter, etc. It has often happened that the water contained up to 1,000,000,000 colon bacilli per cubic centimeter, whereas the most impure natural water rarely contains more than 1,000. Our experimental conditions were therefore very exacting, far more so than would ever occur in practice.

The water from the reservoir passed either into our cylindrical box or into another piece of apparatus devised by Nogier. In the former (fig. 2) (135 volts, 4 to 9 amperes) the sterilization was complete in several seconds, a minute at the longest. Indeed, the sterilization was practically almost immediately accomplished, but we wished an absolute sterilization, for instance, not a single colon bacillus in a liter of previously infected water. This required sometimes a minute (at 0.30 meter from the lamp).

The details of the apparatus designed by Nogier were somewhat different; the water flowed without stopping at the rate of 400 to 500 liters per hour (it could go as fast as 1,000 liters) but passed as a thin layer about the lamp. Such would be the conditions of daily use. With Nogier's apparatus sterilization took place almost immediately and was complete. The water, contaminated as above described, came out absolutely free from germs. One could pollute a liter and more and not a single microbe colony would remain.

These truly surprising results were in all points accurate. They have been verified by all those who, following our experiments, have taken up the study, Miquel,[1] Cernovodeanu and V. Henri,[2] Vallet,[3] and others. These conclusions are now well known.

The following results were obtained by Miquel who investigated this method for the city of Paris. Like us, Miquel polluted artificially the water upon which he experimented (apparatus of fig. 3). In Tables I and II are given two of his tests using colon bacilli.

[1] Miquel. Rapport au Préfet de la Seine, 1909.

[2] Cernovodeanu et V. Henri, Etude de l'action des rayons ultra-violets sur les microbes. Ac. des Sciences, 3 janvier 1910.

[3] Vallet. Ac. des Sciences, 7 mars 1910, 25 avril 1910.

TABLE I.—*Experiment on the sterilization of water polluted with B. coli (Miquel).*

July 8, 1909.	Flow per hour, Nogier's apparatus.	Colon bacilli per liter—	
		Before.	After.
	Liters.		
12h 30m	136.5	145,000,000	0 in 200 c.c.
1 00	136.5	145,000,000	0 in 200 c.c.
1 40	138.0	145,000,000	0 in 200 c.c.
2 40	136.8	145,000,000	0 in 200 c.c.
Total and mean	135.1	145,000,000	0 in 800 c.c.

After having made these trials (we cite but two of them), Miquel wished to put the apparatus to a far more difficult test, the destruction of the spores of the bacilli. He polluted the water to be sterilized

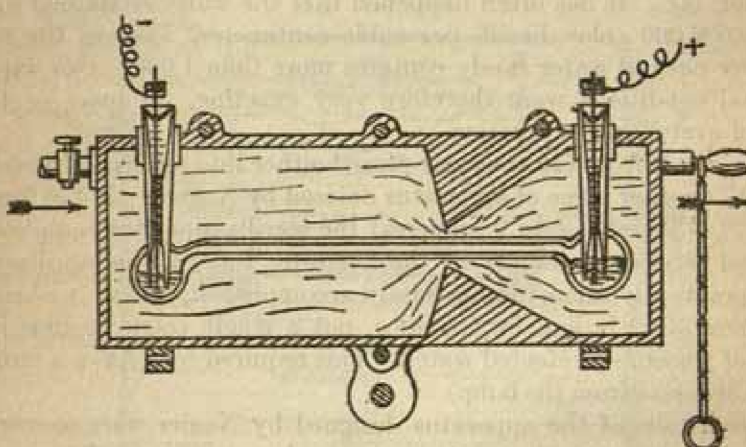


FIG. 3.—Early device of Th. Nogier.

"with a far more resistant species of microbes than the colon bacilli and having very durable spores, related to if not identical with, the

TABLE II.—*Another experiment on the sterilization of water polluted with B. coli.*

Dec. 30, 1909.	Flow per hour.	Temperature of water—		Ordinary bacilli per liter in water—		Colon bacilli per liter in water—	
		Entering.	Leaving.	Before.	After.	Before.	After.
	Liters.	°	°				
12h 30m	180.0	11.1	12.1			55,200,000	0 in 400 c.c.
1 30	180.0	11.1	12.1			55,200,000	0 in 400 c.c.
2 30	180.0	11.1	11.9	3,595,000	0	55,200,000	0 in 400 c.c.
3 30	180.0	11.2	12.1			55,200,000	0 in 400 c.c.
5 30	198.0	11.0	12.0			55,200,000	0 in 400 c.c.
Total and mean	182.6	11.1	12.0	3,595,000	0	55,200,000	0 in 2 liters.

Bacillus mesentericus ruber, whose refractory spores will resist the temperature of boiling water sustained for several hours." In Table III is given a typical example of his results.

TABLE III.—*Sterilization of water polluted with Bacilli mesentericus.*

Dec. 30, 1909.	Flow per hour.	Common bacilli per liter in water—		Bacilli mesenterici per liter in water—	
		Before.	After.	Before.	After.
	Liters.				
12h 30m	46.8	....	....	128,200,000	0 in 400 c.c.
1 00	78.0	3,615,000	0	76,900,000	0 in 400 c.c.
1 30	120.0	....	....	50,000,000	0 in 400 c.c.
Total and mean	81.6	3,615,000	0	85,033,000	0 in 1,200 c.c.

Thus, with water polluted with 128,200,000 bacilli per liter and whose spores will resist boiling for several hours, sterilization is almost immediate (in the time necessary for the water to pass through the apparatus at the mean rate of 81 liters per hour. This experiment should be of special interest to surgeons.

Such are the results. Let me repeat my earlier conclusions, which have been but strengthened: The sterilizing power of the ultra-violet rays emitted by a quartz mercury-vapor lamp immersed in water, face to face with the microbes contained in that water, is so great that the problem of the integral, rapid, and economical sterilization of clear water by this procedure may be considered as solved.

MUST THE QUARTZ MERCURY-VAPOR LAMP BE IMMERSED IN THE WATER?

Should the lamp be immersed in the water or merely placed just above it? Immersion is certainly preferable.

Naturally we tried an apparatus in which the mercury-vapor lamp was placed just above a thin sheet of water for sterilization. The water was sterilized. However, practically and economically, immersion is necessary. The reasons for this are easily given.

The greatest reason is that the utilization of the sterilizing power of the lamp is infinitely more perfect when within the mass of water itself. The water is then in close contact with the source of the rays; all of the rays emanating in all directions are used. A lamp consequently sterilizes a far greater volume of water when it is immersed than when merely placed close to the water—that is surely clear. Economically, therefore, immersion is very advantageous.

And yet further: Immersion seems necessary for the life of the lamp as an emitter of ultra-violet rays. The quartz tube of such a lamp, working in the air, is warmed to some 700° or 800° C. H. Bor-

dier[1] has shown, by means of his chromo-actinometer, that every quartz mercury-vapor lamp gradually loses its power of giving out ultra-violet rays because of the increasing opaqueness of the quartz tube. At the end of a service of about 500 hours, he states, the lamp emits only one-seventh of its original quota of these rays. This defect is without remedy and therefore decisive. If his results are real, then immersion is necessary for cooling the lamp, so as to prevent this change..

Immersion, therefore, has these advantages, economy and long service.

It may be objected that since the immersion cools the lamp, with a given current of electricity there will be a smaller amount of ultra-violet rays emitted. This would be expected in accordance with the results of Retchinsky (1906). However, a lamp thus cooled can be made to emit just as much ultra-violet radiation as a warm lamp (new and unused, see the experiments of H. Bordier) if a greater current of electricity is used. The increased cost of this greater current is practically of small importance compared with the increased efficiency of the immersed lamp where all the radiation is utilized. That is, though an immersed lamp uses a greater amount of electricity, it will sterilize a far greater amount of water.

To sum up: The immersion of the lamp, economically considered, is preferable. If the results of Bordier are confirmed, immersion will be the only method giving a long life to the sterilizing power of the lamps.

NATURE OF THE PROCESS OF STERILIZATION OF WATER BY THE ULTRA-VIOLET RADIATIONS.

The ultra-violet rays kill the microbes in the water by a direct bactericidal action, and not indirectly by a chemical modification of the water.

It might at first have been surmised that the sterilization was due to the production of ozone. That is wholly untrue. With Th. Nogier and Rochaix,[2] I have shown that during the time required for sterilization (only a few seconds or a minute) not even a trace of ozone was produced. If with a longer time it is produced, it would be after sterilization had occurred and have nothing to do with the latter process. It would never occur in practice. The production of ozone is a separate laboratory process. Moreover, sterilization will take place in the absence of oxygen. (Cernovodeanu and V. Henri.)

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[1] H. Bordier, Quantitométrie des rayons ultra-violets. Archives El. Méd., No. 285, p. 306.

[2] J. Courmont, Th. Nogier et Rochaix. C. R. Ac. des Sciences, 12 juillet 1909.

We have obtained similar results as to oxygenated water.[1] Certain investigators have thought that this was produced and caused the sterilization and would itself render the water dangerous for alimentary use. Such an explanation is false and the fear groundless. But a trace of oxygenated water was formed after several hours' exposure to the rays. There was never any oxygenated water formed during the short passage of the water about the lamp necessary for the sterilization.

CHEMICAL MODIFICATION OF THE WATER TREATED WITH THE ULTRA-VIOLET RADIATION.

Chemically water is very little altered by the ultra-violet rays, certainly during the short time required for the sterilization.

With Th. Nogier and Rochaix,[2] I have shown that an exposure of 10 minutes (lamp immersed in a basin of water only a few centimeters deep) hardly altered the chemical composition of the water. The organic matter, ammonia, the nitrites, the nitrates, and other substances dissolved, were almost always in the same proportions at the end of 10 minutes; they were not in the least transformed by the passage (several seconds) in an immersion apparatus, a length of passage sufficient for complete sterilization.

We add that the taste and odor of the water are not altered.

THE WATER THUS TREATED IS HARMLESS.

Although the chemical composition of the water is not changed by the ultra-violet rays, the question as to its harmlessness yet remains. Is the water thus sterilized harmless?

We have fed daily for a month dogs, rabbits, and guinea pigs with water from a Nogier apparatus. Nothing in their general health, in their weight, or their temperature indicated the least ill effect.

THE ACTION OF THE ULTRA-VIOLET RADIATION ON THE FLUORESCENT MATTER CONTAINED IN WATER.

Concerning the processes for controlling the sterilization of water, Dienert[3] has made a very interesting note. There exist in all surface waters fluorescent matter of organic origin. Sterilization by the ultra-violet rays (as well as by ozone or otherwise) causes a notable decrease in the quantity of such matter. Water treated by these rays differs therefore in this respect from the natural river water before its passage through our apparatus.

[1] J. Courmont, Th. Nogier et Rochaix. C. R. Ac. des Sciences, 30 mai 1910.
[2] J. Courmont, Th. Nogier et Rochaix. C. R. Ac. des Sciences, 12 juillet 1909.
[3] Dienert. C. R. Ac. des Sciences, 21 février 1909.

ACTION OF THE ULTRA-VIOLET RADIATION UPON TOXINES.

It may be asked whether the poisons resulting from the microbes and which may be contained in the water (in small quantities, of course) are destroyed by the ultra-violet rays. We are in a position to answer this question.

The toxines such as we have been able to obtain in our bacteriological laboratories can not be destroyed by the ultra-violet rays since they form a liquid very rich in colloidal matter and therefore not transparent to this radiation. It would therefore be necessary to work with very thin strata of the liquid. We have demonstrated this with the tetanus toxine.[1] A very long exposure (one hour under 1 to 2 cm.) scarcely weakened the toxic power of a fibrous culture of the Nicolaier bacilli. If the toxine is sufficiently diluted with water, say 1 part in 2,000, it is neutralized in a few minutes.[2] Cernovodeanu and V. Henri have obtained similar results.[3]

Toxines are, therefore, very sensitive to the action of the ultra-violet rays provided they are so diluted as not to be protected from them by their colloidal state. Such toxines as are apt to be found in potable water will, therefore, be destroyed as well as the microbes.

PRACTICAL APPLICATIONS.

Are the preceding results capable of practical application? Surely. They give rise to a simple and very powerful new method of sterilization, applicable wherever an electrical current (continuous or transformed) is at hand.

The water is not changed or warmed. Nor is it harmful for drinking.

The only condition necessary for the successful sterilization is the transparency of the water; filtration would, therefore, be necessary for muddy water.

Our apparatus can serve three purposes: First, household sterilization (special small-sized apparatus adapted to the supply pipe of an apartment). Second, sterilization for larger establishments (apparatus with greater flow of water placed at the entrance of the water into the building and furnishing sterile water to all the faucets of a hotel, barracks, hospital, school, etc.). Third, sterilization of water for a city (apparatus capable of purifying, if necessary, several thousand cubic meters of water per day; apparatus with which trials are actually being made).

For household apparatus, and even for such as is destined for larger establishments, it is desirable to have some automatic device to stop

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[1] J. Courmont et Th. Nogier. C. R. Ac. des Sciences, 2 mars 1909.
[2] J. Courmont et Th. Nogier. C. R. Ac. des Sciences, 2 août 1909.
[3] Cernovodeanu et V. Henri. C. R. Ac. des Sciences, 2 août 1909.

the flow of water whenever the lamp may not work either through accident or design. Surveillance of the apparatus would then be unnecessary. Only sterile water could be drawn.

Such apparatus as we have described in this article would be of great advantage in certain professions and industries. Surgeons, obstetricians, could have sterile water; pharmacists would feel secure in the preparation of aseptic compounds; brewers would have great advantage in using sterile water. Water thus sterilized could be used by dairymen, beer makers, manufacturers of artificial mineral waters or bottlers of natural water (washing of bottles), etc.

The applications which Th. Nogier and I have made of the bactericidal power of the ultra-violet rays in the sterilization of water have, therefore, an important practical bearing which no one now contests.

[illegible]

THE LEGAL TIME IN VARIOUS COUNTRIES.[1]

[With colored map.]

By Dr. M. Philippot,

Astronomer at the Royal Observatory of Belgium.

TIME IN GENERAL.

Time is measured by the rotation of the earth about its axis. A day is defined as the time taken for one complete rotation. It is assumed that the axis is fixed in the earth and that the rotation is uniform. In order to measure the time taken for this rotation, it is necessary to have reference marks both in the sky and on the earth. For the latter the meridian is chosen, which is the plane passing through the earth's axis and vertical to the place where the time is measured. Two points are used in the sky: The first, the vernal equinox, which is the ascending node (intersection) of the ecliptic upon the equator; the second is the sun's center.[2]

The vernal equinox serves to determine the sidereal day, which is the time between two successive passages of the equinoctial point over the upper meridian of a place. The moment of this passage is taken as the beginning of the sidereal day. The hour angle of the vernal equinox gives the local sidereal time. For the affairs of civil life sidereal time is inconvenient and not used. It is used only for astronomical purposes.

The center of the solar disk is used to define the true solar day. On account of the variable movement of the sun along the ecliptic, the length of the true solar day varies from day to day and it is not feasible to make mechanisms or clocks keeping time with these irregularities. A fictitious sun has therefore been imagined, running its course along the ecliptic at a regular rate and reaching the points of its orbit nearest to and farthest from the earth at the same times as the true sun. A second imaginary sun is likewise supposed to pass along the celestial equator at a uniform rate and to be at the vernal equinox at the same moment with the first fictitious sun. This second imaginary sun is called the mean sun. The day measured by it

[1] Translated by permission, with revisions by the author, from Annuaire Astronomique pour 1912 Belgium.

[2] The ecliptic is the intersection with the celestial sphere of the plane passing through the earth's orbit. The equator is the intersection with the celestial sphere of the plane passing through the earth's equator.

is constant in length and is called the mean solar day. It commences at the moment when the center of the sun passes the upper meridian of the place. Mean solar time is used in all the affairs of civil life and our clocks are therefore regulated to it, not to true solar time. In astronomical use, the beginning of the mean solar day is at the upper passage of the center of the mean sun across the meridian; that is, at mean noon; whereas the civil day commences at the moment of the lower passage (under the earth), midnight. In the first instance, we speak of mean astronomical time; in the second, of civil time. The latter is exactly 12 hours earlier than the former.

The difference between true and mean time is known as the equation of time.[1] The equation of true time is therefore the amount of time which it is necessary to add algebraically to true time in order to get mean time; the equation of mean time, what we must add to mean time to have true time. Accordingly, for the same moment, the equations of true time amd mean time are equal in amount, but opposite in sign. The equation of time varies from day to day, but its greatest value is a little less than 17 minutes.

SOCIAL CONSIDERATIONS.

The principal affairs of daily life go on while the sun is above the horizon; that is, during the daytime. The sun, therefore, controls most of our actions, and it is but natural that it should serve to measure our time. Since the equation of time is always less than 17 minutes, the difference between the true and mean times is of little importance and brings no inconvenience into civil life.

All the general facts just stated apply to any place upon the globe. If each place were to adopt the time appropriate to its own meridian, called local time, the consequent diversity of time would result in great confusion. It is therefore advisable for the convenience of social life to adopt some conventional system of time for all the people of a certain region. Their clocks must be regulated to the time of some conveniently chosen meridian; there must be some standard time fixed either by law or custom. The choice of this depends on various considerations. The principal consideration seems to be that this time shall depart as little as possible from local time. In our choice of the meridian by which to regulate our clocks, we should therefore limit ourselves to one which passes through some central part of the region under consideration; then the difference between the local and the official time will be as small as possible in the extreme parts of that region.

The changing of the time at one locality to that corresponding to the same moment at another place, although a very elementary

[1] The word equation is not used here in its mathematical sense; it is equivalent to the word "error."

process, is one in which the uninitiated is very liable to make errors. As the transformation is generally wished quickly, it is important to reduce the process to its simplest state. Since the time defined by the mean sun is itself purely conventional, it may be used over a considerable region with little inconvenience. Thus, for the whole of a country may be adopted either the time corresponding to some point in its capital or to that of its principal observatory, whichever is preferable.

With the extension of international communication, quite naturally certain countries grouped together in the use of the time corresponding to some place near their center when this did not bring too great discordance with the true local time. But this effected only a partial solution and trouble still remained when it was desired to pass from the time of one group to that of another. An international agreement was necessary for considering this problem and bringing it to a rational solution.

SYSTEM OF ZONES—DIAL OF 24 HOURS.

In 1884, a conference, called together at the initiative of the United States, met at Washington for the purpose of coming to some understanding among the various nations of the world as to the choice of a standard meridian and a universal system of time. Several such systems were proposed. The conference, which, moreover, had no legal power, limited itself, among other resolutions, to recommending the adoption of the meridian of Greenwich and to the expression of their sentiment in favor of a universal system of time without committing themselves to any special system. However, during their sessions the delegates planned a system of hour lunes or spherical sectors, which was already coming into use in certain portions of North America. According to this scheme, the terrestrial globe is divided into 24 sectors, 15° or 1 hour in width; that which extended 7.5° or 30 minutes of time to the west and to the east of Greenwich was adopted as the initial sector. The time in any sector is exactly 1 hour ahead of the neighboring sector just to the west and 1 hour behind that just to the east.

The advantage of such a convention is that at any instant the time indicated by accurately regulated clocks the world over would be the same as to minutes and seconds, differing only in the whole hours; consequently in passing from the time of one place to that of another it is necessary to add or subtract only a whole number of hours. This process consists in combining two numbers of never more than two figures; thus the task is reduced to its minimum.

Evidently such a simple system must finally prevail from its own merits; consequently we find it coming more and more into use.

The conference at Washington also recommended the adoption of a dial of 24 hours, which has the advantage that the use of the abbreviations a. m. and p. m. is unnecessary, as is the case with a dial of 12 hours. Unfortunately the spread of this reform seems to have nearly stopped. It is officially used at present only in Belgium, Canada, Spain, France, Italy, and British India.

The civil day commences at mean midnight. For astronomical purposes a system of 24 hours is universally employed but the zero hour corresponds to mean noon, so that mean astronomical time is exactly 12 hours later than mean civil time. This convention was adopted so that the same date could be used for all the observations of a single night. Although the conference at Washington resolved that as soon as practicable all astronomical and nautical dates over the whole world should commence at mean midnight, astronomers have not so done. English mariners indicate by p. m. the afternoon hours and by a. m. those of the forenoon.

The time corresponding to certain zones have received special designations:

Western European time, or western time, corresponding to the zone of Greenwich.

Central European time, or central time, corresponding to the zone 1 hour east of Greenwich.

Eastern European time, or eastern time, corresponding to the zone 2 hours east of Greenwich.

Eastern standard time, corresponding to 5 hours west of Greenwich.

Central standard time, corresponding to 6 hours west of Greenwich.

Mountain standard time, corresponding to 7 hours west of Greenwich.

Pacific standard time, corresponding to 8 hours west of Greenwich.

Since 1884 many countries have adopted systems of time based upon the zones and the meridian of Greenwich. In the following table are given the principal nations or portions of nations, the meridians adopted, and the differences between their standard times and that of Greenwich. The plus sign (+) indicates that the given difference must be added to Greenwich time in order to obtain the time in a given country; the negative sign (−), that it must be subtracted.

The systems of time in various countries.

Region or country.	Meridian.	Difference.	Remarks.
Africa:			
English south	Greenwich	+ 2h 0m 0s	
German south	do	+ 1 0 0	
Portuguese west	do	+ 2 0 0	Legal time.
Portuguese east	do	+ 1 0 0	Do.
Argentine Republic	Cordoba	− 4 16 48.2	Official time.
Australia:			
Central	Greenwich	+ 9 30 0	
Western	do	+ 8 0 0	

The systems of time in various countries—Continued.

Region or country.	Meridian.	Difference.	Remarks.
Austria-Hungary	Greenwich	+ 1 0 0	Railroads.
Belgium	do	0 0 0	Official time.
Canada:			
Nova Scotia	do	− 4 0 0	Legal time.
New Brunswick	do	− 5 0 0	Do.
Ontario and Quebec	do	− 5 0 0	Do.
Keewatin and Manitoba	do	− 6 0 0	Do.
Alberta, Assiniboia, Athabasca	do	− 7 0 0	Do.
British Columbia	do	− 8 0 0	Do.
Chili	Santiago	− 4 42 46.1	Railroads.
China (eastern coast)	Greenwich	+ 8 0 0	Railroads, ports.
Colombia	Bogata	− 4 56 54.2	
Costa Rica	San Jose	− 5 36 16.9	Railroads.
Cuba	Habana	− 5 29 26.0	Do.
Denmark	Greenwich	+ 1 0 0	Legal time.
Egypt	do	+ 2 0 0	Do.
Ecuador	Quito	− 5 14 6.7	Official time.
England and Scotland	Greenwich	0 0 0	Legal time.
Formosa, Pescadores	do	+ 8 0 0	Do.
France and Algeria	do	0 0 0	Do.
Germany	do	+ 1 0 0	Do.
Greece	Athens	+ 1 34 52.9	Do.
Holland	Amsterdam	+ 0 19 39.0	Do.
Honduras	Greenwich	− 6 0 0	
India and Ceylon	Madras	+ 5 20 59.1	
India, Portuguese	Greenwich	+ 5 0 0	Do.
Ireland	Dublin	− 0 25 21.1	Do.
Italy	Greenwich	+ 1 0 0	Do.
Japan	do	+ 9 0 0	Do.
Korea	Greenwich	+ 9 0 0	Railroads.
Luxembourg	do	+ 1 0 0	Legal time.
Mexico	Mexico	− 6 36 26.7	
Newfoundland	St. Johns	− 3 30 43.6	
New South Wales	Greenwich	+10 0 0	Do.
New Zealand	do	+11 30 0	Do.
Nicaragua	Managua	− 5 45 10	
Norway	Greenwich	+ 1 0 0	Legal time.
Panama	do	− 5 0 0	Railroads.
Peru	do	− 5 0 0	Official time.
Portugal, with Whydah and the islands St. Thomas and Principe.	do	0 0 0	Legal time.
Portugal:			
Azores and Cape Verde Islands	do	− 2 0 0	Do.
Madeira, Portuguese Guinea	do	− 1 0 0	Do.
Mauritius Island	do	+ 4 0 0	Do.
Macao, Portuguese Timor	do	+ 8 0 0	Do.
Queensland	do	+10 0 0	Do.
Roumania	do	+ 2 0 0	Railroads.
Russia	Pulkova	+ 2 1 18.6	Do.
Salvador	San Salvador	− 5 56 32.0	Legal time.
Servia	Greenwich	+ 1 0 0	Railroads.
Spain	do	0 0 0	Official time.
Sweden	do	+ 1 0 0	Legal time.
Switzerland	do	+ 1 0 0	Do.

The systems of time in various countries—Continued.

Region or country.	Meridian.	Difference.	Remarks.
Tasmania	Greenwich	+10 0 0	Legal time.
Turkey	do	+ 2 0 0	Railroads.
United States:			
Eastern standard	do	− 5 0 0	Legal time.
Central standard	do	− 6 0 0	Do.
Mountain standard	do	− 7 0 0	Do.
Pacific standard	do	− 8 0 0	Do.
Alaska	do	− 9 0 0	Do.
Hawaii	do	−10 30 0	Do.
Porto Rico	do	− 4 0 0	Do.
Philippines	do	+ 8 0 0	Do.
Uruguay	Montevideo	− 3 44 51.4	Railroads.
Venezuela	Caracas	− 4 27 43.6	
Victoria	Greenwich	+10 0 0	Legal time.

This table makes easy not only the transformation of a given time to the corresponding time at Greenwich but also its conversion to that of any other place. For instance, when it is 6 hours a. m. in Chicago, in Manila it is 6+6+8=20 hours, or 8 hours p. m.

Upon the terrestrial map given here, the 24-hour zones have been indicated; the central line of the first passes through Greenwich. The countries and territories which have not yet adopted the international system of time are tinted blue, the others rose. For great extents of country like the United States of America it is easy to see at a glance the time in each region.

THE INTERNATIONAL DATE LINE.

It is well known that if we go westward from America to Asia, we find our date one day behind time when we reach Asia; if we travel eastward over the same route we find our date one day ahead of time when we reach America.

In order to avoid this confusion of dates, it is customary, in crossing the one hundred and eightieth meridian from Greenwich, to "jump" a day, if traveling toward the west, and to repeat a day if traveling toward the east. However, because of geographical and political conditions, the international date line does not coincide exactly with the one hundred and eightieth meridian. It is an irregular line so situated that all eastern Siberia has the same date, the Aleutian Islands and Hawaii the same date as the United States of America, and, finally, the Fiji Islands and Chatham Island that of Australia. This line is shown on the accompanying map.

THE TIME SERVICE OF VARIOUS COUNTRIES.

The knowledge of the exact time is of the utmost importance for the transaction of the business affairs of all the nations; especially so for those who have charge of the means of transportation and of rapid communication. This is the case for railroad and telegraph companies and especially for maritime commerce. The captains of vessels, at the moment of clearing for sea, must be able to regulate their chronometers with precision, for upon these instruments depends the determinations, during their voyage, of the geographical positions of their vessels. Accordingly, at the principal ports of the world, a special device (time ball) is used to give the mariners the exact time at known moments. Indeed, in certain ports, special bureaus for this purpose are at the service of sea captains during their stay in port; here they may deposit their chronometers so that their conditions and daily rates may be determined. These time-service bureaus are generally in direct communication with an astronomical observatory, which assures them of the time used.

Various countries of the world have organized, according to their means and local necessities, more or less extensive time services.

Generally, in countries covered by a network of telegraph and telephone lines, a service is established such that the various bureaus connected by wire receive daily the necessary time signal. Those wishing signals can apply to these offices or rely on time furnished to exterior clock dials either at railroad stations or at post offices.

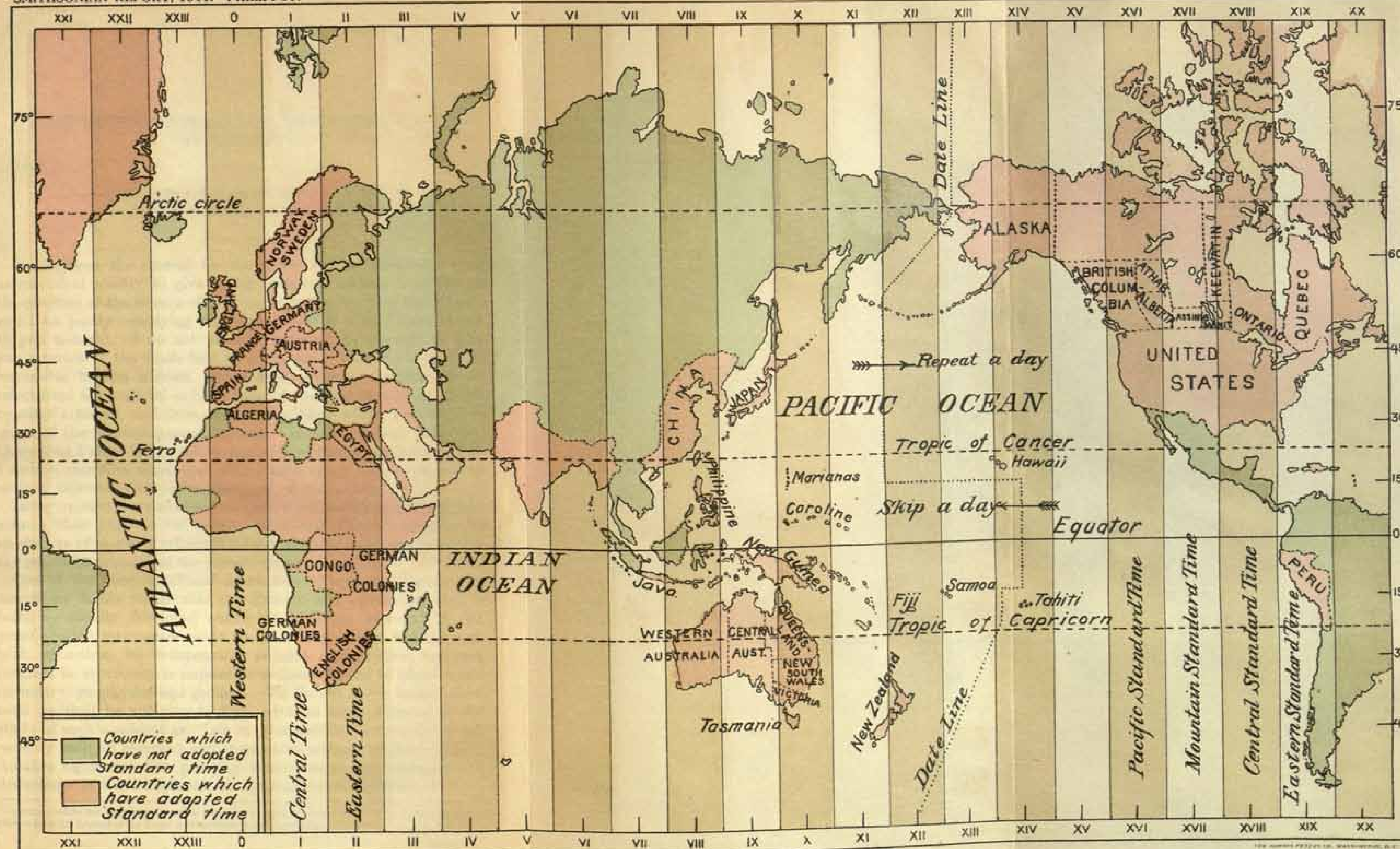
In the United States of America the time is sent over all its immense extent of land. It is transmitted at noon by an accurately regulated pendulum which automatically sends currents of electricity over all the telegraph lines of the country. These currents actuate receiving instruments at all the telegraph stations. The duration of the transmission lasts five minutes. They are sent out from the Naval Observatory at Washington for all the region east of the Rocky Mountains, and from the observatory at Mare Island, Cal., for that to the west. Besides these noon signals, others can be sent during the course of the day when required.

In Portugal the Lisbon-Tapada Observatory furnishes telegraphically the time to the whole country, to the time ball at the arsenal at Lisbon, and to the chronometer station of the meteorological observatory of Ponta Delgada (S. Miguel, Azores).

In Belgium the time is sent daily by telephone to the time-service office at the port of Antwerp where an assistant is detailed to compare such chronometers as may be deposited. An accurate Riefler clock serves to maintain the requisite time and work the time ball. The observatory sends the time also to the central bureau of the tele-

graphs which in turn distributes it to all the telegraph and railroad stations of the kingdom.

The precise time is sent also to the various civic departments as well as to certain private institutions to which it is essential. The transmission of the time is made as follows: As soon as the one in charge of the station is in telephonic communication with some one wishing the time, he states the time he is going to indicate, to the exact minute generally, then, 10 seconds before that time he calls, "attention," and then accurately at the minute he says, "tip." His "tip" is rarely out by two-tenths of a second.



SYSTEM OF TIME IN THE DIFFERENT COUNTRIES.

SOME RECENT INTERESTING DEVELOPMENTS IN ASTRONOMY.[1]

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It has been the custom for the newly elected president of an astronomical society to give in his inaugural address a review of the progress of the science of astronomy during the year just closed, and I am partly complying with that custom in what I have to say to you to-night. I do not propose, however, to attempt to give you a review of the whole field of astronomy. That would be quite impossible in one address. All I shall attempt, therefore, is to select from the material at hand some of the most important results recently attained, and from these again those which are likely to prove of the greatest general interest. In this selection, it is very likely that I shall be guided by my own particular preferences, and I do not, therefore, claim that what I have to lay before you will be entirely representative of the progress of the science.

In my opinion there has been no time in the history of astronomical science when progress has been so rapid and when we seem to be on the eve of so many interesting developments, and I might almost say generalizations, as at the present time.

One of the most significant indications of such development in astronomy is the remarkable coordination and correlation that is being so rapidly developed among the different sciences. A few years ago the astronomer made no use of any science but his own, with, of course, its indispensable adjunct mathematics; but now progress in astronomy is impossible without the aid of physics and chemistry, geophysics and geology. We do not know, indeed, how soon we shall be applying biology, with its allied sciences, in the study of such a subject as "Life in other worlds," on which we had recently such an eloquent and instructive address by Prof. Aitken. Another significant fact pointing toward rapid developments and deductions is the completion or approaching completion of many

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[1] Address before the Royal Astronomical Society of Canada, Ottawa. Feb. 23, 1911. Reprinted by permission from the Journal of the Royal Astronomical Society of Canada, July-August, 1911, pp. 245-265.

extensive researches in our science. Astronomy is, perhaps more than any other, a science which requires long continued and systematic investigations to be carried through with faithfulness, unselfishness, and untiring perseverance before any definite results can be attained. All honor to the astronomers of the past, who spent their lives in making observations of which they themselves could not hope to reap any fruit, and all honor to the astronomers of the present, who are unselfishly collecting data which only a future generation can use. The results of past observations are beginning, in many different branches of our science, to be of inestimable service in unravelling some of the mysteries of the universe.

Let us begin our review of the progress of our science at our own globe, and though one would hardly state that the science of geophysics, as the study of the form and constitution of the earth is called, is astronomy, yet it can not be disputed that only by knowing exactly the dimensions of our earth can we determine the dimensions and distances of the heavenly bodies; and only from a study of the constitution and physical condition of our globe, which must include careful measurements of the spectra of terrestrial elements, can we determine the constitution, the physical conditions, and the radial motions of the heavenly bodies. We have to proceed to the inaccessible by a study of the accessible, and to investigate the the unknown by attacking the knowable, and hence we may safely say that a knowledge of the dimensions and form, the constitution and physical condition, of the earth is a first requisite for a satisfactory study of the heavenly bodies. The science of geodesy, which treats of the figure and size of the earth, is making substantial progress all over the world, and new and more accurate data are constantly being obtained. It is a great satisfaction to me to record that, under the able superintendence of Dr. King, good progress is being made in an accurate geodetic survey of Canada. This work, which has only recently been organized, will furnish at the same time results of the greatest practical usefulness, as well as of the highest scientific value. The allied branches of seismology, terrestrial magnetism, and of the determination of gravity are, along with geodesy, gradually changing and crystallizing our notions of the structure of the interior of the earth from the old idea of a thin crust surrounding a molten interior to that of a solid globe whose density and elasticity increase with the depth, at least for some distance, and which acts on the whole as if it possessed the rigidity of steel. Geodetic measurements show that all local irregularities on the surface such as mountains and valleys are completely compensated for at a depth of about 75 miles. This means that if, from the boundaries of equal areas on any part of the earth's surface, lines are drawn toward the center to a depth of 75 miles from

sea level, the amount of matter inclosed is the same in each. This is called the isostatic layer and acts as if it were floating in equilibrium on a liquid at that depth. The comparatively new science of seismology—in which our observatory is so ably represented by Dr. Klotz, whose method of recording the earth disturbances is, I may say, now being extensively copied—on the other hand shows, from the form and velocity of propagation of earth disturbances, that the interior must be about as rigid as steel. This is further corroborated by measurements, by a kind of seismograph, of the deformation of the solid earth by the luni-solar attraction, which in the sea produces the tides but which also sets up, though, of course, very much reduced in magnitude, a similar effect upon the land. The more recent advances in seismology have been in the direction of improving the sensitiveness of the instruments and the methods of discussion of data, so that we may hope to gradually obtain definite knowledge of the density, rigidity, and elasticity of the interior, layer by layer.

The increase of data in terrestrial magnetism, on the other hand, seems to have complicated rather than simplified the problem, which is, of course, naturally the case when the fundamental underlying cause or principle is unknown; and this, it must be confessed, is the case in this science. There can be no doubt, however, of its ultimate solution; and, indeed, we are beginning to see some glimmerings of light in the magnificent work being carried on at the solar observatory on Mount Wilson, where one of the most recent and wonderful results has been to definitely prove that there are magnetic fields in the neighborhood of sun spots. That changes in the terrestrial magnetic elements and solar activity are in some manner connected has long been inferred from the frequent, nearly coincident appearance of violent magnetic storms following the central transit of prominent sun spots.

We pass naturally, then, from the earth to the sun, to us the most important heavenly body, as on it is dependent all life on our planet. Very great advances have been made in recent years in the study of the constitution of our luminary, and a great deal of attention is now being paid to researches in this most important branch of astronomy. The International Union for Cooperation in Solar Research, a society, or rather group of societies, which was organized about five years ago, and which embraces the workers on the sun in all civilized countries, has done much toward unifying and rendering effective the great amount of material collected. A meeting of this society, which I had the honor and privilege of attending as representing this observatory and also our Royal Astronomical Society, was held last summer at the Mount Wilson Observatory, at which many important

questions were discussed and plans for future work outlined. The work of the union is carried on by several committees, which report at the triennial meetings.

Probably the most important action taken was the adoption of a new system of wave lengths of light. The system in use for the last 20 years was introduced by Rowland, the values being obtained from measurements of spectra made with concave gratings. This system was far in advance of previous ones and was for a long time considered practically perfect. More recent investigations have shown, however, that not only were his absolute values in error, every wave length being too great by about 1 part in 30,000, which is not a matter of much moment, but that also—a much more serious question—there were relative errors of the order of about 1 part in 100,000 among the different lines. These errors, due to unknown defects in the gratings, were only discovered when new measurements were made by a different method, that of interference. The new primary standard was first determined by Michelson in 1892 by actually counting the number of waves of the red line in the spectrum of cadmium in a known fractional part of the standard meter. He found that there were 1,553,163.5 waves in a meter, equivalent to a wave length 0.00064384722 mm., or, as it is usually written, 6438.4722Å. This value has more recently been confirmed by Fabry and Perot and is accepted as the primary standard of the new system. Secondary standards are composed of the wave lengths of 50 lines, in the arc spectrum of iron between $\lambda 4282$ and $\lambda 6495$, which have been independently measured by interference methods by three observers—Fabry and Buisson at Marseille, Eversheim at Bonn, and Pfund at Baltimore. The accordance of these measures is so good that the range is generally less than one part in a million, and the mean of the three is certainly correct, considerably within that margin of error. From these secondary standards tertiary standards are to be obtained by interpolation from grating spectra, and after these tertiary standards have been obtained new measures of the wave lengths of all lines in solar and terrestrial spectra will be required.

The importance of this work in solar and stellar investigations can not be overestimated, as many important results depend on the accuracy of wave-length values, and incorrect values may lead to erroneous conclusions. This is an instance of what I previously said of the necessary interrelation of astronomy and physics and the impossibility of successfully attacking modern astronomical problems without the aid of the allied sciences.

One of the important conclusions reached by the committee on sun spots was the practically unchanging character of sun-spot spectra. To this may be added the fact, conclusively proved by

Prof. Hale, that the umbra of sun spots is at a lower temperature than the rest of the sun's surface, and that in sun spots, as first found by Prof. Fowler, of London, we have the spectra of some chemical compounds, such as titanium oxide, magnesium and calcium hydride, further showing that the temperature is sufficiently reduced to allow the formation of such compounds, which do not appear in the normal solar spectrum. Again, we have the discovery of Evershed, of Kodaikanal, India, of radial motions of the vapors around sun spots, and the final discovery by Hale that many, if not all, sun spots are surrounded by whirls, and that electrically charged particles, which, it has been further shown, are negatively charged, are carried around by these whirls and produce the magnetic field which is shown to exist around sun spots.

At the high temperature of the sun, magnetism as we know it can not exist, and the field must be produced by such whirls or vortices. The manner in which the magnetic field in sun spots was detected and proved is a splendid example of experimentation to test scientific deductions and a full justification of the expenditure on the powerful apparatus needed for such work. The whirls surrounding sun spots are shown on photographs of part of the sun's surface in the light given by the red line of hydrogen. Such photographs are made by the spectroheliograph, an instrument which enables us to photograph the sun's surface in the light of different gases or vapors, and hence records the distribution of these vapors. The great resemblance between these whirls and the lines of force around a magnet, as shown by iron filings, led Prof. Hale, the inventor of the spectroheliograph and the discoverer of this effect, to suspect the presence of a magnetic field; and the next question was to verify this suspicion. It was found several years ago by Zeeman that if a luminous vapor is produced between the poles of a magnet, many of the lines of its spectrum are widened. Prof. Hale found that the spectrum of a sun spot, with the high dispersion available on Mount Wilson, showed some of the same lines widened, strengthening his suspicion. Furthermore, when the widened lines produced by a magnetic field in the spectrum of a luminous vapor are examined through a polarizing apparatus, many of the lines are split up into doublets, triplets, quadruplets, or even sextuplets; and a similar test applied to a sun-spot spectrum gave a similar, though much weaker, effect, conclusively proving the presence of a magnetic field. Comparison showed that its strength was about one-quarter of that needed to saturate iron, too weak to produce any magnetic disturbance on the earth, and therefore incapable of explaining the frequent coincidence of magnetic storms and large sun spots.

The fact that sun spots are at a lower temperature than the rest of the photosphere has been corroborated by the work of Prof. Abbot,

who, in his determination of the solar constant (the amount of heat received from the sun), shows that this is 1 or 2 per cent less at sun spot maximum than at minimum. The absolute amount of the sun's heat at the surface of the earth is 1.9 calories, which may be more simply stated as the amount of heat per square centimeter which will raise 1 cubic centimeter of water 1.9° C. or 3.5° F. in temperature in one minute, if the atmospheric absorption is neglected. It has also been proved by Prof. Abbot that there are irregular variations in this quantity, and it is hoped that a knowledge of these variations may be of value in helping to predict temperature and meteorological changes on the earth; a problem whose solution, even with all the advances in science, seems as far off as ever.

Another interesting problem, which at the meeting of the solar union was advanced a stage, is the determination of the solar rotation by the displacement of the spectral lines at opposite limbs of the sun. Owing to the rotation of the sun on its axis in about 26 days, one limb approaches and the other limb recedes from us, with a velocity at the equator of about 2 kilometers per second. If the spectra of the two limbs are brought side by side on the plate, the lines of the former will be displaced to the violet, of the latter to the red; and with a high dispersion spectrograph this displacement will be quite noticeable, of the order of one-tenth of a millimeter. Some work has been done on this problem by Duner at Upsala and by Halm at Edinburgh visually, and more recently by Adams at Mount Wilson photographically. Besides determining the rate, and the law of decrease of rotation with different latitudes, there are other interesting problems, such as variations of the rate for lines of different substances, which require solution. A combined attack by six institutions, of which the Dominion Observatory is one, on different well-distributed regions of the spectrum has been arranged, and, in addition, each observer is to measure a common region for comparison of results and removal of systematic error.

Besides these definite advances, much other work in the distribution of the gases and metallic vapors over the photosphere, in comparing the spectra of the limb and center of the sun and along many other lines, has been recently accomplished; and we may confidently look for rapid development and increase of our knowledge of the constitution of our luminary in the near future.

Although the study of the sun is most intimately connected with that of the stars, which was recognized at the solar union by the appointment of a committee to discuss the question of the classification of stellar spectra, yet we may perhaps turn for a moment to the other members of our solar system and see if any new light has recently been thrown upon the interesting question of conditions on other planets. The perennial question of the objective existence of

the fine geometrical markings on Mars, commonly called canals, has been, during the last opposition of 1909, strenuously and ably supported by Lowell and one or two adherents, and equally strenuously and ably combated by many astronomers, chief among whom was Antoniadi. As is well known, the majority of astronomers are unable to see these fine sharp lines, although plenty of other detail is visible. During the last opposition photography was used to a much larger extent, but I question whether it has settled the matter. Lowell says the principal canals show on his photographs, while others are unable to see them. The only way this question can be settled is, as Aitken suggested, for Lowell to invite some well-known observers, such as Barnard, Burnham, and others, to Flagstaff at the next opposition and let the whole question be fought out.

Another disputed point is the question of water vapor on Mars. The detection of this water vapor depends upon the visibility of a small band or group of lines in the red end of the spectrum produced by the presence of water vapor. Slipher, Lowell's assistant, photographed the spectrum of Mars and then the spectrum of the moon. The light from Mars, which is, of course, reflected sunlight, passes twice through Mars' atmosphere and then through the earth's atmosphere. The light from the moon, which has no atmosphere, passes through the earth's atmosphere only. If now there is water vapor in appreciable amount in the atmosphere of Mars this band should be stronger in the spectrum of Mars than in that of the moon. Slipher found that it was stronger in the Martian spectrum, but unfortunately some little time elapsed between the two exposures, and there is a possibility that the greater strength of the band was due to change in the amount of water vapor in the earth's atmosphere. Director Campbell, of the Lick Observatory, considered the question of sufficient importance to organize an expedition, carrying instruments to the summit of Mount Whitney, elevation 14,500 feet, at which altitude only one-fifth of the earth's water vapor is above and four-fifths below. Any small difference between the moon and Mars bands will show relatively more conspicuously than at the elevation of Flagstaff, which is about 7,000 feet. His photographs were made within a few moments of one another, and with Mars and the moon at the same altitudes, and are, hence, directly comparable. I saw them myself last summer at Mount Wilson, and I can say that there is no discernible difference in the vapor bands in the two spectra. The bands are very weak and evidently due to the small amount of water vapor present in the earth's atmosphere above Mount Whitney. Campbell comes to the conclusion that there is no spectroscopic evidence of the existence of water vapor on the planet. Although he specifically states that he does not contend that Mars has no water vapor he says that it is too slight to be detected by the spectroscopic

method and is probably considerably less in quantity than that present in the earth's atmosphere above the summit of Mount Whitney.

The question of the suitability of Venus for organic life seems to depend upon the determination of its rotation period. If, as is now mostly believed, it always turns the same face to the sun then the one side will be baked and the other frozen. If, on the other hand, it turns on its axis in about 24 hours, then it is practically certain to be in a condition to support life. The only possible test between the two theories is the spectroscopic one, as in the solar rotation, by observing the line shift at opposite limbs. In this case, however, we have difficulties owing to the bad seeing at the comparatively low altitude of Venus and the disturbance of the image, so that it is difficult to determine in what region of the planet the spectra were made.

The advent of Halley's Comet proved possibly as disappointing to astronomers as to the general public, for it did not show many unusual features, and not much additional knowledge concerning the nature of comets was obtained. The motion of a detached part of the tail, as determined from three photographs at Williams Bay, Honolulu, and Beirut, showed the presence of an accelerating force, as its velocity relative to the head increased from 23 miles to 37 miles a second in seven or eight hours. To my mind the most remarkable feature of its return was the accuracy of the computation so successfully carried through by Messrs. Cowell and Crommelin, in which they predicted its perihelion passage within less than three days. When considered in connection with the large number of disturbing elements to be taken into account and the exceedingly complex and cumbersome calculations required, their ephemeris was a marvelous piece of work, and they well deserved the recognition it received.

Before discussing some of the advances in our knowledge of the sidereal universe it has seemed desirable to refer to the improvements effected in apparatus for observation. At the head comes naturally the large reflecting telescope with a mirror of 60 inches diameter, recently installed on the summit of Mount Wilson, California, at an elevation of 5,886 feet. This telescope was designed and the mirror was figured by Prof. G. W. Ritchey, superintendent of instrument construction of the Solar Observatory, who also is doing much of the photographic work with the telescope. I had the privilege of carefully examining the mechanism and of observing with the telescope, and it is certainly a superb instrument. The optical properties are practically perfect; and the difficulty of temperature changes, the most troublesome met with in reflectors, has been successfully overcome. The mechanical construction is also unexcelled, and the instrument, although its moving parts weigh 23 tons, drives with the greatest smoothness and ease. The most magnificent photographs

of star clusters and nebulæ ever made have already been obtained with the instrument, and its light efficiency in spectrographic work is wonderful. It can obtain in five minutes a spectrum of a fifth magnitude star that requires with our refractor over an hour. It is no wonder that such an instrument excited the envy of all astronomers who saw it, and Prof. Ritchey was pardonably proud of his masterpiece.

We turn from this to, comparatively speaking, a rather insignificant instrument, for measuring the brightness of the stars. The subject of stellar photometry has always been a difficult one, as all the photometers hitherto devised have depended upon eye estimates or comparisons of the relative brightness of the star with either another star or an artificial light, made by ingenious devices to resemble and be brought close beside the star to be measured. There is, in all such methods, the possibility of psychological errors, and it has not been possible to obtain, except in special cases, results with a lower probable error than about one-tenth of a magnitude. In the case of the comparison of two stars brought into the one field and equalized in intensity by polarizing apparatus, the probable error is, perhaps, as low as three or four hundredths of a magnitude. In another method also, in which out-of-focus images of the stars are photographed, the density of the resulting disks have then to be measured by a photometer and we have errors of the same order. The new method, however, does not depend on eye estimates but on the change in electrical resistance of the element selenium when exposed to light. If a selenium cell is placed on the end of a telescope and an image of a star to be measured thrown on it, the change of resistance can be measured by a Wheatstone bridge arrangement and very accurate values of the brightness obtained. Prof. Stebbins, who has been working with much ability and energy on this problem for the last three years, deserves much credit for his success in a difficult research. He has recently made new measures of the light curve of the well-known variable star Algol, and the probable error of a determination at maximum is $\pm$ .006 mag., at minimum $\pm$ .023 mag. The accuracy of his observations enabled him to detect a secondary minimum which had never before been seen and which indicates that the companion whose eclipse of the bright star causes the variability is not dark but light. Taking the most probable value of the parallax or distance of the star, he finds that the bright star, which has about the same diameter as the sun, gives 240 times as much light, while the faint hemisphere of the companion gives 16 and the bright hemisphere 28 times the light of the sun.

Such results as these are most interesting, and it is only by combination of several different methods, in this case of the light variation by a photometer, the orbital elements by the spectroscope, and the

distance by parallax measurements, that we can obtain them, and that we can hope to increase our knowledge of stellar systems. Another interesting variable is *u* Herculis, whose orbital elements were determined by Schlesinger at Allegheny from radial velocity measurements with the spectroscope. He finds that the brighter star is about 5,000,000 miles in diameter—six times our sun—is 7.5 times as massive but only one twenty-seventh as dense as the sun. The fainter star is 2.9 times as massive but only one-seventieth as dense. The parallax of this star is not known, but if it is as luminous as Algol the brighter star must give out about 8,000 times as much light as the sun.

There has been a very marked advance in recent years in stellar spectroscopy, particularly in the line of the determination of the radial velocities of the brighter stars, and several observatories are now engaged in this work. Accurate radial velocity measures were first obtained by Prof. Campbell at the Lick Observatory in 1896 or 1897, and for many years he was practically the only one doing that work. Campbell's work has been the determination of the radial velocity of all stars in the sky, containing spectra with well measurable lines, which are brighter than the fifth visual magnitude. This work is now practically completed, and a preliminary value of the direction and magnitude of the sun's motion in space, with numerous other interesting and valuable deductions, are just being published.

In his work and that of Frost, of the Yerkes Observatory, who is measuring the radial velocities of Orion type stars, many spectroscopic binaries—stars whose radial motion varies, and which are hence accompanied by invisible companions, as distinguished from visual binaries where both stars are seen—have been discovered, and it is believed that not fewer than one in three of all stars must have a companion of approximately the same size, thus eliminating in these cases all possibility of a planetary system like our own. Great advances have been made in determining the orbits, the character of the motion around one another, of these binaries, and the two institutions most active in this line of work are the Allegheny and the Dominion Observatories. Of the 70 spectroscopic binary orbits determined, our observatory has obtained 16, which, considering that the aperture of its telescope is only half or less that of others engaged in the work and that it has been established only a comparatively short time, is a creditable showing. The great strides made in the determination of spectroscopic binary orbits has led to no less than three summaries of the results, containing deductions of important conclusions from them, by Campbell, Schlesinger, and Ludendorff. I have not time to enter into the results deduced from these discussions except to say that it was shown that most binary systems probably originate from a revolving

parent nebula which, while condensing, separates into two masses, and that these masses, as condensation proceeds, and by the influence of tidal action, gradually increase their distance from one another, this being accompanied, of course, by an increase in the period and also, as the results show, by an increase in the eccentricity—a greater departure from the circular form—of their orbits. There is no sharp line of distinction between spectroscopic and visual binary orbits except that the latter have much longer periods and generally higher eccentricities.

The information already obtained, and that which will in the near future be obtained, about these spectroscopic binary systems, has a most important bearing on the problem of the constitution of the sidereal universe, and we must now come to consider recent progress in our knowledge of the extent and form and motion of its parts. This is certainly the most important problem in astronomy, as practically all observing data, whether astrometrical or astrophysical, whether dealing with the absolute positions, proper motions, and radial velocities of the stars, with their distances, dimensions, and densities, with their evolution and spectral type, or with the investigation of variables and binary systems, are all either directly or indirectly obtained with this end in view and all are, undoubtedly, directly of use in its solution. As I said in the early part of the paper, there has been no time when so many different investigations were converging toward this end, and I will try and give you some details of the principal results.

One of the most striking of recent advances has been the discovery of star drifts and star streams in the sidereal universe. These have been discovered by statistical methods applied in the discussion of the absolute positions and proper motions of stars and also by the aid of their radial velocities. The one man to whom we owe more than any other the development of this work is Prof. Kapteyn, who is director of what is called the astronomical laboratory of Groningen, where the instruments of research are not telescopes and spectroscopes but measuring machines and mathematical tables, where no observations are taken but photographs are measured and observations discussed. I will try and give you a general idea of the present state of our knowledge in regard to the motions of the stars. Although we call them the fixed stars the term is a misnomer, for they are all in motion. We can measure this motion in two components. First, the motion at right angles to the line of sight, across the sky, determined from successive observations of the star's position in the sky and measured by the change of position in seconds of arc in a year or a century. The change of position varies between about 9″ per year and 0; the average annual proper motion, as it is called, for first magnitude stars being ¼″ and for sixth magnitude about $\frac{1}{16}$″

or 4″ per century. Second, the motion in the line of sight, or radial velocity, measured by the spectroscope, which again varies between 0 and about 250 kilometers per second, the velocity of a faint star in the Southern Hemisphere determined last year. It is evident that in order to get the true direction and velocity of a star we must know, in addition to its radial motion, its velocity in kilometers per second at right angles to the line of sight. If its proper motion is known this can be readily computed when we know its distance, and hence we can obtain the direction and magnitude of its motion.

In determining these motions we have to remember that we are on a moving body, the earth, which has a velocity of revolution around the sun of about 20 miles per second, and we must also remember that the sun, which is one of the stars, is also in motion. That this is the case has long been recognized, and the direction of this motion was determined from the proper motions of the stars by Sir William Herschel over 100 years ago. The method of doing this can be readily understood, for if we imagine the stars to be moving in all directions at random, it is, nevertheless, evident that in the portion of the sky which we are approaching, the general tendency will be for them to open out, while they will tend to close in in the opposite direction, and to drift backward at the sides. Hence, if the motion of the stars is at random, it is only a question of mathematics to determine the direction and magnitude of the sun's motion in space.

Over 20 different determinations, based upon the proper motions of different numbers of stars, have been worked out, which all agree reasonably well in showing the sun to be moving toward the dividing line between Lyra and Hercules just a little south and east of the bright star Vega. This point has shifted around considerably between Hercules and Lyra, but the last determination, from Boss's Preliminary General Catalogue, issued only last year, places it where I have just stated (R. A. 270.5°, Dec. +34.3°).

If we consider, on the other hand, a determination of the apex of the sun's way, as this point is called, derived from the radial velocities of stars, we find it to be in a somewhat different position. We have had three or four determinations of the solar apex from radial velocity measures; but none of these need be considered here except that obtained last year by Prof. Campbell, director of the Lick Observatory, the pioneer and foremost exponent of accurate radial velocity determinations, whose methods have been universally followed and their accuracy never excelled. I place the results of his 14 years' work as the most important astronomical result announced during the year. In determining the velocity and direction of the sun's motion, the radial velocities of 1,073 stars brighter than the fifth magnitude, well distributed over the sky, were used, 1,020 of which

were determined by spectrographs at Lick and Santiago, 40 were obtained from other observations and 13 were of nebulæ visually observed by Keeler. The position of the apex, or point toward which the sun is moving, is somewhere, about 7° south of that obtained from the proper motions of the stars (R. A. 272° ± 2.5°, Dec. 27.5° ±3°), nearly 10° due south of Vega.

Of the two determinations, the one obtained from a discussion of the proper motions is of the greater weight, for two reasons—first, the method is more suitable for determining direction; second, the number of stars employed is considerably greater.

On the other hand, the discussion of radial velocities gives us a much more reliable value of the velocity of the solar system than proper motions. The velocity from Campbell's discussion comes out as 17.77 kilometers (11 miles per second), and this is undoubtedly very near the truth.

Many other interesting conclusions were reached by Campbell, but time will not permit me to dwell on them, and we must consider further the question of motion of the stars.

It is evident that if a comparison of the motions of the stars shows the sun to be moving toward Vega, then the apparent motions of the stars themselves must, on the whole, be to a point on the celestial sphere directly opposite. Such a motion of the stars, made up not of motions all in the one direction, but of motions in all directions with a preponderance in one direction, is called a drift of the stars; and there is thus a drift of the stars due to the solar motion toward or having as apex a point in the Southern Hemisphere nearly opposite Vega, with a velocity of about 11 miles per second.

About five years ago Kapteyn, from a careful examination and discussion of the proper motions of the Bradley stars, came to the conclusion that there is not one drift of stars, that due to the solar motion, but two drifts, moving in different directions. This conclusion has been confirmed by Eddington, Dyson, Hough, and Halm, and the latest values by Eddington from the proper motions of Boss's Catalogue place the apexes of these two drifts as follows: Drift I toward the constellation Lepus between Canis Major and Orion, about 10° west of Sirius (R. A. 90.8°, Dec. −14.6°; drift II toward the southern constellation Pavo or away from the northern constellation Camelopardalis (R. A. 287.8°, Dec. −64.1°). He finds that drift I is moving apparently nearly twice as fast as drift II and contains about 60 per cent of the stars.

When, however, allowance is made for the solar motion we find that these two drifts are moving, one toward the constellation Orion about 8° northeast of α Orionis (Betelgeux), R. A. 94.2°, Dec. +11.9°, and the other in the opposite direction; exactly as if we were in the midst

of two sidereal systems interpenetrating one another—a very fascinating hypothesis.

This hypothesis of the two drifts deduced from a discussion of the proper motions of the stars is strongly confirmed by Campbell's investigation of the radial velocities. We should expect, if there are two drifts of stars toward and from this point in Orion, that the radial velocities of stars in this and the opposite point of the sky should be greater than at points at right angles to these directions. Campbell found that the velocities in the vertex and antivertex are 33 per cent greater than at points about 90° from these.

Besides the two drifts of stars we have smaller groups of stars in different regions of the sky, all the stars in a group having a motion approximately in the same direction and of the same velocity. Such groups are quite different from drifts where there is only a preponderance of motion in one direction, and are called star streams. Perhaps an analogy may help to make the matter of star drifts, star streams, and solar motion clearer. If you imagine yourself walking in a park where there are many people moving about at random it is evident that, speaking generally, the space between those you are approaching opens out, between those you are moving away from closes in, while people at either side, on the whole, appear to move backward. The apparent motion of the mass due to your own motion is analogous to the star drift due to the solar motion. If among the people there are, say, a company of soldiers or a picnic party moving in a given direction we have an analogue of a star stream.

It was first pointed out by R. A. Proctor, about 40 years ago, that five of the stars of the Dipper have proper motions in the same direction and of approximately the same magnitude; and this stream has within the last two years been thoroughly investigated by Ludendorff, of Potsdam, who determined their radial velocities, and more recently by Herzsprung, who found that the stars Sirius and α Coronæ Borealis, as well as some fainter stars, also belong to the group. It is a comparatively simple problem mathematically to determine the mean parallax or distance of such a stream when we know the convergent point or apex and the proper motions of the group with the radial velocities of two or three of them. The parallax of the five stars of the Dipper comes out as .0352″, which is equivalent to a light journey of about 90 years, while they are all moving at a velocity of 20 kilometers per second toward a point in the southern part of the constellation Sagittarius ($\alpha=303.2°$, $\delta=-36.6°$). It is shown further that the stars of this group are at the same order of distance apart as the sun is from some of the nearest stars—about 20 or 30 light years—and that they are about 100 times as bright as the sun.

Another group or star stream has recently been found in the constellation Taurus by Prof. Boss, consisting of 39 stars, forming a

roughly globular cluster about 15° in diameter. These stars are all moving with a velocity of about 40 kilometers (25 miles) per second toward a point in the northeastern part of Orion, about 35° from the center of the group. Their parallax, computed as before, is 0.025″, or 130 light years distant. Boss has calculated that in 65,000,000 years they will form a globular cluster about 21′ in diameter and of magnitudes 9 to 12.

The most recent discoveries in star streams were given by Prof. Kapteyn, at the solar union meeting, on Mount Wilson, last August. He has found, by selecting from Boss's Catalogue all the stars of the Orion type characterized by the appearance of helium lines in their spectrum and so called since most of the stars in the constellation of Orion are of this class, that in a large region of the sky they are moving in nearly the same direction and at nearly the same rate. This region contains the constellation Scorpio and Centaurus, covering 4,500 square degrees and extending roughly from 12^h to 18^h R. A. to and from Dec. 0° to −60°. In another region of 1,300 square degrees in Perseus from 2^h 50^m to 4^h 30^m R. A. and from +15° to +55° in Dec., all the stars of the same type are moving in a different direction. When motion of the sun among the stars is allowed for, Prof. Kapteyn finds that these apparent motions are equivalent to streams moving in exactly opposite directions and at equal rates. He finds these stars are very distant from the sun—from about 125 to 500 light years.

It is evident that the sidereal universe is a complex structure and having complex drifts and motions of stars and systems of stars in its part. We may be able to get a further idea of the magnitude of the problem by considering some of the recent results obtained for stellar distances. We all know, of course, that the nearest fixed star, α Centauri, is slightly over 4 light years distant, about 275,000 times the distance of the earth from the sun, 25 millions of millions of miles. There has been a very marked advance in recent years in the determination of the distances of the stars, so that we now know with reasonable accuracy by direct methods the parallax or distance of about 200 stars. There are several indirect methods, one of which has been mentioned in connection with star streams, which give us what may be called mean or average parallaxes of groups of stars. I have not time to go into these methods, but it may suffice to give a couple of tables indicating in a general way the average distances of stars of different magnitudes and of different types. If we take the blue stars, those of the second magnitude are on the average 100; of the fourth, 200; of the sixth, 400; of the eighth, 800; of the tenth, 1,600; and so on, light years away, doubling for a change of 2 magnitudes, while if we consider stars of different types we have from a

recent paper of Kapteyn's that the average distance of fifth magnitude stars is for the helium stars 500 light years; for the hydrogen, 300; for the solar, 130; for the late solar or fluted spectra, 270; and for the carbon or deep red stars, 4,500 light years.

Recent spectroscopic studies of some of the nebulæ have indicated, from the fact that their spectra are somewhat similar to our sun, that they are probably composed principally of solar type stars. If we consider the Great Nebula in Andromeda, which is a typical example, we are forced to the conclusion, if such is the case, that it must be thousands of light years distant and probably forms a universe by itself. Indeed, it is practically certain that the globular clusters, like that in Hercules, which some of you have seen through the telescope, are compact aggregations of stars whose average distances from one another are of the same order as the distances of our sun from the nearer stars, say 5 to 20 light years, and, in that case, the clusters are of the order of 10,000 light years distant from us.

It is quite certain then that the visible sidereal universe is of almost inconceivable dimensions and of a structure so complex that, although we are gradually obtaining a knowledge of some of the motions and some idea of its form and arrangements in part, we are yet far from any clear notion of its constitution. Yet when we consider how the human mind, though inhabiting for only a few years this minute planet, accompanying a comparatively insignificant star of the system, has been able to reach out to the inconceivable depths of space and reduce some of the confusion of stars to orderly systems, has been able to deduce the laws which govern these systems, thus unifying, in a certain degree, all the wonderful phenomena of suns and planets, comets, stars, nebulæ and clusters, into one whole, we do not lose hope that eventually it will be able to much further unravel the mystery of the universe.

THE AGE OF THE EARTH.[1]

By J. Joly, F.R.S.

The recent contributions to the data bearing on the subject of the age of the earth have strengthened the evidence derived by two very different methods of computation; that based on the study of solvent denudation and that based on the accumulation of radioactive waste products in minerals. While the indications of both lines of inquiry seem individually rendered more definite by these advances, the divergence in their final results have, if anything, become intensified. I propose in the following pages to review the opposing methods, as briefly as the many details permit, and to discuss the possibility of reconciliation.

THE AGE OF THE OCEAN DERIVED FROM SOLVENT DENUDATION.

Three recent contributions to this subject have appeared: Prof. Sollas's Presidential Address to the Geological Society of London, 1909; a paper on "A preliminary study of chemical denudation," by F. W. Clarke (Smithsonian Miscellaneous Collections, vol. 56, June, 1910); and a paper by G. F. Becker on "The age of the earth" (Smithsonian Miscellaneous Collections, vol. 56, June, 1910).

These recent discussions chiefly center round the ascertainment of the true present rate of supply of sodium to the ocean. The limitations of the method are also discussed.

My own original estimate of the age of the ocean [2] was based on the only data then available—the estimates made by Sir John Murray of the average chemical composition of river water and the probable total annual discharge of the rivers into the ocean. Calculating from its estimated volume and mean chemical composition the mass of sodium now in the ocean, and dividing this by the calculated amount of sodium entering annually from the rivers, the uncorrected age of 99.4 million years was obtained. To this I applied certain corrections, to some of which I shall refer later. The final result of these corrections left the age as from 80 to 90 million years.

[1] Reprinted by permission, after revision by the author, from the Philosophical Magazine, London, S. 6, vol. 22, No. 122, September, 1911, pp. 358-370.

[2] Trans. Roy. Dublin Soc., vol. 7, 1899.

Prof. Sollas approaches the question by a recalculation of the average amount of sodium discharged by the rivers annually. He finds that the added results available, as derived from the rivers of North and South America and Europe, give the uncorrected age as 78 million years. After a careful and detailed discussion of the corrections, Sollas concludes that the age lies between 80 and 150 million years; the latter figure being based on extreme assumptions.

Clarke bases his discussion of the question upon what he terms the denudation factor, i. e., the number of metric tons annually removed in solution from a square mile of drainage area. This is estimated for a number of important rivers of the world, accounting in this way for a drainage area of 28 millions of square miles out of the total of about 40 millions which drain to the ocean. The mean value found for the denudation factor is 68.4 tons. Assuming that this denudation factor is a fair average for the whole, the entire matter in solution discharged into the ocean in a year is 2,735 millions of tons. From the chemical analyses of this saline matter for the several rivers, an average composition for each continent is found. When this is weighted for the quantity of water contributed by each continent, a final weighted mean composition is obtained which may be applied to determining the integral of the sodium passing annually from rivers to ocean. In this way it is found that 175,040,000 metric tons of sodium are annually discharged into the sea. Clarke next finds the total amount of sodium in the ocean to be $14{,}130 \times 10^{12}$ tons. My own results were based on a slightly higher value—$15{,}611 \times 10^{12}$ tons. From his figures, Clarke now gets the uncorrected age as 80,726,000 years.

Although the numerous analyses which go to build up this result are not of equal value, there are certain satisfactory features in the computation.

It is explained by Clarke that in the wonderfully detailed analyses of the Mississippi by Dole and Stabler, taken along with their work on other great rivers of North America and with the observations of Forbes and Skinner for Colorado, data have been obtained for the United States which are not likely to be much altered by any future analyses. Twenty-two river basins enter into the mean for the United States, giving a mean denudation factor of 79 tons. For the rest of North America an estimate only is possible; but, for reasons given, Clarke concludes that "if we assume that 6 millions of square miles of North America lose 79 metric tons in solution per square mile per annum, and that the composition of the saline matter so transported is that found for the United States alone, we shall not be very far from the truth." Possessing thus a standard based on the drainage of a great continent, we feel confidence in our criticism of other data. The quantity of water thus dealt with is rather more

than one-fourth of that supplied by the entire drainage areas of the earth.

It will be seen from the tables given by Clarke that the mean denudation factor of 68.4 tons is in good agreement with the standard result from North America, nor is it very largely departed from by the factors derived from other continents.

There can, I think, be little doubt that the results arrived at by Clarke and Sollas are not likely to be seriously disturbed in the future. It is most improbable that they require amendment to the extent of 50 per cent. This being so, we conclude that the uncorrected estimates of the age of the ocean as based on solvent denudation is of the order of 100 million years. It remains now to consider the legitimate corrections to be applied to this figure.

At the present moment the most important aspect of this method of evaluating the age of the ocean is involved in its degree of reliability as affording a maximum value of the time elapsed since solvent denudation began. This point I shall therefore specially consider.

The errors affecting the crude result found by dividing the sodium of the ocean by the annual river supply, and tending to make this estimate too small, are:

(*a*) Underestimation of the sodium now in the ocean.

(*b*) Neglect of sodium which at some period in the past may have been in the ocean, but is now removed from it.

(*c*) Overestimation of the legitimate river supply of sodium.

(*d*) Decreased river supply of sodium in the past.

Of these possible sources of error (*a*) may be at once dismissed. The average depth and area of the ocean and its average chemical composition are sufficiently well known to preclude the possibility of any serious error.

In considering (*b*) it is necessary to bear in mind the magnitude of the quantities involved. The saline matter in the ocean would represent a volume of over 4,800,000 cubic miles on Clarke's estimation. I have formerly pointed out that the rock salt alone would suffice to cover the land area of the globe to a depth of 122 meters. In comparison with quantities so vast all the salt deposits known sink into insignificance; nor is it likely that deposits adequate to enter into consideration exist.

The errors referred to in (*c*) must be of the nature of cyclic sodium—that is, sodium which circulates from the sea to the land and back through the rivers to the ocean. Cyclic sodium exists in the form of wind-borne spray, which, descending on the land with the rainfall, augments that which is truly derived by denudation. In arid regions it may settle as dust, to be, under special circumstances, washed ultimately into the sea. Again, the sodium which the rivers

may derive from the ancient salt deposits which have been impounded from the sea is cyclic.

The influence of wind-borne sodium has been fully discussed by Sollas, Clarke, and Becker. There can be no doubt that it is relatively unimportant. My own original correction was 10 per cent of the river supply. Becker, by examining typical cross sections of the isochlors, determined for the rainfall of western North America by the United States Geological Survey, finds that an allowance of 6 per cent is sufficient. Sollas shows that these isochlors indicate that but a small fraction of the sodium chloride of the American rivers can be referred to this source. Clarke, by a somewhat different line of attack, concludes that a correction of 7 per cent on the sodium conveyed by the rivers of the United States is a maximum allowance. Clarke further considers that a correction for sodium chloride carried as dry dust is unnecessary.

In a paper contributed by me to the Geological Magazine (May, 1900) I considered the possibility of oceanic sodium existing disseminated in the sedimentary rocks. Such sodium would be of course cyclic. It was easy to show that, even on excessive estimates of the occluded sodium chloride in such rocks, taken in conjunction with their rate of removal by denudation, this source of supply to the rivers is less than 1 per cent. Clarke reconsiders the question and finds the allowance would not be more than 1 per cent. Three per cent is regarded by Clarke as a maximum deduction for sodium artificially supplied in modern times to the rivers.

Oceanic salt deposits are not very abundant over the surface of the earth, being generally confined to particular formations. That they seriously affect the river analyses of all the great rivers of the world is in the highest degree improbable. In any case if we deduct all the chlorinated sodium from the river supply we must include also all sea-derived sodium. If we effect this calculation, we obtain an age of about 150 million years. I do not think it will be disputed that this figure is in its nature excessive.

There remains the possibility (*d*) that the assumed uniformity of past and present conditions is illusory; in other words, that special conditions now exist tending to bring about an abnormally great river supply of sodium.

The present is admittedly a period of large land exposure. This, however, involves a fact which must be held in mind. At the present time the land area actually draining into the ocean is about 39.7 millions of square miles. The total land area is, however, rather over 55 millions of square miles. It follows that about 30 per cent of the land area contributes nothing to the ocean. Or, again, the areas which are classed as "rainless"—that is, which have less than an annual rainfall of 10 inches and have no run-off—are estimated as

one-fifth of the whole. Under such circumstances transgression of the ocean upon the land simply results in the diminution or disappearance of the great continental desert regions. It has been shown by Murray that it would require a vertical depression relatively to the ocean of 600 feet in order to reduce the existing land area by 26.7 per cent. Penck, on the same data, concludes that a submergence of 200 meters would reduce the area 29 per cent. A submergence of nearly 1,500 feet is required to diminish the land area 50 per cent.

It is for geologists to judge whether world-wide transgressions of these magnitudes obtained for any long periods in the past. So far as I know, paleography would not support such transgressions. A recent study of the Paleography of North America by C. Schuchert[1] leads to the conclusion that the mean area of that continent throughout the past has been about eight-tenths of its present area. In his Traitê de Géologie, De Lapparent, in a series of well-known restorations of ancient geography, shows how far, as judged by the sediments, there was transgression of the sea upon the land at various epochs. It does not appear that we can infer, even at the climax of the great Cenomanian transgression, that the existing land was at any time covered to one-half its extent. And mindful of the fact that the area of denudation is in most cases much greater than that of deposition, when the latter is greatest the necessity of accounting for the former involves the assumption that tracts of land now submerged were then exposed. Without assuming the former existence of lost continents in the central oceanic basins, there seems very strong evidence for the disappearance of former land. The evidence is found in our own islands, in North America, in India, South Africa, and Australia and elsewhere. We have to recognize continual fluctuations, but the evidence for a prevailing reduction of continental areas by as much as 50 per cent, or even 25 per cent, in the past is, so far as I know, not forthcoming. We might go further and state that so great a diminution of existing land area as 50 per cent certainly did not prevail in the past. Such a reduction involves about 25 per cent of the present rate of solvent denudation and increases the age accordingly.

Meteorological conditions, unless occasioned by a prevailing change in the amount of solar heat, can not be supposed to have steadily affected in one direction the rate of denudation. It is worthy of note that the testimony derived from the solvent denudation of the continents shows that climatal conditions do not, within the limits, seriously affect the rate of solvent denudation. This finds explanation in the extremely complex nature of the factors concerned in rock weathering and rock solution. Now, the mere abundance of

[1] Bull. Geol. Soc. America, vol. 20, 1910.

life throughout the world in every age since the Cambrian, and very certainly in pre-Cambrian times also, is sufficient indication that climatal conditions can not have been so extreme as to seriously inhibit denudation. It would be easy to cite evidence from sun-cracked sediments dating back to Torridonian times from teeming oceanic life now confined to tepid seas, but at various periods of geological history inhabiting every part of the ocean, and finally from forest growth and insect life on the land, that there is no evidence for continued lessened solar heat in past ages.

But existing soil conditions might be exceptional. There are to-day great sheets of glacial clays spread over the northern lands of the earth. May they not affect the river discharge of sodium? The answer is to be found in the river analyses. It is sufficient to refer to the figures cited by Clarke in his Data of Geochemistry. There is no indication of excessive supplies from northern rivers.

I am not aware of any sources of error other than those now considered. It would appear that solvent denudation estimated in the only manner open to us assigns an age to the ocean which at its probable maximum does not exceed 100 million years. Assuming that certain sources of error combined to lower this age, for instance, that more complete knowledge will reveal a lesser sodium supply than has been determined on existing data; that the cyclic sodium should be taken as somewhat more than we have assumed; that former fluctuations of land area on the whole produced an effect on solvent denudation; assuming all this, we might be somewhat out in our reckoning. We have, however, neglected all those sources of error tending to *increase* the age unduly. Chief among these are the following: Primitive sodium existing in the ocean; marine solvent denudation effected directly on the coasts and sediments; sodium supplied with volcanic ejectamenta; sodium supplied by submarine rivers and springs. For a discussion of these sources of error I must refer to the several papers cited above. It is generally conceded that any precise evaluation of their effects is not possible; so that a considerable margin must be left when considering the minor limit of the age of the ocean by this method. They certainly produce some effect as a set off to the corrections already dealt with. When all is considered, I believe it will be found that the most probable result based on solvent denudation is 100 million years, or close to this, and rather under this than over. It is against probability to add 50 per cent to this value. We can only double it by appealing purely and simply to the imagination for effects of which we possess no indication, and the existence of which is at variance with what we know.

The age as determined is based upon the summation of the sodium supplied by the rivers during geological time. This integral can,

obviously, give us no information as to the relative durations of the geological epochs. The latter question can be approached in two ways. (1) By means of the stratigraphical column or measured maxima of detrital and chemical deposits, assuming that these were laid down at an approximately uniform rate; and (2) by the radioactive method. I shall first consider the former method.

THE AGE FROM THE SEDIMENTARY COLUMN.

As the result of the observations of geologists in many parts of the world, the maximum thickness of the strata deposited in the various geological periods may be estimated as follows:

	Feet.	
Recent and Pleistocene	4,000	
Pliocene	13,000	
Miocene	14,000	
Oligocene	12,000	
Eocene	20,000	
		63,000
Upper Cretaceous	24,000	
Lower Cretaceous	20,000	
Jurassic	8,000	
Trias	17,000	
		69,000
Permian	12,000	
Carboniferous	29,000	
Devonian	22,000	
		63,000
Silurian	15,000	
Ordovician	17,000	
Cambrian	26,000	
		58,000
Keweenawan	50,000	
Animikian	14,000	
Huronian	18,000	
		82,000
Archæan	?	
Total		335,000

This compilation is due to Prof. Sollas.[1]

It is not probable that there will be in the future any very large amendment of these figures so far as they refer to post-Algonkian time. The Jurassic, as Sollas observes, seems deficient. The pre-Cambrian is the most obscure among the estimates. It claims our special attention, not only with reference to the thickness of accumulated sediments, but in so far as the observations may throw light on the denudative conditions of the time.

In no part of the world are pre-Cambrian rocks better developed and exposed than in and around the Archæan shield of Canada; and

[1] Presidential Address, Geological Society, London, 1909.

fortunately no rocks have been more carefully studied within recent years. The appearance of the monograph of Van Hise and Leith[1] places the known facts at our disposal along with explanatory remarks of the most helpful character.

It will be remembered that most American geologists now subdivide pre-Cambrian rocks as follows:

$$\text{Algonkian}\begin{cases}\text{Keweenawan.}\\ \text{Upper Huronian (Animikian).}\\ \text{Middle Huronian.}\\ \text{Lower Huronian.}\end{cases}$$

$$\text{Archæan}\begin{cases}\text{Laurentian.}\\ \text{Kewatin.}\end{cases}$$

Prior to 1904 the Lower and Middle Huronian were together called Lower Huronian. Alternative names for the three divisions of the Huronian are Lower, Middle, and Upper Marquettian. The lines represent unconformities.

A study of the recorded facts shows that the higher estimates of Keweenawan rocks include preponderating amounts of igneous rocks, both effusive and volcanic. The time value of these materials is probably—nay, certainly—small. Van Hise cites a case where the accumulation of 7,000 to 8,000 feet of Huronian volcanic materials is paralleled by the collection elsewhere of 700 to 800 feet of ordinary sediments.[2] The estimates which approximate to as much as 45,000 feet include some 30,000 feet of igneous or mixed igneous and sedimentary materials.[3] No sedimentary column thicker than 17,000 feet is cited.

The Huronian, or lower division of the Algonkian, is nowhere, save in an early estimate of Winchell's, found to embody more than 15,000 feet of sediments. Winchell's estimate[4] is obscured by the nomenclature, and would seem to include Archæan rocks. If his Marquettian, which name he applies to rocks formerly known as Kewatin, includes Lower Huronian only, we have an estimate of 27,000 feet for this division. The estimate would be unique. The highest distinct estimate of Lower Huronian which I have found in the Bulletin is "a possible maximum thickness" of 16,000 feet, of which 5,000 feet are true sediments.[5]

The Algonkian generally is variously estimated, but in no case is a thickness greater than 50,000 feet cited. In the Cordilleras the Belt series—30,000 feet—plus the Cherry Creek series may amount to more. It does not seem likely, however. The former series is characterized by Van Hise and Leith as unique among the pre-Cambrian series of North America for wide extent, thickness, and lack of deformation. There is no apparent unconformity between the Cherry

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[1] Bulletin 360, U. S. Geol. Survey, 1909.
[2] Loc. cit., p. 146.
[3] Loc. cit., p. 191.
[4] Loc. cit., p. 206.
[5] Loc. cit., p. 164.

Creek series and the gneissic rocks beneath. In the Selkirk Range 40,000 feet of deposited rock are recorded, but the correlation is somewhat obscure, suggesting that its age may not be entirely pre-Cambrian. In Nova Scotia sedimentary rocks, probably Algonkian, amount to 26,000 feet. The Canadian Huronian (equivalent to Algonkian) has been estimated up to 50,000 feet. It is largely volcanic, and contains unstratified igneous masses.

It is remarkable that recent work has in many cases tended to reduce the estimates of earlier observers. Chamberlin and Salisbury [1] point out the liability to overestimation which exists in these cases. These same observers state:[2]

> The maximum thickness of the system (Keweenawan) has been estimated as nearly 50,000 feet, but it is not impossible that this estimate is an exaggerated one. If it be correct, the Keweenawan is the thickest body of post-Archæan rock referred to any one period. This seemingly incredible thickness may merely mean inclined deposition and subsequent tilting and shearing and the estimate be altogether correct.

And of the proterozoic systems collectively in the Lake Superior region they write:[3]

> If none of the estimates are exaggerated, there is an aggregate of more than 30,000 feet of sedimentary rock in the proterozoic systems.

It would appear, then, that the Keweenawan at its maximum, so far as observed, is less than 50,000 feet, and its true sedimentary thickness evidently considerably less. The Huronian does not appear to have been reliably estimated as above 15,000 feet. Together the maximum estimates for the Algonkian are not above 60,000 to 65,000 feet, inclusive of igneous materials. In its great development in the Cordilleras it would appear that a maximum of 40,000 feet of true sediments would be safe, on the existing data.

With the Archæan we are not here concerned. Van Hise and Leith briefly summarize our knowledge of the earlier rocks in these words:[4]

> The Algonkian is characterized by well-assorted fragmental and chemical sediments giving evidence of extensive decomposition of land areas and of the passage of normal cycles of erosion. Igneous rocks are abundantly present, but for the most part are subordinate in amount to the sediments. The Archæan is characterized mainly by igneous rocks with the sediments in very small quantity. The Archæan sediments, moreover, are frequently of wacke type, and, so far as known, are not largely of the cleanly assorted kinds resulting from complete decomposition as in the Algonkian.

Similar testimony is borne by Chamberlin and Salisbury.[5]

According to the definition of Algonkian and Archæan we must draw a line at the base of the former as representing that limit at which geological time, as an era of sedimentation and solvent denudation, began. "The Archæan was essentially a period of world-wide vulcanism, and in the relative proportions of rocks of igneous and sedi-

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[1] Textbook of Geology, p. 257.
[2] Loc. cit., p. 192.
[3] Loc. cit., p. 198.
[4] Loc. cit., pp. 21-22.
[5] Textbook of Geology, vol. 2, p. 199.

mentary origin represents a departure from the uniformity of conditions of later geological times." [1]

Turning to the pre-Cambrian geology of other parts of the world we find that the Torridonian and Lewisian of northwest Scotland in their mutual relations and petrographical characters resemble the Algonkian and Archæan divisions of North America. The aggregate thickness of the Torridonian has been estimated at not less than 10,000 feet. To this the Dalradian has, possibly, to be added.

The pre-Cambrian rocks of Finland have been divided by Sederholm as follows:

Jotnian.

Jatulian, Upper.
Jatulian, Lower.

Kalevian, Upper.

Kalevian, Lower.

Bottnian.

Ladogian.
Katarchæan.

Sederholm makes the same statement regarding the Jotnian, Jatulian, Kalevian, and Bottnian as has been made with reference to the Algonkian. Sederholm says:

> At least as far back as during Bottnian time the climatic conditions were not sensibly different from those of later geological periods, as shown by the existence of rocks which, in spite of their metamorphic character, show themselves to be sediments with the same regular alternation of clayey and sandy material (annual stratification) as the glacial clays of that same region, explainable only by assuming a regular change of seasons.[2]

The parallel suggested by Sederholm with the Lake Superior rocks is as follows:

Jotnian equivalent to Keweenawan.
Jatulian equivalent to Animikian or Upper Huronian.
Kalevian equivalent to Lower Huronian.

Van Hise and Leith further suggest the correlation of the Ladogian and Katarchæan with the Kewatin and Laurentian; the Ladogian being intruded by the granites and gneisses of the Katarchæan.

In China a basal complex of gneisses having very subordinate masses of sedimentary materials underlie four sedimentary groups, originally muds, grits, conglomerates, and limestones; having, in fact, all the characteristics of the Algonkian. In short this prevailing relation of an older gneissic and dominantly igneous system with an unconformably overlying metamorphosed sedimentary and volcanic

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[1] Van Hise and Leith, loc. cit., p. 30.
[2] Sederholm, J. J., Bull. Comm. Géol. de Finlande, No. 23, p. 95, 1907.

series—which again is divided by unconformities—is a significant feature observed in many widely separated parts of the world.

The above cited facts seem to show (1) that we are entitled to commence our reckoning of the sedimentary column at the base of the Algonkian; (2) that the existing sedimentary deposits of that epoch are probably not greater than the more or less concordant observations from several localities indicate; (3) that the early sedimentation was similar in character to that which proceeded in subsequent periods.

Although much is gained by these deductions, it is difficult to determine any approximate time equivalent for these ancient deposits. It is true that there is no reason to suppose that their derivation proceeded at a different rate from more recent ones; their rate of accumulation, however, may have been and indeed probably was quickened by less stable crust conditions, permitting more localized depressions and greater concentration. The geographical disposition of the earlier sediments sometimes affords evidence of this. There are, again, several unconformities in the pre-Cambrian succession which do not appear to be represented in the known sedimentary accumulations. Van Hise and Leith recognize the principal unconformity as separating the Archæan from the Algonkian. Adams, however, recognizes one of equal significance beneath the Upper Huronian. Three unconformities occur within the Algonkian. That these are indicative of considerable lapses of geological time is highly probable.

A discussion of the time allowance for these early unconformities would lead us too far into speculation. It may be observed, however, as regards the evidence for prolonged periods of denudation deduced from regional base leveling, that the instability of the early crust must again be kept in mind. It is probable that the Algonkian mountains were not of the dimensions of those of later periods and that, therefore, they were at once more rapidly formed and more rapidly removed. Van Hise and Leith suggest that the unconformities may represent as much sediment again as now remains to observation. This, of course, can only be matter of opinion; and I have as far as possible endeavored to exclude what is purely matter of opinion from this review of the subject. It would seem, however, that Sollas's estimate of 82,000 feet of sediment includes such an allowance as appears possible to Van Hise and Leith.

Taking all into account—and much has been omitted which might be said upon the subject—it does not appear that Prof. Sollas's compilation of the stratigraphical column need be seriously disturbed. If we double the estimate for the Jurassic we at least tend to reduce the possibility of error of deficiency in the thickness assigned to this system. This brings the column up to, say, 345,000 feet.

What now, finally, is the time value of this enormous total? Unfortunately the average rate of collection is a very indeterminate

quantity. We are, I believe, at liberty to assume that the rate of deposition and sinking was anything from, say, 1 foot to but a few inches in a century. A rate of accumulation of 4 inches in a century interprets the geological column as indicating 103 millions of years. Three inches gives us 148 millions. The order of the time value is probably indicated in these figures.

It is important to note that the facts of solvent denudation place a quite definite limit on the amount of sediments which have been formed during geological time. The sodium which has reached the ocean has originated in the conversion of igneous into sedimentary rocks. It is easy to calculate from the composition of a generalized igneous and a generalized sedimentary rock and from the quantity of sodium in the ocean that the denudation of about 84 million cubic miles of igneous rock, producing about 60 million cubic miles of sediment, accounts for the sodium in the ocean. Such a quantity of sedimentary rock would, if all was now on the land, cover the present land area (55 million square miles) to a depth of a little over 1 mile.[1] As it can be shown that somewhat less than a third of the sediments have been precipated as oceanic deposits,[2] the average depth of the sedimentary rocks on the land is less than 1 mile; about 4,000 feet. The total sedimentation throughout geological time must be restricted within this limit. Possibly the limit is too high, for there may have been some sodium in the primitive ocean. It is difficult to show wherein it is too low. This limit must define not only sediments which keep their recognizable characters as such, but those which may possibly have been metamorphosed beyond certain recognition. It is significant that the guesses (for they can only claim to be such) of several writers as to the amount of recognizable sediment upon the land areas, do not diverge very far from the suggested limits. Thus Van Hise thinks these rocks may be taken as on an average covering the continents to a depth of 2 kilometers. Clarke thinks that the sediments certainly do not occupy a bulk equal to the whole land extending above sea level. This would amount to less than an average of 2,411 feet deep over the continents. The sediments in the sea would be additional to this.[3] These estimates may be guesses, but it is improbable that they are several times in error. The observed amounts of sediment are not then in discord with the limitations imposed by solvent denudation.

THE AGE OF THE EARTH BY RADIOACTIVITY.

The radioactive investigation of the age of the earth is based upon the accumulation in minerals of the inert products, helium and lead.

The rate of production of helium by a given amount of uranium

[1] Trans. Roy. Dublin Soc., vol. 7, 1899, p. 48.
[2] Address to section C, British Association, 1908, p. 6.
[3] Data of Geochemistry, p. 29.

may be regarded as known with considerable accuracy. It may be assumed that 1 gram of uranium in equilibrium gives rise to, closely, 10.7×10^{-8} cubic centimeters of helium (measured under standard conditions) per year. Thorium and its products of change are just as widespread in occurrence as uranium. The contribution of helium derived from the thorium group must, therefore, in most cases be also taken into account. Failing direct measurements of the rate of generation of helium by thorium, it is possible to estimate this in terms of the output due to uranium by a comparison of the ionization effects of the two families of substances. This comparison has been made by Boltwood. Allowance has further to be made for the different ionizing activity of the alpha rays from the uranium and thorium series due to their differing velocity and range. The final result is that 1 gram of thoria (ThO_2) is equivalent, in its rate of production of helium, to 0.203 gram of U_3O_8. The "helium ratio" of a mineral is the helium in cubic centimeters per gram of "total equivalent" uranium oxide present. This is the usage adopted by Strutt. In a recent paper [1] Strutt experimentally verifies this procedure by direct measurement of the helium evolved by minerals rich in uranium and thorium.

The use of lead as a measure of geological time involves the assumption that Boltwood's theory is correct, i. e., that lead is the final product of decay in the uranium series. There is strong evidence in favor of this view. Notably the fact that the atomic weight of uranium, less that of the eight alpha particles which are known to be emitted during its several stages of disintegration, descends to that of lead. The universal association of the two elements and the connection of this association with geological time, constitute further evidence.

The mass of lead generated in one year per gram of uranium is easily found from a knowledge of the mass of helium produced. The latter, calculated from the volume, is found to be 1.88×10^{-11} gram. The associated lead will be 1.22×10^{-10} gram. That is, the presence of one gram of uranium involves the production of 1.22×10^{-10} gram of lead per annum. A small correction may be required for the exhaustion of the uranium.

The most obvious criticism which the radioactive method suggests may be embodied in the following possibilities:

(*a*) Risk of the original presence of helium or lead in the minerals investigated.

(*b*) Risk of loss of helium or lead, or their gain from spurious sources.

As regards the first of these heads there is evidence that helium or lead may be originally present in the substance. In fact, we may

[1] Proc. Roy. Soc., October, 1910.

in a general way consider that the same causes which lead to the segregation of uranium or thorium most probably led to the concentration of other substances. This at least is probable where, as in the case of zircon, none of the substances dealt with are essential parts of the molecule of the mineral. The magma or menstruum from which the parent radioactive substances are derived may be very rich in helium or lead, and the amounts of these constituents which enter into the mineral may be considerable. It follows that the absolute value of the helium or lead ratio involves the events attending the genesis of the mineral. It is even quite probable that substances crystallized out within a plutonic mass, and which, at first sight, might be thought secure from impurities of this sort, would be seriously affected. Consider the case of a mineral of early consolidation such as biotite. It is held by many petrologists that the substances first to crystallize are not necessarily those whose molecules were first formed in the magma. Biotite or hornblende may, indeed, crystallize in advance of feldspar or quartz, but they do so in presence of already formed molecules of these bodies or of molecules which are forerunners of these bodies. If this were not the case the adjustment of the alumina to the potash, soda, and lime which appear in the feldspars would be inexplicable.[1] On this view a clear explanation is found of the heterogeneous concentration of elements in bodies of early consolidation. These minerals, in a sense, are residual, receiving those elements which have been excluded from taking part in earlier molecular grouping. The final result is a "forced isomorphism."

The same phenomena, on an intensified and more demonstrable scale, appear in the formation of pegmatitic minerals. Here very often it may be inferred that mother liquors rich in the rarer elements and the products rejected by the magma, generate on a large scale minerals which are quite subordinate within the mass of the rock. Extruded gases, under great pressure, also act under such conditions. In the internal cavities and druses of granites, doubtless, all these factors operate. Under such circumstances are generated the beryls and zircons which find their way into museum collections.

In keeping with the conditions attending vein minerals Strutt found that such minerals from the Cornish granite contained more helium, relatively to the radioactive elements present, than did the granite itself, although the vein must be younger than the rock containing it. The fact, also shown by Strutt, that beryls often contain a quite unaccountable quantity of helium, probably finds its explanation in the original occlusion of this substance.

Brögger, in writing of the syenitic pegmatites of Norway, concludes that the minerals of the thorite-orangite group, including urano-

[1] Harker, The Natural History of Igneous Rocks, London, 1909, p. 167.

thorite, crystallized in the first phase of vein formation, "that of magmatic consolidation with the cooperation of pneumatolytic processes," and that in the second and principal phase of pneumatolytic activity galena crystallized out.[1] If the undifferentiated magma has been fairly radioactive, may not the pegmatitic substances, representing a large part of the rejected elements of the magma, be rich in the products of radioactive decay? It would seem that we are reasonably entitled to expect this. There might even be a certain proportionality between the amounts of radioactive bodies and segregated products of decay.

The results of the experiments themselves alone can indicate how far sources of error of this kind have operated. The final ratio—whether of helium or lead—to the parent radio-active substance is, we may suppose, compounded of two ratios, a segregation ratio which obtained from the first, and a generative ratio which kept on increasing throughout geological time. Consider the case of lead. We have no prima facie right to conclude that the originally segregated lead is, relatively to the uranium, more for, say, Archæan minerals than for Devonian. If, then, the gross lead ratio for the former is very much greater than for the latter, the effect of the occluded lead must only exercise an insignificant influence in invalidating the results regarding Archæan time. To take a concrete example. The assumption that of the total lead found in Devonian minerals a quantity equal to 2 per cent of the uranium present in each case is not of radioactive origin but was originally introduced, amounts to saying that one-half the ratio (about) is due to original segregation and one-half to radioactive genesis. The time value of the corresponding deduction from Devonian time (as derived from the gross ratio) is about 160 million years. A quantitatively equal correction applied to the ratio observed in Archæan minerals will not be very important, as will presently be seen. Unless, then, we have some reason to infer that the conditions attending the formation of the minerals having the higher ratios were such as to lead to the inclusion of greater relative amounts of lead, the objection under this head is not of serious weight, at least in the case of the higher ages which have been arrived at.

Acting either to increase or diminish the observed deduced age, errors under the head (*b*) may exist. The volatile escape of helium has been demonstrated by Strutt. Under past conditions of heating and percolation, etc., its escape is very probable. On the other hand, the accretion of radium is not impossible, for radium is known to migrate from its parent elements, and in considerable amounts. Lead is certainly at least equally liable to migration under suitable

[1] Brögger, Die Mineralien der Syenitpegmatitgänge, pt. 1, pp. 160, 164, and pt. 2, p. 10.

conditions. These sources of error would also tend to go on augmenting with the lapse of time. Unless, however, it can be shown that a special sort of selective absorption for one or more of the elements likely to bring in error is exercised within the minerals dealt with, the error can be apprised at its true worth by comparative observations upon associated substances which do not contain appreciable amounts of the parent radioactive bodies, and which have been exposed to like vicissitudes of history.

The earliest determination of age by the radioactive method is, so far as I am aware, that made by Rutherford.[1] The helium in a specimen of fergusonite was determined by Ramsay and Travers as amounting to 1.81 cubic centimeters per gram. The mineral contained about 7 per cent of uranium. From this Rutherford deduced the age as about 240 millions of years. The geological position of this mineral is not specified, nor is the possible influence of thorium taken into consideration.

The principal development of the method by helium ratio is due to Strutt, whose work upon the subject has appeared in five papers in the Proceedings of the Royal Society (1908–1910). These experiments deal with phosphatized fossil remains and nodules, hæmatite and other iron ores, zircons, and sphenes. Some of these determinations are evidently not available as an estimate of the time since their formation, being plainly deficient in helium. Such results of course strengthen the conviction that loss of helium must occur in some cases.

The results arrived at by Strutt are not always concordant. Thus we find two sphenes of Archæan age and from the one locality (Renfrew County) affording 222 and 715 millions of years; and again two Archæan sphenes from the one locality (Twederstrand, Norway) 213 and 449 millions of years. Zircons show for Palæozoic time 140.8 to 321 millions of years. Here the lower figures are supported by results on hæmatite. This one mineral gives for the time since the Eocene age 30.8, since the Carboniferous 141, and since the Devonian 145 millions of years. Limonite gives for post-Carboniferous time 145 million years. These are closely agreeing results. Other iron ores give, however, inconsistent results. All are, of course, reconcilable if we assume that the lower results are in every case due to loss of helium. It is a little unfortunate in this connection that the minerals used for the greater ages are more retentive in their nature (sphene and zircon) than the substances dealt with for determination of the lesser periods of time.

Strutt, in his final paper, selects from his results the following as summarizing the data of his earlier papers:

[1] Phil. Mag., October, 1906, p. 368.

	Years.
Sphærosiderite from Rhine Provinces—Oligocene............	8.4×10^6
Hæmatite, County Antrim—Eocene	$31\ \times10^6$
Hæmatite, Forest of Dean—Carboniferous Limestone	$150\ \times10^6$
Sphene, Renfrew County, Ontario—Archæan................	$710\ \times10^6$

These are advanced as minimum values, the loss of helium being impossible to estimate.

Boltwood first investigated the age by the accumulation of lead.[1] Very high figures were obtained, ranging from 246 to 1,320 millions of years. Becker criticizes these results,[2] pointing out that certain radioactive minerals of well-determined age (Llano Group, not far below the Cambrian) afford on the same principles ages which are quite incredible, ranging from 1,671 to 11,470 millions of years. Boltwood questions the suitability of the minerals on the score of incipient or advanced alteration. Becker in reply urges that there is no evidence to show that alteration can affect the ratios. Becker considers, further, that Brögger's views, as cited above, show that lead may be occluded as an impurity in such minerals, and that the amount of this impurity will vary from crystal to crystal, in accord with the results of the observations.

The subject of the lead ratio has been lately taken up by A. Holmes.[3] Holmes selects minerals from the intrusive nephelene syenite of the Christiania district, supposed by Brögger to be of Middle or Lower Devonian age; most probably the latter. Seventeen minerals are investigated, among which are thorite, biotite, zircon, ægerine, nepheline, feldspar, etc. The ratio of lead to uranium ranges from 0.041 to 0.500. There is found to be an increase in the value of the ratio with diminution in the amount of uranium; a result suggesting the presence of original lead. Holmes, accordingly, rejects about half the results (those which give the higher ratios) and finds a mean among eight results which range from 0.043 to 0.050. The mean of these gives for post-Lower Devonian time 370 million years. It must be admitted that this result is not entirely satisfactory; it contains an element of arbitrary choice, and although it is possibly true that the minerals with least uranium contain too much original lead to be reliable, we are by no means sure that even larger amounts of original lead did not enter into the constitution of the others. The agreement among the ratios renders this improbable, however.

Holmes enters into the question of the geological positions of the results cited by Boltwood, and concludes that they may be tabulated as follows. His own mean result is included in the table.

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[1] Amer. Journ. Sci., vol. 23, 1907.
[2] Bull. Geol. Soc. Amer., vol. 19, p. 113, 1908.
[3] Proc. Roy. Soc., June, 1911.

Geological period.	Pb/U.	Millions of years.
Carboniferous	0.041	340
Devonian	.045	370
Pre-Carboniferous	.050	410
Silurian or Ordovician	.053	430
Pre-Cambrian:		
Sweden	.125	1,025
	.155	1,270
United States	.160	1,310
	.175	1,435
Ceylon	.20	1,640

The Swedish minerals are from pegmatites of an age younger than Jatulian. The results obtained from them show, among 17 specimens examined, two well-marked groups, having the ratios tabulated. There is nothing in the rocks to indicate any difference in age. Of the United States minerals, those having the lesser ratio are from granites intruded into the Llano Group (Texas) of metamorphosed sediments. Their age is, therefore, younger than the sediments, which are early Algonkian. Those with the higher ratio are from Burnet County, Tex., and Douglas County, Colo. The geological evidence is similar to that of Llano County.

The evidence for the pre-Cambrian age of the Ceylon thorianite is the resemblance of the rocks to the fundamental complex of India. The tabulated values are the means of several results cited by Boltwood, some of which are in closer mutual agreement than others.

These results greatly transcend Strutt's in the antiquity they assign to Palæozoic and pre-Cambrian time. This fact can be explained by the escape of helium. The possibility of occluded lead entering seriously into such determinations will, doubtless, form the subject of future research. Meanwhile it seems improbable that the higher average ratios of the oldest minerals can find explanation in this manner. I have already dwelt sufficiently, in view of our very deficient knowledge, on these points.

The discordance between the radioactive indications of time and those derived from the stratigraphical column appears clearly when we plot one against the other (fig. 1). The assumption made in plotting the sedimentary thicknesses is that these, inter se, are roughly comparable as regards the rate of accumulation. As I have already pointed out, this seems probable save in the case of the earlier pre-Cambrian sediments, which we might expect would have been accumulated more locally. The thicknesses of the several strata I have laid out according to the data collected by Sollas. The radioactive times are plotted above the points on the base line to which their geological positions assign them. We have from the lead ratios two early-

Algonkian results and two post-Jatulian results. The Archæan results by helium and lead can not be located on the base line save by the indications of the other results.

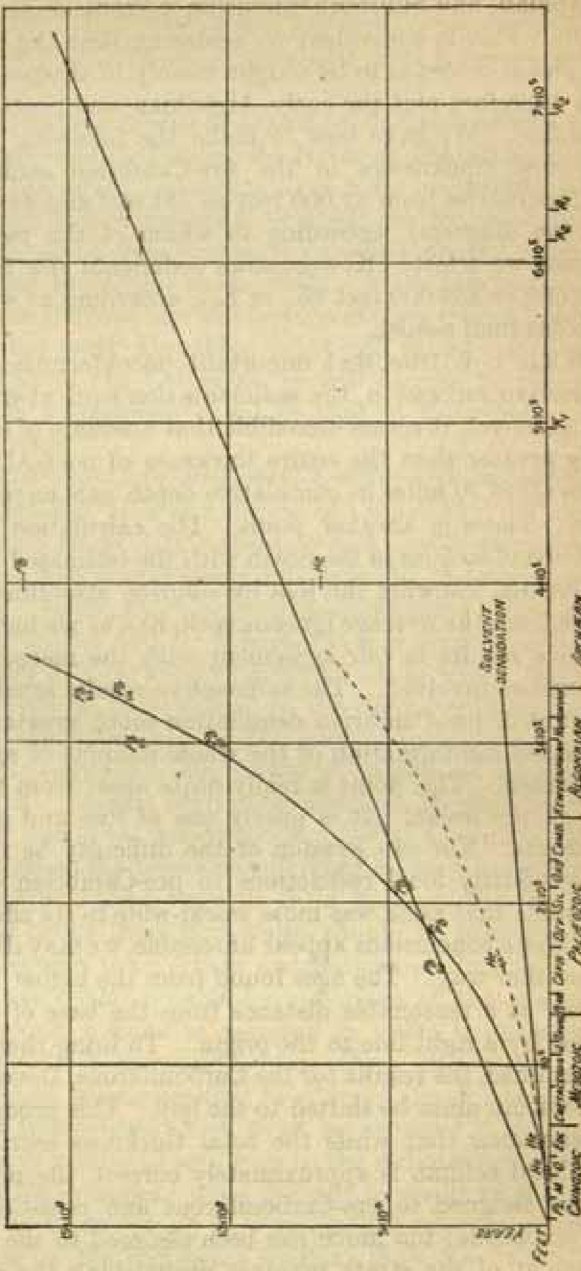

FIG. 1.

If there was accord between the stratigraphical column and the radioactive data, the latter should be ranged on straight lines which necessarily pass through the origin (present time). We find them, however, ranged upon curves. I have plotted a rather excessive value of the age of the ocean as determined by solvent denudation, erecting for this purpose an ordinate of 150,000,000 of years at the beginning of Algonkian time. Joining the summit of this ordinate to the origin we see that the curves for helium and lead flow into this line in recent periods.

If now we assume that the time indications of the lead ratios are correct, we are presented with the following alternatives as regards the amendment of the sedimentary column.

We assume that the stratigraphical column for post-Carboniferous time is in actuality much as we have plotted it, and draw a right line from the origin through the three results for the age of Carboniferous, Devonian, and Silurian-Ordovician periods as derived from the lead ratio. This is equivalent to assuming that the error in the stratigraphical record is to be sought mainly in the pre-Cambrian records. We therefore plot the early Algonkian and post-Jatulian results on this line. We have now to make the following amendment on the recorded thicknesses of the pre-Cambrian sediments. Algonkian sediments rise from 82,000 feet to 381,000 and 441,000 feet (A_1 or A_2 on the diagram), according to which of the two early Algonkian results we select. Keweenawan sediments rise from 50,000 feet to 245,000 or 359,000 feet (K_1 or K_2), according as we select among the two Jatulian results.

While it is true that important unconformities exist in the pre-Cambrian succession, the sedimentation equivalents of which are not found as yet, it seems incredible that amounts of sediments considerably greater than the entire thickness of post-Algonkian rocks and from 60 to 70 miles in cumulative depth can have escaped investigation. There is another point. The calculation which equates the amount of sodium in the ocean with the estimated bulk of the detrital sediments, knowing the loss by solution attending the derivation of these from the average igneous rock, has, as we have seen, been found to give results in fair agreement with the measurements of all the quantities involved. The radioactive results must now postulate an amount of pre-Cambrian denudation much greater than would have attended the formation of the whole amount of sediment previously estimated. This point is really quite apart from the question of the age of the ocean. It is purely one of loss and gain, of balance of accounts. Nor can evasion of the difficulty be found by ascribing exceptionally local restrictions to pre-Cambrian denudation. It is probable that none was more world-wide in its effects.

If these conclusions appear untenable, we may deal with the results in another way. The ages found from the higher lead ratios may be placed at a reasonable distance from the base of the Cambrian and joined by a right line to the origin. To bring them on to the line so determined, the results for the Carboniferous, Devonian, and Silurian-Ordovician must be shifted to the left. This procedure is equivalent to assuming that while the total thickness ascribed to the stratigraphical column is approximately correct, the proportionate thicknesses assigned to pre-Carboniferous and post-Carboniferous strata are erroneous; too much has been assigned to the latter. The readjustment of the strata involves diminishing the post-Carboniferous deposits about 50 per cent and increasing the pre-Carboniferous by nearly 40 per cent.

The assumptions involved in making these adjustments are inherently improbable, and it might be thought easier to assume that the time values of the post-Carboniferous strata were, as compared with the earlier strata, less. This emendation requires us to assume that the more recent materials were laid down about three times as fast as the earlier.

These are the alternative modes of adjustment of radioactive time to the stratigraphical column, leaving the latter on the whole intact. If we assume that the recent sediments have been overestimated in thickness, we can, by discarding about one-half the recorded thicknesses since Carboniferous time, produce an effect on the diagram equivalent to moving the origin to the right. With this particular numerical assumption the lead line will become steeper than it appears on the chart, and the early Algonkian point will remain at such a distance to the right of the Cambrian as will ascribe to the pre-Cambrian sediments a thickness equal to that of the whole post-Algonkian accumulation.

The important question is, of course, as to how far such assumptions are permissible consistent with any degree of probability. There is much that is uncertain about data respecting rock thickness, not only as regards the actual field observations, but as to the real significance of what is observed. Again, the relative time equivalents of deposited rocks are not really known to us. Whether it is a detrital sediment forming in an estuary or a coral-reef building in clear water, the rate of growth must depend to some extent on the downward movement of the sea bottom, either induced by the load or taking place from other causes. Some sediments are, however, plainly of rapid and some of slow growth. Amidst such considerations we find no very definite grounds for numerical computation. So far as crustal yielding affects the question, the probable inference is, as I have stated above, that the earlier strata were in their greatest development more localized, and hence their time value should be less than the more recent. As regards the vertical distribution of definitely fast or slow collecting materials, a careful comparison of the materials throughout the geologic column is required in order to gather any evidence that may be forthcoming from these indications. At present, however, there seems nothing to support the different time values or amended thicknesses which must be assumed if we are to adjust the radioactive results in any way to the sedimentary record.

What will prima facie appear most difficult to credit in the foregoing assumptions is the extremely slow rate which must be ascribed to the accumulation of the sediments even at their maximum. If the recorded depths of sediment have taken 1,400,000,000 years to collect, the average rate has been no more than 1 foot in 4,000 years! This seems incredible; and if we double the depth of maximum sedi-

mentation it still remains incredible. But, if possible, still more incredible is the conclusion respecting solvent denudation to which radioactive time drives us. *If the sodium in the ocean has taken 1,400,000,000 years to accumulate, the rivers are now bearing to the sea about fourteen times the average percentage of the past—not less than nine times. It seems quite impossible to find any explanation of such an increase.*

With these difficulties in view it is excusable to direct attention to the foundations of the radioactive method and ask how far they are secure. The fundamental assumption is that the parent radioactive substance, uranium, has always in the past disintegrated at the present rate. Is this assured? I am not now suggesting that the rate of change has been effected by external physical conditions, such as heat or pressure, but I assume that there may have been a different, and from the evidence as well as from probability, a greater rate of decay in the past, arising intrinsically, and ultimately due possibly to conditions of origin.

I venture to suggest—I do so with diffidence—that our assumption of a constant rate of change for the parent substances—uranium or thorium—is really without any very strong basis. It rests upon analogy with the behavior of the substances which have been derived from them. But there may be a very profound distinction. The latter are of radioactive origin. That particular distribution of stability or of intrinsic energy among the atoms of these bodies obtaining at the moment of their formation, upon which the subsequent constant change rate depends,[1] may be conditioned by the events of radioactive transformation, or by their past history, or by both. In a word, a radioactive origin may be essential.

Now we know nothing as to the origin of the primary radioactive elements. No substances of greater atomic weight are known from which they may be derived. Nor is it unphilosophic to assume that they have had some other mode of origin, seeing that the radioactive ascent must terminate somewhere. Uranium can not be regarded, therefore, as in all senses one of a series any more than we should regard lead as such.

The matter seems to turn upon the legitimacy of the assumption that the mere existence of radioactive change progressing in the substance involves such a particular distribution of instability among its atoms as will insure that a constant fraction of these disintegrate each unit of time from their first origination—however this was brought about—till all are transformed. If such an hypothesis is not sufficiently secure to overbear the opposing evidence we must agree to judge the former by the latter. In this case the accumulation of

[1] See Sir J. J. Thomson's Presidential Address to the British Association, 1909.

transformation products in minerals, in place of being a measure of geologic time, serves to shed light upon the rate of transformation of the primary radioactive bodies in the past. Apart from its interest in other respects, the importance of such a conclusion to geologic science would be great. If we supposed the curve, found by plotting the time results derived from lead ratios against the sedimentary thicknesses, represented an approximation to the facts, the rate of change of uranium 150,000,000 years ago may have been many times what it now is. The radiothermal effects of the whole series must have been proportionately increased, and the convergence of the radioactivity must have had an influence upon the secular cooling of the earth.

July 18, 1911.

INTERNATIONAL AIR MAP AND AERONAUTICAL MARKS.[1]

By Ch. Lallemand,[2]

President of the French Association for the Advancement of Sciences.

1. PRELIMINARY ACCOUNT.

The dirigible air balloon, and more especially the aeroplane, which are scarcely out of the period of research and experiment, will soon enter into the area of practical politics. To-day, still mere instruments of sport or of military reconnaissances, they will become, to-morrow, valuable means of transport. It is time that aviators were given means for finding their way, similar to those which, for a long time, have existed for navigation and travel.

Whether on sea, land, or in the air, the pilot has always before him the same triple problem to be solved. He must from time to time—

1. Recognize his position.
2. Determine the direction of the point to be reached.
3. Rapidly estimate the distance remaining to be covered.

For terrestrial locomotion, the solving of these various problems was greatly simplified by producing special maps for the use of travelers and by erecting along the principal routes easily visible signs, such as milestones, plates indicating the names and distances of more or less remote towns, signposts at road junctions, etc. But the marking or buoying of routes presupposes a course fixed in direction and limited in extent. Admirably suited for travel by land, this system is still, to a certain extent, applicable to coasting trade, that is, for sea voyages along coasts or in estuaries. But, on the other hand, for travel on the high sea this method is unsuitable, and for aerial navigation quite useless in foggy weather or at night. In the latter case it is necessary to use a compass. In spite of fog, darkness, or the absence of marks, the use of the compass enables the pilot to follow the desired direction, which direction has been previously

[1] British Association, Portsmouth, September, 1911. Reprinted by permission from The Geographical Journal, London, vol. 38, No. 5, November, 1911.

[2] Inspecteur-Général des Mines, Directeur du Service du Nivellement général de la France, Membre de l'Institut et du Bureau des Longitudes.

marked off on the map, and, in the case of aerial travel, determined by a prominent object on the horizon, such as a clock tower, an isolated tree, etc. Knowing his speed, the pilot may, at any subsequent time, roughly estimate the distance already run and approximately deduce his proper position.

This position will, of course, be very frequently rectified, according to the indications of the map compared with the features of the terrain. The aviator will endeavor to recognize characteristic points, such as a high building, for instance, or the crossing of a canal with a railway line, or the junction of two rivers, etc. Now, the compass will not always suffice. Unknown to the pilot, a water current may cause the ship to drift; similarly, an unseasonable change of wind may pull the dirigible or aeroplane out of its course, when traveling in log or above the clouds. Both the seaman and the aerial pilot, when opportunity occurs, by the lifting of the fog or daylight reappearing, must recognize their position and, if necessary, rectify their route.

For this the seaman must make use of the sun or stars and deduce from their observation the geographical coordinates, that is, the longitude and latitude of his position. Owing to the rather precarious conditions of the arrangements on board it would be pretty difficult for airmen to use this method. Fortunately for them traveling over sea is rather an exception. They would be saved any reckoning by placing all over the country, at convenient intervals, *aeronautical marks,* that is, by writing, on the ground itself or on the roofs of buildings (by means of conventional signs or very conspicuous numerals) the longitude and latitude of the corresponding site. Having read these, the pilot with the help of a map, would be enabled to recognize his proper position and to reckon the distance of his destination, as well as its new orientation, that is, the inclination, to the meridian, of the new direction to be followed.

Notwithstanding every artifice, however, this method is still long and difficult enough, and would only be useful were it possible to exactly follow the arc of a great circle cutting the pilot's destination which, as a matter of fact, is rendered impossible by side winds and terrestrial obstacles. Airmen, like most seamen, will prefer to mark off the point on a map, or more simply to trace it on a simplified sketch, such as the index diagram (fig. 1, showing the fitting together of the sheets of the detailed map), upon which can be read the approximation of both required elements—distance and orientation.

For instance, an aviator flying over Bourges (the town marked by a black point at the bottom of sheet 72 of the index diagram) toward Pau (black dot in the lower half of sheet 39) would at once see that the distance remaining to be covered is nearly equal to 4.25° of latitude measured on the diagram. Each degree being 67 miles long, the required distance would be roughly 285 miles. Moreover, the

direction to be followed is 26° to 27° W. of the meridian to the south, say, magnetic S. 40° W. (the magnetic declination at Bourges being 13.5° W.). The compass should therefore show the complement, say, N. 140° W.

If necessary, this diagram could even suffice for traveling. A straight line having been drawn joining starting point and destination, the pilot can see that his way will run successively right across the upper left angle of sheet 62, then cross the lower half of sheet 61, thereafter cut the upper edge of sheet 51 about the center, pass through the right-hand corner of the lower half of sheet 50, cut diagonally across sheet 40, graze the upper left corner of sheet 30, and finally end about the middle of the lower half of sheet 39.

Let us suppose that at any moment the pilot observes on the ground below a mark similar to that of figure 2, with the two figures 5 and 0 on either side, respectively, and with a large dot occupying the proper position of the town of Angoulême in the upper part of sheet 50 of the index map. He would at once conclude that he had deviated to the right of his route, and after a rough estimation he would incline 25° to 30° to the left. But, in every case, a detailed map would be necessary for landing.

Having examined many systems, the permanent committee for aerial navigation of the public works department of the French Government recently proposed for this map and for aeronautical signs the following solutions that seem to be the simplest ones and also the most likely to be adopted by other countries:

2. AIR MAP.

In order to attain the required object and to keep to the necessary clearness, an air map must show only the details required by airmen, either for finding their way or for landing.

To the first category belong the characteristic geographical features of the terrain, such as railways, main roads, channels, streams and rivers, lakes, forests, bushes, clumps of isolated trees, large areas of a similar cultivation, large boroughs with their outline and principal streets, chimneys of factories, clock towers, high towers, and, briefly, all objects liable to attract the attention of the pilot from a distance, either by means of their shape, dimensions, color, or situation.

To the second category belong turf pits, thick hedges, irrigation or drainage canals, electrical power lines traversing fields, and generally all objects liable to impede landing; and, in addition, gasometers, aerodromes and sheds where, if necessary, refuge or help could be obtained.

In the opinion of all competent authorities, the scale of 1 to 200,000 seems to be the most convenient one. On a smaller scale the map would be less clear; on a larger scale unwieldy without

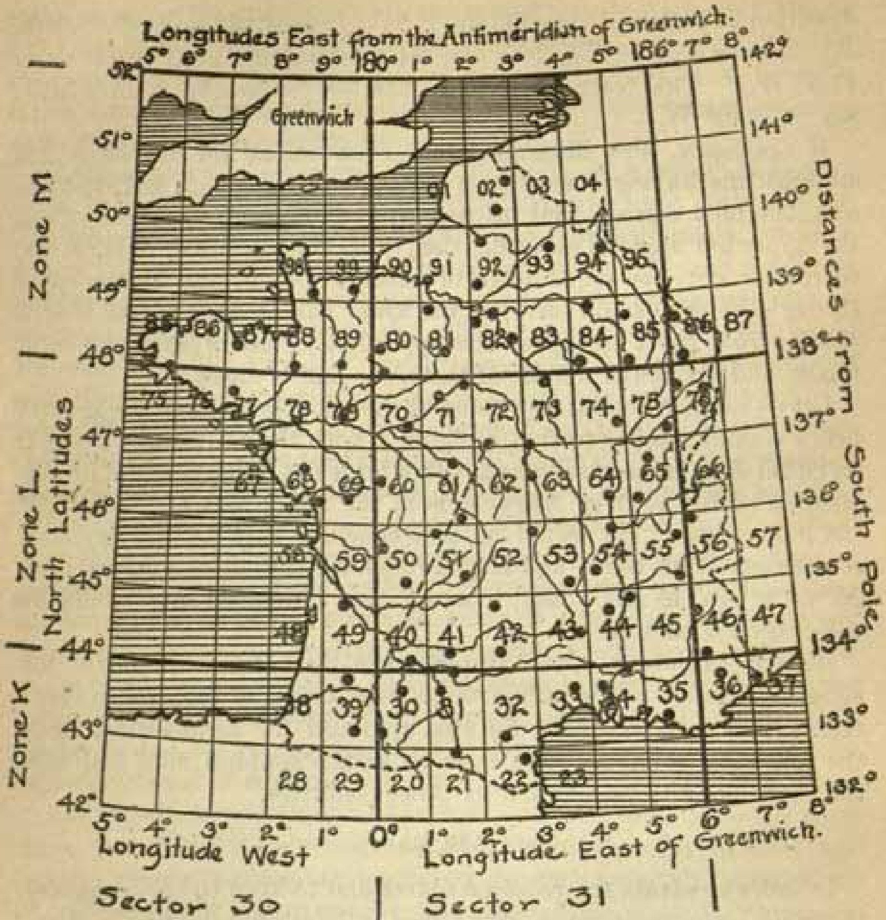

FIG. 1.—Index diagram showing for France the sheet lines of the Air Map.

——— Limits of the sheets of the Air Map.
——— Limits of the sheets of the World Map.
37....72 Numbers of the sheets PAU .... BOURGES, etc.
30, 31, 32 Numbers of the sectors of the World Map.
K, L, M Letters of Zones of the World Map.
● Chief towns of Departments.
.... Itinerary from Bourges to Pau.

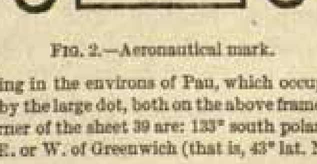

FIG. 2.—Aeronautical mark.

Erected on the roof of a building in the environs of Pau, which occupies, in the lower half of sheet 39, the relative position represented by the large dot, both on the above frame and on the index diagram (fig. 1). The coordinates of the SW. corner of the sheet 39 are: 133° south polar distance and 179° new longitude E. reckoned from meridian 180° E. or W. of Greenwich (that is, 43° lat. N. and 1° long. W. of Greenwich).

appreciable advantage. In many countries maps on this scale already exist, but having been produced with special objects, either economical or strategical, they only imperfectly satisfy the wants of airmen. A new special map is therefore necessary. A provisional model, submitted by the Aero Club of France, showing specially the typical buildings by their profile in black, was adopted by the committee.

At my suggestion it was decided that the new map should be a subdivision of the International Map of the World, on a scale of 1 to 1,000,000,[1] for the production of which, on the happy initiative of England, a common agreement was recently arrived at between the principal States of the civilized world.

The "world map" would furnish index diagrams for the fitting together of the sheets of the "air map." It would also be useful for drawing up schemes for long journeys, or for measuring the distance between two widely separated points and obtaining the orientation of the line adjoining them.

The "world map" is to be designed with the meter as unit of lengths, and the meridian of Greenwich as origin of the longitudes. The sheets are limited by meridians drawn out at successive intervals of 6°, extending from Greenwich, and by parallels traced out at successive intervals of 4°, reckoning from the Equator.

The meridian sectors, from longitude 180° east or west of Greenwich, are given numbers from 1 to 60, increasing in an easterly direction. The zones, extending from the Equator on each side to 88° latitude, are given letters from A to V preceded by the words "north or south." The polar areas are lettered Z. Each sheet shall bear the name of the locality or most important geographical feature on the territory represented, and in addition the number of the sector and the letter of the zone crossing each other on the sheet in question. For example, the sheet of Paris will be named "North M. 31."

For each sheet the corresponding part of the terrestrial ellipsoid is represented by a modified polyconic projection constructed on its central meridian. The meridians are straight lines and the parallels arcs of circles the centers of which lie on the prolongation of the central meridian, so that the radius of each one is equal to the generatrix of the cone tangent to the ellipsoid along the corresponding parallel. The alterations of angles, distances, and areas are practically small enough to be neglected.

On the other hand, the sheets of the air map will be limited by meridians and parallels at successive intervals of 1°, reckoned from the same origins as for the world map. Each sheet should cover an area of 1° of longitude and 1° of latitude. Twenty-four sheets of this map will therefore cover the same area as the corresponding sheet of

[1] That is not to say that the air map will be an exact amplification of the world map, but nearly so.

the world map on the scale of 1: 1,000,000. As the scale is five times as large, each of these sheets will be of approximately the same dimensions as the corresponding sheet of the 1: 1,000,000 map.

It is necessary, however, to introduce a more simple method of notation. It is customary to distinguish between longitudes east and west of the initial meridian and between latitudes north and south of the Equator. The nomenclature of the latitude and longitude therefore changes as one passes across either of these lines of origin. In other words, degrees of longitude increase to the right cr left from the initial meridian and degrees of latitude increase both north and south from the Equator. This notation is apt to cause trouble.

In order to overcome this disadvantage, the committee at my suggestion has decided to number the longitudes from 0° to 360° in an easterly direction, commencing from longitude 180° east or west of Greenwich, and to substitude for latitudes polar distances measured from the South Pole and reading from 0° to 180°. This is done in order that in the Northern Hemisphere, in which are situated most of the inhabited countries, the number may increase as usual from the Equator northward. Moreover, in the Northern Hemisphere the units of degrees would be the same for a south polar distance as for the corresponding latitude. The units of the longitude thus adopted will be the same, between 180° and 360°, as they are now for longitudes east of Greenwich. The tens of degrees, in the case of south polar distances, will be increased by 9 units, and in the case of longitudes east of Greenwich by 18 units.

In the Southern Hemisphere the polar distances will be the complements of the corresponding latitudes, and in the hemisphere extending from 0° to 180° of longitude the new longitudes of places will be the supplements of the present longitudes west of Greenwich. In addition to the usual notations, these new ones should be printed on the world map and on the index diagram, figure 1.

Each sheet of the air map will bear the name of the most important locality on the area covered by it and shall be numbered by the coordinates of its southwestern corner. This number shows the number of degrees of longitude and south polar distances in the coordinates of any point in the sheet, and in order to obtain the complete coordinates of any given point it will be sufficient to add to these figures the tenths of degrees or minutes obtained from the marginal scales.

The air map will be constructed on the same modified polyconic projection as that used for the world map. Each sheet shall be 56 centimeters, or 22 inches, high and from 41 centimeters to 34 centimeters broad (in France). The corresponding breadth near London would be 12 inches. Each sheet in France would therefore cover an

area of 111 kilometers, or 67 miles, north and south and from 82 to 68 kilometers (61 to 41 miles) east and west.

In this system the distortion, which increases as the square of the distance from the central meridian, would be 36 times as small in the air map as in the world map, since a sheet of the air map covers only 1° of longitude instead of 6°. As, however, the scale of the air map is five times as large, the errors from this source are reduced to one-seventh of those in the world map.

In order to facilitate handling, each sheet should be cut in half, the cutting lines running east and west, each half measuring some 28 by 38 centimeters (11 by 15 inches). The two half sheets should be pasted on either side of a piece of cardboard, and should have the name and number of the sheet shown in a conspicuous manner.

The Aero Club of France have prepared, this year, three trial sheets of this map, covering the area to be used in the next military maneuvers, with a view to obtaining the remarks of the aviator officers previous to publishing a final edition.

3. AERONAUTICAL MARKS.

As has been previously mentioned, each mark shall show the approximate longitude and polar distance of the point over which the aviator is flying. The sign adopted by the committee consists of half a rectangle (fig. 2) reproducing, on a sufficiently large scale, the frame of the half sheet of the air map in which the mark lies. The sides of this frame appear as broad lines, except the side where the cut is, which is shown by a fine dotted line; thus it is easy to distinguish between the upper and lower halves of a sheet. In this frame a large black dot will indicate the correct position, on the sheet, of the mark of the ground.

The half rectangle is correctly oriented, the small sides, parallel to the meridians, being due north and south.

Two large figures, reading toward the north, will be marked on either side of this rectangle, the left one giving the number of the units of degrees of the polar distance, and the right one the number of the units of degrees of the longitude.

The combination of these two figures, forming a number easy to read and remember, will be sufficient to define the number of the corresponding sheet of the map, and to give the rough coordinates of the mark itself. In every case where confusion might exist, each of the figures should be underlined.

Owing to the absence of the digits showing the hundreds and tens of degrees of longitude and polar distance, any two marks which are 10° or a multiple of 10° apart will have the same number. The disadvantage of this would not be of great importance. For an airman to confuse two such marks would mean that he would make

an error of 10° of either longitude or latitude. In latitudes between 40° and 50° this error would amount to 1,100 kilometers (700 miles) of latitude, or from 700–800 kilometers (400–500 miles) of longitude.

In an area covering the whole of France, only the extreme points of Brittany and the Vosges will have marks showing the same numbers. Consider, for instance, the marks numbered 39 in the environs of Pau. The same number as this, on land, would not occur again nearer than points in Algeria, England, Belgrade, or Hamburg, and would not appear at all in Spain or Italy. To mistake such dissimilar countries would be practically impossible.

To determine the correct coordinates of a mark, an aviator would only have to add to the number shown the hundreds and tens of degrees of polar distance and longitude. The remainder, with an error of perhaps a tenth of a degree (or a few minutes), could be estimated by examining the position of the dot, with reference to the sides of the mark. The position of the mark could thus be estimated with an error of less than 10 kilometers (6 miles) in either direction.

4. CONCLUSION.

The initiative thus taken by France in producing an air map and establishing aeronautical marks will very probably be followed by other countries. In such a case it would be necessary to have an international agreement to give definitely the conventional signs of the air map and other details.

In May last the cartographical committee of the International Aeronautical Federation, which met in Brussels to consider such questions, adopted in principle the meridian of Greenwich as the origin of the longitudes, a scale of 1:200,000 for the air map, and for the limits of the sheets, meridians and parallels one degree apart, starting from Greenwich and the Equator, and decided that electrical power lines, which are so dangerous for airships and aeroplanes when landing, should be shown on the map.

As regards the aeronautical marks, this committee did not venture to select any one system out of the numerous ones that were proposed, and only suggested that the names of the respective localities should be marked, in large letters, on roofs, especially on those of railway stations. As many stations, however, would thus show the same name, this would be a source of error and confusion; in addition to this, the aviator would have to consult a dictionary of names of boroughs, in order to find the number of the sheet of the air map which he requires. A system of marks showing the cutting lines of the sheet concerned, together with an abbreviated distinguishing number, seems to be much more precise, significant, and certain. It is therefore to be hoped that sooner or later this system will be universally adopted.

GEOLOGIC WORK OF ANTS IN TROPICAL AMERICA.[1]

[With 1 plate.]

By J. C. Branner.

INTRODUCTORY.

In 1900 I published a short paper on the geologic work of ants in the Tropics.[2] Since then a good many additional observations, notes, and photographs have been made, and the most important of them are here brought together in a single article.

There are many brief notes on the work of ants scattered through the writings of travelers in tropical countries, but these notes are for the most part repetitions of rather vague and sensational stories which make no claim to accuracy of statement, so that they would add little or nothing to the value of the article. No attempt has therefore been made to use such notes except in so far as they seem to afford new or important corroborative evidence. At the same time it is realized that some of the things that ants do in tropical countries are so remarkable that those who have no personal experience of them may be pardoned for regarding the stories told about them with a certain amount of suspicion. For this reason I have confined myself to my own observations and to some of our most trustworthy scientific writers, such as Bates, Belt, and Spruce, who are naturalists to be taken seriously.

The best anyone can do who has not seen the work of ants in tropical countries is to turn to what can be seen in temperate regions. But the work done by ants in temperate zones is, with a few exceptions, of no geologic importance at all as compared with that done by them in some parts of the Tropics.

The work of the ants, in so far as it is of geologic importance, consists chiefly of their nests, habitations, refuse heaps, or mounds, above ground and their burrows, tunnels, passageways, and other excavations beneath the surface, and the opening up of the soil and the subjacent rocks to the various atmospheric influences.

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[1] Read before the Cordilleran Section of the Geological Society of America Mar. 25, 1910. Manuscript received by secretary of the society Apr. 29, 1910. Published Aug. 20, 1910. Reprinted by permission (condensed by author) from Bulletin of the Geological Society of America, vol. 21, pp. 449–496.

[2] Journal of Geology, vol. 8, pp. 151–153. Chicago, 1900.

In the United States we have very little evidence of ants making either underground passageways or mounds of sufficient size or extent to have attracted much attention. Indeed, it seems to be generally conceded by entomologists that the ants of the northern part of North America are not as enterprising as those farther south, or even as those of Europe. Forel seems to have found the structures of our North American ants so insignificant that he avoided speaking of them as having mounds at all. Certainly the little ant hills we have seen in most parts of the United States are too insignificant to attract the attention of geologists. In the South and Southwest they are somewhat more conspicuous, and in the semiarid portions of western Texas and in Arizona, New Mexico, and parts of California they have attracted not a little attention.

The western halves of Oklahoma, Kansas, and Nebraska and the eastern portion of Colorado are inhabited by mound-building prairie ants that are sufficiently abundant and sufficiently pugnacious to have attracted the attention of farmers and entomologists, if not geologists.[1]

In the Western States generally ants are more abundant than they are in the East, but a writer on the ant hills of southwestern Wisconsin says that in that part of the country he knows at least a hundred so-called ant hills within a radius of 5 miles, and he appears to regard this number as quite striking. Their mounds, he says, are as much as 75 centimeters in diameter and 40 centimeters in height.[2] These cases are mentioned simply for the purpose of contrasting the size and number of ant hills in a region that seems to be regarded as pretty thickly inhabited with some of the typical localities in the tropical portions of South America.

Furthermore, in the tropical parts of America ants are not the simple and easily ignored insects with which we are acquainted in the temperate zones of the earth. Save in the cities, they are almost omnipresent. To the housekeeper they are not only never-sleeping pests, but they are bold and defiant robbers or sneak thieves, as circumstances require or permit. To the planters they are veritable plagues; they destroy the growing crops as completely as if they had been burned over. They do not wipe out a field of grain in a few hours as completely as do the locust swarms of Argentina, and then disappear, but they stay with their work right alongside of the crops, and with time they destroy them no less certainly. Unlike the locusts, they do not come and depart, but they stay right in one circumscribed area all their lives. Farinha de mandioca, the meal prepared from the cassava plant, or grain of any kind and of a size small

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[1] T. J. Headlee and George A. Dean: The mound-building prairie ant (*Pogonomyrmex occidentalis* Cresson). Bull 154, Kansas Agricultural Experiment Station. Manhattan, 1908.

[2] Hermann Muckermann: Psyche, vol. 9, pp. 355–360. Boston, 1902.

enough for them to carry, require to be guarded with constant care. I have known entire bagfuls of farinha de mandioca to be carried away by them. In short, the inhabitants have to be constantly on their guard against the ants, both indoors and out of doors, to say nothing of the mere inconvenience of their presence. Nor can their importance be regarded as whimsical in any sense; indeed, I am convinced that they are social, and even national, factors that are not to be ignored.

Nothing in the way of a biologic or systematic study of tropical ants is attempted in the present paper. However valuable such a study might be, it is the number of individuals, rather than the number of species, that concerns the geologists, though it is recognized, of course, that some species are much more active agents than others. We need concern ourselves with only two large orders—the true ants belonging to the *Hymenoptera*, and the termites, or so-called white ants, neuropteroid insects which belong to the *Isoptera*, and are known all over Brazil by the popular Indian name of "cupim." And nothing is attempted in the way of a study of the architecture of their nests and underground passages, save in so far as such details will give a better idea of the geologic bearing of these matters.

In studying the work of ants in the Tropics one is constantly reminded of Mr. Darwin's studies of the work of earthworms. Mr. Darwin was able to give the quantitative results of his studies; in the case of the ants, unfortunately, quantitative results have not been possible. The time occupied by them in doing a given amount of work varies so much that quantitative observations, in order to have any value, would have to be carried on upon many colonies and for a long period of time. The results given at page 316 are an attempt at quantitative determination, but it will be observed that it is not known how many individuals took part in the work or how long they were at it.

To illustrate this article especial pains have been taken to get as many photographs and sketches as possible of the above-ground structures of ants and termites, and the accompanying illustrations have been carefully made from photographs, most of them taken in Brazil. It seemed better to have the drawings made rather than to use the original photographs, in spite of the evident suspicion of exaggeration or alteration, whether intentional or accidental, to which all drawings are open. This redrawing was the more necessary because the photographs were taken hastily and under many unfavorable circumstances, and they are therefore often not good, or they are not available for reproduction as photographs. Abundant illustrations are given because it is felt that they are the most trustworthy witnesses one can put in evidence regarding the subject.

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THE TRUE ANTS.

ABUNDANCE.

Although ants are not everywhere equally abundant in tropical South America, their numbers are so large on an average as to promptly attract the attention of travelers, even when they do not excite their wonder. Residents, who might be expected to have conservative views on the subject, often speak of them as the owners of the land. Such a remark is at first regarded as merely facetious, but the character of some of the writers who make it entitles it to serious consideration. As long ago as 1648 Piso said that the Portuguese not inappropriately called the ant the "king of Brazil."[1]

Another naturalist who spent some time in the country says, "Brazil is one great ants' nest."[2] Belt says, "They are one of the greatest scourges of tropical America."[3]

A Brazilian traveler says of the region of the upper Rio, Paraguay, "The ant and the different kinds of termites own the land."[4] Another puts it in this fashion: ". . . ants . . . deserve to be considered the actual owners of the Amazon Valley far more than the red or the white man."[5]

These characterizations and others that might be given are so sweeping that, taken alone, they are open to the suspicion of being merely picturesque and extravagant ebullitions rather than serious statements of fact. If they are based on some knowledge of the ants, these expressions seem to spring from more or less personal animosity toward those insects. And yet this very animosity, if it really exists, must come from a pretty uniform personal experience of them. Dr. Auguste Forel says that "the ant fauna of South America is perhaps the richest in the world from the systematic point of view."[6] In the book cited 440 species of true ants are noted as inhabiting Brazil, out of a total of 2,000 known in the world.

But though it is with the number of individuals rather than the number of species that we are concerned, it is worth remembering that in many considerable regions a single species may occupy about all the ground space that it is possible for ants to occupy. A single species may thus fairly swarm and do a vast deal more work than several different species.

The true ants, evidently of a large number of species, are so abundant and are such serious pests in some places that the land is

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[1] Formicæ autem hæ (*Rey do Brasil* Lusitanis non immerito dictæ, quod perpetuam tyrannidem exercent) aliquæ Europæarum plane similes, aliquæ triplo majores & alatæ, omnivoræ sunt. De Aeribus, Aquis, & Locis. Gvilielmi Pisonis Historiæ Naturalis & Medicæ, p. 9. Amsterdam, 1658.

[2] Rev. H. Clark: Letters home from Spain, etc., pp. 131, 173. London, 1867.

[3] Thomas Belt: The naturalist in Nicaragua, p. 79. London, 1874.

[4] Dr. João Severiano da Fonseca. Viagem ao redor do Brazil, vol. 1, p. 352. Rio de Janeiro, 1880.

[5] Richard Spruce: Notes of a botanist on the Amazon and Andes, vol. 2, p. 366. London, 1908.

[6] A. Forel: A fauna das formigas do Brazil. Bol. do Museu Paraense, vol. 1, p. 89. Para, 1895.

practically preempted by them. Travelers passing the night in the open have to be constantly on their guard against colonies of ants. Fighting such colonies under the circumstances is simply out of the question. When one finds himself in disagreeable proximity to them, the only thing to be done is to move at once and leave the ants masters of the situation.

Bates, speaking of a certain species, says (page 354):

These Ecitons are seen in the pathways of the forest at all places on the banks of the Amazons, traveling in dense columns of countless thousands.

On the Rio Tapajos, in the Amazon Valley, he noted the

quantity of drowned winged ants along the beach; they were all of one species, the terrible *formiga de fogo* (*Myrmica sævissima*), the dead or half-dead bodies of which were heaped up in a line an inch or two in height and breadth, the line continuing without interruption for miles at the edge of the water. The countless thousands had been doubtless cast into the river while flying during a sudden squall the night before, and afterwards cast ashore by the waves.[1] . . . I was told that this wholesale destruction of ant life takes place annually, and that the same compact heap of dead bodies which I saw only in part extends along the banks of the river for 12 or 15 miles (op. cit., p. 206).

I have seen similar accumulations of dead female ants on the lower São Francisco and the Rio Paraguay, near Corumba, and at two places on the shores of estuaries near Aracaju, in the State of Sergipe.

Bates says the *formiga de fogo*, or fire ant, was so abundant at one place on the Tapajos that there was scarcely a square inch of ground free from them. (Op. cit., p. 202.)

The only figures I am able to give in regard to the sizes of ant colonies are the estimates given by Azevedo Sampaio, a Brazilian entomologist who has studied the *saúbas*. He estimates the colonies at from 175,000 to 600,000 individuals.[2]

DESTRUCTIVENESS.

The destruction wrought by the true ants is confined chiefly, but not entirely, to agricultural products. It is no uncommon thing to find spots where certain ants are so abundant and so destructive that the planters simply leave them alone. Sometimes it happens that after clearing a piece of land, and beginning their planting, the farmers find the ants so destructive that those particular fields are abandoned. In the coffee regions certain ants, popularly known as the *saúbas*, are so destructive that a systematic and unceasing war has to be waged upon them in order to save the coffee trees. But their attacks are not confined to coffee trees by any manner of means. They cut and carry away the leaves of the mandioca plants, orange and lemon trees,

[1] H. W. Bates: The naturalist on the River Amazons, 4th ed., p. 201. London, 1875.
[2] Azevedo Sampaio: Sauva ou Manhu-uára, pp. 50, 54. S. Paulo, 1894.

and all kinds of garden vegetables. Indeed, there seem to be very few or no cultivated plants that they do not attack.

They generally move along well-beaten paths that are almost as wide and as well defined as sheep paths in a pasture.

The expense of fighting these ants is a really serious item in the cost of the production of Brazilian coffee. A distinguished Brazilian planter says, with perfect justice, that "among the obstacles with which the planters have to contend * * * there stands perhaps in the front rank the destructive force represented by the *saúba*." [1]

One can get some idea of the economic importance of ants in Brazil from the fact that in the seventies and early eighties an enormous number of privileges or patents were asked of the Brazilian Government for machines and devices of various kinds for killing ants, and especially the *saúbas*.

In 1857 the Province of Rio de Janeiro voted a reward of $25,000 for the discovery of a means of destroying *saúbas*.[2]

It is impossible to keep things out of their reach on any large scale. Certain devices are used with more or less success for protecting things indoors when they are constantly watched, but standing crops or considerable stores require constant watchfulness and war.

In regard to the *saúbas* in the Amazon region Bates says:

> This ant (the *saúba*) is seen everywhere about the suburbs, marching to and fro in broad columns. From its habit of despoiling the most valuable cultivated trees of their foliage, it is a great scourge to the Brazilians. In some districts it is so abundant that agriculture is almost impossible, and everywhere complaints are heard of the terrible pest.[3]

ATTACKS ON MAN.

The *formiga de fogo*, or fire ants, are so called on account of the painfulness of their sting. When they are met with in large numbers there is simply no withstanding them.

One of the reasons for calling ants the kings, rulers, and owners of the country is due to the vicious attacks they make upon all kinds of animals. Bates tells of one case in which a town on the Tapajos was actually depopulated by ants of this kind. This statement seems so remarkable that it is quoted here at length:[4]

> Aveyros was deserted a few years before my visit on account of this little tormentor (*formiga de fogo*), and the inhabitants had only recently returned to their houses, thinking its numbers had decreased. It is a small species, of a shining reddish color, not greatly differing from the common red stinging ant of our own country (*Myrmica rubra*), except that the pain and irritation caused by its sting are much greater. The soil of the whole village is undermined by it; the ground is perforated with the en-

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[1] Henrique de Paula Mascarenhas: Revista Agricola do Imperial Instituto, vol. 14, p. 215. Rio de Janeiro, December, 1883.

[2] Auxiliador da Industria Nacional, vol. 37, p. 64. Rio de Janeiro, 1869.

[3] H. W. Bates: The naturalist on the River Amazons, 4th ed., p. 9. London, 1875.

[4] Naturalist on the Amazons, p. 205.

trances to their subterranean galleries, and a little sandy dome occurs here and there, where the insects bring their young to receive warmth near the surface. The houses are overrun with them; they dispute every fragment of food with the inhabitants, and destroy clothing for the sake of the starch. All eatables are obliged to be suspended in baskets from the rafters and the cords well soaked with copauba balsam, which is the only means known of preventing them from climbing. They seem to attack persons out of sheer malice; if we stood for a few moments in the street, even at a distance from their nests, we were sure to be overrun and severely punished, for the moment an ant touched the flesh he secured himself with his jaws, doubled in his tail, and stung with all his might. When we were seated on chairs in the evenings in front of the house to enjoy a chat with our neighbors, we had stools to support our feet, the legs of which, as well as those of the chairs, were well anointed with the balsam. The cords of hammocks are obliged to be smeared with the balsam in the same way to prevent the ants from paying sleepers a visit.

Anyone who wishes to get a clear understanding of the seriousness of the bite of these ants should read Dr. Richard Spruce's account of his personal experience of them [1]:

August 15, 1853.—Yesterday I had the pleasure for the first time of experiencing the sting of the large black ant called tucandera in Lingoa Geral. * * *

I had gone after breakfast to herborise in the caapœra north of San Carlos, where there were a good many decayed trunks and stumps. I stooped down to cut off a patch of a moss on a stump, and remarked that by so doing I exposed a large hollow in the rotten wood; but when I turned me to put the moss into my vasculum I did not notice that a string of angry tucanderas poured out of the opening I had made. I was speedily made aware of it by a prick in the thigh, which I supposed to be caused by a snake until, springing up, I saw that my feet and legs were being covered by the dreaded tucandera. There was nothing but flight for it, and I accordingly ran off as quickly as I could among the entangling branches, and finally succeeded in beating off the ants, but not before I had been dreadfully stung about the feet, for I wore only slippers without heels, and these came off in the struggle. I was little more than five minutes' walk from my house, * * * and I wished to walk rapidly, but could not. I was in agonies, and had much to do to keep from throwing myself on the ground and rolling about as I had seen the Indians do when suffering from the stings of this ant. * * *

BENEFICIAL ANTS.

Not all the ants, however, are to be looked upon as pests. Certain carnivorous ants are rather to be regarded as beneficial to agriculture, and to mankind generally, on account of their destruction of caterpillars and other noxious insects. In districts where cotton is grown the larvæ of the cotton moths are kept in check by the ants destroying the young ones, especially during the early part of the season. The invasion of houses by ant colonies is a common occurrence in every part of Brazil. Ordinarily these invasions are only temporary. During the hour or two when these ants swarm through one's house or rooms they are certainly annoying, but they soon disappear, and one feels that he has been relieved to a considerable extent from the cockroaches and other more offensive and more serious plagues.

[1] Richard Spruce: Notes of a botanist on the Amazon and Andes, vol. 1, pp. 362-364. London, 1908.

Many writers have described the operations of these ants, but the following, quoted from Dr. Richard Spruce, will give a clear idea of them:[1]

One morning soon after sunrise the hut was suddenly filled with large blackish ants, which ran nimbly about and tried their teeth on everything. My charqui proved too tough for them; but they made short work of a bunch of ripe plantains, and rooted out cockroaches, spiders, and other such like denizens of a forest hut. So long as they were left unmolested they avoided the human inhabitants; but when I attempted to brush them away they fell on me by hundreds and bit and stung fiercely.

Thomas Belt has a good deal on the swarms of ants in Central America. The following extract is from his "Naturalist in Nicaragua," page 17:

One of the smaller species (*Eciton predator*) used occasionally to visit our house and swarm over the floors and walls, searching every cranny and driving out the cockroaches and spiders, many of which were caught, pulled, bitten to pieces, and carried off. The individuals of this species were of various sizes, the smallest measuring one and a quarter lines and the largest three lines, or a quarter of an inch.

I saw many armies of this, or a closely allied species, in the forest. My attention was generally first called to them by the twittering of some small birds, belonging to several different species, that follow the ants in the woods. On approaching, a dense body of the ants, three or four yards wide, and so numerous as to blacken the ground, would be seen moving rapidly in one direction, examining every cranny and underneath every fallen leaf. On the flanks and in advance of the main body smaller columns would be pushed out. These smaller columns would generally first flush the cockroaches, grasshoppers, and spiders. The pursued insects would rapidly make off, but many in their confusion and terror would bound right into the midst of the main body of ants.

Bates has the following regarding the Ecitons, page 354:

When the pedestrian falls in with a train of these ants, the first signal given him is a twittering and restless movement of small flocks of plain-colored birds (ant thrushes) in the jungle. If this be disregarded until he advances a few steps farther, he is sure to fall into trouble, and find himself suddenly attacked by numbers of the ferocious little creatures. They swarm up his legs with incredible rapidity, each one driving its pincer-like jaws into his skin, and with the purchase thus obtained, doubling in its tail, and stinging with all its might. There is no course left but to run for it; if he is accompanied by natives, they will be sure to give the alarm, crying, "Tauóca!" and scampering at full speed to the other end of the column of ants. The tenacious insects who have secured themselves to his legs then have to be plucked off one by one, a task which is generally not accomplished without pulling them in twain, and leaving heads and jaws sticking in the wounds.

The errand of the vast ant armies is plunder, as in the case of Eciton legions; but from their moving always amongst dense thickets, their proceedings are not so easy to observe as in that species. Wherever they move, the whole animal world is set in commotion, and every creature tries to get out of their way. But it is especially the various tribes of wingless insects that have cause for fear, such as heavy-bodied spiders, ants of other species, maggots, caterpillars, larvæ of cockroaches, etc., all of which live under fallen leaves or in decaying wood. The Ecitons do not mount very high on trees, and therefore the nestlings of birds are not much incommoded by them.

[1] Richard Spruce: Notes of a botanist on the Amazon and Andes, vol. 2, pp. 371-373. London, 1908.

ANTS AS FOOD.

In the Amazon region some of the ants are even used by the Indians for food.

> The head and thorax are the parts eaten, the abdomen being nipped off (at San Carlos I constantly see them eaten entire), and it is eaten uncooked. The taste to me is strong, fiery, and disagreeable, but those who have eaten the bacháco fried in turtle oil tell me it is quite palatable.[1]

Orton [2] says the *saúbas* "are eaten by the Rio Negro Indians, and esteemed a luxury, while the Tapajos Tribes use them to season their mandioca sauce."

In the more thickly settled parts of Brazil the custom of eating these ants is either not practiced nowadays, or, if it is, it is not generally known. In the early history of the country, however, when the native Indians were much more abundant than they are now, the custom appears to have been common.

STRUCTURES ABOVE GROUND.

Origin of the structures.—The word "nests" frequently applied to the superficial structures of ants should not be understood to mean nests in the ordinary signification of the word. These structures sometimes contain the queens, eggs, and larvæ, but at other times these are kept in excavations below the surface.

The mounds made by the true ants all begin as small funnel-shaped ridges around the excavations started by individual females. The large mounds are the results of the work of many generations and of a vast number of individuals.

Without going into any detailed description of the habits of the ants, it is worth while to give, for those unfamiliar with their habits, a general idea of the methods followed by these ants in establishing new colonies and in increasing them. When the swarming or mating season of the *saúba* ant comes, the young females leave their homes and fly away. They seem to fly about very much at random—at least, I have rarely seen them going in any particular direction—and when they have been seen going together it was apparently due to the direction of the wind or the position of the sun at the time, rather than to any definite purpose on their part.

When the female alights after a flight of only a few minutes, she breaks off her wings and at once falls to work at excavating a burrow. All kinds of places are selected for these burrows. It does not appear that the selection is deliberate, but it seems to be determined by the accident of alighting from an aimless flight. Judging from the large number of individual females I have frequently seen in the air and on

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[1] Richard Spruce: Notes of a botanist on the Amazon and Andes, vol. I, p. 484. London, 1908.

[2] James Orton: The Andes and the Amazon, 3d ed., p. 301. New York, 1876.

the ground at one time, the great majority of these young colonies must fail to survive. Often I have seen the young females so abundant that there must have been an individual to every square meter of land surface over areas of many hundreds of acres.

In some places where the new arrivals alight the mounds are already so thick that there is little or no room for new colonies, and it is probable that some of these young females must either be adopted into the old colonies or they are killed or die.[1]

It is evident from the nature of the case that where such a large number of new colonies is started most of them must perish from mere overcrowding, if for no other reason.

The excavation first made by a young female is small and simple, and the earth taken from it is heaped about the opening without any apparent order. Dr. Huber, in the paper just cited, states that at Para, in a colony started by a single female, the first workers appear at the end of 40 days. Shortly thereafter the queen, or founder of the colony, ceases to be an active worker, and all subsequent excavating is done by the constantly increasing number of workers. As the colonies increase in numbers more underground room is required, and the amount of earth excavated and carried to the surface increases proportionately. This earth is brought to the surface in the jaws of the workers in the form of small pellets which are thrown down apparently without any other object than to be rid of them. Sometimes they are heaped up in funnel-shaped pits; sometimes they are thrown out on the downhill side of the opening. At first these bits of earth form heaps of loose, incoherent material, but in time, and with rain and sunshine, it packs down until it is often as hard as an unbaked brick. As long as the colony is active and growing, additions are constantly being made to these accumulations, and these additions may be at any point over the sides or at the top. Passageways are either kept open through these heaps of earth or they are reexcavated. This is demonstrated by digging into the mounds, but it is evident without opening them, from the fact that the fresh material is brought out and spread over any and all parts of the surface.

Size of the mounds.—It might be inferred that there would be practically no limit to the size of the mounds built in this fashion, and I am not sure that there are any limits save those which may be imposed by certain physical conditions, such as the amount and distribution of the rains, the character of the soil, the area over which the necessary plants or food can be obtained, etc. Of course, the mounds are of different sizes according to their ages; but consid-

[1] Just how new colonies of saubas can be established by a single female is described by Dr. J. Huber in Biologisches Centralblatt, vol. 25, pp. 606-618, 624-635, and in the Boletim do Museu Goeldi, vol. 5, pp. 223-241. Para, 1907-8. Also in the Annual Report of the Smithsonian Institution for 1906, pp. 355-367.

ering only the largest and oldest ones made by a single species, and found in various different localities, it is noteworthy that there is a great difference in the sizes of the largest of them. Just what determines this variation I can not say positively, but the influences referred to above—that is, rainfall, character of soil, and vegetation—naturally suggest themselves as possible influences.

Nowhere do I remember to have seen more or larger ant hills than along Rio Utinga, in the diamond regions of the interior of the State of Bahia. From the town Riachao, down the river to the village of Pegas, the examples are big and abundant. In a few places they are so close together that, big and little, they appear to cover half of the ground. My notes, written on the spot, say "more than half of the ground." Such places, however, are exceptional. The distribution is always more or less irregular—bunched apparently on account of characteristics of soil or drainage, or for some other reason that does not appear. In some areas of from 10 to 20 acres the ant hills occupy from a fifth to a third of the ground, while over larger tracts they take up from one-eighth to a seventh of the ground. In height the mounds are often as much as 5 meters high, with bases 15 or 16 meters in diameter. In the forests these mounds are generally overgrown with young trees. On many of the big mounds I have seen trees more than 30 centimeters in diameter. At the village of Antonio Jose the people have planted pineapples upon the mounds.

At fazenda Bello Horizonte, about 18 kilometers north of the village of Pegas, the ant hills are so large and stand so thickly upon the ground that they form one of the most striking illustrations I have ever seen of the work of these insects. An area of some 30 acres or more is there covered with mounds resembling haycocks. They probably average 2 meters in height and a diameter of 4 or 5 meters at the base.

At a place called Ponte Nova, on Rio Utinga, 8 kilometers north of the village of Pegas, the ant hills are a remarkable feature of the landscape. To the east and northeast of the Protestant college the mounds cover the old fields. One of the accompanying photographs (fig. 2, pl. 1) and text figure 1 were made in this region.

Six kilometers north of the station one was found by measurement to be 1.8 meters high and 4.5+ meters wide at the base. This mound was not regarded by the people of the locality as anything unusual.

To the east of Serrinha several mounds were observed with a height of 3 meters and a diameter at the base of 10 meters. These mounds, therefore, contain each 78.5 cubic meters of earth.

Along the western half of the Bahia and Minas Railway, that starts from the coast near Caravellas, in the southern part of the State of

Bahia, and runs west 376 kilometers into the State of Minas Geraes, ant hills are big and abundant. The newer ones are steeply conical, but with age they become more or less rounded and flattened. In

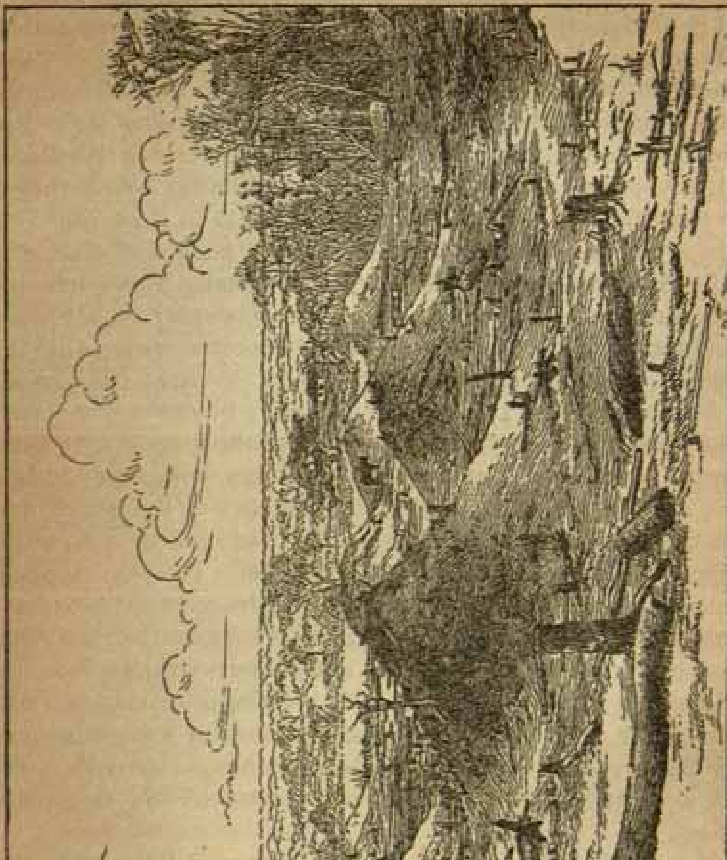


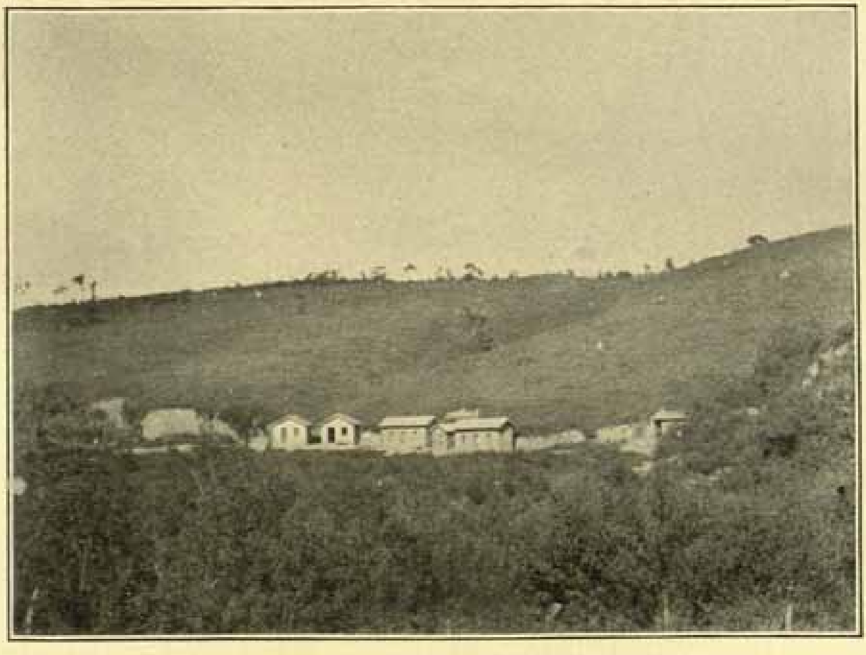
FIG. 1.—Ant hills on Rio Utinga, near the village of Pegas, State of Bahia.

[From a photograph by R. Crandall, 1907.]

the vicinity of Urucu Station (kilometer 226) the mounds are so thick and so close together that the country looks like a field of gigantic potato hills.

1. NEWLY CLEARED FIELD COVERED WITH MOUNDS OF ANTS NEAR RIO UTINGA, STATE OF BAHIA, BRAZIL.

The largest of these mounds have bases of six or seven meters. Photograph by R. Crandall, 1907.



2. MOUNDS OF TERMITES IN AN OLD FIELD NEAR QUELUZ, STATE OF MINAS GERAES, BRAZIL.

White spots in the background are the mounds. Photograph by Dr. Gonzaga de Campos, 1909.

In some places they stand so close that their bases touch each other, though such cases appear to be rather exceptional. The mounds in this part of Minas and Bahia that appear to have reached their full development range from 1 to 4½ meters in height and from 3 to 10 meters in diameter at the base. The biggest of these mounds—that is, one 4.5 meters high and 10 meters in diameter—contains approximately 117 cubic meters of earth.

At one place in the Rio Utinga region, where the forests had been cleared away so that the mounds were clearly visible, I selected a

FIG. 2.—Ant hill (Formiga de mandioca) near Mundo Novo, State of Bahia, Brazil.

[From a photograph by R. Crandall, 1907.]

spot where they were strikingly abundant, and measuring a space 100 by 100 meters, as nearly as it could be done by pacing, counted the mounds within the area and estimated their heights and diameters at the base.

The slopes of these mounds vary from less than 30 degrees up to 47 degrees, and on some parts of them there are even perpendicular places. It was thought that 38 degrees was a fair average for the ones in this particular area.

The figures obtained are given in the table below:

Table of areas and cubical contents of mounds of different sizes within an area of 10,000 square meters.

[All measurements are in meters.]

Number of mounds.	Diameter of base.	Area of each in square meters.	Total area in square meters.	Height.	Cubical contents.	Total contents in cubic meters.
1	15	176.71	176.71	4.5	265	265
2	11	95.03	190.06	4.2	133	266
6	10	78.54	471.24	3.9	102	612
8	8	50.26	402.08	3.1	51	408
12	7	38.48	460.76	2.9	37	444
5	6	28.27	141.35	2.3	21	105
4	5	19.63	78.52	2.0	13	52
7	4	12.56	87.92	1.7	7	49
8	3	7.06	56.48	1.2	3	24
53	....	....	2,064.82	....	....	2,225

This estimate makes the area actually covered by the mounds close to one-fifth of the total area under consideration. My notes show that within areas of a few acres the ground covered by the mounds is sometimes as high as one-half of the total area. The cubical contents of the mounds, if evenly distributed over the entire 10,000 square meters, would have a thickness of 22.25 centimeters.

Although the mounds within the area here considered were large, they were not the biggest I have seen, nor do they average as large as can be found. The largest ones measured were on the upper drainage of Rio Utinga; several of these were found to be 5 meters high and 16 and 17 meters in diameter at the base, and each contained, therefore, about 340 cubic meters of earth. There were no other mounds closer to these than 10 or 15 meters.

The reader should be reminded, however, that this sort of thing is not to be seen in all parts of the country, by any manner of means. So far as my own observations go, ant mounds are unusually large and unusually abundant in this particular part of Brazil.

Age of the mounds.—The amount of work done by these ants in a region where they seem to be favorably located is fairly well shown in the preceding table. Trustworthy data for calculating the time required to build a mound of a given size or to do any given amount of work are lacking. Necessarily the time must vary with the size of the colonies, other things being equal. The colonies, however, appear to have their ups and downs, for while some of them increase in numbers and continue to add to the mounds for long periods, others appear to be less active, while still others disappear, whether by migrating or through the death or captivity of the members is not certainly known at present. It is interesting to note that the Brazilians generally regard the size of the ant hill as directly related

to the age of the colony. At Serrinha, on the São Francisco Railway, I was told that mounds about 2 meters high and having a base of about 5 meters were probably as much as a hundred years old. This was an expression of views based simply upon a general impression and not upon records.

UNDERGROUND WORK.

So far as I can learn, there has never been any careful examination or study of the character, extent, and uses of the underground excavations made by ants in the Tropics. What is known about them has been learned accidentally, and our knowledge of the passages is, therefore, fragmentary. I have frequently dug into the mounds,

FIG. 3.—Ant hills made by the "Formiga de mandioca," near Ventura, State of Bahia, Brazil.
[From a photograph by R. Crandall, 1907.]

but always without the time necessary for satisfactory results. The most I have been able to make out in these hasty explorations is that the superficial mounds are penetrated in every direction with passageways. The large mounds were in no case opened down to the original surface of the ground; but when small mounds were opened they were found to connect through small tunnels with the underground excavations.

A pit started by the removal of a large ant hill east of Timbo, in the interior of Bahia, and continued to a depth of about 4 meters, showed the arrangement of the underground tunnels better than I have seen it

elsewhere. The section did not pass through the main shaft or tunnel that connected the ant hill with the subterranean excavations, but a little to one side of it. The upper layer of the earth, to a depth of half a meter, was undisturbed; then there was one tunnel with a flat floor, about 20 to 25 centimeters across, and having a low arched roof; below this, at a distance of about 25 centimeters, were two tunnels at the same level and of about the same size and shape; below these, at a further depth of about 25 centimeters, were three similar openings. This arrangement continued to a depth of nearly 2 meters, the tunnels being more numerous always at the lower levels. The tunnels at the lowest level did not form a complete row, but the work seemed to have been commenced at the outside.

This same arrangement of the tunnels has been seen frequently in railway cuts and ditches, but nowhere else have I seen so many levels or such a clearly defined plan in the placing of the excavations.

In some other cases noted the number of tunnels connecting the above-ground mounds with the underground galleries seemed to vary

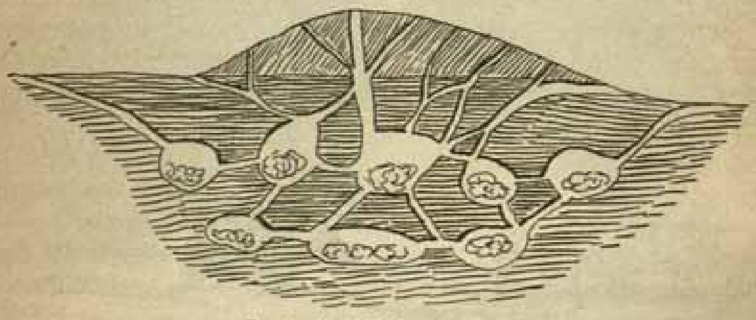


FIG. 4.—Nest of leaf-cutting ant.
After Belt. "The Naturalist in Nicaragua," p. 80.

with the size of the mounds—that is, the more ground the mound covered, the more passageways there seemed to be to connect with the galleries beneath.

The section through the burrows given by Belt is reproduced in figure 4. This section, however, is diagrammatic, and does not claim to show the great extent of the galleries. Belt tells, however, of galleries 1.5 meters in depth (p. 76). The best evidence I have been able to gather in regard to the depth to which the ants penetrate has been obtained in cuts along railways and canals, and in deep ditches often dug to serve as fences. On Rio do Peixe, near Serro, in the State of Minas Geraes, I found the galleries as deep as 2.5 meters at several places along a canal under construction. Most of them, however, were only about 1.5 meters below the surface at the deepest points exposed. At Bomfim, on the Bahia and São Francisco Railway, I found the burrows exposed in a deep ditch at a depth of 2.1 meters.

Sampaio, a Brazilian entomologist who has given much attention to the *saúba* ants, shows one burrow as much as 3.5 meters below the surface.[1]

Dr. Jaoquim Lustosa, of Lafayette, State of Minas Geraes, Brazil, writes:

> Competent persons assure me that the true ants burrow to a depth of 10 meters or more, and that they exhibit a strange and remarkable intelligence, and that they even cross wide and deep streams by means of tunnels so deep as to avoid the infiltration of the water.

The length of the tunnels has often been demonstrated by forcing smoke through them. I have myself seen fumes blown into one opening and issuing from others as much as 300 meters away.

Ants excavated a tunnel under the bed of the River Parahyba, at a place where it is as broad as the Thames at London Bridge. At the Magoary rice mills, near Para, these ants once pierced the embankment of a large reservoir; the great body of water which it contained escaped before the damage could be repaired.[2]

Another writer, Rev. J. C. Wood, tells of the *saúbas* having "ruined a gold mine for a time, breaking into it with a tunnel some 80 yards in length and letting in a torrent of water, which broke down the machinery and washed away all the supports, so that the mine had to be dug afresh." [3]

The diameter of an underground passage varies from 1 or 2 centimeters up to 5 centimeters or more. They widen out and narrow down without any apparent reason, and those made by the *saúbas* that have been examined have here and there local enlargements that are commonly from 1 to 2 decimeters in height and from 1 to 3 decimeters in length. These chambers, when freshly opened, I have generally found filled, or partly filled, with loose, moldy masses of dead leaves.

Belt describes the underground passages in Nicaragua as follows: [4]

> In our mining operations we also, on two occasions, carried our excavations from below up through very large formicariums, so that all their underground workings were exposed to observation. I found their nests below to consist of numerous rounded chambers, about as large as a man's head, connected together by tunneled passages leading from one chamber to another.

RELATIONS TO THE SOIL.

The distribution of ant colonies as shown by their mounds suggests, if it does not prove beyond question, that the character of the soil has an important influence on the distribution of the ants themselves.

[1] A. G. de Azevedo Sampaio: Sauva ou Manhu-uára, pp. 22, 52, 64. Sao Paulo, 1894.

[2] H. W. Bates: Naturalist on the Amazons, 4th ed., pp. 9-15. London, 1875.

[3] Charles Waterton: Wanderings in South America. Explanatory Index, Rev. J. G. Wood, p. 47. London, 1882.

[4] The Naturalist in Nicaragua, p. 80.

In view of the habits of ants, it seems highly probable that at the time of leaving their nests the young females scatter over the surrounding region pretty much at random. When they alight, some of them find themselves in locations where ant colonies, on account of the character of the ground, can not possibly survive, and as these young females break off their wings as soon as they alight, they can not renew their flight and seek more favorable ground, but they must perish without having founded a new colony. And this must happen over and over again, with the final result that localities unfavorable for ants do not have ant colonies, while the favorable localities may have a superabundance of them. Favorable and unfavorable conditions are not always sharply defined, but merge into each other.

In some cases it is quite evident what constitute unfavorable conditions. Ground that is constantly wet or liable to inundation can not be occupied; hard, rocky surfaces, or even very thin soils, are not available; soils so sandy or friable that underground tunnels dug in them will not stand are evidently not available for the establishment of colonies.

Between soils most favorable and unfavorable ones there are all sorts of gradations, so that one is prepared, for this reason alone, to find the ant hills bigger and more abundant in some places than in others. It is evident that it is all a question of adaptability, however, rather than a matter of choice on the part of the ants.

Just what kind of soil is most favorable for the ants I can not state positively. My general impression is that the mounds are most abundant on clayey soils, whether the clay comes directly from the decomposition of feldspathic rocks or from the disintegration of shales and slates.

This preference for the clayey soils is well shown at many places through the diamond-bearing highlands of the interior of Bahia, where the diamond-bearing quartzites, known as the Lavras series, are underlain by a thick series of shales called the Caboclo series. The Lavras beds being quartzites, or sandstones, break down into a very sandy soil, while the Caboclo shales form a stiff, clayey soil, and as they are adjacent to each other the line of demarcation between the two soils is usually well defined. While traveling through that district in 1907, I was frequently able to locate myself geologically by the abundance or absence of the ant hills. Not infrequently the line of parting between the two series was concealed by a thick soil and overgrown with forests, but the distribution of the mounds would often show the line of parting within 20 or 25 meters.

My former assistant, Mr. Roderic Crandall, who has traveled extensively in Bahia, Pernambuco, Piauhy, Minas, and Goyaz, writes, in reply to my inquiries, as follows regarding the preference of the ants for certain soils: "In Bahia the ants of all kinds show a preference for

the Estancia and Caboclo shales; next to these the granites seem to have the biggest nests."

I infer that the smaller number of the mounds on the sandy soil is due to the fact that during the rainy season water soaks through into the burrows, and the excavations do not stand up where the soil is wet.

Thinking it possible that the exposure of the mounds or of the ground on which they stand to the sun might influence location and distribution, an outlook has been kept with these questions in mind. It does not appear thus far that such exposure influences the location or size of the mounds, even in the southern part of Brazil, where the sun is on the north most or all of the year.

THE WHITE ANTS, OR TERMITES.

GENERAL CHARACTERISTICS.

The so-called white ants, or termites, belong to the *Isoptera*, and are therefore not ants at all. They are included in this paper solely on account of the geologic work done by them in the Tropics, which bears a certain similarity to the geologic work of the true ants.

In Brazil the white ants are commonly known by the name of *cupim*. In their habits the white ants both resemble and differ from the true ants. They generally avoid the light, carrying on their work, even when it is above ground, in galleries which they construct as they go. Their nests are sometimes attached to tree trunks or rocks, but they are often built directly upon the ground. Not infrequently these nests are as large, or even larger, than the nests of the true ants, but they are very different in shape and character.

ABUNDANCE.

Here, again, I am unable to give anything regarding the biology of the white ants.[1]

Dr. Fritz Muller, who lived for many years in southern Brazil, reports 15 or 16 species of termites in that part of the country, but not all of these live on or in the ground.

M. Jules Desneux, in his monograph on the Termitidæ, reports 45 species from Brazil and some 15 or more from other tropical parts of America.

White ants, like other animals, are not evenly distributed in the tropical parts of South America. They are so much less obtrusive and pugnacious, however, that they do not attract the attention as promptly as do the true ants.

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[1] For the benefit of those who are interested in the biology of white ants I cite the following.

K. Escherich: Die Termiten oder weissen Ameisen. Eine Biologische Studie, vol. 12, p. 198. Leipzig. 1909.

Genera Insectorum publiés par P. Wytsman. Fasc. 25, Isoptera, fam. Termitidæ par Jules Desneux, Bruxelles, 1904.

The fact that the white ants live and work entirely under cover might naturally lead one to infer that they were much less abundant than the true ants. But nowhere have I found the ground as thickly covered with the termites' nests as with those of the true ants, a fact probably due to some extent to the methods by which the two kinds of insects procure their food supplies.

I have never been able to estimate the number of individuals in the old colonies, nor have I found such an estimate made by any-one else. In the matter of numbers we are obliged to depend on general impressions gained from the abundance of the above-ground structures of the separate colonies and from certain of their habits. For example, it is stated that the queen of an allied species whose habits have been studied has "an egg-laying rate of 60 per mintute, or something like 80,000 per day." [1]

ANIMALS FEEDING ON TERMITES.

As the white ants have no means of defense against their natural enemies, they are easily destroyed and are preyed on by many other insectivorous animals. Indeed, one of the impressive evidences of the great numbers of the white ants in South America is the existence there of certain large vertebrate burrowing animals that are said to feed almost exclusively upon the white ants.[2]

The great ant-eater, known in Brazil as the *tamanduá bandeira*, is said to live entirely on ants. Brazilians acquainted with the habits of the *tamanduá* tell me, however, that the ant-eater does not eat the *saúbas* or other biting or stinging ants, but that it lives chiefly and almost exclusively on the *cupim*, or so-called white ant. To give an idea of the size of the animal, I quote the following measurements of an ant-eater as given by Wells: Head, 16 inches; back, 4 feet; tail, 4 feet; total length, 9 feet 4 inches.[3]

The existence of an animal as big as an ordinary dog, over 2 feet high at the shoulder, with its long, slender muzzle, its powerful forelegs and claws adapted to the excavation and exploration of ant-mounds, and its tongue nearly a yard in length, and living chiefly, if not entirely, upon white ants, is an important witness on the side of the abundance of termites in the region in which it lives. Bates reports four species of ant-eaters in the Amazonas region, two of which are large and two small ones (op. cit., 2d ed., p. 110), while Wallace says there are five species in tropical America, besides one extinct form.[4]

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[1] C. L. Marlatt: Circular 50, p. 3, 2d ser., Bureau of Entomology, U. S. Department of Agriculture. Washington, 1908.

[2] Holes often found in the mounds of the true ants show that some of these large ant-eating animals feed on the true ants also.

[3] J. W. Wells: Three thousand miles through Brazil, vol. 2, p. 141. London, 1886.

[4] A. R. Wallace: The geographical distribution of animals, vol. 2, p. 247. New York, 1876.

The armadillos, known in Brazil as *tatús*, are also ant-eaters. As Mr. Wallace points out,[1] the armadillos are highly characteristic of tropical South and Central America, and at the time of the publication of his famous work on the geographical distribution of animals they embraced 6 genera and 17 species, to say nothing of many extinct species found by Lund in the caves of Minas Geraes. Some of these armadillos are so large that a single individual will weigh as much as 75 pounds, or even more.

They live upon insects chiefly, and the white ants seem to be their favorite food. They enter the nests by digging openings at the base of the cones with their powerful fore feet.[2]

The white ants also form the principal food of the South American ostrich (*Rhea americana*), which is the largest bird in tropical America.[3]

In addition, there are large numbers of birds and reptiles, such as toads, frogs, lizards, and snakes, that habitually feed upon these insects.

The true ants are enemies of the white ants worthy of especial mention. The abundance of the ants and their pugnacious dispositions make them serious obstacles to the development of the termites' colonies, and they are probably their worst natural enemies. The termites have in their colonies forms that are known among biologists as soldiers, but so far as I have been able to determine from personal observations these soldiers do not attack the true ants, though they do take the place of soldiers in obstructing the passage of the ants into the termites' nests and galleries.

The result of the relations existing between the true ants and the termites is that the two kinds do not thrive together; at least I have never found the termites' nests where the *saúbas* or other true ants were notably abundant. Preyed on by the true ants and by animals of so many different kinds, and even by insects themselves, it occurs to one that their chances of survival in the midst of so many enemies must be very small. That survival appears to be due largely to their habit of living and working under the protection of their covered roadways, and to the fact that their roads are constructed of materials that are remarkably inconspicuous. Nothing could look more thoroughly abandoned and lifeless than the common run of white ants' nests and their covered passages; yet if one breaks through these coverings he will usually find them fairly swarming with life.

My general impression is that those white ants which build mounds of earth are especially abundant in the highlands of Minas Geraes and through the semiarid portions of Sergipe, Bahia, Goyaz, Matto

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[1] Alfred R. Wallace: The geographical distribution of animals, vol. 1, pp. 245-246. New York, 1876.

[2] The flesh of the *tatús* is very much prized for food, and this naturally leads to the hunting and killing of these animals, which should be protected.

[3] George Gardner: Travels in the interior of Brazil, p. 280. London, 1846.

Grosso, and the interior of Ceará, Maranhão, and Piauhy. Mr. Crandall tells me that he finds them most common on the Diamantina Plateau.

STRUCTURES ABOVE GROUND.

General characteristics.—The nests of the white ants, or *cupim*, have no visible external openings. When a mound is new or is

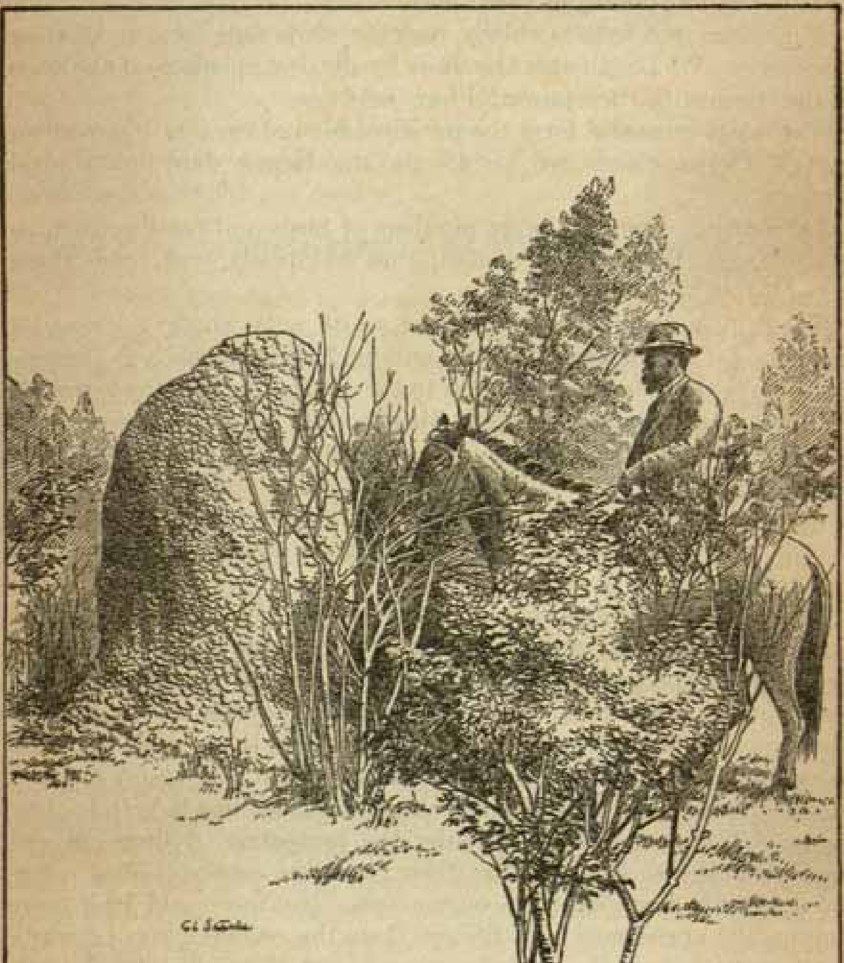

FIG. 5.—Above-ground structure of white ants.

[Seven kilometers west of Queluz, between Piquiry and S. Gonçalez, State of Minas Geraes. From a photograph by the author, Aug. 4, 1907.]

being added to, the outside of the new portion is so soft that it can be readily broken off with a stick; but with time the outside usually becomes as hard as a sun-dried brick. This hard outside covers the entire mound, and is usually about 6 inches thick, but in the very

big nests it is sometimes nearly or quite a foot thick. Inside of this hard, thick covering the materials are quite soft and brittle, and the partitions are sometimes almost as thin as paper, though thicker in the larger nests. Where the mound stands on the ground, the cavi-

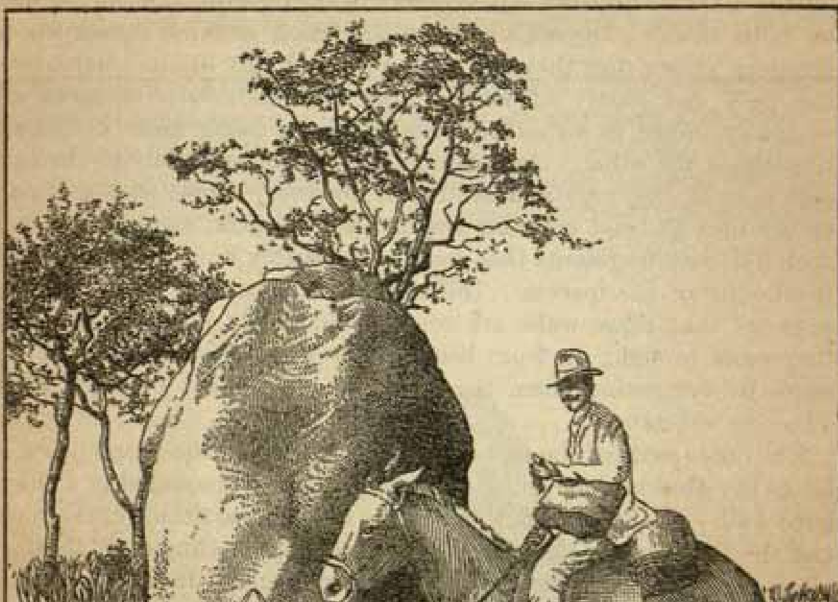

Fig. 6.—Mound of termites or white ants, State of Minas Geraes, Brazil.

[From a photograph by R. Crandall, July, 1909.]

ties of the upper portion connect through the perforated base with subterranean excavations.

Parts of the nests are made of the excrement of the inhabitants. I have often broken the nests or the covered roads of these insects

in order to observe the workers repair them. In every case observed the repairs were made by building up a wall or covering of excrement or something of the kind. At least it is voided from the posterior part of the body in a plastic condition, and is smoothed down on the sides so that the later layers always override the earlier ones on both sides of the wall. An examination of their construction, however, shows that they are made partly of clay or the earth about the nest and partly of woody fiber. These two substances are variously mixed in structure, sometimes one being more abundant, sometimes the other. An examination of the materials of the outside part of the large and old nests, however, shows that this part of the nest at least contains fragments of quartz, sand grains, and such like rock fragments that could not possibly have passed through the bodies of the insects. The structure of some of the nest walls suggests that these walls are constructed partly of earth and rock fragments brought up from beneath the ground and built into the nests by cementing them together with excrement or some other adhesive substance.

The outer parts of the nests, when they stand on the ground, are, so far as my observations go, always made of earth cemented in a thick, hard wall. In the inner portions of the nest the partitions are thinner, and though they are made largely of an easy-spreading clay, they are often made partly, or at least overspread, with a dark, friable substance that has the appearance of being masticated wood, leaves, or other organic matter.

The openings through the mass of the nests are pretty uniform in size, being from 3 to 10 millimeters in diameter and averaging close to 5 or 6 millimeters. The openings within the nests sometimes have the appearance of being arranged in rude tiers; sometimes they are apparently haphazard labyrinths.

The external forms of the nests vary considerably, but unfortunately I do not know whether this variation is due to difference in the species of termites, to difference in the nature of the ground, or to other causes.

As a rule, the mounds are rudely domed, rounded or conical, and the method of adding to the outside gives them a bumpy, lumpy appearance, so that, as Burmeister suggests, they resemble gigantic Irish potatoes. In some localities they are mostly tall and slender. Most of the tall, slender forms observed have been in wet ground or on ground that is sometimes overflowed. For this reason it is inferred that these forms are due to the presence of water rather than to a different species of termites. In size they also vary greatly. I have seen them as much as 6 meters high and 8 meters in circumference, but these very large ones are exceptional.

In southern Minas, south of Barbacena, Dr. R. Walsh notes mounds of the white ants 10 or 12 feet high.[1]

In the vicinity of Caximbu, in southern Minas, white ants' nests are said to be 4 meters high and nearly 2 meters in diameter at the base. In the vicinity of Taubaté, São Paulo, they are often 2.4 meters high, while about the city of São Paulo they usually are 1 meter and less in height.

Over the level table-lands of the interior of Piauhy, where the soil is red clay, the mounds of white ants are abundant and often 6 or 8 feet high.[2]

At and about Asuncion, in Paraguay, I found the nests very abundant on the clayey soils, and many of them as much as 3 meters high.

Fig. 7.—White ants' nest built of earth, in the State of Minas Geraes.

[From a photograph by R. Crandall, July, 1909.]

The outer portion of the nest being thick, hard, and compact, and the inside being friable and easily removed, it is a custom in the interior of Brazil and Paraguay to scoop out the inside of white ants' nests and to use them for ovens. The door is cut near the base of the cone, and the inside parts removed through it.

The accompanying illustrations will probably give a better idea of the sizes and shapes of the nests than verbal descriptions.

Sir Woodbine Parish speaks of "Corrientes and Paraguay, where whole plains are covered with their dome-like and conical edifices, rising 5 and 6 feet and more in height."[3]

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[1] Rev. R. Walsh: Notices of Brazil in 1828 and 1829, vol. 2, p. 50. Boston, 1831.

[2] George Gardner: Travels in the interior of Brazil, p. 280. London, 1846.

[3] Sir Woodbine Parish: Buenos Ayres and the Provinces of Rio de la Plata, 2d ed., p. 252. London, 1852.

In the region about the headwaters of the Paraguay the nests of the white ants are extremely abundant in favorable localities, and the forms of the nests are different from those noted in other parts of tropical America. The tall and very slender forms are especially noticeable in the low, flat prairie lands south of Cuiaba. (See fig. 8.) These slender forms are known in that part of Brazil by the Indian name of *tacurú*.

Age of the mounds.—The method of building the mounds and the habits of the termites, so far as I am acquainted with them, lead to the conclusion that the size of a mound is determined by its age and by the size of the colony building it. Just how long it requires to build the large mounds I have but little means of judging. One frequently sees nests built on houses and fences, and in these cases it has been possible to determine the maximum ages of these particular nests. These

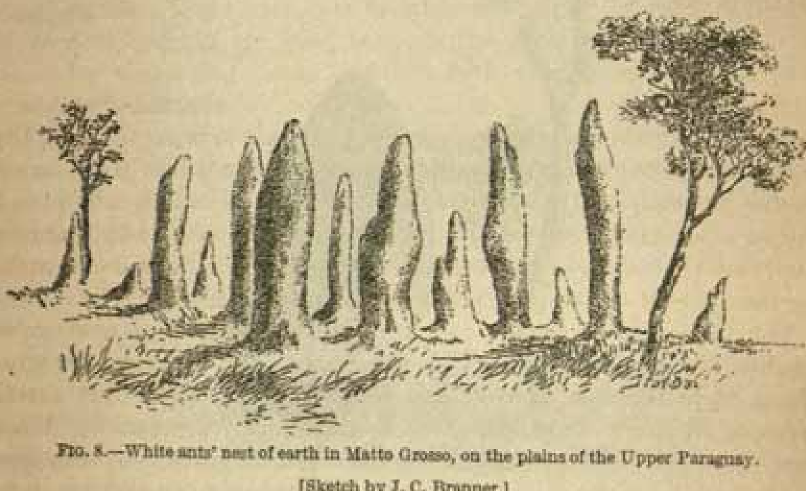

FIG. 8.—White ants' nest of earth in Matto Grosso, on the plains of the Upper Paraguay.
[Sketch by J. C. Branner.]

cases, however, afford only a suggestion. The oldest nests I have seen, and of which I could get an idea of their ages, were not more than 50 years old, and the biggest of them contained a little less than 1 cubic meter of earth, the estimate being made without reference to the cavities within the mass.

It is evident that the size and age in one of these cases may or may not help one to determine the time occupied in the construction of one of the very large nests figured in this paper, for the rates of building may have been very different.

UNDERGROUND STRUCTURES.

The above-ground structures of the white ants connect with underground passageways, but wherever I have seen these passageways opened they appeared to have been excavated and then to have been

filled with smaller chambers made of materials like that used to make the chambers of the mounds above ground. An examination of the thin chamber walls found in some of the underground excavations shows that they have been constructed of soft, plastic materials, so piled up that each later addition overlaps the preceding one on both sides of the wall. The materials are partly of reddish clay like that of the ground in which the nest is made and partly of a dark brown substance that I take to be organic matter—probably masticated plants.

I have never seen the excavations made by the white ants more than a meter and a half below the surface, but I have heard of them being found considerably deeper. My friend, Dr. Joaquim Lustosa, of Lafayette, State of Minas Geraes, writes me on this subject: "As for the depth to which they penetrate the ground, it is my impression that it is but little more than 3 meters."

RELATION OF NESTS TO THE SOIL.

The white ants do not seem to be so dependent on the character of the soil as do the true ants. This is probably due to the fact that when the true ants excavate their tunnels in the earth they depend on the character of the ground and the form of the excavations to support the structures. The white ants, on the other hand, depend partly on the nature of the soil, but partly on their method of cementing the materials of which their nests are made.

The preference, however, of the termites for certain soils and certain localities is very evident in some districts. On the upper Paraguay places have been seen where the nests are quite thick over certain areas, while there were none, or but few, on an adjoining area. Wherever these marked contrasts have been observed, however, they have apparently been due to a difference in the amount of moisture in the ground. I have thought that the white ants are sometimes found in rather wet ground, because they are there comparatively free from the attacks of their enemies, the true ants.

Opinions of Brazilians in regard to the distribution of the termites' nests vary considerably; some think they are more abundant in the open campo regions than in the forests; others think they prefer fields; still others think they are favored by a dry climate. All of these views appear to have more or less support. I have much doubt, however, about the theory of their preferences for campos. It is true that they do appear very abundant in the campo regions, but I am of the opinion that the apparent abundance is deceptive and due to the fact that all the nests are visible at once over a wide area (pl. 1, fig. 2), while in a forest-covered area no nests, or but few nests, can be seen on account of their being concealed by the dense vegetation. This im-

pression has been deepened by the fact that in several instances where the forests have been cleared away the mounds of the white ants appear to be quite as abundant as they are in the old clearings or on the open campos.

Further support is given this theory by Maximilien, Prince de Wied-Neuwied, who, in speaking of the white ants' nests near Conquista, in the southwestern part of the State of Bahia, says that they are extremely abundant in covered and wooded places.[1]

RELATIONS TO VEGETATION.

Compared with the true ants, the white ants are harmless. At least they do not attack crops and animals or render certain localities uninhabitable. The harm they do to agriculture is confined to the mere encumbrance of the ground by their big, hard, rock-like nests. They do, however, destroy wood used in the construction of fences, houses, bridges, and furniture, and they sometimes burrow into books and papers that are left to stand for a long time undisturbed.

I quote below some remarks of other writers in regard to the destruction of timbers by termites, but I must add that I am disposed to question the rate at which these insects are said to destroy wood. My own observations lead me to conclude that the idea expressed by Drummond and others that a piece of furniture may be destroyed in a night is simply a picturesque way of putting it. In the first place, there are certain kinds of wood (in Brazil at least) that the termites do not attack at all. I am unable to say just now what kinds they are, but it is a matter of common information among Brazilian carpenters and cabinetmakers.

In the second place, the method of discovery of their destructive work frequently leaves an erroneous impression. In accordance with their general habit of keeping away from the light, termites attack a piece of wood that forms a part of a building from within. Their work does not appear at the surface at all, and it may be carried on for months, or even for years, without its being discovered. But some day a window sill crushes in, a doorpost is shattered by a trifling blow, or a rafter gives way without its ever having been suspected that they were being attacked by the cupim. The suddenness of the discovery not unnaturally leads to the unwarranted inference that all this work was done during the preceding night.

It should be noted that although the white ants are abundant in forests, I am not aware that they ever attack the living trees. They appear to eat only the dead trunks or dead limbs or bark. Many of them build their nests on the trees. Nests found high up on tree trunks are always, so far as I have observed, made of woody matter

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[1] Voyage au Brésil, vol. 3, p. 129. Paris, 1822.

and not of earth. Those on trunks, only a meter or two above the ground, are often made partly of woody matter and partly of earth.

GEOLOGIC WORK.

EARTH MOVED.

The amount of earth brought to the surface by ants in a few instances has been given. The calculations at page 316 show that in one case the earth brought up would cover the ground to a depth of 22.25 centimeters. An estimate by Gounelle[1] makes the earth brought up 15 centimeters thick. In neither of these cases is it known how long the building of the mounds occupied.

Mr. Darwin's study showed that the earthworms in many parts of England bring to the surface annually 10,516 kilograms of earth to the

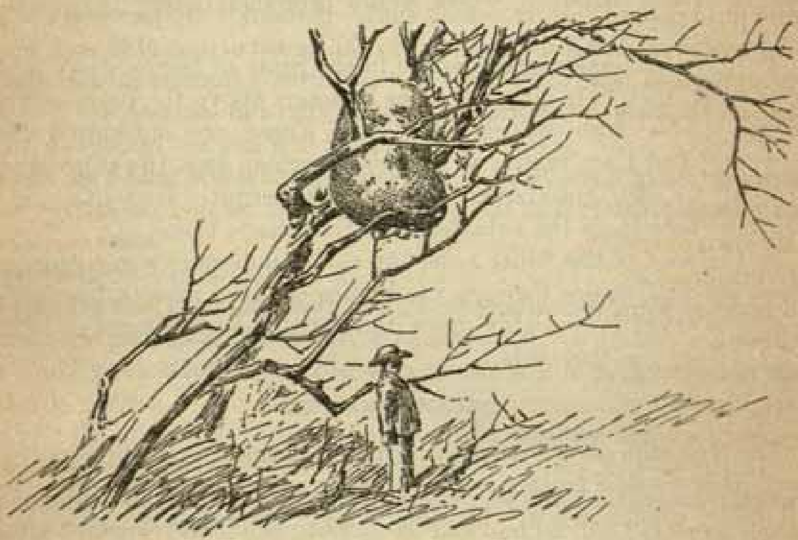

FIG. 10.—White ants' nest in a tree, Salitre Valley, State of Bahia. [J. C. Branner, 1907.]

acre.[2] In order to compare the work of ants with that of earthworms, it would be necessary to know how long the ant hills were in process of formation. Unfortunately, I have no trustworthy means of determining the ages of the mounds. If we assume an average of 100 years for the age of the mounds over the area measured (an average which seems to me quite conservative in this case), the total work of worms and ants would compare as follows:

Total weight of earth brought to the surface in 100 years over 1 hectare (10,000 square meters):

	Kilograms.
By worms in England	2,598,500
By ants in Brazil	3,226,250

[1] E. Gounelle: Ann. Loc. Entom. France, 7 ser. No. 6, 1896, pp. 332-333.

[2] Charles Darwin: The formation of vegetable mold through the action of worms, p. 305. New York, 1882.

It is to be noted that the amount of work done in both instances is rather exceptional—that is, localities were selected favorable for exhibiting the activities of worms in one case and of ants in the other.

I have no trustworthy data showing the amount of earth brought to the surface by termites over a definite area. The places seen where the nests were most abundant were in low, inaccessible grounds on the upper Paraguay. My impression is that in those particular localities there was less earth brought up than in the case of the true ants cited above.

The sizes of individual white ants' nests were frequently measured. One of the largest I ever saw in Minas Geraes was 6 meters high and 8 meters in circumference 2 meters above the ground, and contained 30.55 cubic meters of earth, no account being taken of the porous nature of the structure, which would probably reduce this total by 3 or 4 cubic meters.

Another unusually large mound in the State of Minas was 4 meters high and 7 meters in circumference 2 meters above the base, and contained 15.59 cubic meters of earth. These are individual cases, however, and I am unable to say how large an area the contents can properly be distributed over, how long the termites were in doing the work, or how large the colonies were that made them.

In the case of the white ants, the earth undergoes some process of digestion and passes through the bodies of these insects, so that the chemical effect is probably more important than the mere upturning it gets from the true ants.

ORGANIC MATTER.

The true ants carry into their burrows enormous quantities of leaves and other organic matter. These leaves must yield either directly or indirectly organic acids, which help attack the soil, the minerals, and the rocks with which they come in contact.

The organic matter carried into their burrows by the termites consists chiefly of the decayed wood and other vegetation eaten by them. These materials, however, can not fail to contribute organic acids that help attack the minerals of the soil and adjacent rocks.

OPENINGS IN THE SOIL.

The extensive subterranean excavations, especially those of the true ants, permit the freer circulation of atmospheric air and of carbon dioxide. These channels must also serve from time to time for the passage of meteoric waters, and their great extent and ramification must hasten very considerably all the processes of atmospheric disintegration and alteration of soils, minerals, and rocks.

Unfortunately we have no observations at present that enable us to give quantitative values to these underground agencies and activities.

We only know that the openings beneath the surface are rudely equal to the amount of soil in the above-ground structures.

RÉSUMÉ.

Ants and termites are vastly more numerous in tropical America than they are in the temperate regions.

They show a marked preference for, or rather their structures stand up better on, clayey than on sandy soil.

They affect the geology, especially the soil and subsoil, both directly and indirectly.

Directly:

1. By their habits of making underground excavations that radiate from a central nucleus and often aggregate several miles in length.
2. By opening the soil to atmospheric air and gases.
3. By bringing to the surface large quantities of soil and subsoil.
4. By introducing into their subterranean excavations large quantities of organic matter which must yield acids that affect the soil and the subjacent rocks.
5. By using these excavations for habitations and the production of gases that attack the soil and its contained minerals.

Indirectly:

6. By the periodic passage and circulation of meteoric waters through their extensive tunnels.
7. By affecting the availability of the soil for agricultural purposes.
8. By affecting the habitability of the land by man.
9. By the destruction of crops.
10. By the consumption (by termites) of dead plants and of timbers and lumber used in houses and for the manufacture of furniture, machinery, etc.

Although the data available are defective, we seem to be warranted in concluding that ants and termites are quite as important geologic agents in tropical America as are the earthworms of temperate zones.

They are also factors of great importance from an agricultural, economic, and social point of view.

ON THE VALUE OF THE FOSSIL FLORAS OF THE ARCTIC REGIONS AS EVIDENCE OF GEOLOGICAL CLIMATES.[1]

By Prof. A. G. NATHORST, of Stockholm.

Translated from the French original[2] by E. A. NEWELL ARBER, M. A., F. G. S.

Among the problems which are constantly called to mind during geological explorations in the Arctic regions, that of the climates of the past naturally demands special attention. The contrast between the present and the past is there more striking than in any other region. Beneath the snow and ice bordering the Arctic Sea one marvels to find, for example, large corals in beds belonging to the Carboniferous system, or again the remains of saurians, ammonites, or nautiloids in those of Triassic age. But when one bears in mind the extreme richness of the invertebrate fauna of the Arctic Seas to-day, when one remembers the colossal whales which find their subsistence in these waters, one may be inclined to ask if it has not been an error to conclude, from the occurrence of the fossils above mentioned, that the climate was formerly more genial than it is to-day. Should we not be underestimating the creative power of life if we imagine that, among the saurians, the ammonites, and the nautiloids, no species has been able to develop which was adapted to life in the Arctic Seas? If the reindeer and the musk ox were extinct, who would imagine that these beasts were able to flourish on the scanty vegetation of the high parallels north of 80° of latitude? And who would suppose that such monsters as the mammoth and the woolly rhinoceros could find sufficient nourishment in the poor vegetation of the tundras or the coniferous forests? Such examples teach prudence; there is certainly no question which requires so much caution as the problem of deducing from the faunas of the past the climatic conditions under which they flourished.

This remark applies with equal force to the floras. Although to-day the cycads only occur in warm regions, it would be an error

[1] A paper read before the Eleventh International Geological Congress on Aug. 25, 1910. "Sur la valeur des flores fossiles des régions arctiques comme preuve des climats géologiques," Stockholm, 1910. Also in Compt. Rend. Eleventh Intern. Geol. Congr., Stockholm, 1912. Reprinted by permission from the Geological Magazine, London, Decade V, vol. 8, No. 563, pp. 217-225, May, 1911.

[2] The English translation has been revised by Prof. Nathorst, and references added.

to conclude that the cycadophyta of the past have always flourished under similar conditions. On the contrary, we must admit that during the Mesozoic period, when these plants were abundant, it would no doubt have been possible to find several species which had adapted themselves to an Alpine climate if such a one had then existed. And if, since then, the differentiation of climates has begun to make itself felt, it would be again a case of overlooking the creative power of life if we assumed that none of the species of cycadophytes were able to adapt themselves to a temperate climate in the Polar regions. Again we meet with difficulties, even when we study the plants of the Tertiary period, which are assigned to genera still living. Our common juniper (*Juniperus communis*, Linn.), which exists in northern Europe as far north as the North Cape, exceeds by 20 to 25 degrees of latitude, in the Eastern Hemisphere, the northern limit, not only of the other species of this genus, but also the whole family of the cupressineæ. Now, if one imagined that the common juniper were extinct, one would naturally draw conclusions relative to the fossil remains from the distribution of the other species, and one would consequently suppose that it lived under a climate much warmer than is actually the case. One would scarcely imagine that we were concerned with a plant adapted not only to temperate but also to Arctic climates. (One finds the juniper, on the western side of Greenland, up to the sixty-fourth parallel.)

These examples counsel prudence, and the matter should be treated with judgment and circumspection. But, even if it is necessary to make reservations, when one seeks to determine from the fossil plants the nature of the former climates in the Arctic regions, at least one can not doubt that they were distinctly warmer than that of the present day. The difficulty of explaining these former climates, especially when one has to take into consideration the length of the winter night, is without doubt the reason which has led some scientists to evade the question, instead of seeking to solve it. It is indeed a case of evading the question when it is boldly asserted that the plant-remains, on which Heer[1] has based his theories of ancient Arctic climates, have been drifted by marine currents to the places where they have been found.

It is not to be disputed that plant débris may be transported in water for a very great distance without being damaged, provided that they are carried at a sufficient depth to escape the influence of the movements of the surface layers of the water. When Agassiz was engaged in dredging on the American coasts, he found that the bottom of the sea—sometimes to a depth of nearly 3,000 meters—was covered with plant débris, such as wood, branches, leaves, seeds, and fruits,

[1] O. Heer, *Flora fossilis arctica*, vols. 1-7, Zürich, 1868-1883.

in all stages of decay. Also, in certain places, these remains were still fairly abundant at a distance of 1,100 to 1,200 kilometers from the shore. This distance corresponds to about 10 degrees of latitude. It is thus proved that the remains of plants may be transported for very considerable distances. But this is true only of marine deposits. If we are concerned with fresh-water sediments, the example given has no bearing on the case.

One might, however, reasonably suppose that a river, flowing in the direction of the meridian from south to north, might have carried from the southern regions leaves and other fragments of vegetation which became buried in some deposit of the stream itself, or of a lake, which it traversed, or of its delta. This is a possibility which must not be neglected, but on the other hand it must not be treated as though it were an ascertained fact, since we do not know how far it applies to the case in point.

The fact is, it is puerile to attempt to draw conclusions as to the ancient climates of the Arctic regions, before the nature of the deposits in which the fossil plants have been found has been ascertained. It is especially important that an attempt should be made to answer the question, Did the plants once flourish in the neighborhood of the deposits in which they are found, or were they transported from far-away lands? It is this question which an attempt will here be made to solve, by furnishing a concise résumé of the principal beds containing fossil plants in the Arctic regions.

In Bear Island,[1] and in Ellesmere Land,[2] beds extremely rich in plant remains are met with belonging to the Devonian system. The fossil plants of Bear Island occur in the series of beds which also include several seams of coal. Beneath the coal, which is composed essentially of the bark and trunks of *Bothrodendron*, one finds, as elsewhere, bituminous schists containing roots, and from this one can show that the plants of which we speak flourished, at least in part, in situ. This is likewise proved by the actual nature of the plants, as much in the older beds with *Archæopteris fimbriata* Nath., as in the more recent with *Pseudobornia ursina* Nath. The latter species has been found with large stems or rhizomes, as well as very small ones, only a few millimeters in diameter, to which extremely delicate, almost membranous, leaves are still attached. It is hence quite certain that there is here no question of the plants having come from distant regions. The materials have not been sorted out. One sees a medley of branches, small and large, and the perfection of the

[1] A. G. Nathorst, "Zur Oberdevonischen Flora der Bären Insel:" Kongl. Svenska Vet.-Akad. Handl. vol. 36, No. 3, Stockholm, 1902.

[2] Id., "Die Oberdevonische Flora des Ellesmere Landes:" Rep. 2nd Norweg. Arctic Exped. in the Fram vol. 1, Christiania, 1904.

preservation of their delicate leaves demonstrate conclusively that they have not undergone transportation from afar. The same applies to *Archæopteris fimbriata*. The beds of coal, the clay with rootlets, and the very nature of the plants themselves, all point to the same conclusion, namely, that we have here a flora which flourished in part on the very spot where it is now found.

As I have already pointed out in my description of the Devonian flora of Ellesmere Land, one arrives at the same conclusions here also, and it is unnecessary to enter into further details.

In the Arctic regions, culm deposits, yielding fossil plants, are known from Spitsbergen,[1] from the northeast of Greenland,[2] and probably from the south of Melville Island, in the Arctic Archipelago of America.

We will here concern ourselves only with Spitsbergen, although it may be mentioned in passing that the flora of the culm discovered by the Danish expedition to Northeast Greenland, in latitude 81° north, consists of nearly the same species as that of Spitsbergen. The latter flora has been observed in many localities up to 79° of latitude. It is characterized by the presence of *Stigmaria*, with appendicular organs radiating in all directions, still in continuity, and penetrating the clay beneath. We are thus able, in several places, to observe the presence of *Stigmaria* in situ, which furnishes undeniable evidence of the fact that the plants lived in the place where we now find them. The stems of *Lepidodendron* found in the same place have a diameter of at least 40 cm. It would be superfluous to give other examples, for one can scarcely doubt that the plants of the culm have flourished in the very place in which they are now found, or in its vicinity.

On the other hand, the observations which relate to the Triassic plants of Spitsbergen and eastern Greenland are somewhat different. The latter ones belong to the Rhætic Series and include several species of *Pterophyllum, Podozamites, Cladophlebis*,[3] etc. In Spitsbergen one finds them as far north as 78°. Neither there nor in Eastern Greenland, where one meets with them between the 70th and 71st parallel, are they associated with beds of coal, but the manner in which they occur in Greenland indicates that in no case have they traveled from very distant localities. One has not with certainty observed any marine petrifactions associated with the plants, but it has not yet been clearly determined whether the Triassic beds with fossil plants of Spitsbergen are of marine or of freshwater origin.

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[1] A. G. Nathorst, "Zur Paläozoischen Flora der Arctischen Zone:" Kongl. Svenska Vet.-Akad. Handl., vol. 26, No. 4; Stockholm, 1894.

[2] Id., "Contributions to the Carboniferous Flora of Northeastern Greenland:" Meddelelser om Grönland, vol. 43; Copenhagen, 1911.

[3] N. Hartz, "Planteforsteninger fra Cap Stewart i Östgrönland:" Meddelelser om Grönland, vol. 19; Copenhagen, 1896.

The most ancient Jurassic sediments of Spitsbergen are marine, and belong to the Sequanian stage. There was consequently a long interruption in sedimentation after the formation of the Rhætic beds.[1] The upper part of the Jurassic formation (Portlandian) furnishes a series of plant-bearing sandstones, seams of coal, and beds of undoubted fresh-water origin, containing *Unio* and *Lioplax polaris*. The fossil plant remains belong to two different floras,[2] one, the more ancient, being characterized by the presence of *Ginkgo digitata* Brongn., sp.; the other, the more recent, by *Elatides curvifolia* Dkr., sp. The two floras are associated with beds of coal, and one may here also put forward the view that the plants originally flourished in the place where they are now found. One of the coal seams at Cape Boheman furnishes a great abundance of *Podozamites* and *Pityophyllum;* sometimes the surface of the schists is as completely covered with the leaves of *Ginkgo digitata*, as the soil beneath a living ginkgo tree may be in autumn. Since branches and seeds of the same plant are also associated, it is natural to suppose that a ginkgo forest occurred not far away from this spot. The same observation applies to *Elatides curvifolia* of the more recent flora, which occurs locally in the fresh-water beds containing *Unio* and *Lioplax*. Floras of the same age and composition are also known from King Karls Land, the islands of New Siberia,[3] from Northern Siberia, and Arctic Alaska.

The Neocomian series of King Karls Land is overlain by sheets of basalt, often amygdaloidal, and containing chalcedony and agates. Fragments of silicified woods, large and small, also occur here, and these, without doubt, owe their mineralization to the volcanic phenomena. Some of these trunks are fairly large, and I have myself measured one, which, although incomplete, was 70–80 cm. in diameter, and showed 210 annular rings. Some of these remains consist of the lower portion of the trunk and the primary ramifications of the roots.

The microscopic examination of these specimens, undertaken by Dr. W. Gothan,[4] has shown that the annual rings of the fossil stems from King Karls Land were much more accentuated than those of stems found in the corresponding beds of the European continent, which indicates that the trees lived in a region where the difference between the seasons was extremely pronounced. They can not therefore have been transported from the south by marine currents, and as

[1] A. G. Nathorst, "Beiträge zur Geologie der Bären Insel, Spitzbergens, und des König Karl Landes": Bull. Geol. Inst. Upsala, vol. 10, 1910.

[2] A. G. Nathorst, "Zur Mesozoischen Flora Spitzbergens": Kongl. Svenska Vet. Akad. Handl., vol. 30, No. 1; Stockholm, 1897.

[3] Id., "Über Trias und Juraspflanzen von der Insel Kotelny": Mém. Acad. Imp. Sci. St. Pétersbourg, ser. 8, vol. 21, No. 2, 1907.

[4] W. Gothan, "Die fossilen Hölzer von König Karls Land": Kongl. Svenska Vet.-Akad. Handl., vol. 42, No. 10; Stockholm, 1907.

the trunks found in the corresponding beds of Spitsbergen[1] show the same peculiarity, it is quite safe to conclude that we are here concerned with large trees, which have actually flourished in these latitudes, and which have not been transported from more southern regions.[2]

The Cretaceous system, as we know it, is represented in western Greenland, between the parallels of 69° and 71°, by an important series of beds containing fossil plants belonging to the Urgonian, Cenomanian, and Senonian, the two first mentioned containing coal seams. I have been able to show, as the result of the studies which I made in Greenland in 1883, that beds, full of roots, underlie those containing fossil plants at Unartoarsuk, as well as at Igdlokanguak. Without doubt the Urgonian flora, like the Cenomanian flora, is a relic of vegetation which once flourished in the same regions where we now find the fossils. But, on the contrary, the Senonian flora, or flora of Patoot, is in part contained in marine beds, containing *Inoceramus*, etc., and thus it may have been transported from some distance. The Urgonian flora, or flora of Kome, is composed of ferns, cycadophytes, and conifers, while the Cenomanian or Atane flora, in addition to arborescent ferns (*Dicksonia*) and cycadophytes (*Pseudocycas*),[3] is particularly rich in the leaves of Dicotyledonous trees, among which are found those of planes, tulip trees, and bread fruits, the last mentioned closely resembling those of the bread-fruit tree (*Artocarpus incisa*)[4] of the islands of the southern seas.

In the limited space at my disposal I have had to be content with a brief summary of the strata containing fossil floras of Palæozoic and Mesozoic age. But from what has been said it is clear that we have every reason to regard the flora of the Devonian, Culm, Jurassic, and Cretaceous of the Arctic regions as being composed of plants which flourished in these very regions. There are no proofs that the Triassic flora has been transported from more southern regions by marine currents, but there is, however, some uncertainty on this point.

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[1] Id., "Die fossilen Holzreste von Spitsbergen": Kongl. Svenska Vet.-Akad. Handl., vol. 45, No. 8; Stockholm, 1910.

[2] It may be mentioned here that a silicified *Dadoxylon*, from the Carboniferous deposits of Spitsbergen, described by Dr. Gothan (loc. cit.) does not show any annual rings at all, as is precisely the case with the corresponding Palæozoic stems of Europe. As has been pointed out to me by Dr. Th. Halle, this is a most curious circumstance, since the darkness during the long winter night in these regions—provided that the position of the North Pole were the same as now—ought to have caused an interruption of growth, even if the climate was a warm and genial one. As the specimen, however, was not found *in situ*, it is possible that it originates from some marine deposit into which the wood had been brought by ocean currents from more southern latitudes. But a *Dadoxylon* from the Triassic of Spitsbergen also shows only slight indications of annual rings (Gothan, loc. cit.).

[3] A. G. Nathorst, "Paläobotanische Mitteilungen, 1. *Pseudocycas*, eine neue Cycadophytengattung aus den Cenomanen Kreideablagerungen Grönlands": Kongl. Svenska Vet.-Akad. Handl., vol. 62, No. 5; Stockholm, 1907.

[4] Id., "Über die Reste eines Brotfruchtbaumes, *Artocarpus Dicksoni*, n. sp., aus den Cenomanen Kreideablagerungen Grönlands": Kongl. Svenska Vet.-Akad. Handl., vol. 24, No. 1; Stockholm, 1890.

In relation to the present problems, the Tertiary floras are undoubtedly the most important, and for this reason I will enter into the subject in some detail. But the materials are so wonderfully rich that I shall have to restrict myself to giving some examples indicating the nature of the beds containing the Tertiary plants in Spitsbergen, Iceland, and Greenland. More especially, I shall recall that they are found at 79° of north latitude in Spitsbergen; on the east coast of Greenland between 74° and 75°, and on the west coast between 69° and 73°; at Lady Franklin Bay, in Grinnell Land (81° 42″); in Ellesmere Land between 77° and 78°; on the River Mackenzie at 65°; in Alaska south of 60° (and therefore outside the Polar Circle); and, lastly, in the islands of New Siberia (75°). Iceland, it is true, is outside the Polar Circle, but nevertheless its Tertiary flora may be included in this consideration.

The Tertiary formations of Spitsbergen, which have a thickness of perhaps 1,200 meters or thereabout, contain fossil plants and seams of coal, both in the upper and lower beds, though the middle portion is marine. As an example of the deposits with fossil plants from the base of this formation the shales called the "Taxodium Shales," at Cape Staratschin, may be mentioned. These are fine-grained black soft shales, which form the roof of a small bed of coal. In the shales the leafy branches, the flowers, the seeds, and the ovuliferous scales of the Swamp Cypress (*Taxodium distichum miocenum*), the leafy branches of *Sequoia Nordenskiöldi* Hr., and *Librocedrus Sabiniana* Hr., are particularly common. There are also associated a large number of remains of gramineæ, cyperaceæ, several species of pines and firs, a *Potamogeton*, and the leaves of various dicotyledonous trees. Thus, as Heer has shown, one is dealing here with fresh-water sediments, in the neighborhood of which it is evident that the swamp cypresses have formed forests, as in the swamps in the southern portion of the United States to-day. This conclusion is also confirmed by the occurrence of the remains of rather numerous insects, among which there are a score of coleopterids, two of which are hydrophilous coleopterids (*Hydrobius* and *Laccophilus*).

These beds with fossil plants, at the base of the Tertiary formations of Spitsbergen, are overlain by thick marine sediments. In their upper portion the latter show indications of a retreat of the ocean and a recurrence of fresh-water conditions. It is possible that the leaves found in the lower part of the higher horizon containing fossil plants have been transported from afar by a river, and deposited near its mouth, but as regards the upper portion deposition must have taken place in vast swamps, on which the majority of the plants actually lived. In these beds one notices thin seams of coal, a great quantity of leafy branches, and also cones of *Sequoia Langsdorfii*

Brongn., (closely allied to the redwood of California, *Sequoia sempervirens* Endl.) and the swamp cypress (*Taxodium distichum miocenum*). Here and there a large horsetail (*Equisetites Nordenskiöldi* Nath.) occurs in such abundance that one would imagine that it formed small forests. There are also associated rhizomes, with their roots and tubercles still attached. I may mention in passing that *Equisetum arcticum* Heer, occurs in the same manner in the lower zone of the plant-bearing beds. There is also found a great abundance of *Osmunda spetsbergensis* Nath., and on the same horizon nodules of clay ironstone, entirely filled with leaves and stems of the latter plant, in which the tissues have been so completely mineralized that one can study the microscopic structure as minutely as in the living *Osmunda*. One sees in the carbonaceous petrified layers rootlets and spores of ferns, as well as fragments of branches, etc. This might justly be called a mineralized peat. Among the dicotyledonous trees, the leaves of which occur in great quantity, one finds leaves of all dimensions belonging to the more common species. I have examples, among others, of the leaves of *Ulmiphyllum asperrimum* Nath., varying from 1–17 cm. in length. All the observations indicate that we have here a deposit formed by the delta of a stream passing through a marsh on which grew trees requiring humidity, while the remains of other plants which lived at some distance away have been transported, either by the wind or by water, and become mingled with those of the marsh.

The beds of this horizon, discovered at Cape Lyell, are remarkable for the enormous quantity of leafy branches of *Sequoia Langsdorfii*, leaves of *Grewia crenata* Hr. and of *Acer arcticum* Hr., the fruits of the last mentioned also occurring. A bed full of rootlets was also met with, showing that the plants flourished on the spot where they are now found. Among the marsh plants an *Alisma* occurs. Among the dicotyledonous trees of this horizon are poplars (*Populus*), willows (*Salix*), alders (*Alnus*), birches (*Betula*), hornbeams (*Carpinus*), hazels (*Corylus*), beeches (*Fagus*), oaks (*Quercus*), elms (*Ulmus*), planes (*Platanus*), magnolias (*Magnolia*), limes (*Tilia*), and maples (*Acer*), etc. We can thus show that during the Tertiary period all these plants have flourished at 78° or 79° of latitude. In Grinnell Land we find, even at nearly 82°, the swamp cypresses, the spruces, pines, firs, poplars, birches, elms, limes, etc.

In Iceland the Tertiary flora may be studied in the volcanic tuffs or in the alluvium formed from them, and at Brjàmslaekur, for instance, in a deposit which may be compared with a laminated peat. Thus, as Heer had suggested, and Thoroddsen has proved, we here meet with formations laid down above sea level, which are overlain by thick basaltic beds. A glance at the specimens from Brjàmslaekur serves to

show that we have here to deal with fresh-water deposits. M. Östrup's[1] microscopic examination of the diatoms, found in the same beds as the fossil plants, confirms this conclusion, for they are fresh-water species.

Among the beds furnishing Tertiary plants, so abundant in Greenland, I will only mention those of Harön (Hare Island), near Waigattet. Here the plants occur either in a true basaltic tuff, or in an altered tufa or a sediment formed from it, which is overlain with basalts.

The investigation of two beds, which I made in 1883, has proved that they can not be other than formations laid down above sea level. In one of these deposits the fossil flora consisted almost exclusively of leaves of the maple (*Acer*), crowded like those which cover the ground in autumn, and among these leaves large samaras, like those of *A. otopteryx* Gp., occur. In another bed the tuff was formed of cinders and small lapilli, and the way in which the vegetable fragments were inbedded leads one to suppose that the branches, leaves, and fruits of the trees were broken off by a shower of cinders and lapilli. A medley of silicified branches of different sizes occurs, and among them are the cones of the spruce, the nuts of the walnut (*Juglans*), and the hickory (*Carya*), with the leaves of *Ginkgo*, etc. In the finer tuffs we likewise find the leaves of the walnut, the leaves and fruits of an ash (*Fraxinus macrophylla* Hr.), and the leaves of species common in the Tertiary flora of Greenland, such as the plane, oak, chestnut, beech, etc.

The presence of the leaves of *Potamogeton*, associated with a fresh-water mussel (*Unio*), indicates that the deposits were of fresh-water origin. Some of the branches of the trees are silicified and exhibit, under the microscope, an extremely well-preserved structure. Dr. J. Schuster, who has undertaken a preliminary examination of these remains, concludes that they all belong to one species, which was probably either an arborescent member of the leguminoseæ or of the rosaceæ. It is clear that we have here to deal with fragments of vegetation broken off by a shower of ashes and entombed in them, though some fragments may have been transported into a fresh-water basin containing mussels and aquatic plants.

The Tertiary plants discovered by the Norwegian expedition to Ellesmere Land deserve special mention on account of their state of preservation. They consist almost entirely of branches of *Sequoia Langsdorfii*, contained in a bituminous laminated clay, from which I have been able to remove them by a process of washing, with the result that they are now isolated like dried specimens in a herbarium.

[1] E. Östrup, "Diatoméerne i nogle islandske Surtarbrandlag," pt. 1: Meddel. fra Dansk Geol. Forening, No. 3; Copenhagen, 1896. Pt. 2, ibid., No. 6, 1900.

I must now bring to a close my review of the ancient plant-bearing beds of the Arctic regions. We may conclude that in the greater number of cases it is evident that the plants really grew in the regions in question. Although we know of fossil plants in some marine deposits, as, for instance, in the Senonian of Greenland and perhaps also in the Trias of Spitzbergen, these are exceptions which lack importance, since other deposits of a closely corresponding age are of fresh-water origin. While it may be admitted that even in Spitsbergen part of the Tertiary flora may have been transported from a more or less distant country by a river, yet other deposits on approximately the same horizon indicate that the greater number of the species, and among them the most important types, have actually flourished in the region itself.

Taking into account the facts which I have enumerated, it is evident that the fossil floras of the Arctic should be still regarded as the foundation of every discussion of the former climates of that region. How are these favorable climates to be explained? That is a question to which we are not able to reply at the present moment and of which the solution belongs to the future.

RECENT ADVANCES IN OUR KNOWLEDGE OF THE PRODUCTION OF LIGHT BY LIVING ORGANISMS.

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INTRODUCTION.

The original paper (48)[1] upon which the following is based was read under the title "The Chemistry of Biophotogenesis," before the Chemical Society of Washington, D. C., on October 13, 1910, and subsequently published in the Scientific American Supplement, No. 1842. In revising this paper for publication here it has been found that so much new work of importance has been published or has come to the author's attention in the interim, that it has been decided to reconstruct the paper along the line indicated by the above title, taking up the more significant recent work, and adding a few heretofore unpublished observations of the author.

The term "Biophotogenesis," in its complete sense of the production of light by living organisms, covers a group of phenomena accompanying the vital processes in a wide range of animal and vegetable forms. The fireflies (Lampyridæ) are to most of us the commonest and most brilliant of these forms, and the following will therefore have special reference to these insects.

An excellent monograph (45) of the subject of the emission of light by living forms, including an extensive bibliography of the important papers and a general review of the literature, has appeared under the title "Die Produktion von Licht," by Prof. E. Mangold, as the second half of the third volume of Winterstein's Handbuch der vergleichende Physiologie. The whole literature of the subject is very extensive, although much of the older work is without significance to-day. A considerable number of scientific men, including workers in the fields of chemistry, physiology, biology, entomology, and physics, are working on the problems presented by the phenomena of luminous organisms, and important developments in our knowledge of this subject are to be expected.

[1] Numbers refer to literature references at the end of paper.

For the sake of convenience the subject will be considered in the following sections in this paper:

1. Physical properties of physiologic light.
2. The chemistry of the photogenic process.
3. The effect of chemical reagents, etc., on the luminous tissue.
4. The photogenic organs.
5. Fluorescent substances in luminous insects.
6. Biologic relations of the phenomena.

1. PHYSICAL PROPERTIES OF PHYSIOLOGIC LIGHT.

It is an interesting and significant fact that the luminous radiations of the majority of luminescent organisms produce upon the human retina the sensations of yellowish green, green, or bluish green. That this color is the result of the actual composition of the emitted light and not a subjective phenomenon, has been demonstrated by a number of investigators.

The light of one of the common fireflies of the eastern United States, *Photinus pyralis*, has recently been made the subject of a very interesting spectrophotographic study by Drs. Ives and Coblentz, ([31]) at the Bureau of Standards. These observers found the light of this insect to resemble very closely the light of the Cuban cucuyo (*Pyrophorus noctilucus* Linn.), as studied and described by the late Prof. S. P. Langley and Prof. F. W. Very ([33]) 20 years ago. Briefly, the spectrum of the light of *Photinus pyralis* consists of a structureless, unsymmetrical band in the red, yellow, and lower blue portions of the visible spectrum, with a maximum at about that portion having the greatest illuminating effect with the minimum of actinic and thermal effects. It gives no hint of continuation in the infra-red or ultra-violet portions of spectrum. More recently, Ives ([32]) has shown that there is no infra-red radiation between 0.7065 micron and 1.5 microns in the light of the firefly, nor is any ultra-violet radiation present. Coblentz ([5]) has shown that the chitin covering the luminous organs of the firefly has a very low transmissivity for radiations of greater wave length than 2.5 microns; so low, in fact, that it would be difficult, in these wave lengths, to distinguish radiations from the photogenic organs from those due to the ordinary animal heat. However, the same author ([54, 6]) has found that the luminous segments of the firefly do give evidence of being at a slightly higher temperature than the rest of the insect's body, and that the ventral side of the luminous segments is at a higher temperature than the dorsal. He did not observe an increase of temperature during light emission.

While it seems probable that the light of most other luminous organisms is essentially similar to that of *Photinus pyralis*, slight differences may be noted even between closely related species. A few

marine forms, e. g., the Cephalopoda and the Pennatulidæ, give lights of several colors. Among the insects the only forms known definitely to present wide differences from this general similarity are the tropical species of *Phengodes* as observed by Barber (2) and others, which possess a photogenic organ, located back of the head, that gives a distinctly reddish light. No spectroscopic studies of this red light of *Phengodes* have been made. Coblentz (5a, 6) has given spectrographic proof of the differences in the color of the lights of *Photinus pyralis*, *P. consanguineus*, and *Photuris pennsylvanica*, attention having been called to the physiologic differences by the author (46) and others, [Knab (36), Turner (68)]. The author has recently had an opportunity to examine the light of *Phengodes laticollis* (female) with the pocket spectroscope referred to in his paper in the Canadian Entomologist, 1910 (46), and found it to consist mainly of a narrow band in the yellow-green and green, with very much fainter ends stretching toward the red and blue; the definite ends of the band could not be made out on account of the feebleness of the light, and the predominance of the greenish band may, of course, be mainly due to the greater retinal sensitiveness to these tones.

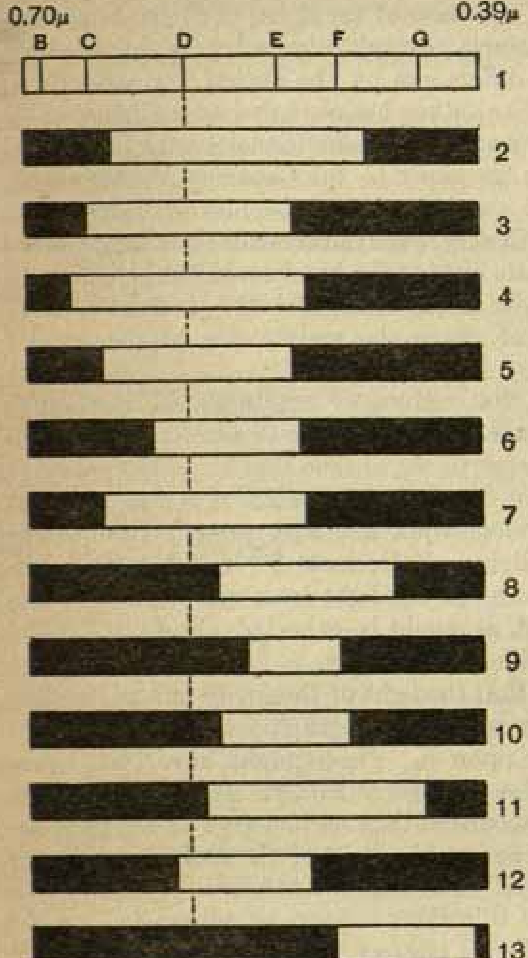
Forsyth (21) has claimed that cultures of certain photobacteria give spectrophotographic evidence of the existence of ultra-violet rays in their emitted light. It seems to the author that this observation is in need of confirmation, not that it is impossible, of course, but that it is at variance with previous work and with present ideas of the properties of physiologic light. McDermott (49) failed to find evidence of ultra-violet radiation in the light from cultures of *Pseudomonas lucifera* Molisch, and, as would be expected, also failed to find any indication of appreciable radioactivity.

It need scarcely be said that the light of the firefly affects the photographic plate; obviously spectrophotographic studies could not otherwise have been made upon it. Photographs have been taken by means of the light of the photogenic bacteria and of the cucuyo.

In 1896 Muraoka (54) announced that he had proved the penetration of metal films by means of the light of the firefly in a manner similar to that of the X-rays. The author has failed to find any evidence of the penetration of thin sheet copper, aluminum foil, or the black paper with which X-ray plates are wrapped by the light of *Photinus pyralis*. It seems that under certain circumstances substances which do not actually emit penetrating radiations may affect the photographic plate, and an explanation of Muraoka's results has been offered by Molisch (53a, 55) based upon bacterial or vapor influence; but when we consider that his results were published only a little while after the discovery of the X-ray it seems possible that Muraoka was just a little over-enthusiastic. However, Singh and

Maulik (61a) have recently published some results similar to those of Muraoka.

Judged from the fact that the light produced by many chemiluminescent reactions appears greenish to the human eye, it would seem that these should give spectra approximating that of the firefly [see Radziszewski (60), Trautz (67)], but in view of the facts that the light



1. Portion of the visible solar (grating) spectrum.
2. Spectrum of *Pyrophorus noctilucus* (Langley and Very [illegible]).
3. Spectrum of *Lampyris noctiluca* (Conroy [illegible]).
4. Spectrum of *Photinus pyralis* (Ives and Coblentz [illegible], Coblentz [illegible]).
5. Spectrum of *Photinus consanguineus* (Coblentz [illegible]).
6. Spectrum of *Photuris pennsylvanica* (Coblentz [illegible]).
7. Spectrum of *Phengodes laticollis* ♀ (original).
8. Spectrum of *Bacterium phosphoreum*, *B. phosphorescens*, and *Bacillus photogenus* (Molisch [illegible]; Mangold [illegible]).
9. Spectrum of *Photobacterium indicum* (Barnard [illegible]).
10. Spectrum of *Mycelium X* (Molisch [illegible]; Mangold [illegible]).
11. Spectrum of luminous bacteria from sea fish (Forster; Mangold [illegible]).
12. Spectrum of *Agaricus* (Ludwig; Mangold [illegible]).
13. Fluorescent spectrum of fluorescent material (luciferesceine) from *Photinus pyralis* (Coblentz [illegible]).

Numbers 2 to 7 inclusive, are from insects. Numbers 8, 9, and 11 are from microorganisms. Numbers 10 and 12 are from fungi.

Only the extreme ends of the bands are shown, no attempt being made to indicate the relative density of different portions of the spectra; thus in 7 the maximum intensity is confined to a very much narrower band than shown for the whole spectrum.

FIG. 1.—Spectral ranges of light from different organisms.

emitted in most of these cases is very feeble and that the human eye is decidedly more sensitive to the greenish tones than to others, it may be simply that the amount of radiation, other than that giving the sensation of green, produced by these reactions is insufficient to cause the human retina to respond. However, it is difficult to class the production of light by living forms as other than a vital expression of

chemiluminescence, and the fact (to be referred to in the next section) that the luminous tissues may be removed from the organism and desiccated and still induced to produce light under certain circumstances, confirms the view that the only essential difference between the two phenomena is that biophotogenesis takes place in a living organism instead of a test tube.

A comparison of the spectral ranges of the light from different organisms is of some interest, and the accompanying chart has been compiled from data from the references given, and redrawn to a uniform scale, the extreme left-hand end representing wave length 0.70μ and the extreme right-hand end wave length 0.39μ; a few of the more important Fraunhofer lines are shown in the first spectrum, and the sodium D line is continued through the series by the dotted line.

2. THE CHEMISTRY OF THE PHOTOGENIC PROCESS.

Our knowledge of the chemical processes involved in biophotogenesis is rather meager. It is fairly well established that all photogenic organisms require at least two constant chemical factors in addition to the specific photogenic substance in order to exhibit their luminous property, viz, the presence of oxygen and of moisture.

Dubois's ([17,18]) theory assumes the oxidation of a substance of unknown composition, to which he has given the name "luciferine," through the agency of the oxidase "luciferase." Prof. Kastle in his monograph on "The Oxidases and Other Oxygen-Catalysts Concerned in Biological Oxidations" ([34]) refers to this claim of Dubois that the photogenic process in organisms involves the action of "luciferase." Prof. Kastle's observations on this point led him to believe that no oxidase was present, but that peroxidase and catalase were present; he found that aqueous extracts of the luminous tissue of the common firefly failed to turn tincture of guaiacum blue, except in the presence of hydrogen peroxide, and the bluing in the presence of the latter was accompanied by the rapid disengagement of oxygen. Quite recently Dubois ([20]) has put forth the view that luciferase is a peroxidase, for the reason that it can be replaced to some extent by hydrogen peroxide. Loew ([40]) found that the luminous tissue of the firefly showed no greater catalase activity than other tissues from the same insect. Lund ([42]) has made similar observations on the enzymes in these insects. Until more definite data are at hand, it would seem that the enzyme theory requires some caution in acceptance, but the facts so far as known certainly present some analogy to other known biologic processes of an enzymotic nature, and it is not at all impossible that his explanation may be correct. Watasé ([70]) expresses the view that in *Noctiluca miliaris* and other simple luminous forms the "phosphorescence"

is associated with the contractility of protoplasm, as a potential property of all protoplasm, whether exhibited or not, and he rather leaves the reader with the impression that he believes that the particles of food materials are actually burned in the living tissues with the production of an incandescent temperature.

There has been a good deal of discussion, to and fro, as to whether the chemical processes involved in the production of light by the firefly and analogous forms are really oxidations, and evidence both for and against the oxidation hypothesis has been offered. At present the great weight of the evidence is that in all cases the fundamental process is an oxidation, though not necessarily the oxidation of the same photogenic substance. Polimanti (58) has asserted that the luminous process in *Pyrosoma elegans* can not be an oxidation, and gives several arguments in favor of the nonoxidative nature of the process, one of which is that the light has a greenish tone. In view of the fact that, as mentioned before, a good many chemiluminescent reactions known to be oxidations produce the sensation of green upon the human retina, this argument certainly does not seem to be valid. Lund (42) states that while oxygen is a necessary factor to light production in the Lampyridæ, this does not prove that the chemical process is an oxidation.

Jousset de Bellesme (33) in 1880 stated that he believed the light to be due to the spontaneous combustion of phosphine, liberated by the decomposition of protoplasm, and Sir Humphry Davy (8) noted that Lavoisier held a similar view. The nature of the substance consumed in this biologic oxidation—the *Noctilucin* of Phipson (57) the *Luciferine* of Dubois (17, 18, 20) and the *Photogen* of Molisch (52)—has been variously regarded by different authors. Many seem to have regarded it as a fat or a fat-like substance; Phipson, who apparently isolated and analyzed a culture of photogenic bacteria, concluded that it contained nitrogen; Kölliker (37) and Macaire (43) believed it to be an albuminous body. Embryologically, it appears to be an extension of the fat layer in many, though not in all cases. (See Dahlgren and Kepner (7).)

Of the more recent theories, Dubois (20) states that the photogenic material of *Pholas dactylus* gives some reactions for a nucleo-albumin, while Polimanti (58) regards the luminous secretion of *Pyrosoma elegans* as of a fatty nature; McDermott (50) is inclined to regard the active substance as a lipoid or phosphatid.[1] Golodetz (26) has shown that the blackening of fats by osmic acid is due to the presence of the oleic (or other unsaturated) acid radical; the present interest in this point is that the luminous tissues of the Lampyridæ and of *Phengodes laticollis* blacken intensely on exposure to osmic acid, indicating

[1] However, it must be said that both Dubois (private communication) and the author have failed to extract a photogenic lipoid with the usual lipoid solvents.

generally, the presence of a reducing agent, and more particularly, probably of an unsaturated fatty-acid radical.

Lund (42) has recently brought forth some evidence tending to show that in the photogenic process in the Lampyridæ, there is an actual using up of some material by oxidation, with the deposition of a crystallin waste product in the tissues, forming to so-called urate or reflecting layer, and states that it appears that there is present a substance related to if not identical with some of the derivatives from nucleic acids. His work is also strongly in support of the oxidation hypothesis, or at least that the process requires the presence of oxygen, even if it be not a simple oxidation. He suggests that the reduction of osmic acid may be due to the presence of a "reductase;" the latter, however, might still be dependent on an unsaturated fatty-acid radical for its activity. Coblentz (34) also notes the expenditure of the photogenic substance, without regeneration.

All attempts to isolate and analyze the active substance have failed. When the luminous organs of the firefly are treated with alcohol or ether in an atmosphere of hydrogen, the liquid acquires a yellow color, but no light emission occurs when it is exposed to the air or treated with hydrogen peroxide. Lecithin does seem to exist in the insect in small amount.

Emmerling (20a) has studied the hydrolysis products of *Noctiluca* and finds a number of the ordinary physiologic amino acids. Lankester (38a) remarks that the products of metabolism in *Noctiluca* are albuminoid and fatty granules.

The interesting fact that the photogenic tissue of luminous life forms preserves after desiccation the power to evolve light on the application of water in the presence of air or oxygen, has long been known, and it at once suggests other known instances of the preservation of biologic activity by drying, as exemplified by the yeasts and ferments. By drying the photogenic tissue of *Photinus pyralis* over sulphuric acid in hydrogen or a hydrogen vacuum, dry material has been prepared which has retained its photogenic activity apparently without loss when kept in sealed tubes for over 18 months. Indeed, there seems to be no good reason why, under these circumstances, it should deteriorate. In its conduct toward various chemical substances, the dried tissue, after moistening, does not differ essentially from the live insect or the freshly detached luminous organ. It glows on moistening in the air, somewhat brighter on moistening in oxygen, and but dimly or not at all when moistened in nitrogen, hydrogen, and carbon dioxide. Moistened with 3 per cent hydrogen peroxide instead of water, the dried tissue produces a much brighter light than with water alone, accompanied by the decomposition of the peroxide.

Lund (42) also calls attention to the effect of hydrogen peroxide on the fresh tissue.

McDermott ([50]) has recently recorded the results of some experiments with liquid air, which show that exposure of the photogenic tissue, fresh or desiccated, to this temperature, and grinding while so exposed does not in the least affect the ability of the substance to produce light upon restoration to the normal temperature. Macfadyen ([44]) found that, while exposure of the luminous bacteria to the temperature of liquid air did not inhibit their ability to produce growth and light upon return to the normal conditions, trituration at this temperature permanently destroyed the photogenicity. It would appear, then, that there is some essential difference between the microorganism and the insect in this regard.

The photogenic bacteria present many interesting problems; their ability to grow and luminesce in a medium consisting only of a solution of 3 per cent of sodium chloride and 1 per cent of asparagin in water; the dependence of the marine species on the presence of certain mineral salts, and these in certain concentrations, and upon the presence of oxygen, for light production; the pathogenic and symbiotic relations existing between some species of these photobacteria and some higher organisms are all matters of great interest. McDermott ([49]) made some experiments with the view of determining any chemical resemblances that might exist between these bacteria and the fireflies. The work was on the whole inconclusive, but indicated that if proper conditions could be arranged liquid cultures of the bacteria might be dried and afterwards caused to produce light on moistening. Molisch ([52a]) found that the thicker layers of growth of photobacteria on solid media could be dried and would exhibit their photogenic activity on moistening.

The well-known work of Radziszewski ([60]) has already been referred to, and also the more recent researches of Trautz ([67]). Delépine ([9]) has experimented with a large series of thiocarbonic esters and related bodies, which appear to be "phosphorescent" as the result of oxidation, a phenomenon to which this writer has given the name "Oxyluminescence." Hernandez and Cerdan ([28]) have questioned Delépine's view of the nature of the "phosphorescence" in these cases, and refer it to a form of triboluminescence. In any event, work along this line has some bearing on the problems of biophotogenesis, and it seems not too much to expect that it may develop that in organic chemistry there will be found to be "photophore" or "photogen" groupings, just as we now have chromophore and fluorophore groupings, fluorogens, etc.

Various observers have found the urates and phosphates of ammonium, sodium, potassium, and calcium in the luminous tissue and its ash. Dubois at one time seems to have rejected the oxidation theory and to have believed that the light was due to the spontaneous crystallization of ammonium urate (crystallo luminescence).

Guanine appears to have been found in the reflecting layers of the photogenic organs of some marine forms, and Lund ([2]) states that the dorsal layer in the firefly's organ gives the test for guanine under some conditions.

In summary it may be said that the biophotogenic process is probably an oxidation in all cases, and that the substances whose oxidation produces light is a complex product of cell metabolism containing both fatty and albuminous radicals, and probably differing in composition in each type of organism. The mechanism of the process may vary—the oxidation may be direct or indirect—according to the type of photogenic organ and the particular species of organism in point.

Light is a form of energy, just as are heat, electricity and chemical affinity. We know that in many chemical reactions a great deal of the energy of chemical affinity is transformed, probably directly, into heat, and sometimes some of it appears as electricity. If sufficient heat is generated, a portion of the original chemical energy may be transformed into light indirectly through the agency of the heat, the phenomenon being known as incandescence. But there appears to be no good reason why some of the chemical energy might not appear directly as light if the conditions are favorable, and indeed it is quite evident that such is sometimes the case, unless we adopt the view of the "combustion of food particles in the tissues," referred to Watasé a little while ago. For instance, the light-producing reaction between hydrogen peroxide and an alkaline solution containing pyrogallol and formaldehyde, generates considerable heat, enough to make the container uncomfortable to hold in the hand, yet nothing approaching that required for incandescence, and it is certainly inconceivable that there could be particles heated to incandescence by chemical action in a solution. It seems possible, however, that in the lecture experiment described by Schwersenski and Caro ([61]), in which it appears that alcohol is oxidized by ozone in the presence of the powerful dehydrating agent sulphuric acid, there may actually be small explosions, with incandescent temperatures, in the liquid, though it is not impossible that the flashes of light observed result from the direct transformation of chemical into radiant energy. If, in the pyrogallic acid reaction, solid sodium peroxide be used instead of alkaline hydrogen peroxide, a flame may be produced, but the characteristic light in the solution is produced at the same time, and it seems probable that the flame is due to the combustion of the vapor of formaldehyde (driven off by the heat of the reaction) in the oxygen-rich atmosphere produced by the evolution of oxygen during the solution of the sodium peroxide. It is of some interest in connection with Radziszewski's work, that in both this reaction and that of Schwersenski and Caro the active substance *may* be an aldehyde.

3. THE EFFECT OF CHEMICAL REAGENTS, ETC., ON THE LUMINOUS TISSUE.

During the summer of 1909 the writer was associated with Prof. Joseph H. Kastle in a study of the effect of various chemical reagents on the luminous tissue of *Photinus pyralis*.(35) Prof. Kastle and the writer tried the effect of a large number of chemical substances upon the live insect, the freshly detached luminous organ, and the luminous tissue which had been dried in hydrogen, and some of these results seem worthy of special attention. Taking first the live insect: Injections of solutions of the metallic nitrates, of strychnin, and of adrenalin caused the emission of light. Immersion of the insect in methyl and ethyl alcohols, in ether and in chloroform, resulted in the production of light. Immersion in pure oxygen appeared to stimulate the photogenic function somewhat, but not as much as might have been expected. Immersion in nitrous oxide caused a considerable increase in the intensity of the light. In the cases of injection and immersion in liquids, the reagents kill the insect, but not until they have caused light emission. Nitrous oxide narcotizes the insect, but in the air it recovers again. Hydrocyanic acid and cyanogen kill the insect, of course, but not until they have caused the emission of light. The luminous organ of one of the local species of *Lampyridæ* has been observed to glow in the mixture of air and prussic acid in the cyanide killing bottle for over an hour, long after the actual death of the insect. Ammonia water causes the evolution of light either by injection or immersion; Watasé is authority for the statement that if a tissue suspected of being luminous refuses to give light with any other stimulus, it will, if a true photogenic tissue, glow on moistening with dilute ammonia water. The injection of 3 per cent hydrogen peroxide solution also caused the evolution of light. Lund (42) has also studied the effect of H_2O_2 on the tissue.

With the freshly detached luminous segments, the most notable results were obtained with the vapors of methyl and ethyl alcohols, carbon tetrachloride and bisulphide, and mononitrobenzene acting in the presence of air. All of these reagents caused light emission and the light given out was not the continuous faint glow frequently the result of weak chemical stimuli, but was accompanied by a series of distinct flashes or pulsations of light similar to the normal flashes of the insect. With the detached organ, the effect of powerful poisons was in almost every instance to produce the evolution of light, sometimes faint and of short duration, but definite. As examples of poisons acting thus may be cited hydrofluoric acid, iodine cyanide, and bromine.

Thus far one substance alone has conducted itself as a positive inhibitor of the photogenic function. This is sulphur dioxide. Carradori observed this fact with the *Luciola italica* over 100 years ago, and Dubois has made a similar observation with regard to the cucuyo. The live insect, the freshly detached luminous organ, and the dried tissue, placed in this gas, all fail to glow, or glow but weakly and momentarily, and are dead to all other stimuli when removed from it. As a rule even those substances which tend to poison the luminous tissue caused the evolution of a dim light at first, but not so with sulphur dioxide in the majority of cases in which we used it. It has since been found by McDermott (50) that liquid sulphur dioxide and liquid ammonia both destroy the photogenic power of the dried tissue.

Mechanical stimuli, such as friction and percussion, and physical stimuli, such as electricity and heat, also cause the production of light by the luminous organs of the firefly, whether attached to the living insect or detached. The effects of various temperatures and of electric discharges of various strengths have been extensively studied by other observers. Lund's (42) observations on the effect of heat on the tissues are very interesting and important, as showing definite temperatures as the fatal points for light production, reduction of O_sO_4, etc. Transferring the detached luminous organs from one gas to another, even though one or both be chemically neutral, may cause light production, apparently due to some osmotic effect. Currents of air and other gases exert an effect on these detached organs, which Prof. Kastle has compared to the effect of air currents on the strychninized frog. It is obvious from these facts that the luminous tissue is one of great irritability.

Some of these results indicate that the effect of reagents is exerted on the nervous system rather than directly on the luminous tissue, and this probably accounts for some of the irregular and conflicting results obtained by those who have experimented in this field.

The significant fact that osmic acid is reduced by the luminous tissue has already been referred to. It has been observed that fixing fluids containing this oxide increase the intensity of the light of fresh luminous organs placed in it, but whether this is due to direct oxidation by the osmic and chromic acids present, or to irritation of the nervous system produced by them, can not be said.

The writer has observed that liquid luminous cultures of *Pseudomonas lucifera* are extinguished and killed by the addition of solutions of hydrogen peroxide and sodium perborate, and of mononitrobenzene, but that the effect of adding solutions of potassium perchlorate was, if anything, to increase the intensity of the light, and the culture was not killed in two days.

4. THE PHOTOGENIC ORGANS.

The luminous apparatus of the male of *Photinus pyralis*—the more commonly seen of the sexes—occupies the entire ventral surfaces of the two abdominal segments next to the last, and a portion of the preceding segment. That of the female is a small rectangular area on the third abdominal segment from the last; both sexes have also two very small points of luminous tissue on the last abdominal segment. In general the luminous apparatus of other Lampyridæ is confined to a similar location on the body, though some species of *Phausis* and *Phengodes* show a wider distribution of the organs.

The luminous organ of *Photinus pyralis*, in common with those of the other *Lampyridæ* which have been studied, consists of two layers of cells, under the outer transparent chitin. These layers of cells are penetrated by numberless tracheæ, the ends of which are connected by a network of very fine tracheoles, the whole system resembling the finer veining of a leaf. On the inner surface of the organ these tracheæ unite to form larger passages, which unite near the spiracle with the breathing tracheæ. It is practically certain that during the life of the insect these tracheæ are filled with air. Of the two cell layers, the outer consists of a mass of some special type of nucleated cell, of unknown nature, penetrated by the aerophore cylinders, while the inner layer is composed mainly of urates, and probably serves as a sort of reflector.

Several studies of the structures in different species of Lampyridæ have been made, which agree with each other in a general way. McDermott and Crane ([52]) have shown that the structures in *Photinus pyralis*, *P. consanguineus*, and *Photuris pennsylvanica* are quite similar, and agree very well with those described by Townsend ([66]) for *Photinus marginellus*. The organs of *Photuris* presented some slight differences from those of the other species. Lund ([43]) has recently examined the photogenic tissues in a number of Lampyrids, and come to very similar conclusions.

Bongardt ([3]) has studied the photogenic organs of *Phausis* (*Lampyris*) *splendidula*, *Lampyris noctiluca*, and *Phosphaenus hemipterus*, three European Lampyrids, and apparently failed to find anastomosis of the tracheoles. However, the author has recently examined some sections of the luminous tissue of *Lampyris noctiluca* (female), and had little difficulty in seeing the tracheolar anastomosis; the structures differed somewhat from the American Lampyridæ, the distribution of the tracheal branches being less regular, and the "cylinders" (as in *Photuris* also) less sharply defined than in *Photinus*. He has also examined the tissues of *Photinus scintillans* and *Lecontea lucifera* and found them to be practically identical with those in the insects previously studied.

The luminous organs of *Phengodes laticollis* (female) present a different structure. The photogenic tissue does not show the definite and more or less regular boundaries seen in the other species studied, but seems to be simply small masses of tissue, without regular margins; the urate layer, moreover, appears to be entirely absent. As compared with the tissues of the Lampyridæ above described, the individual cells are very much smaller, and the number of tracheæ is much less. At this time nothing can be said regarding the arrangement and distribution of the tracheal capillaries, except that only a very few have been observed and none could be traced to points of anastomosis.

Among the other luminous organisms, considerable attention has been directed to the fish, the sea-stars (Ophurians), the Annelids (*Odontosyllis*) and *Acholæ*, and to a variety of other marine forms. Much of the more recent work is contained in Mangold's monograph, and treated therein quite exhaustively. Briefly, many of the photogenic organs in marine forms appear to be typically gladular, and of degrees of complexity varying from simple secreting cells to complex arrangements of glands, reflectors, and lenses.

Pütter ([59]) has divided biophotogenicity into intra- and extra-glandular processes and into intra- and extra-cellular luminescence. Under this classification the process in the fire-flies, the fish investigated by Steche ([62]), etc., is intra-glandular and intra-cellular. In the cephalopods and certain fish which are supposed to secrete a photogenic product in one portion of the organ and then utilize it in another portion serving as a receptacle, the process is intra-glandular and extra-cellular, while in the annelids (Odontosyllids) [Galloway and Welch ([22, 23])], *Acholæ* [Kutschera ([37])], the myriapods [Dubois ([15,16]), Thomas ([65]) and others], certain prawns [Alcock ([1])], and some species of cephalopods [Hoyle ([29])], the process is extra-glandular and extra-cellular. ("Intra-" and "extra-organic" would perhaps be better general words than intra- and extra-glandular.)

The photogenic organs of some fish and cephalopods show a network of blood vessels, corresponding roughly to the aerophore tracheoles of the fire-flies. Many of the organs in these forms and in certain crustaceans (see Mangold), show a "search-light" or "bull's-eye" structure in which there is more or less well-defined lens, a light-producing body, and a reflecting layer of approximately parabolic outline.

There is a considerable field for further investigation in this matter of the structure of the light-giving organs of different forms, and some of the work that has been done is in need of confirmation. We can not but wonder at the processes which during the ages have operated to produce these structures in present-day organisms—how they

originated, and why? The phylogenetic problems are certainly very interesting, and present remarkable instances of "convergence." It is hoped to collect some of these cases and develop them in a future paper.

5. FLUORESCENT SUBSTANCES IN LUMINOUS INSECTS.

An interesting circumstance in this connection is the existence in certain luminous organisms of a substance whose solutions exhibit a brilliant blue fluorescence. Dubois ([13, 14]) found this substance in the cucuyo, and in *Luciola italica*, and named it "Pyrophorine," from *Pyrophorus noctilucus*, the entomologic name of the cucuyo. More recently Coblentz ([4]) has found it in *Photinus pyralis*, *Photinus corrusus*, and *Photuris pennsylvanica*, and the author has found it in *Photinus consanguineus*, *P. scintillans*, and *Lecontea lucifera*. It is also present in the larva of *Photinus pyralis*, and in other lampyrid larvæ. Dubois ([13, 14, 19]) regarded this substance as a glucoside, analogous to esculin (a glucoside which is present in the bark of the horse-chestnut, and whose solutions possess a blue fluorescence), while the present author ([47]) concluded that it had an alkaloidal nature, and not at the time being aware that Dubois had offered the name "Pyrophorine" for the fluorescent material from the cucuyo, suggested the name "Luciferesceine" for the substance from the Lampyridae. Neither view as to its chemical nature is at all definite, however, and more work will be necessary to elucidate this point.

Fluorescent extracts of the *pyralis* are produced by extraction with alcohol, ether and water, but not by chloroform, benzene, or carbon tetrachloride. The fluorescent material is not precipitated by lead acetate, mercuric chloride, ammonium sulphate, nor chlorplatinic acid. It appears to be a solid at ordinary temperatures, though as emitted by the insect it is contained in a sticky exudation, which soon hardens in the air.

Luciferesceine dissolves readily in liquid ammonia, the solution presenting the blue fluorescence characteristic of aqueous and alcoholic solutions, the solution itself being very pale yellow.

Dubois seems to have regarded this substance as of use to the insect in transforming useless into visible radiation, and thus improving the quality or intensity of the emitted light; and he states that on this theory he first advanced the idea of the use of fluorescent materials with artificial illuminants to improve the quality of the light, as is now done in the use of rhodamine with the mercury vapor arc. Two things, however, stand in the way of the acceptance of the view that the fluorescent property of this substance is of use to the insect; first, the internal juices of the insects (at least of *Photinus pyralis*) are slightly but distinctly acid, and it has been found that even a weak acid reaction destroys the fluorescence; second, Ives and Co-

blentz (ante) photographed the spectrum of the fluorescent light from solutions of luciferesceine and of the emitted light of the fire-fly itself, and showed that the spectra are almost complementary, and that the fluorescent spectrum does not appear on the plates of the emitted light of the insect, although these plates were sensitive to the wave-lengths embraced in the fluorescent spectrum. In any event the intensity of the fluorescence of the material in a single insect would be too slight to have any appreciable effect in modifying the color of the emitted light. (See Coblentz ([5a])). In fact it seems probable from the work of Tappeiner and Iodlbauer ([64]) that if the substance should actually fluoresce in the bodies of the insects, it would kill them. Pigments and other substances showing fluorescence are not uncommon in animals; Stübel ([63]) has claimed that all animal tissues exhibit fluorescence when exposed to ultraviolet light, while Arndt (private communication) states that he has observed the presence in most insects of substances which are fluorescent under the influence of the X-rays.

Personally, the writer is inclined to regard the fluorescence simply as an incidental property dependent on the structure of some compound frequently met with in insects of this nature, much as Jordan ([32a]) regards the fluorescent pigment of *Bacillus fluorescens liquefaciens*.

Dr. Coblentz finds that these fluorescent extracts exert a strong + rotation on polarized light.

5. BIOLOGIC RELATIONS OF THE PHENOMENA.

There has been a good deal of discussion as to the significance of the photogenic functions for the forms possessing it. There are four recent papers of considerable importance in this connection.

Galloway ([22]) [Galloway and Welch ([23])] has observed the use of "phosphorescence" as a mating adaptation in an Odontosyllid, *Odontosyllis Enopla* Verrill, this apparently being the first instance in which the relation between this function and the reproductive life of the organism has been definitely established. McDermott ([31]) has confirmed the old and frequently over-looked observation of Osten-Sacken ([56]) that the photogenic function plays an important part in the mating of *Photinus pyralis*, and has extended the observation to a few other species of Lampyridae. Mast ([45a]) has confirmed this result as applied to *Photinus ardens*, and brought out the bearing of the phenomenon on the problems of phototaxis and orientation. Lund ([41, 42]) has made observations on Odontosyllids, Lampyrids, and Elaterids, which tend to support the observations recorded in the above-mentioned papers. An extended study of the relation of the photogenic function to the reproductive life of a large number of species of Lampyridae of different genera would be of great interest, especially as the females of a great many of the species of this family

are unknown, while in some other instances, the females alone are known. A number of observations of the relations between size of eyes, length and complexity of antennae, and the development of the photogenic function in the sexes have been made, the extreme of which appears to be reached in forms like *Phengodes laticollis*, where the male is winged, has very large eyes, large, plumose antennae and is non-luminous, while the female is intensely luminous from a large number of photogenic organs, is entirely apterous, has very small eyes, and only rudimentary antennae.

The reported luminosity of midges (*Chironomus*) has long been a matter of curiosity and speculation. It has at last been proven by Issatschenko ([30])—as was previously suspected—that the light emission in these insects is due to bacterial infection, apparently pathogenic. This strongly recalls Giard's observation ([25]) of the pathogenic relation of a species of photogenic microorganism to *Talitrus*. It may also have a confirmatory value toward the explanation offered by Distant ([10]) of the alleged luminosity of *Fulgora*. In view of the known propensity of owls to hide during the day in hollow trees, and the frequent infection of such trees by photogenic molds, etc., it seems that a similar explanation might be advanced for the occasional instances in which these birds have been reported to be luminous, such as those cited by Dobbs and Moffatt ([11]), and Purdy ([58a]).

A number of observers have, at various times, reported the luminosity of various species of earth-worms. Walter ([69]) attributes this property to the secretion of certain glands in the skin of the worm, which is of interest when considered with the studies of Galloway ([22, 23]) on the related marine Odontosyllids, and those of Kutschera ([28]) on *Acholoe;* in this latter instance the luminosity appears to have a defensive function.

So far as marine forms in general are concerned, the photogenic function appears to have a variety of uses, its significance to a given organism depending on the method of life of the species. Alcock ([1]) brings out this variation in the use of the function in marine organisms very well. Nutting ([55]) has also had a very interesting paper on this phase of the subject. With the increasing knowledge of the existence of light-giving structures in numbers of species of fish, cephalopods, crustanceans, and many lower forms, the views as to the use of such organs to their possessors are gradually broadening, and the conception of the conditions of life in the depths of the sea becoming more and more definite and interesting.

Several studies of the structure and development of the luminous organs in various fish have been made, perhaps the most interesting and complete of which are those of Greene ([27]) and Gatti ([24]); neither of these papers can be conveniently quoted here, but both are important.

It seems to the author that the question of the relation of the photogenic function to the lives of the creatures possessing it has not had the attention it deserves. Reliable and definite observations are scattered, and sometimes conflicting, and there is much ground that has not been covered that would form an inviting field for some extremely interesting biologic studies.

Moore ([53a]) has made the interesting observation that certain luminous marine organisms show a diurnal periodicity of light-emission, even when kept in complete darkness for several days; this periodicity shows itself by the appearance of light at approximately the same time in the evening and its cessation at about dawn, even though the creatures are kept away from light during the whole time of observation.

CONCLUSION.

We can not say now what possibilities lie before us in the discovery of the "secret of the firefly," particularly as to the kind of "oil" he uses in his little lamp. Perhaps it will be discovered and turned to practical account. The emitted light of the firefly is far from being a good light for general illumination, in spite of its high luminous efficiency, on account of the very limited range of color effects possible under it. A single firefly has been variously estimated to give from $\frac{1}{50}$ (Coblentz,[5a]) to $\frac{1}{1600}$ (Langley and Very,[39]) of a candle power, so we would need quite a high "firefly power" to light our homes and streets by biophotogenic light. There are still many gaps in our knowledge of this interesting subject, in spite of the large amount of work that has already been done, but one by one we hope to close these up and discover the secret of the cheapest form of light.

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ORGANIC EVOLUTION: DARWINIAN AND DE VRIESIAN.

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The term "organic evolution" implies that existing organisms are children of the past and the parents of the future. As biologists we hold that this order of things is the result of natural processes of growth and change working throughout past ages; in fact, that existing plants and animals are the lineal descendants of ancestors on the whole somewhat simpler in organization, and that these are derived from still simpler forms, and so backward to pre-Cambrian geological periods, when we have reason to believe that living organic matter first came into existence on the earth. Of one thing we may be sure, which is that evolution, according to the above definition, depends on the fact that the living substance which constitutes the essential part of organisms on the one hand is capable of passing its form and functions on to its descendants, and on the other hand possesses an organic changefulness which we call variability.[1]

Organic evolution implies a definite structural arrangement and combination of an aggregate of elements into a form which constitutes a unit or cell; one or it may be a mass of these units form the body of an organism. This form of matter is known as protoplasm or the basis-substance of life, because the complete series of phenomena which collectively we call life are manifested through the instrumentality of this kind of matter.[2]

The protoplasm of living cells, among its other constituents, invariably contains a chemical compound known as protein, a wonderfully complex substance. For instance, the protein which exists in our red blood cells is said to be composed of molecules having a chemical formula of $C_{600}\ H_{960}\ N_{154}FeO_{179}$, whereas the formula of water is H_2O. And just as the peculiar properties of water are given to it by the

[1] Heredity, by J. Arthur Thomson, p. 12, London, J. Murray, 1908.

[2] These phenomena include the power possessed by living protoplasms of replacing its worn-out elements from surrounding materials without changing its form or functions, of reproducing its like, of respiring, and by chemical action of forming enzymes; it is also capable of being modified by external and internal forces in such a way as to become a transformer of energy into psychical and other processes.

properties of the hydrogen and the oxygen which combine to form it, so the marvelous properties of protein are due to the assemblage of the properties of the carbon, hydrogen, and other elements which enter into its composition. The molecules of protein, in some at present unknown way, are built up so as to form the still more complex body, living protoplasm.[1]

The fundamental principle we have to bear in mind is that living protein, without alteration in its chemical composition, is capable of existing in a multitude of forms. As Prof. W. B. Hardy states, all proteids are not the same proteids; there are proteids of men, others of beasts, others of fishes, and others of birds. The properties of a complex substance like protein are defined not so much by the kind of atoms or number of elements of which it is built up, as by the structural arrangement and the motion of those atoms in space.[2] He gives as an example the molecules of two chemical substances, benzonitrile and phenylisocyanide, each of these being composed of seven atoms of carbon, five of hydrogen, and one of nitrogen. There is a small difference in the arrangement of these atoms; this difference so alters the properties of the two substances that one is a harmless fluid with an aromatic smell; the other an offensive poison. It is evident from the complex nature of the elements of a proteid that its molecules must be of far larger dimensions than the molecules of inorganic substances; but the larger the size the greater the probability of variation of its elements in detail by the action upon them of various forms of energy. As we have elsewhere stated, it is, we hold, in consequence of the unique structural arrangement and motion of the elements which constitute protoplasm, that it acts as a transformer of chemical and other kinds of energy into phenomena characteristic of living matter.[3]

The majority of persons who have studied the subject are of opinion that organic evolution is a natural process, the existing orders of animals and plants having been progressively developed out of specially adapted protoplasmic elements. Nevertheless, a considerable number of educated people have misgivings on this subject, for they fail to comprehend how, if the various classes of animals have been gradually evolved out of a common form of organic matter, it comes to pass that some of them should possess a nervous system, through means of which they have gained the power of guiding their actions

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[1] The Doctrine of Evolution, by Prof. H. E. Crampton, p. 22.

[2] Science Progress, vol. 1, p. 195.

[3] It may be shown that we can fix certain qualities on the surface layer of solids such as protoplasm by the use of minute amounts of salts. The salts may be washed out, but its effects remain and exert a direct influence on the succeeding molecular events, so far this action lasts for all time in the absence of active chemical intervention. See Journal de Chem. Physique, vols. 2 and 3, pp. 61, 50; Human Speech, by N. C. Macnamara, International Scientific Series, vol. 95, p. 12.

Prof. Villa, in his admirable work on Contemporary Psychology, states "What we call 'life' or biological organization is the result of a peculiar combination of elements," pp. 268, 271.

by intelligent thought, while other classes of beings, derived from the same forms of matter, have failed to develop these powers, their movements being governed by automatic and reflex processes. In attempting to give a reason for this state of affairs, we assume that at a certain stage of our earth's formation an aggregation of elements came into existence such as that to which we have above referred.[1] Our object is, if possible, to ascertain under what conditions and demonstratable properties, this organic matter has developed into the orders of animals and plants now living in the world.

In attempting to master the complex mass of phenomena which are involved in the solution of a problem of this kind, there is only one rational course to pursue in order to get a view of its cause; we must invent an hypothesis—that is, we must place before ourselves some more or less likely supposition respecting the cause; and, having framed our hypothesis, we must endeavor, on the one hand, to prove that the supposed cause exists in nature, that it is competent to account for the phenomena, and that no other known cause is competent to account for them.[2]

Various hypotheses have from time to time been promulgated to account for the natural evolution of animals and plants. Of these theories two at present occupy the serious attention of biologists. The one known as Darwin's hypothesis, or natural selection, assumes the progressive evolution of the simpler into more complex orders of beings. The other is De Vries's hypothesis of mutation, which assumes that new species of animals and plants have suddenly been produced from preexisting fully formed beings.[3]

We may best appreciate Darwin's hypothesis by referring to his own remarks on the subject. He states that in his opinion "animals have descended from at most only four or five progenitors, and plants from an equal or lesser number. This would lead us one step further, namely, to the belief that all animals and plants have descended from some one prototype." [4] We may suppose that the primeval prototype began by producing beings like itself, or so slightly affected by external influences as at first to be scarcely distinguishable from their parent. When the progeny multiplied and diverged, they came more and more under the influence of "natural selection," and thus through countless generations under the operation of this law human beings were finally developed.

Darwin refers to the multitude of the individuals of every species, which from one or another cause perish either before or soon after attaining maturity. He states that in consequence of the struggle

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[1] Evolution Darwinian and Spencerian. The Herbert Spencer Lecture, by Raphael Meldola, F. R. S., p. 20. Also Human Speech, by N. C. Macnamara, p. 12.

[2] Huxley's Essays. Phenomena of the Origin of Matter. Everyman's Library Edition, p. 247.

[3] Species and Varieties: their Origin by Mutation, Heredity, and Evolution. By Hugo de Vries.

[4] Origin of Species, p. 484.

for existence, any variation however slight, and from whatever cause proceeding, if it be in any degree profitable to an individual of any species in its infinitely complex relation to other beings, and to its environment, will tend to protect that individual and will generally be inherited by its offspring. Darwin calls the principle by which each slight useful variation of an organism was preserved, the principle of natural selection, in order to emphasize its relation to man's power of selective breeding. For it is well known that by careful selection of the stock, we can adapt organic beings to our own use through the accumulation of slight but useful variations. Natural selection, however, is a power constantly ready for action, and is as immeasurably superior to man's efforts as the work of nature is to that of art.[1]

Darwin repeatedly insists on the fact that natural selection could not have been effective, unless very long periods of time were allowed for its complete action. It is evident that time must have been an all-important factor if we are to suppose, that by the interaction of the inherent properties possessed by the elements of living organic matter, its structural arrangement became gradually modified in such a way, that the existing classes of animals and plants have been evolved out of it. For, as the late Prof. Huxley states, natural selection implies not only the existence of organic matter, but also its tendency to transmit its properties, and its tendency occasionally to vary; and lastly, given the conditions of existence, that these put together are the cause of the present and the past conditions of organic nature.

The only evidence we can bring to bear on the subject of the progressive evolution of the animal kingdom is derived from a study of their fossil remains, in the various geological strata of our own, and other parts of the world.[2] The length of time these strata have taken to form is an open question, but we may be sure that our chalk rocks, for instance, consist of the shells of marine species of animals, and that these remains of once living beings must have taken long periods of time to have been deposited layer upon layer at the bottom of the sea. Darwin states that the fineness of gradation in the shells of successive substages of the chalk formations led him to maintain the gradual as against the sudden evolution of species. The fossil shells in these rocks have been thoroughly investigated by Mr. A. W. Rowe, who states that "the white chalk of England offers

[1] On the Origin of Species by Means of Natural Selection, by Charles Darwin, M. A., 1859, p. 61.

[2] Many of the attacks made upon the hypothesis of natural selection have been founded on the imperfection of geological records to show the transitional links, which, according to this theory, must have connected the closely allied species of animals. If, however, we take into account the perishable nature of the bodies and limbs of these creatures, the probable changes that have occurred in the surface of the earth since they were deposited, and the imperfect state of our geological records, we can readily understand the reason for there being missing links in the fossil remains of former geological periods.

an almost unique field for observation, on account of its thickness (considerably over 1,000 feet), its slow, uniform, and continuous deposit in a sea of moderate depth, with no closely adjacent land, the abundance and wonderful state of preservation of its fossils, together with the facility with which they can be cleared of their chalky covering."[1]

Among the most common chalk fossils is the flattened, heart-shaped sea-urchin. These are first found in their shelled, sparsely ornamented forms, from which spring, as we ascend the zone, all the other species of the genus. The progression is unbroken and minute in the last degree. We can connect together into continuous series each minute variation and each species of gradation of structure so insensible that not a link in the chain of evidence is wanting. In the other common sea-urchin of the chalk, although evidence derived from the details of structure is not equally available, that afforded by the gradual variation in shape as we ascend through the zones of formation is convincing and complete. Equally clear proof of continuous evolution is provided by the study of the belemnite Actinocamax. Although this genus reaches at definite zonal levels a sufficiently accentuated degree of variation in its intrinsic character to warrant, for purely stratigraphical purposes, the use of trivial titles, the fact remains that these so-called species are but landmarks in the progressive and unbroken evolution of a single though somewhat plastic genus. The bearing of this evidence upon the question of continuity or discontinuity in evolution is of paramount importance. Nowhere has evidence been collected so fully as in the case of the white chalk; nowhere have such conclusive proofs of continuity in evolution been established.[2]

Prof. W. B. Scott, referring to the evolution of the existing species of horses, states that in the Lower Tertiary deposits of North America, "each one of the different Eocene and Oligocene horizons has its characteristic genus of horses, showing a slow, steady progress in a definite direction, all parts of the structure participating in the advance—which, it should be emphasized, the changes are gradual and uninterrupted."[3] This series of fossils points to the fact that existing species of horses are derived from individuals less highly capable of evading enemies, and obtaining food; that is, they point to progressive improvement through long periods of time in structural arrangement of this species of animals.

Prof. E. B. Poulton was much impressed by the series of mammalian skulls from the Lower Tertiary beds of North America, arranged in

[1] Darwin and his Modern Critics, by E. B. Poulton. The Quarterly Review, July 1909, p. 19.
[2] Prof. E. B. Poulton. The Quarterly Review, p. 20, July, 1909.
[3] The Cambridge Darwin Memorial Volume, p. 190.

the American Museum of Natural History, New York, in the order of succession in time as determined by the strata from which the fossils had been taken. One series showed the most gradual and continuous modification in the characters of teeth, another a similarly continuous evolution of horns.

Again, the well-known fossil Archaeopteryx, found in a series of slates in Germany, would certainly seem to constitute a link between groups now widely separated by divergence in evolution from the same ancestors. This animal is at once a feathered flying reptile and a primitive bird with many reptilian structures. Although Archaeopteryx was a primitive bird, it is in a true sense a "link" between reptiles and the group of modern birds; the gap between these types is filled up by fossil forms like Hesperornis, whose remains are found in strata of a later date. "That these links are not unique is proved by numerous other examples known to science, such as those which connect amphibia and reptiles, ancient reptiles, and primitive mammals, as well as those which come between the different orders of certain vertebrate classes. The important element in these examples of evolution is, first, their adaptation; secondly, the origination of new parts, and thirdly, the retention of the better invention."[1] Evidence of this kind does not enable us to decide upon the cause of evolution; but in the instances referred to progressive development has occurred gradually, and not by mutation or sudden leaps.[2] On the other hand, they have much to do with the building up of the fittest. As Darwin states: "The tendency to the preservation (owing to the severe struggle for life to which all organic beings at some time or generation are exposed) of any variation in any part, which is of the slightest use or favorable to the life of the individual which has thus varied, together with the tendency to its inheritance. Any variation which was of no use whatever to the individual would not be preserved by the process of natural selection."[3]

Another kind of evidence favoring the idea of the progressive evolution of human beings from simpler orders of animals is the presence of what are known as nonfunctional vestigial structures, relics of past phases of existence, such, for instance, as the unused external muscles of our ears and rudimentary third eyelids; the gill-clefts of reptiles, birds, and mammals, and the hind limbs of whales. The study of these vestigial structures is of importance in showing that ancestral features have great power of hereditary

[1] The Doctrine of Evolution, by Prof. H. E. Crampton, p. 99.

[2] E. B. Poulton, The Quarterly Review, July, 1909, p. 18.

[3] More Letters, I. Pp. 126. Quarterly Review, July, 1909, p. 26. Also The Evolution of Living Purposive Matter, by N. C. Macnamara, vol. 97, International Scientific Series, pp. 2, 53.

persistence. These traces of ancestral history are intelligible only by means of the hypothesis of natural selection.[1]

Prof. G. Elliot Smith insists on the fact that a knowledge of the evolution of the brain affords us a reliable and important clue in understanding the factors which have led to the making of mammals what they are, as well as supplying evidence to show whence they came. He demonstrates the fact that from the earliest development of the structures forming the cerebral cortex (or that portion of it included in the neopallium), its function has been to regulate "skilled" movements of the animal's body.[2] The superior development of the brain of Pithecanthropus with its rudimentary sensori-motor center of speech, gave this order of beings an advantage over its nearest competitors, the anthropoid apes, and as the progressive evolution of the brain of man was raised to a higher standard by the exercise of his skilled movements, so his psychical powers increased, and led him to manufacture weapons and implements of various kinds, and to appreciate the use of fire to aid his brute force. Thus the gap between man and apes widened more and more as the reasoning power of the former increased through successive generations.[3]

Having thus given an outline of the evidence which leads us to accept Darwin's hypothesis as being as near an approximation to the truth as, for example, the Copernican hypothesis was to the true theory of the planetary motions,[4] we must refer to some of the reasonable objections that have been advanced against this theory.

As far back as the year 1863 Huxley found he was unable, without reserve, to accept the theory of natural selection, because although in his opinion this theory accounted for the structural origin of species, it was incapable of explaining their physiological differences.[5] For, he argued, it was a well-known fact that distinct species in a state of nature were, when crossed, incapable of perpetuating the species. On the other hand, selective breeding was incapable of producing species which on crossing were, as a rule, sterile. Since Huxley's time, however, it has been proved that fertile pairing between distinct species of animals is by no means a rare occurrence.[6]

We have already referred to another difficulty experienced by many educated people in accepting, without reserve, the theory of natural selection; they are unable to conceive how slight beneficial

[1] Heredity, by Prof. J. A. Thomson, p. 127.

[2] British Association for the year 1911. Sec. D. "The Origin of Mammals."

[3] Prof. H. E. Crampton, "The Doctrine of Evolution," p. 175. Human Speech, by N. C. Macnamara, p. 210, figs. 37 and 42.

[4] Huxley's Essays, p. 100.

[5] Huxley's Essays, p. 228.

[6] J. A. Thomson on Heredity, pp. 338, 387.

variations in the structural arrangement of the protoplasmic elements of living organisms could have become established, and subsequently developed in succeeding generations, in the constantly changing environment (climatic and otherwise) to which these organisms must have been exposed. It certainly seems necessary, that the modes of energy which, by their action on the living elements of protoplasm had caused its molecular modifications, should have continued to act on these elements for considerable periods of time, in order that these beneficial variations should be established and become hereditary. This objection, if valid, would seem seriously to affect the soundness of the foundations on which the theory of natural selection rests. This difficulty, however, is one capable of being satisfactorily met; for there is good reason to suppose that, in spite of the adverse influences to which primitive organisms must have been subjected, certain of the forces acting upon their living protoplasm have been continuously in operation; such, for instance, as that form of energy we call light, which we may suppose by its constant action on these elements gradually changed their molecular structures, and adapted them to its own specific mode of action.

To illustrate our meaning we may take, as an example, the development of structures such as those which enter into the formation of the eyes of two different classes of animals, viz, mollusks and vertebrates.

It seems probable that these structures were derived from a common ancestral stock, for they both consist of similar tissues adapted to concentrate a definite mode of energy on a specialized form of nervous elements, which, in conjunction with work performed by corresponding cerebral matter, gives rise to visual sensations. There is, however, a difference in the arrangement of the internal structures of the eyes of mollusks and vertebrates, especially in those tissues which are concerned in the adjustment of the focus of the eyes to near and distant objects, and also in its nervous apparatus. The question is: How are we to account for these differences, supposing the eyes of these creatures to have been evolved from a common ancestral stock?

It seems unlikely that the delicate tissues entering into the formation of the eyes of vertebrates and mollusks have been built up on similar lines by the play of chance variations in their protoplasmic elements, produced in response to the action of a constantly varying environment. Even supposing slight identical beneficial changes in the living matter of these structures had thus been effected, this action must have been persistent, otherwise these molecular changes would soon have become obliterated; but, as above stated, it would be different supposing light acted continuously and directly on the protoplasmic elements, so as to change its molecular structure and

to adapt it to its own specific mode of action. The resemblance of the tissues of the eyes of vertebrates and mollusks would thus be referable to an identical force or cause. The more and more complex eyes of vertebrates would be something like the deeper and deeper impression of light on a substance, which, being organized, possesses a special aptitude for receiving it.[1]

In many unicellular and some invertebrate beings, red spots of coloring matter may be seen on their outer surface. These are known as "eye-spots," for in some of them lens-like structures exist which are analogous to those of the eyes of the higher orders of animals. There is reason to suppose that by the action of light on the substance forming these eye-spots, organisms possessing these structures are enabled to distinguish light from darkness. Animals having more highly developed eye spots seem to be sensitive to alterations in the intensity of light; their rudimentary organs of vision may therefore, in a vague way, assist these organisms to guide the movements of their bodies.[2]

There must have been very many stages in the evolution of eye-spots into structures such as those which constitute the eyes of mollusks and vertebrates, and some of these stages may be traced from one to another through the ascending order of beings. Each stage consisting in the purposive adaptation of the structures entering into the formation of the eye to the requirements of each order of individuals. Beyond this natural selection is no longer operative, because a further specialization of structures entering into the construction of the organ of vision would not assist this particular order of beings in their struggle for existence. It would, for instance, be of no advantage to a scallop, as it is to human beings, to possess a complex arrangement of structure adapted to instantaneously focus its eyes on near and distant objects.[3]

So far as our knowledge extends regarding existing orders and species of animals, we do not find any indications of sudden changes taking place in the structures entering into the construction of their organs of vision. On the other hand, we can account for their undoubted progressive development by supposing their eyes to have been evolved by the continued action of light on living matter, which under the operation of the laws of natural selection has gradually been molded into a form adapted to respond to this mode of energy. In other words, the action of light on the living purposive elements of

[1] Creative Evolution, by H. Bergson, p. 73. It is as Prof. Crampton remarks (Doctrine of Evolution, p. 31) that organisms are in a true sense complicated chemical mechanisms adapted to meet the conditions under which they must operate.

[2] The rudimentary eyes of these lower kinds of beings have been developed from the living protoplasm of the outer layers of their body (somatic) cells by chemico-physical action, the color producing enzymes of thisspecialized form of matter being stimulated and brought into action by energy derived from sunlight.

[3] The Evolution of Living Purposive Matter, by N. C. Macnamara, p. 32.

a differentiated form of protoplasm has gradually produced changes in the structural arrangement of its molecules, whereby they have effectively responded to the exigencies of their environment. Structural changes thus effected have a tendency to become hereditary qualities. To this extent light may be said to have evolved the structures which enter into the formation of the eyes of the various classes of animals. Herbert Spencer, when referring to molecular changes of the kind to which we have referred, states that there go on in all organisms certain changes of structure and functions that are directly consequent on changes in the incident forces, inner changes by which outer changes are balanced, and the equilibrium restored—rearrangements which produce an exactly counterbalancing force.[1] But the result, though as a rule progressive under the laws of natural selection, is not always so, as for instance in the case of internal parasites which lack even a digestive tract, because a stomach is unnecessary in an animal which lives bathed in the nutrient fluids of its host.

The other hypothesis which we mentioned as, at present, engaging the attention of biologists to enable them to explain the origin of new species of animals and plants, is the theory which has been advocated by the well-known Dutch botanist, Prof. Hugo de Vries.

De Vries, in the preface to his work "Species and Varieties, their Origin by Mutation," observes that the current belief assumes that species are slowly changed into new types. In contradiction to this conception, the theory of mutation assumes that new species and varieties are produced from existing forms by sudden leaps. The parent type itself remains unchanged throughout this process, and may repeatedly give birth to new forms. These may arise simultaneously, and in groups, or separately at more or less widely distant periods.

De Vries lays stress on the difference between slight structural changes in plants, and mutations; the former he holds are subject to fluctuations and occur continually from one to other generations. Mutations, on the other hand, are rare and occur intermittently; they do not show any ascending law of frequency. Fluctuations do not lead to a permanent change in the increase of the species unless there be very rigorous selection, and even then, if the selection be slackened, there is regression to the old mean; mutations lead per saltum to a new specific position, and there is no regression to the old mean. De Vries maintains that fluctuations do not yield anything really new, they imply a little more or less of characters already present; mutations are novelties, they imply some new pattern, some new position of organic equilibrium. De Vries holds that no new species can be established without mutation. "When a mutation has

[1] Principles of Biology, by H. Spencer, vol. 1, pp. 434, 442.

occurred a new species is already in existence, and will remain in existence unless all the progeny of the mutation are destroyed." According to De Vries, therefore, species originate by mutation instead of by continuous selection. He adds: "Natural selection may explain the survival of the fittest, but it can not explain the arrival of the fittest."[1]

It is clear that De Vries's hypothesis of evolution of species by mutation, if established, would mean a profound change in the ideas received from Darwin. The survival of the fittest among a crowd of fresh elementary species or subspecies ready-made by mutation is a different conception from that of the progressive building up of the fittest types, by the improvement through selection of existing characters and qualities, and the gradual addition of a unit here and a unit there to a complex structure of species.[2]

Darwin, as far back as the year 1859, stated that it was the fineness of gradation in the shells of substages of the chalk formations, which led him to maintain the gradual, as against the sudden evolution of species.

The evidence upon which De Vries founds his hypothesis as to the sudden production of new species from existing types—that is, by mutations—is largely derived from his own observation of changes which took place in specimens of plants of the evening primrose (*Œnothera lamarckiana*) he found growing in the sandy soil of a field at Hilversum. De Vries took seeds from two species of these wild plants and sowed them in a well-manured garden in Amsterdam. Seeds collected from these cultivated plants produced, according to De Vries, seven constant elementary species of the evening primrose; but these species differed so slightly from one another and from the parent stock, that we should rather refer them to varieties than as constituting distinct species. Varieties of this kind might be accounted for by a change of environment, the plants having originally grown in a sandy soil and been transferred to a well-manured garden. De Vries, however, attributes the changes observed in these plants to the latent qualities possessed by the parent stock. He assumes that the characters of organisms are made up of elements that are sharply separated from each other, and that at certain periods these elements become impressed by an impulsive mutability. It was at one of these periods De Vries supposes he chanced to secure his evening primrose, hence the changeful state of the plant and its production of seven elementary species within a short time.

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[1] Heredity, by J. Arthur Thomson, M. A., regius professor of natural history in the University of Aberdeen, pp. 90, 98.

[2] The Quarterly Review, July, 1909, p. 25. E. B. Poulton, Darwin and his Modern Critics.

The history of the Maltese family of Kelleia is often referred to as an example of mutative changes in the case of human beings. The father and mother of this family had the ordinary number of toes and fingers, but their eldest son possessed six fingers on each hand and six toes on each foot. This child, Gratio, subsequently married and had children, several of them having six fingers and toes. This malformation was absent in the following generation, but reappeared in the succeeding family; it then seemed to have died out. Another remarkable instance of this kind is that of the flock of Massachusetts Ancon sheep. The deformity which characterized these sheep, however, disappeared in the course of a few years, it is said in consequence of the introduction of the Merino sheep into the United States. In both these cases of the sudden development of monstrosities it can not be said that new species, but only varieties, had suddenly come into being. Our knowledge, however, concerning the evolution of the simpler into complex orders of plants, like that of animals, must to a large extent be guided by information we derive from the study of their fossil remains—a branch of science which has only been taken seriously in hand within the last few years. Palaeobotanists of repute, such as MM. Barrois, Bertrand, and Cayeux, are of opinion that in the earliest sedimentary or pre-Cambrian formations they have obtained evidence of the existence of rudimentary animals and plants, in the shape of protophytes and protozoans.[1] However this may be, we know that numerous species of diatoms, seaweeds, and fungi exist in a fossil state in the coal measures of England and other parts of the world, and that the structure of these beings resembled those now flourishing. The higher plants, however, on which these fungi fed "have changed profoundly since" the coal-measure epoch, "stimulated by ever-changing surroundings."[2] All the plants which existed during the Carboniferous period have become extinct; they were flowerless and otherwise differed from those of the present day; but this difference was in outward form, or the grouping of their cells, rather than in the functions performed by their vascular, respiratory, and other structures. Thus we find in fossil plants of our coal measures a layer of chlorophyll bearing cells situated beneath their epidermis, indicating the existence of a starch-forming system, worked by energy derived from sunlight. In each succeeding geological period the main types of vegetation changed, and each succeeding change advanced a step toward the types of the existing flora.[3] It was not, however, until we arrive at the Cretaceous epoch that the existence of fossil flowering plants appear.

[1] Annual Report of the Smithsonian Institution for the year 1903, p. 512.
[2] Ancient Plants, by M. C. Stopes, D. Sc., p. 165.
[3] Idem, p. 40.

The advent of these plants in the flora of this period, according to existing fossils, appears somewhat sudden, so much so that palaeobotanists have been disposed to think that this epoch indicates the existence of a mutative period in plant life. In fact, that during the time the chalk rocks were forming that plants suddenly all over the world produced species differing essentially from those which had preceded them. It is necessary, however, to take into consideration the existence of a group of fossil plants known as Cycads, which were probably derived from a common stock and "which are in close connection with the ancestors of modern flowering plants; thus flowering plants can be linked on to the series that runs through the Cycads directly to the primitive ferns."[1] It is only within the last few years that the important extinct group of plants—Pteridosperms—has been recognized. Nevertheless, they form the most numerous plants of the Carboniferous period and have displaced the ferns from the position they were hitherto supposed to hold as the dominant plants of the coal measures. Facts such as these render us cautious in accepting the idea that the flowerless flora of the ancient world became suddenly changed during the Cretaceous epoch into flowering plants. It is clear that the vascular and reproductive organs of the plants of ancient geological periods, as they grew taller and came to inhabit a dry soil, must, under the laws of natural selection, have undergone certain modifications. From the microscopical examination of the tissues forming these primitive plants we find that alterations in their structure have gradually taken place, culminating in the appearance of the flowering plants of the Cretaceous epoch.

Dr. M. C. Stopes in the concluding chapter of his excellent work on "Ancient Plants" (p. 178) states that "the group of fossil plants do not now appear isolated by great unbridged gaps, as they did even 20 years ago;" by means of the fossils either direct connections or probable links are discovered which connect series and families. We may add that plants now growing in the Nile Valley are similar in character to those represented on the monuments of the earliest Egyptian dynasties. In the stable climate and conditions of the Nile Valley these plants for thousands of years have retained their character; but if removed to a different soil and climate such as that of England, in the course of a few generations they become variable and thus undergo marked modifications. We hold this result to be attributable to the response of their living protoplasm to the action of changes of environment, which in the course of time we believe, under the influence of natural selection, might possibly lead to the production of new varieties, if not actual species. The following details concerning a remarkable series of variations in certain Fox-

[1] Ancient Plants, by M. C. Stopes, p. 108.

glove plants appear to afford us reliable evidence in favor of the idea, that under certain unknown conditions the flowers of a wild plant may become suddenly and completely altered in character, and that variations of this description are passed on from one to succeeding generations by means of the germ cells.[1]

From a packet of Fox-glove seeds (*Digitalis purpurea*) sown in the year 1906, 54 plants were, in June, 1907, planted in a shrubbery of fir trees with an undergrowth of laurels. Of these plants, 51 grew into normal Fox-gloves, but the 3 remaining plants were sports, which we may distinguish by the letters A, B, and C.

A. In this plant the flowers of the lower half of the stem possessed only a bifid upper petal and seven stamens united at their bases. The flowers of the upper part of the spike were normal.

B. A fine, well-grown plant 4½ feet high; throughout the whole length of the spike the flowers consisted of a bifid upper petal, seven stamens, and style. The upper part of this spike was isolated; it produced abundant self-fertilized seed.

C. The spike of this plant grew to be 5 feet high; from base to apex its flowers consisted of nine stamens and a style, with no vestige of petals.

It is unnecessary to follow the history of plant A, as it was only the lower part of the spike in which the flowers were abnormal, and the stem was not isolated.

Seed taken from the upper covered part of the plant B, whose flowers consisted of a bifid petal, 7 stamens, and a style, germinated abundantly; 21 of these plants flowered in 1909. Thirteen of these 21 plants produced spikes of the parent type, and 8 of the 21 plants produced normal Fox-glove flowers. One of the 13 plants grew to be 5 feet 1 inch high, its spike producing 1 bifid petal and a style; but its terminal flower consisted of 22 stamens and a large flask-shaped carpel (divided into 7 compartments) and style, but having no corolla; that is, it had no petals. (As shown in photograph exhibited.)

The season of 1909 was sunless, with constant rain; consequently, all covered plants suffered much from mildew, but I managed to collect some self-fertilized seed from the terminal flower of the plant referred to, and this seed germinated and flowered in 1911. Every one of the 12 plants I reared from the seed of the terminal flower produced flowers precisely like the parent. Two of these plants were isolated and their self-fertilized seed germinated freely (September, 1911).

The seed originally collected from the covered part of plant C of 1907 had produced plants which, in 1909, gave flowers precisely

[1] N. C. Macnamara, on Mutations in Fox-glove Plants. Linnean Society of London, General Meeting Nov. 16, 1911.

similar to the parent plant. Self-fertilized seed from these plants (1909) in 1911 produced plants exactly like those of 1907—i. e., flowers having nine stamens and a style, but no petals. Self-fertilized seed from these plants are now (September, 1911) germinating freely. Some of the plants, however, of 1909, in place of a tall single spike, grew some seven or eight shorter spikes, each flower of which had nine stamens but no petals.

It seems that a certain number of the Fox-glove seeds sown in the year 1906 contained elements in a condition such as that described by De Vries as being "impressed by an impulsive mutability," for some of the flowers produced by these seeds were sports. Seeds from these sports produced their like in 1909; and, further, these latter plants bore some terminal flowers totally different in character from the parent sport from which they were derived. Seeds from these terminal flowers produced their like in the year 1911, so that I have now two different strains of Fox-glove plants derived from the seed sown in 1906, and these strains have resulted from self-fertilized flowers—that is, from flowers carefully protected from insects or other means of cross fertilization. It is, however, doubtful if these varieties would have been maintained in a state of nature. While specific stability under constant conditions appears to be the rule in nature, it is widely different in cultivation. When a plant is brought under cultural conditions it maintains its type for some time unaltered, then gives way and becomes practically plastic.[1] It is certain, therefore, that before we can accept De Vries's hypothesis of the origin of species by mutation we must have further and more conclusive evidence on the subject than that which is now available. On the other hand, Huxley's conclusion regarding the Darwinian hypothesis still holds good. He states that all species have been produced by the development of varieties from common stocks; the conversion of these, first into permanent races, and then into new species, by the process of natural selection, which process is essentially identical with that of artificial selection by which man has originated the races of domestic animals, the struggle for existence taking the place of man; and exerting, in the case of natural selection, that selective action which he performs in artificial selection.

The evidence brought forward by Darwin in support of his theory is of three kinds. First, he endeavors to prove that species may be originated by selection; secondly, he attempts to show that natural causes are competent to exert selection; and, thirdly, he tries to prove that the most remarkable and apparently anomalous phenomena exhibited by the distribution, development, and mutual

[1] Nature, Nov. 28, 1907.

relations of species can be shown to be deducible from the general doctrine of their origin which he propounds, combined with the known facts of geological change; and that, even if not all these phenomena are at present explicable by it, none are necessarily inconsistent with it; on the other hand, since Huxley's time Darwin's theory has been strengthened by many new facts.[1]

[1] Huxley's Essays. Everyman's Library, p. 331. See also The International Scientific Series, vols. 95 and 97. Kegan Paul. London, 1908 and 1910.

MAGNALIA NATURÆ: OR THE GREATER PROBLEMS OF BIOLOGY.[1]

By D'Arcy Wentworth Thompson, C. B.,

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The science of zoology, all the more the incorporate science of biology, is no simple affair, and from its earliest beginnings it has been a great and complex and many-sided thing. We can scarce get a broader view of it than from Aristotle, for no man has ever looked upon our science with a more farseeing and comprehending eye. Aristotle was all things that we mean by "naturalist" or "biologist." He was a student of the ways and doings of beast and bird and creeping thing; he was morphologist and embryologist; he had the keenest insight into physiological problems, though his age lacked that knowledge of the physical sciences without which physiology can go but a little way; he was the first and is the greatest of psychologists; and in the light of his genius biology merged in a great philosophy.

I do not for a moment suppose that the vast multitude of facts which Aristotle records were all, or even mostly, the fruit of his own immediate and independent observation. Before him were the Hippocratic and other schools of physicians and anatomists. Before him there were nameless and forgotten Fabres, Rœsels, Réaumurs, and Hubers, who observed the habits, the diet, and the habitations of the sand wasp or the mason bee; who traced out the little lives and discerned the vocal organs of grasshopper and cicada; and who, together with generations of bee-keeping peasants, gathered up the lore and wisdom of the bee. There were fishermen skilled in all the cunning of their craft, who discussed the wanderings of tunny and mackerel, swordfish or anchovy; who argued over the ages, the breeding places, and the food of this fish or that; who knew how the smooth dogfish breeds, two thousand years before Johannes Müller; who saw how the male pipefish carries its young, before Cavolini; and who had found the nest of the nest-building rockfishes before

[1] Presidential address delivered to the zoological section of the British Association Aug. 31, 1911. Reprinted by permission from author's printed copy.

Gerbe rediscovered it almost in our own day. There were curious students of the cuttle fish (I sometimes imagine they may have been priests of that sea-born goddess to whom the creatures were sacred), who had diagnosed the species, recorded the habits, and dissected the anatomy of the group, even to the discovery of that strange hectocotylus arm that baffled Della Chiaje, Cuvier, and Koelliker, and that Vérany and Heinrich Müller reexplained.

All this varied learning Aristotle gathered up and wove into his great web. But every here and there, in words that are unmistakably the master's own, we hear him speak of what are still the great problems and even the hidden mysteries of our science; of such things as the nature of variation, of the struggle for existence, of specific and generic differentiation of form, of the origin of the tissues, the problems of heredity, the mystery of sex, of the phenomena of reproduction and growth, the characteristics of habit, instinct, and intelligence, and of the very meaning of life itself. Amid all the maze of concrete facts that century after century keeps adding to our store, these, and such as these, remain the great mysteries of natural science—the magnalia naturæ, to borrow a great word from Bacon, who in his turn had borrowed it from St. Paul.

Not that these are the only great problems for the biologist, nor that there is but a single class of great problems in biology, for Bacon himself speaks of the magnalia naturæ, quoad usus humanos, the study of which has for its objects "the prolongation of life or the retardation of age, the curing of diseases counted incurable, the mitigation of pain, the making of new species and transplanting of one species into another," and so on through many more. Assuredly, I have no need to remind you that a great feature of this generation of ours has been the way in which biology has been justified of her children in the work of those who have studied the magnalia naturæ, quoad usus humanos.

But so far are biologists from being nowadays engrossed in practical questions, in applied and technical zoology, to the neglect of its more recondite problems, that there never was a time when men thought more deeply or labored with greater zeal over the fundamental phenomena of living things; never a time when they reflected in a broader spirit over such questions as purposive adaptation, the harmonious working of the fabric of the body in relation to environment, and the interplay of all the creatures that people the earth; over the problems of heredity and variation; over the mysteries of sex and the phenomena of generation and reproduction, by which phenomena, as the wise woman told, or reminded, Socrates, and as Harvey said again (and for that matter, as Coleridge said, and Weismann, but not quite so well)—by which, as the wise old woman said, we gain our glimpse of insight into eternity and immortality. These, then, together with

the problem of the origin of species, are indeed magnalia naturæ; and I take it that inquiry into these, deep and wide research specially directed to the solution of these, is characteristic of the spirit of our time and is the password of the younger generation of biologists.

Interwoven with this high aim which is manifested in the biological work of recent years is another tendency. It is the desire to bring to bear upon our science, in greater measure than before, the methods and results of the other sciences, both those that in the hierarchy of knowledge are set above and below and those that rank alongside of our own.

Before the great problems of which I have spoken the cleft between zoology and botany fades away, for the same problems are common to the twin sciences. When the zoologist becomes a student not of the dead but of the living, of the vital processes of the cell rather than of the dry bones of the body, he becomes once more a physiologist, and the gulf between these two disciplines disappears. When he becomes a physiologist, he becomes, ipso facto, a student of chemistry and of physics. Even mathematics has been pressed into the service of the biologist, and the calculus of probabilities is not the only branch of mathematics to which he may usefully appeal.

The physiologist has long had as his distinguishing characteristic, giving his craft a rank superior to the sister branch of morphology, the fact that in his great field of work and in all the routine of his experimental research, the methods of the physicist and the chemist, the lessons of the anatomist, and the experience of the physician, are inextricably blended in one common central field of investigation and thought. But it is much more recently that the morphologist and embryologist have made use of the method of experiment and of the aid of the physical and chemical sciences—even of the teachings of philosophy—all in order to probe into properties of the living organism that men were wont to take for granted or to regard as beyond their reach under a narrower interpretation of the business of the biologist. Driesch and Loeb and Roux are three among many men who have become eminent in this way in recent years, and their work we may take as typical of methods and aims such as those of which I speak. Driesch, both by careful experiment and by philosophic insight; Loeb, by his conception of the dynamics of the cell and by his marvelous demonstrations of chemical and mechanical fertilization; Roux, with his theory of autodetermination and by the labors of the school of Entwickelungsmechanik which he has founded, have all in various ways, and from more or less different points of view, helped to reconstruct and readjust our ideas of the relations of embryological processes, and hence of the phenomenon of life itself, on the one hand, to physical causes (whether external to or latent in the mecha-

nism of the cell), or, on the other, to the ancient conception of a vital element, alien to the province of the physicist.

No small number of theories or hypotheses, that seemed for a time to have been established on ground as firm as that on which we tread, have been reopened in our day. The adequacy of natural selection to explain the whole of organic evolution has been assailed on many sides; the old fundamental subject of embryological debate between the evolutionists or preformationists (of the school of Malpighi, Haller, and Bonnet) and the advocates of epigenesis (the followers of Aristotle, of Harvey, of Caspar Fr. Wolff, and of Von Baer) is now discussed again, in altered language, but as a pressing question of the hour; the very foundations of the cell theory have been scrutinized, to decide, for instance, whether the segmented ovum, or even the complete organism, be a colony of quasi independent cells or a living unit in which cell differentiation is little more than a superficial phenomenon; the whole meaning, bearing, and philosophy of evolution has been discussed by Bergson, on a plane to which neither Darwin nor Spencer ever attained; and the hypothesis of a vital principle, or vital element, that had lain in the background for near a hundred years, has come into men's mouths as a very real and urgent question, the greatest question for the biologist of all.

In all ages the mystery of organic form, the mystery of growth and reproduction, the mystery of thought and consciousness, the whole mystery of the complex phenomena of life, have seemed to the vast majority of men to call for description and explanation in terms alien to the language which we apply to inanimate things; though at all times there have been a few who sought, with the materialism of Democritus, Lucretius, or Giordano Bruno, to attribute most, or even all, of these phenomena to the category of physical causation.

For the first scientific exposition of vitalism we must go back to Aristotle, and to his doctrine of the three parts of the tripartite soul; according to which doctrine, in Milton's language, created things "by gradual change sublimed, to vital spirits aspire, to animal, to intellectual." The first and lowest of these three, the *ψυχὴ ἡ θρεπτική*, by whose agency nutrition is effected, is *ἡ πρώτη ψυχή*, the inseparable concomitant of life itself. It is inherent in the plant as well as in the animal, and in the Linnæan aphorism, vegetabilia crescunt et vivunt, its existence is admitted in a word. Under other aspects it is all but identical with the *ψυχὴ αὐξητική* and *γεννητική*, the soul of growth and of reproduction; and in this composite sense it is no other than Driesch's "Entelechy," the hypothetic natural agency that presides over the form and formation of the body. Just as Driesch's psychoid or psychoids, which are the basis of instinctive phenomena, of sensation, instinct, thought, reason, and all that directs that body

which entelechy has formed, are no other than the αἰσθητική, whereby animalia vivunt et sentiunt, and the διανοητική, to which Aristotle ascribes the reasoning faculty of man. Save only that Driesch, like Darwin, would deny the restriction of νοῦς, or reasoning, to man alone, and would extend it to animals, it is clear, and Driesch himself admits,[1] that he accepts both the vitalism and the analysis of vitalism laid down by Aristotle.

The πνεῦμα of Galen, the vis plastica, the vis vitæ formatrix, of the older physiologists, the Bildungstrieb of Blumenbach, the Lebenskraft of Paracelsus, Stahl, and Treviranus, "shaping the physical forces of the body to its own ends," "dreaming dimly in the grain of the promise of the full corn in the ear"[2] (to borrow the rendering of an Oxford scholar), these and many more, like Driesch's "Entelechy" of to-day, are all conceptions under which successive generations strive to depict the something that separates the earthy from the living, the living from the dead. And John Hunter described his conception of it in words not very different from Driesch's, when he said that his principle, or agent, was independent of organization, which yet it animates, sustains, and repairs; it was the same as Johannes Müller's conception of an innate "unconscious idea."

Even in the Middle Ages, long before Descartes, we can trace, if we interpret the language and the spirit of the time, an antithesis that, if not identical, is at least parallel to our alternative between vitalistic and mechanical hypotheses. For instance, Father Harper tells us that Suarez maintained that in generation and development a divine interference is postulated, by reason of the perfection of living beings; in opposition to St. Thomas, who (while invariably making an exception in the case of the human soul) urged that, since the existence of bodily and natural forms consists solely in their union with matter, the ordinary agencies which operate on matter sufficiently account for them.[3]

But in the history of modern science, or of modern physiology, it is, of course, to Descartes that we trace the origin of our mechanical hypotheses—to Descartes, who, imitating Archimedes, said: "Give me matter and motion and I will construct the universe." In fact, leaving the more shadowy past alone, we may say that it is since Descartes watched the fountains in the garden and saw the likeness

[1] Science and Philosophy of the Organism (Gifford Lectures), ii. p. 83, 1908.

[2] Cf. Jenkinson (Art. "Vitalism" in Hibbert Journal, April, 1911), who has given me the following quotation: "Das Weitzenkorn hat allerdings Bewusstsein dessen was in ihm ist und aus ihm werden kann, und traümt wirklich davon. Sein Bewusstsein und seine Traüme mögen dunkel genug sein"; Treviranus, Erscheinungen und Gesetze des organischen Lebens, 1831.

[3] "Cum formarum naturalium et corporalium esse non consistat nisi in unione ad materiam, ejusdam agentis esse videtur eas producere, cujus est materiam transmutare. Secundo, quia cum hujusmodi formæ non excedant virtutem et ordinem et facultatem principiorum agentium in natura, nulla videtur necessitas eorum originem in principia reducere altiora." Aquinas, De Pot. Q., iii. a 11. Cf. Harper, Metaphysics of the School. iii. 1. p. 152.

between their machinery of pumps and pipes and reservoirs to the organs of the circulation of the blood, and since Vaucanson's marvelous automata lent plausibility to the idea of a "living automaton," it is since then that men's minds have been perpetually swayed by one or other of the two conflicting tendencies, either to seek an explanation of the phenomena of living things in physical and mechanical considerations, or to attribute them to unknown and mysterious causes alien to physics and peculiarly concomitant with life. And some men's temperaments, training, and even avocations, render them more prone to the one side of this unending controversy, as the minds of other men are naturally more open to the other. As Kühne said a few years ago at Cambridge, the physiologists have been found for several generations leaning, on the whole, to the mechanical or physico-chemical hypothesis, while the zoologists have been very generally on the side of the vitalists.

The very fact that the physiologists were trained in the school of physics, and the fact that the zoologists and botanists relied for so many years upon the vague, undefined force of "heredity" as sufficiently accounting for the development of the organism, an intrinsic force whose results could be studied but whose nature seemed remote from possible analysis or explanation, these facts alone go far to illustrate and to justify what Kühne said.

Claude Bernard held that mechanical, physical, and chemical forces summed up all with which the physiologist has to deal. Verworn defined physiology as "the chemistry of the proteids"; and I think that another physiologist (but I forget who) has declared that the mystery of life lay hidden in "the chemistry of the enzymes." But of late, as Dr. Haldane showed in an address a couple of years ago, it is among the physiologists themselves, together with the embryologists, that we find the strongest indications of a desire to pass beyond the horizon of Descartes, and to avow that physical and chemical methods, the methods of Helmholtz, Ludwig, and Claude Bernard, fall short of solving the secrets of physiology. On the other hand, in zoology, resort to the method of experiment, the discovery, for instance, of the wonderful effects of chemical or even mechanical stimulation in starting the development of the egg, and again the ceaseless search into the minute structure, or so-called mechanism, of the cell, these I think have rather tended to sway a certain number of zoologists in the direction of the mechanical hypothesis.

But on the whole, I think it is very manifest that there is abroad on all sides a greater spirit of hesitation and caution than of old, and that the lessons of the philosopher have had their influence on our minds. We realize that the problem of development is far harder than we had begun to let ourselves suppose; that the problems of organogeny and phylogeny (as well as those of physiology) are not

comparatively simple and well-nigh solved, but are of the most formidable complexity. And we would, most of us, confess, with the learned author of The Cell in Development and Inheritance, that we are utterly ignorant of the manner in which the substance of the germ cell can so respond to the influence of the environment as to call forth an adaptive variation; and again, that the gulf between the lowest forms of life and the inorganic world is as wide, if not wider, than it seemed a couple of generations ago.[1]

While we keep an open mind on this question of vitalism, or while we lean, as so many of us now do, or even cling with a great yearning to the belief that something other than the physical forces animates and sustains the dust of which we are made, it is rather the business of the philosopher than of the biologist, or of the biologist only when he has served his humble and severe apprenticeship to philosophy, to deal with the ultimate problem. It is the plain bounden duty of the biologist to pursue his course, unprejudiced by vitalistic hypotheses, along the road of observation and experiment, according to the accepted discipline of the natural and physical sciences; indeed I might perhaps better say the physical sciences alone, for it is already a breach of their discipline to invoke, until we feel we absolutely must, that shadowy force of "heredity," to which, as I have already said, biologists have been accustomed to ascribe so much. In other words, it is an elementary scientific duty, it is a rule that Kant himself laid down,[2] that we should explain, just as far as we possibly can, all that is capable of such explanation, in the light of the properties of matter and of the forms of energy with which we are already acquainted.

It is of the essence of physiological science to investigate the manifestations of energy in the body, and to refer them, for instance, to the domains of heat, electricity, or chemical activity. By this means a vast number of phenomena, of chemical and other actions of the body, have been relegated to the domain of physical science, and withdrawn from the mystery that still attends on life, and by this means, continued for generations, the physiologists, or certain of them, now tell us that we begin again to descry the limitations of physical inquiry, and the region where a very different hypothesis insists on thrusting itself in. But the morphologist has not gone nearly so far as the physiologist in the use of physical methods. He sees so great a gulf between the crystal and the cell that the very fact of the physicist and the mathematician being able to explain the form of the one, by simple laws of spatial arrangement where molecule fits into molecule, seems to deter, rather than to attract,

[1] Wilson, op. cit., 1906, p. 434.

[2] In his Critique of Teleological Judgment.

the biologist from attempting to explain organic forms by mathematical or physical law. Just as the embryologist used to explain everything by heredity, so the morphologist is still inclined to say, "the thing is alive, its form is an attribute of itself, and the physical forces do not apply." If he does not go so far as this, he is still apt to take it for granted that the physical forces can only to a small and even insignificant extent blend with the intrinsic organic forces in producing the resultant form. Herein lies our question in a nutshell. Has the morphologist yet sufficiently studied the forms, external and internal, of organisms, in the light of the properties of matter, of the energies that are associated with it, and of the forces by which the actions of these energies may be interpreted and described? Has the biologist, in short, fully recognized that there is a borderland not only between physiology and physics, but between morphology and physics, and that the physicist may, and must, be his guide and teacher in many matters regarding organic form?

Now, this is by no means a new subject, for such men as Berthold and Errera, Rhumbler and Dreyer, Bütschli and Verworn, Driesch and Roux have already dealt or deal with it. But, on the whole, it seems to me that the subject has attracted too little attention, and that it is well worth our while to think of it to-day.

The first point, then, that I wish to make in this connection is that the form of any portion of matter, whether it be living or dead, its form and the changes of form that are apparent in its movements and in its growth, may in all cases alike be described as due to the action of force. In short, the form of an object is a "diagram of forces"—in this sense, at least, that from it we can judge of or deduce the forces that are acting or have acted upon it; in this strict and particular sense it is a diagram: in the case of a solid of the forces that have been impressed upon it when its conformation was produced, together with those that enable it to retain its conformation; in the case of a liquid (or of a gas) of the forces that are for the moment acting on it to restrain or balance its own inherent mobility. In an organism, great or small, it is not merely the nature of the motions of the living substance that we must interpret in terms of force (according to kinetics), but also the conformation of the organism itself, whose permanence or equilibrium is explained by the interaction or balance of forces, as described in statics.

If we look at the living cell of an Amœba or a Spirogyra, we see a something which exhibits certain active movements and a certain fluctuating, or more or less lasting, form; and its form at a given moment, just like its motions, is to be investigated by the help of physical methods and explained by the invocation of the mathematical conception of force.

Now, the state, including the shape or form, of a portion of matter is the resultant of a number of forces which represent or symbolize the manifestations of various kinds of energy; and it is obvious, accordingly, that a great part of physical science must be understood or taken for granted as the necessary preliminary to the discussion on which we are engaged.

I am not going to attempt to deal with or even to enumerate all the physical forces or the properties of matter with which the pursuit of this subject would oblige us to deal—with gravity, pressure, cohesion, friction, viscosity, elasticity, diffusion, and all the rest of the physical factors that have a bearing on our problem. I propose only to take one or two illustrations from the subject of surface tension, which subject has already so largely engaged the attention of the physiologists. Nor will I even attempt to sketch the general nature of the phenomenon, but will only state a few of its physical manifestations or laws. Of these the most essential facts for us are as follows: Surface tension is manifested only in fluid or semifluid bodies, and only at the surface of these, though we may have to interpret surface in a liberal sense in cases where the interior of the mass is other than homogeneous. Secondly, a fluid may, according to the nature of the substance with which it is in contact, or, more strictly speaking, according to the distribution of energy in the system to which it belongs, tend either to spread itself out in a film or, conversely, to contract into a drop, striving in the latter case to reduce its surface to a minimal area. Thirdly, when three substances are in contact and subject to surface tension, as when water surrounds a drop of protoplasm in contact with a solid, then at any and every point of contact certain definite angles of equilibrium are set up and maintained between the three bodies, which angles are proportionate to the magnitudes of the surface tensions existing between the three. Fourthly, a fluid film can only remain in equilibrium when its curvature is everywhere constant. Fifthly, the only surfaces of revolution which meet this condition are six in number, of which the plane, the sphere, the cylinder, and the so-called unduloid and catenoid are important for us. Sixthly, the cylinder can not remain in free equilibrium if prolonged beyond a length equal to its own circumference, but, passing through the unduloid, tends to break up into spheres, though this limitation may be counteracted or relaxed, for instance, by viscosity. Finally, we have the curious fact that in a complex system of films, such as a homogeneous froth of bubbles, three partition walls and no more always meet at a crest, at equal angles, as, for instance, in the very simple case of a layer of uniform hexagonal cells; and (in a solid system) the crests, which may be straight or curved, always meet, also at equal angles, four by four, in a common point. From these

physical facts or laws the morphologist as well as the physiologist may draw important consequences.

It was Hofmeister who first showed, more than 40 years ago, that when any drop of protoplasm, either over all its surface or at some free end (as at the tip of the pseudopodium of an amœba), is seen to "round itself off" that is not the effect of physiological or vital contractility, but is a simple consequence of surface tension—of the law of the minimal surface; and on the physiological side, Engelmann, Bütschli, and others have gone far in their development of the idea. Plateau, I think, was the first to show that the myriad sticky drops or beads upon the weft of a spider's web, their form, their size, their distance apart, and the presence of the tiny intermediate drops between, were in every detail explicable as the result of surface tension, through the law of minimal surface and through the corollary to it which defines the limits of stability of the cylinder; and, accordingly, that with their production the will or effort or intelligence of the spider had nothing to do. The beaded form of a long, thin pseudopodium, for instance, of a Heliozoan, is an identical phenomenon. It was Errera who first conceived the idea that not only the naked surface of the cell but the contiguous surfaces of two naked cells, or the delicate incipient cell membrane or cell wall between, might be regarded as a weightless film whose position and form were assumed in obedience to surface tension. And it was he who first showed that the symmetrical forms of the unicellular and simpler multicellular organisms, up to the point where the development of a skeleton complicates the case, were one and all identical with the plane, sphere, cylinder, unduloid, and catenoid, or with combinations of these. Berthold and Errera almost simultaneously showed (the former in far the greater detail) that in a plant each new cell partition follows the law of minimal surface and tends (according to another law, which I have not particularized) to set itself at right angles to the preceding solidified wall, so giving a simple and adequate physical explanation of what Sachs had stated as an empirical morphological rule. And Berthold further showed how, when the cell partition was curved, its precise curvature, as well as its position, was in accordance with physical law.

There are a vast number of other things that we can satisfactorily explain on the same principle and by the same laws. The beautiful catenary curve of the edge of the pseudopodium, as it creeps up its axial rod in a Heliozoan or a Radiolarian, the hexagonal mesh of bubbles or vacuoles on the surface of the same creatures, the form of the little groove that runs round the waist of a Peridinian even (as I believe) the existence, form and undulatory movements of the undulatory membrane of a Trypanosome, or of that around the tail of the spermatozoon of a newt—every one of these, I declare, is a

case where the resultant form can be well explained by, and can not possibly be understood without, the phenomena of surface tension. Indeed, in many of the simpler cases, the facts are so well explained by surface tension that it is difficult to find place for a conflicting, much less an overriding force.

I believe, for my own part, that even the beautiful and varied forms of the foraminifera may be ascribed to the same cause, but here the problem is a little more complex, by reason of the successive consolidations of the shell. Suppose the first cell or chamber to be formed, assuming its globular shape in obedience to our law, and then to secrete its calcareous envelope. The new growing bud of protoplasm, accumulating outside the shell, will, in strict accordance with the surface tensions concerned, either fail to "wet" or to adhere to the first-formed shell, and will so detach itself as a unicellular individual (*Orbulina*); or else it will flow over a less or greater part of the original shell, until its free surface meets it at the required angle of equilibrium. Then, according to this angle, the second chamber may happen to be all but detached (*Globigerina*), or, with all intermediate degrees, may very nearly wholly enwrap the first. Take any specific angle of contact, and presume the same conditions to be maintained, and therefore the same angle to be repeated as each successive chamber follows on the one before; and you will thereby build up regular forms, spiral or alternate, that correspond with marvelous accuracy to the actual forms of the foraminifera. And this case is all the more interesting, because the allied and successive forms so obtained differ only in degree, in the magnitude of a single physical or mathematical factor; in other words, we get not only individual phenomena, but lines of apparent orthogenesis, that seem explicable by physical laws, and attributable to the continuity between successive states in the continuous or gradual variations of a physical condition. The resemblance between allied and related forms, as Hartmann demonstrated, and Giard admitted years ago, is not always, however often, to be explained by common descent and parentage.[1]

In the segmenting egg we have the simpler phenomenon of a laminar system, uncomplicated by the presence of a solid framework; and here, in the earliest stages of segmentation, it is easy to see the correspondence of the planes of division with what the laws of surface tension demand. For instance, it is not the case (though the elementary books often represent it so) that when the totally segmenting egg has divided into four segments, these ever remain in contact at a single point; the arrangement would be unstable, and the position untenable. But the laws of surface tension are at once seen to be

[1] Cf. Giard, "Discours inaugurale," Bull. Scientif., iii, p. 1, 1888.

obeyed, when we recognize the little cross-furrow that separates the blastomeres, two and two, leaving in each case three only to meet at a point in our diagram, which point is in reality a section of a ridge or crest.

Very few have tried, and one or two (I know) have tried and not succeeded, to trace the action and the effects of surface tension in the case of a highly complicated, multisegmented egg. But it is not surprising if the difficulties which such a case presents appear to be formidable. Even the conformation of the interior of a soap froth, though absolutely conditioned by surface tension, presents great difficulties, and it was only in the last years of Lord Kelvin's life that he showed all previous workers to have been in error regarding the form of the interior cells.

But what for us does all this amount to? It at least suggests the possibility of so far supporting the observed facts of organic form on mathematical principles as to bring morphology within or very near to Kant's demand that a true natural science should be justified by its relation to mathematics.[1] But if we were to carry these principles further and to succeed in proving them applicable in detail, even to the showing that the manifold segmentation of the egg was but an exquisite froth, would it wholly revolutionize our biological ideas? It would greatly modify some of them, and some of the most cherished ideas of the majority of embryologists; but I think that the way is already paved for some such modification. When Loeb and others have shown us that half, or even a small portion of an egg, or a single one of its many blastospheres, can give rise to an entire embryo, and that in some cases any part of the ovum can originate any part of the organism, surely our eyes are turned to the energies inherent in the matter of the egg (not to speak of a presiding entelechy), and away from its original formal operations of division. Sedgwick has told us for many years that we look too much to the individuality of the individual cell, and that the organism, at least in the embryonic body, is a continuous syncytium. Hofmeister and Sachs have repeatedly told us that in the plant, the growth of the mass, the growth of the organ, is the primary fact; and De Bary has summed up the matter in his aphorism, Die Pflanze bildet Zellen, nicht die Zelle bildet Pflanzen. And in many other ways the extreme position of the cell theory, that the cells are the ulimate individuals, and that the organism is but a colony of quasi independent cells, has of late years been called in question.

There are no problems connected with morphology that appeal so closely to my mind, or to my temperament, as those that are related

[1] "Ich behaupte aber dass in jeder besonderen Naturlehre nur so viel eigentliche Wissenschaft angetroffen werden könne, als darin Mathematik anzutreffen ist." Kant, in Preface to Metaphys. Anfangsgründe der Naturwissenschaft (Werke, ed. Hartenstein, vol. iv., p. 360).

to mechanical considerations, to mathematical laws, or to physical and chemical processes.

I love to think of the logarithmic spiral that is engraven over the grave of that great anatomist, John Goodsir (as it was over that of the greatest of the Bernouillis), so graven because it interprets the form of every molluscan shell, of tusk and horn and claw, and many another organic form besides. I like to dwell upon those lines of mechanical stress and strain in a bone, that give it its strength where strength is required, that Hermann Meyer and J. Wolff described, and on which Roux has bestowed some of his most thoughtful work; or on the kindred conformations that Schwendener, botanist and engineer, demonstrated in the plant; or on the "stream-lines" in the bodily form of fish or bird, from which the naval architect and the aviator have learned so much. I admire that old paper of Peter Harting's, in which he paved the way for investigation of the origin of spicules, and of all the questions of crystallization or pseudocrystallization in presence of colloids, on which subject Lehmann has written his recent and beautiful book. I sympathize with the efforts of Henking, Rhumbler, Hartog, Gallardo, Leduc, and others to explain on physical lines the phenomena of nuclear division. And, as I have said, I believe that the forces of surface tension, elasticity, and pressure are adequate to account for a great multitude of the simpler phenomena, and the permutations and combinations thereof, that are illustrated in organic form.

I might well have devoted this essay to these questions, and to these alone. But I was loath to do so, lest I should seem to overrate their importance and to appear to you as an advocate of a purely mechanical biology. I believe all these phenomena to have been unduly neglected, and to call for more attention than they have received, but I know well that though we push such explanations to the uttermost and learn much in the so doing, they will not touch the heart of the great problems that lie deeper than the physical plane. Over the ultimate problems and causes of vitality we shall be left wondering still.

To a man of letters and the world like Addison, it came as a sort of revelation that light and color were not objective things but subjective, and that back of them lay only motion or vibration, some simple activity. And when he wrote his essay on these startling discoveries, he found for it, from Ovid, a motto well worth bearing in mind, causa latet, vis est notissima. We may with advantage recollect it when we seek and find the force that produces a direct effect, but stand in utter perplexity before the manifold and transcendent meanings of that great word cause.

The similarity between organic forms and those that physical agencies are competent to produce still leads some men, such as

Stephane Leduc, to doubt or to deny that there is any gulf between and to hold that spontaneous generation or the artificial creation of the living is but a footstep away. Others, like Delage and many more, see in the contents of the cell only a complicated chemistry and in variation only a change in the nature and arrangement of the chemical constituents. They either cling to a belief in "heredity" or (like Delage himself) replace it more or less completely by the effects of functional use and by chemical stimulation from without and from within. Yet others, like Felix Auerbach, still holding to a physical or quasi physical theory of life, believe that in the living body the dissipation of energy is controlled by a guiding principle, as though by Clerk Maxwell's demons; that for the living the law of entropy is thereby reversed; and that life itself is that which has been evolved to counteract and battle with the dissipation of energy. Berthold, who first demonstrated the obedience to physical laws in the fundamental phenomena of the dividing cell or segmenting egg, recognizes, almost in the words of John Hunter, a quality in the living protoplasm, sui generis, whereby its maintenance, increase, and reproduction are achieved. Driesch, who began as a "mechanist," now, as we have seen, harks back straight to Aristotle, to a twin or triple doctrine of the soul. And Bergson, rising into heights of metaphysics where the biologist, quâ biologist, can not climb, tells us (like Duran) that life transcends teleology, that the conceptions of mechanism and finality fail to satisfy, and that only "in the absolute do we live and move and have our being."

We end but a little way from where we began.

With all the growth of knowledge, with all the help of all the sciences impinging on our own, it is yet manifest, I think, that the biologists of to-day are in no self-satisfied and exultant mood. The reasons that for a time contented a past generation call for reinquiry, and out of the old solutions new questions emerge, and the ultimate problems are as inscrutable as of old. That which, above all things, we would explain baffles explanation; and that the living organism is a living organism tends to reassert itself as the biologist's fundamental conception and fact. Nor will even this concept serve us and suffice us when we approach the problems of consciousness and intelligence and the mystery of the reasoning soul; for these things are not for the biologist at all, but constitute the psychologist's scientific domain.

In wonderment, says Aristotle, does philosophy begin,[1] and more than once he repeats the saying and more than once he rings the changes on the theme. Now, as in the beginning, wonderment and admiration are the portion of the biologist, as of all those who contemplate the heavens and the earth, the sea, and all that in them is.

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[1] Metaph., I, ii, 982b, 12, etc.

And if wonderment springs, as again Aristotle tells us, from ignorance of the causes of things, it does not cease when we have traced and discovered the proximate causes, the physical causes, the efficient causes of our phenomena. For behind and remote from physical causation lies the end, the final cause of the philosopher, the reason why, in the which are hidden the problems of organic harmony and autonomy, and the mysteries of apparent purpose, adaptation, fitness, and design. Here, in the region of teleology, the plain rationalism that guided us through the physical facts and causes begins to disappoint us, and intuition, which is of close kin to faith, begins to make herself heard.

And so it is that, as in wonderment does all philosophy begin, so in amazement does Plato teach us that all our philosophy comes to an end.[1] Ever and anon, in presence of the magnalia naturae, we feel inclined to say with the poet,

Οὐ γάρ τι νῦν γε κἀχθὲς, ἀλλ' ἀεί ποτε
Ζῇ ταῦτα, κοὐδεὶς οἶδεν ἐξ ὅτου 'φάνη.

"These things are not of to-day nor yesterday, but evermore, and no man knoweth whence they came."

I will not quote the noblest words of all that come into my mind, but only the lesser language of another of the greatest of the Greeks: "The ways of His thoughts are as paths in a wood thick with leaves, and one seeth through them but a little way."

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[1] Cf. Coleridge, Biogr. Lit.

A HISTORY OF CERTAIN GREAT HORNED OWLS.[1]

[With 8 plates.]

By Charles R. Keyes.

My experiences with great horned owls (*Bubo virginianus*, especially with a pair under my observation for several years, have often suggested a contrast and comparison with Mr. Finley's work on the California condor. In several respects our subjects and experiences show a certain broad resemblance. Both birds belong to the family of birds of prey, the one being the largest of the North American vultures, the other the greatest of all the owls. The condor has passed into legend and literature as the largest bird of flight and the most graceful when on the wing; the great horned owl occupies a place no less important in legend and literature as the symbol of brooding wisdom and solemn mystery. In both our studies, too, the rare privilege was enjoyed of extending our observations over the whole home period of the bird's life, from the eggs in the nest to the young ready for their first excursion into the outside world.

In most respects, however, our stories are as much in contrast as they could well be. The condors had their home in one of the wildest and most inaccessible of Californian mountain regions; from their nest rim the owls could look out upon five farmhouses, with their numerous outbuildings, and one schoolhouse, all within a radius of 500 yards, and all neighbors of other homesteads and schoolhouses set down in the very peaceful and nonmountainous State of Iowa. The condors, in their wild environment, were tame and well-disposed from the first and grew constantly more docile as the study of their home life proceeded, proving to be, apparently, the gentlest of all the raptorial birds; the great horned owls, with surroundings that would seem to teach peace, had bad dispositions to begin with, and these constantly grew worse, until, after six weeks of suspense and with the longest of our claw marks still unhealed, my assistant and I felt a sense of relief when the young owls finally took to the tree tops, leaving us with fairly whole physiognomies and the feeling that we

[1] Reprinted by permission from The Condor, a magazine of western ornithology, Hollywood, Cal., vol. 13, No. 1, January-February, 1911, pp. 5-19.

had done the best we could, under the circumstances, to preserve the record of an unusual set of conditions. The great horned owls had proved to be, without much doubt, the fiercest of all the birds of prey. In one further respect, unfortunately, our experiences were in contrast to those of Mr. Finley and Mr. Bohlman. We found it impossible, by any means at our command, to secure satisfactory negatives of the adult birds.[1] We were unable to take them at distances of less than 30 feet, and in every case they so blended with their background of gray bark, or gray bark and patches of snow, as not to be worth while. We regretted our inability to try the effect of a blind to operate from, but the mechanical difficulties in the way of such an attempt demanded more time for their solution than we had to give. We therefore gave our attention to the nest and contents, or rather as much attention as the old birds would allow us to give. As the adults were necessarily much under observation, it is hoped that a record of their conduct may add some interest to the present article.

The beautiful deciduous forest, stretching for miles along the north bluffs of the Cedar River to the west of Mount Vernon, had by 1890 been reduced to various detached groves of from 10 to 100 or more acres each in extent. About February of this latter year I was hunting through one of the larger of these groves, which, if one struck straight across the fields, was only a mile and a half from town. I remember watching the short, uneasy flights of a great horned owl, but without locating his mate. I also remember talking with Mr. McFarland, a sturdy Scotchman who has occupied his homestead just across the road from the owls' hunting grounds since the early fifties, and learning that "big hoot owls have always been in that timber." Soon after the great oaks and hard maples of the eastern two-thirds of the grove fell under the ax, leaving to the west only a 25-acre remnant and, in the cut-over area, only some old white elms and a few young maples and lindens. Among these latter the forest soil soon gave way to a thick carpet of blue grass, and so what had been heavy forest was gradually transformed into a rather open and still very beautiful timber pasture. It was taken for granted that the owls had moved elsewhere, and for a series of years what had been famous Sugar Grove was practically forgotten. From 1901 on, however, my way several times led across the pasture and into the timber tract, and I was surprised to note there each time the presence of great horned owls. Once or twice I even took some pains to find a possible nesting site. There appeared to be none, so I concluded that the owls were merely transients. On February 6, 1906, just at nightfall a friend and I were walking along the public highway which

[1] The portrait of the adult owl shown herewith (pl. 2.) was taken several years ago from a fine specimen brought in to the Cornell College biological laboratory. The picture was made by a student of zoology, who left the negative as property of the college.

forms the north boundary of the pasture and the woods. Suddenly the hooting of big owls boomed out from a near-by linden of the timber pasture, and there, sure enough, were both birds engaged in ardent courtship and not minding our presence in the least. They stood facing each other on the same branch and, with feathers ruffled and heads bobbing, were hooting in low tones as they side-stepped toward one another and greeted one another with low bows. Finally they flew away, side by side, into the timber tract. That these were transient birds was beyond belief; so, on February 17, after allowing what seemed to be a fair margin of time, I decided to give the vicinity a thorough search. To make the story short, the nest was at last found in the very place where previously it had not seemed worth while to look. It was not in the heavy timber at all, but in one of the large elms of the pasture, and, moreover, hardly more than 50 yards removed from the above-mentioned public road where teams were constantly passing. Toward the south the view was wild, open, and picturesque enough; to the west, north, and east, at distances varying from 200 to 500 yards, were the schoolhouse and farmhouses, as above stated.

A more fortunate set of conditions for the study of the owls' home life could hardly be hoped for. The short distance from town has already been indicated. The nest was in a large shallow hollow, 28 by 32 inches in diameter at the bottom, with an entrance 18 by 20 inches in diameter set at an angle of 45° and facing toward the south-east. The hollow was only 8 inches deep on the exposed side, thus permitting fairly good illumination. Of still more importance the nest site was only 22 feet from the ground and a strategic branch some 5 feet above the nest afforded a point of attachment for a ladder combination from which pictures might be taken. As great horned owls generally make use of old hawks' nests placed in the tops of the largest trees the good fortune of this modest elevation can readily be appreciated. At the very moment when this nest was discovered a second pair of these birds was domiciled in a redtail's nest placed in a tall white elm in heavy timber 3½ miles to the northwest and just 92 feet above the ground. Further, the proximity of farmhouses made certain the necessary supply of ladders and ropes. Mr. Benedict, who lived just across the road and only 200 yards to the east, and Mr. McFarland, whose house stood only 75 yards farther to the east, were our interested and generous benefactors. Our opportunities were indeed great and, as I said, we greatly regretted our inability to make better use of them.

The weather on February 17 was fairly moderate, with the snow melting slightly, though the preceding days from February 6 had been stormy enough, with temperatures as severe as 10 below zero. But the sitting bird was wonderfully protected from the storm

winds of the north and west and flushed from three large perfect eggs that lay in a slight hollow of the decayed wood on the north side of the cavity. It seemed to me out of the question, with such temperatures as February and March were sure to bring, to obtain any pictures without having the owls put their date a little later in the season; so, after a little quick thought, I pocketed these eggs and went home. My conviction that the owls would not abandon so ideal a site after a probable occupancy of years was fully confirmed when, on March 23, three more eggs were found, just like the first and lying in exactly the same little hollow.

Saturday, April 7, was the first warm day of spring. On this day Mr. W. W. White, a student in Cornell College, and I made the first attempts to secure pictures of the owls' home and surroundings. Mr. White's ingenuity proved greater than my own and to him are to be credited the scheme for getting a camera within range of the nest and the successful picture of the eggs in situ. He also took the front view of the nest tree, looking northwest and showing the general situation and the interesting structure of the big elm itself. I merely helped him with the necessary ladders and ropes. Our two 20-foot ladders, lashed together and drawn up with a guy rope so as to rest on the aforesaid strategic branch, made anything but a solid foundation from which to work. Nevertheless all the near views of the nest were taken from this unsteady perch, the camera being tied with strings to the sides and rungs of the topmost ladder.

On April 14 two young were found in the nest and the remaining egg was much pipped. Both young were entirely blind and only one gave much sign of life. This was done by uttering a querulous little note somewhat like that of a very young chicken when excited but not sufficiently frightened to peep. The older one was able to hold its head up slightly while the smaller was entirely helpless. Both shivered as if from cold, the day being cool and showery. In the nest cavity were a headless bobwhite and the hind parts of an adult cottontail rabbit. The weather conditions prevented our trying to secure a negative. On April 19 only two young were found in the nest, with nothing at all to indicate the fate of the third egg. The young appeared quite lifeless, allowing their bills, which were of a slaty color with darker tips, to rest in the decayed wood of the nest bottom. The feather sheaths were pushing out on the dorsal and scapular tracts, and at the tips of these the brown juvenile plumage was beginning to show. The primary quills were also sprouting but the feathers themselves were still entirely concealed. The nest cavity contained a headless adult rabbit and a headless coot, also the hind parts of a young rabbit about the size of a striped gopher. No assistant was available on this day. On April 21 the young showed very noticeable increase in size, the brown feathers now showing

all over the dorsal and scapular areas. The eyes had partially opened in the form of a rather narrow ellipse. Still quite listless the young emitted the querulous note as described but did not snap their mandibles. The view inside the nest hollow was rather a pitiful one. In addition to half a coot and half a rabbit (probably the leavings of two days before) there lay scattered about four young cottontails hardly as large as an adult striped gopher. Two were whole, one headless, and only the hind parts of the fourth remained. A high wind and a chilly day caused Mr. White and me to lose this extraordinary picture. By April 26 the eyes of the young birds were nearly or quite open, the iris being of a milky yellow or light lemon yellow. The mandibles, which were now grayish yellow in color, were snapped vigorously. The primary quills were an inch and a half long, the feathers just beginning to show at the tips. The food in the nest consisted of the hind parts of an adult cottontail, an entire striped gopher and a headless bobwhite. Various feathers of a flicker also indicated a capture of this species. I was again without an assistant. On April 28, with the help of Mr. George H. Burge, I was able to repeat Mr. White's performance of three weeks before and get a successful negative of the nest and contents. The young were now 2 weeks old, still quite drowsy and inert, and entirely disinclined to open their eyes toward the light. The only food in the nest was the hind quarters of an adult cottontail.

Thus, for 1906, weather conditions thought to be insuperable and frequent inability to get a helper when one was needed had permitted a net return of only three good negatives. Further trips were made alone to the owls' home and a few further observations recorded. By May 9 the young seemed to have doubled in size and were wide-awake and combative. In size they were even then, at 3½ weeks, as large in appearance as a two-thirds grown Plymouth Rock hen. In the nest lay the hind quarters of an adult rabbit, a headless young rabbit about one-third grown, and a large headless brown rat. Being away from town myself, on May 16 Mr. White, with a student assistant, went to the timber pasture intending to secure a fourth picture. The nest was found empty, the owlets having occupied it this season only about 4 weeks. Soon after that, as I learned from one of the neighbors, two little girls gathering flowers in the timber tract came across both owlets as they were scrambling along the ground and evidently still unable to fly. The girls reported the strange creatures to a hired man who was temporarily in the neighborhood and he hunted up the "varmints" and clubbed them to death. The real neighbors of the owls would not have done this. They were all interested in the big birds and all reported that their large flocks of chickens had not suffered from their presence.

A further word should be added on the behavior of the adult birds during the first season. With two of us at the nest their demonstrations, although energetic enough, never proved dangerous. Both birds merely came near, flying back and forth at distances varying from 30 to 100 feet, snapping their mandibles, ruffling their feathers, and hooting out vigorous protests. It was different when one person was at the nest alone. On April 28 I had arrived at the old elm about 20 minutes ahead of Mr. Burge and, standing on the next to the top round of a 20-foot ladder, was making some examination of the young and the other contents of the nest cavity. The ladder necessarily stood as nearly vertical as possible to reach the cavity at all and, as the big tree was about 5 feet in diameter just below the hollow, the hold was none too secure. Fortunately a small horizontal branch shot out from the heavy trunk on the northeast side and against this the top 3 inches of the ladder found some support. Without this I dislike to think what might have happened when that stunning blow came in from the south quarter. It was absolutely unexpected and so violent as to leave the left side of my head quite numb. With my hand I discovered that blood was running down my cheek and a quick glance around showed my assailant stepping up and down on a nearby limb and clearly ready to come again. Under the circumstances I slid down the ladder to firmer vantage ground. The slash, which began on the left cheek and ran across the left ear, was rather ugly but not dangerous. Considering the eight claws of a great horned owl, each 1¼ inches in length, I had gotten off easily. Evidently only one claw had taken effect, the curvature of the great tree trunk and my clinging position over the nest rim having given, doubtless, some protection. The numbness was probably caused by the stroke of a rushing wing.

When on May 9 I was again compelled to visit the nest alone I knew what to expect and so was constantly on my guard. About 3 seconds' study of the young birds and nest contents was alternated with about the same amount of scrutiny of the immediate horizon. In this way it was possible to define an adult owl's manner of attack. Three times on this occasion one of the birds flew in from a neighboring tree and with strong stroke of wing came straight at my head. It was not at all the stoop of hawk or falcon, but rather the onrush of a heavy projectile with a very flat trajectory. Like a large projectile, too, the flight was visible and so all the more disconcerting; unlike a projectile, it was noiseless as a flying shadow. Audubon speaks of the hunting flight of the great horned owl as possessing incomparable velocity and, kind reader, I am quite ready to agree with him. The big bird, perched on a branch from 30 to 50 feet away, first shifts nervously from one foot to the other, then launches swiftly into space. There is just time to brace oneself a little, swing

one's cap, and quickly duck one's head as the great missile rushes past. The owl keeps straight on her course and alights with heavy impact on a branch of a neighboring tree. Here she faces about and very likely comes straight back again. This process became finally a bit too exciting and, after making certain that the headless quadruped lying in the nest over behind the owlets was just a big house rat, I slipped down the ladder and went home.

February 7, 1907, was cold and clear after the terrific snowstorm of the night before. On this day Mr. James R. Smith, a young farmer of the vicinity who had always been interested in birds and who was destined to be my skillful assistant throughout the season, accompanied me to the snow-covered timber pasture. As we approached the nest tree of the year before a fox squirrel leaped from one of the smaller adjacent trees and, starting up the big elm, ran along the rim of the great knothole which formed the owls' doorway and scampered onto a topmost branch. If the owl were at home the saucy fellow surely passed within 10 inches of her face. For a moment we felt dubious as to the nest being occupied. As we approached the tree, however, a great horned owl flew from one of the higher branches, aroused either by the squirrel or, more likely, by our own approach. This was more favorable. We gave the tree a few kicks, when the sitting bird hopped up lightly to the rim of the cavity, looked across the white landscape for several seconds, then spread her nearly 5 feet of wings and flew silently away.

Our first mistake for 1907 was in not looking into the nest on this first day. Our reasons for not doing so were the belief that the set of eggs could hardly be complete at this time and especially the fear that the egg or eggs could not stand exposure even for a short time on so cold a day. My present belief is that this fear was unfounded. Just two days later, on February 9, at about 3 o'clock in the afternoon, I visited the nest again and found the set of three eggs complete. These were lying in a slight hollow as before, but as far back in the cavity as possible. Except for a small space about the eggs the house was filled, even to the doorsill, with snow. It was a picture, indeed, but one over which we did not dare tarry in freezing weather. All the eggs were nest stained and it did not look as if any one of them had been laid that day. However, this was uncertain, and I had lost a possible opportunity of learning just when the set became complete. This was regrettable, for no one seems to know the period of incubation of an egg of the great horned owl. The older ornithologists made their guess at 3 weeks. Bendire later expresses his belief that this period is too short and that 4 weeks is probably nearer to the truth. I have not determined the point, though my data still possesses some interest. Toward the end of the

month I began to visit the nest as often as possible to ascertain as nearly as I could when the chicks appeared and how long the hatching process lasted. It was not until March 6, at 2 p. m., that I found one of the eggs pipped, a small round area no larger than a pea being broken. On March 7 at the same hour the broken area was the size of a dime. I could distinctly hear, however, several times repeated, the low twittered note of the still imprisoned chick. The other eggs still showed no sign. Bad weather and pressure of other work now prevented a further visit until March 11 at 2.30 o'clock. Two very callow owlets were now in the nest and one slightly pipped egg. The young birds were not completely protected by their white down as yet, the bare skin being visible between the tracts. On March 16 three young owls of different sizes were found in the nest, one being quite markedly smaller than the other two. The query remains: How long does it take a great horned owl's egg to hatch? The above are the data kept and anyone can make estimates on them. It seems certain that these birds did not lay an egg oftener than once in two days and that the period of incubation could not have been less than 30 days, with the probabilities on the side of a rather longer period.

For our second year's work we had the experience of the first to go on, we were more confident of the owlets' ability to bear exposure, and so decided to photograph them at least once a week, let the weather offer what it would. And the offerings were of sufficient variety. On March 16, with the young 4, 6, and 8 days old, approximately, the temperature was well above freezing and comfortable, but we were unable to expose a plate until 4 p. m., the sun became covered with black clouds, and we were on the shady side of the tree. We were not hopeful, but a long exposure accomplished our purpose. In addition to the parts of three adult cottontails and one bobwhite, which the camera shows, a fourth rabbit and a second bobwhite, also a plump field mouse, do not appear in the picture, being tucked away under the overhanging roof to the left or buried under other remains. It was chilly on March 30 and a high wind was blowing in from the northwest. On April 13 we had a regular northwest gale to contend with and freezing temperature added. We varied our work with the camera by runs across the frozen timber pasture. Why it was that our negatives taken on these last two dates did not show motion we have never satisfactorily explained to ourselves, for only time exposures could be used. Certain it is that both the big elm and our nearly 30-foot stretch of ladder were swaying back and forth under the lash of that roaring wind. The gentle rain that was falling when, on April 18, Mr. Benedict helped me bring the now lively owlets to the base of the old nest tree, proved to be really no obstacle at all. It splashed water against the lens of the camera but the negatives

gave no sign. The first fine weather of spring was calling forth the backward buds of the young hard maples when, on April 22, the owlets posed for the last time on an old oak stump, just east of the nest tree. The weather encountered on dates not mentioned was composed of variations of the above, but the rule was freezing temperatures, with high winds. Under all the conditions the young owls thrived and did not seem to mind seriously our intrusion into their home life.

During the season of 1907 the food contents found in the nest cavity were as follows: Five bobwhites, 2 meadow mice, 1 domestic pigeon, 1 flicker, 2 American coots, 1 king rail, 19 adult cottontails. This list is not, of course, an accurate account of the various captures brought to the nest. It merely records what was seen there on the 16 trips made. The same bird or mammal was doubtless sometimes counted twice, and captures were in all probability brought in of which no remnants were seen. I think not more than 3 different bobwhites were seen, quite likely only 2, and the number of cottontails is also probably too high. The fact seems to be that both birds and quadrupeds of the larger size, after being eaten from the head to the tougher hind parts, were then left two or three days untouched and finally removed from the nest altogether. These were not dropped about the base of the tree, however, and in fact no trace of food remnants was found at any time except in the nest itself. That some refuse was removed from the nest seems probable from such facts as the following: The above-mentioned 2 bobwhites, 1 meadow mouse, and 4 rabbits found in the nest cavity on March 16 were all in fairly whole condition, aside from the heads. On March 23 parts of 5 rabbits were found, represented by the hind quarters only, and 1 bobwhite with the breast eaten away. These were mostly rather desiccated remnants and I took them to be, for the most part, leftovers from the week before. On March 30 the nest was entirely clean except for a freshly killed white pigeon. Generally speaking, the nest cavity was well kept, a fact which seemed to indicate removal of the excrement of the young by the old birds.

Our second season's active work with the owls was not without its exciting features. Twice when alone I had had, in spite of close watchfulness, pretty close brushes with one of the old birds. But it was not until the young were removed from the nest for the last two attempts to get clearer pictures that there was any real element of danger. With the three pugnacious owlets grouped on the ground at the base of the nest tree, both old birds now closed in, teetering and dancing and hooting on branches about 30 feet from our heads or brushing close past us as they took up new positions or sought for an opening. Mr. Benedict, who was my helper this time, literally stood guard *over* me as, with camera close to the ground, I stooped

under the focusing cloth. Except for his full-voiced yells and well-aimed sticks I am sure my position would have been utterly untenable.

The last try for pictures, when the young were placed on the old stump a few feet to the east of the big elm, did not pass off so smoothly. Whether the city friend who had become interested in the proceedings and who was this time trusted as my bodyguard was less effective with voice and missiles than he should have been, or whether the owls no longer feared an ordinary demonstration, it would be hard to say. Two of the youngsters were already on the oak stump and I was somewhere aloft in quest of the third. Presumably I was either just reaching over the nest rim for the last snapping owlet or else had just started down with him. My memory has never been clear on the point nor was my excited friend ever able to elucidate fully. At any rate my position for the moment must have been strategically bad. The sharp cry "Look out" barely gave me time to duck my head, when a resounding whack was administered across my shoulders. This was not damaging, but the return stroke would come quickly and doubtless be better placed. It came and I ducked again, but not quite far enough, or possibly not at exactly the right instant. The shock was profound. The list of damages showed three scalp wounds from 1 inch to nearly 3 inches in length, while my cap had disappeared entirely from the scene. This was later found under a tree some hundred yards to the south, a punctured souvenir of our last intimate contact with the great horned owls.

After each sitting the young were replaced in the nest and two days after the stormy last one, on April 24, the house was found empty and the family was in the treetops. It will be noted that the owlets remained in the nest about two weeks longer in 1907 than in 1906. One youngster was in the very top branches of the old elm of his nativity, fully 50 feet above the deserted home or more than 70 feet above the ground; another was 100 yards away in the timber tract and some 18 feet up in a linden; both were motionless and inconspicuous among the budding branches. In the time at disposal the third brother could not be found. Two days before this the young had shown neither inclination nor ability to fly. It seems certain that no one of them could have mounted a vertical distance of 50 feet through any powers of his own. The conclusion seems inevitable that in some way the old birds carried the young to the places where I found them. But the secret belongs to the owls, for no one witnessed the leave-taking.

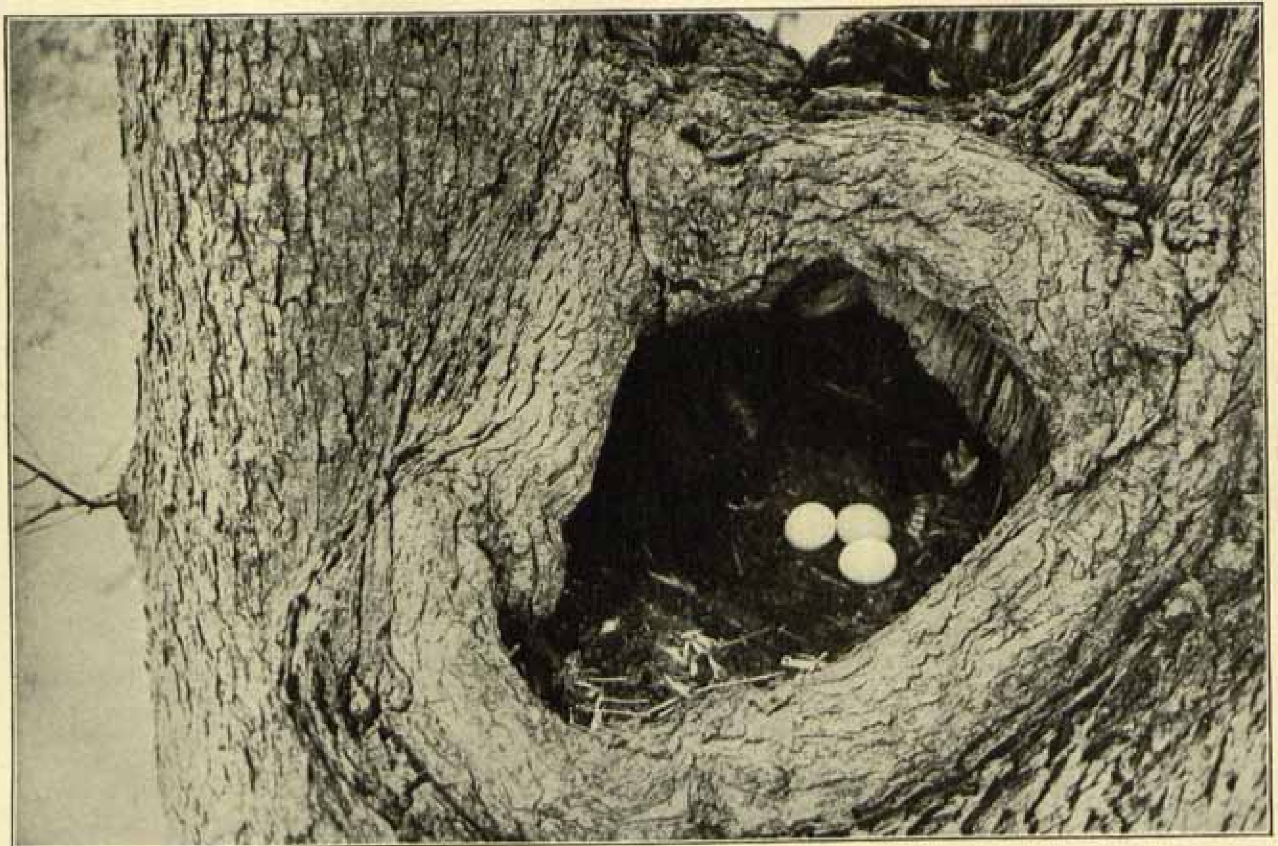
A little more than two months passed by and on a walk through their now heavily foliaged retreat two great heavy owls, seemingly, and doubtless actually, larger than adults, were startled from the ground near some prostrate tree trunks, from which they flew slowly into the nearby trees. Almost at the same moment a third dropped

from the lower branches of an oak and took up a new position deeper in the shadows of the woods. So far as mere size was concerned the owlets had reached and even surpassed the adult owl estate, though probably still under the care and tutelage of their elders. From now on they would need to shrink and harden into the strength and agility necessary to enter the competition of adult owl life and maintain themselves in the general struggle for existence.

February of 1908 again found Mr. Smith and me rapping anxiously at the old elm of the timber pasture. With the facilities at our disposal we could accomplish little more with the young birds, but during the year we had formulated a plan by which there might be a bare possibility of securing a portrait of the old owl as she sat within her doorway. Our hopes were raised by the reports of both Mr. Benedict and Mr. McFarland that, as the nesting season approached, the owls had been heard hooting as usual. Our misgivings began when we found piled about the nest tree the cordwood from a number of the neighboring young lindens. The old nest cavity was found empty. The owls were able to endure intrusion into their home life for two seasons, but evidently did not take kindly to radical changes in their immediate environment.

A mile west of the old home is another forest fragment of perhaps 60 acres and in this a pair of red-tailed hawks had built their bulky aerie in a tall white-ash tree, 75 feet from the ground. Following the custom of most of their tribe when suitable hollow trees are no longer to be had, the big owls appropriated this new refuge and in it, in spite of rain, sleet, snow, and wind, successfully raised their brood. To be sure we had no exact proof that these were the very owls with which we had dealt in other years, nevertheless we felt morally certain. The new locality was the nearest available one and for many years, until 1908, had not boasted its pair of owls.

The years 1909 and 1910 add nothing new to the history of the owls except that in the former year a January gale destroyed the nest in the ash tree and the valiant pair were apparently forced to a new, but similar, retreat. Their history, so far as we were concerned, was a closed one. During the season of 1907 I had located five pairs of great horned owls within a radius of 7 miles of Mount Vernon. None of these could be intimately studied except the pair whose history I have tried to trace. In February of 1910 I again tried to locate breeding birds of this species, but without success. In spite of the big fellow's tenacity in clinging to a locality once chosen, in spite of his cleverness in escaping observation, it almost seems now that the coming of the shotgun army and the going of the protecting forests were gradually making the great horned owl, along with many another species without which the woods are stiller and humanity poorer, in the more settled parts of our country at least, a member of a slowly vanishing race.



THE HOME OF THE GREAT HORNED OWLS AS TAKEN ON APRIL 7, 1906.

FIG. 1.—ADULT MALE GREAT HORNED OWL; DURING A DAY'S CAPTIVITY HE WAS SILENT, PROUD, AND DEFIANT.

FIG. 2.—A PORTION OF THE OWLS' HUNTING RANGE AS SEEN FROM THE PUBLIC HIGHWAY; NEST TREE ON EXTREME RIGHT.

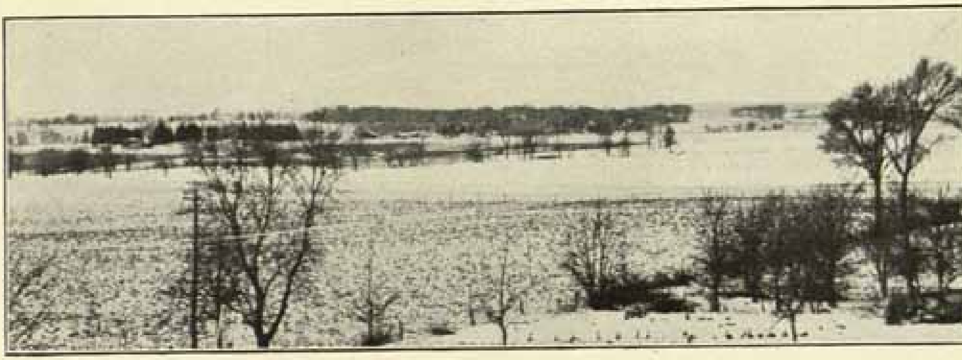


FIG. 1.—THE OWLS' NESTING TIME; FROM TOWN THE TIMBER TRACT AND ENVIRONMENT ARE SEEN IN PANORAMIC VIEW.

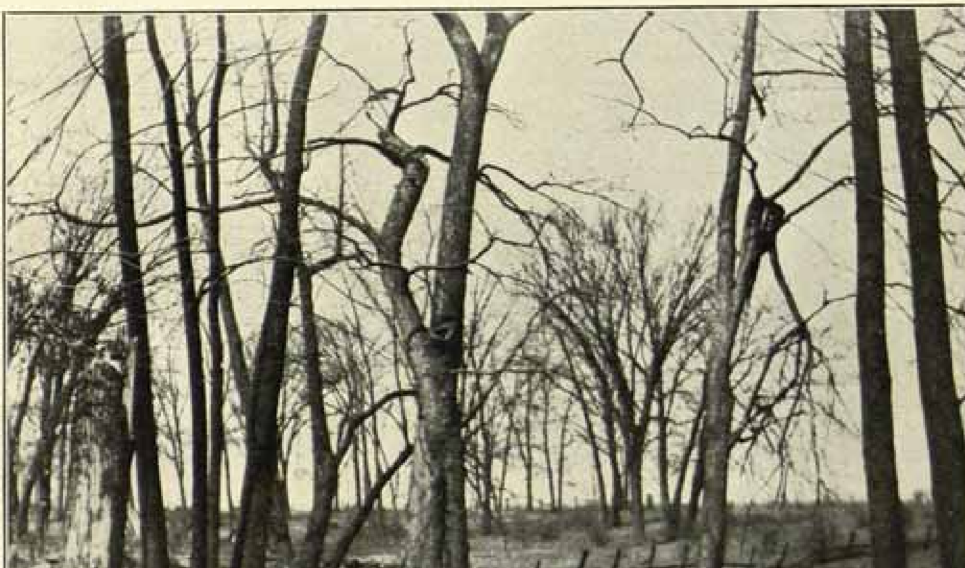
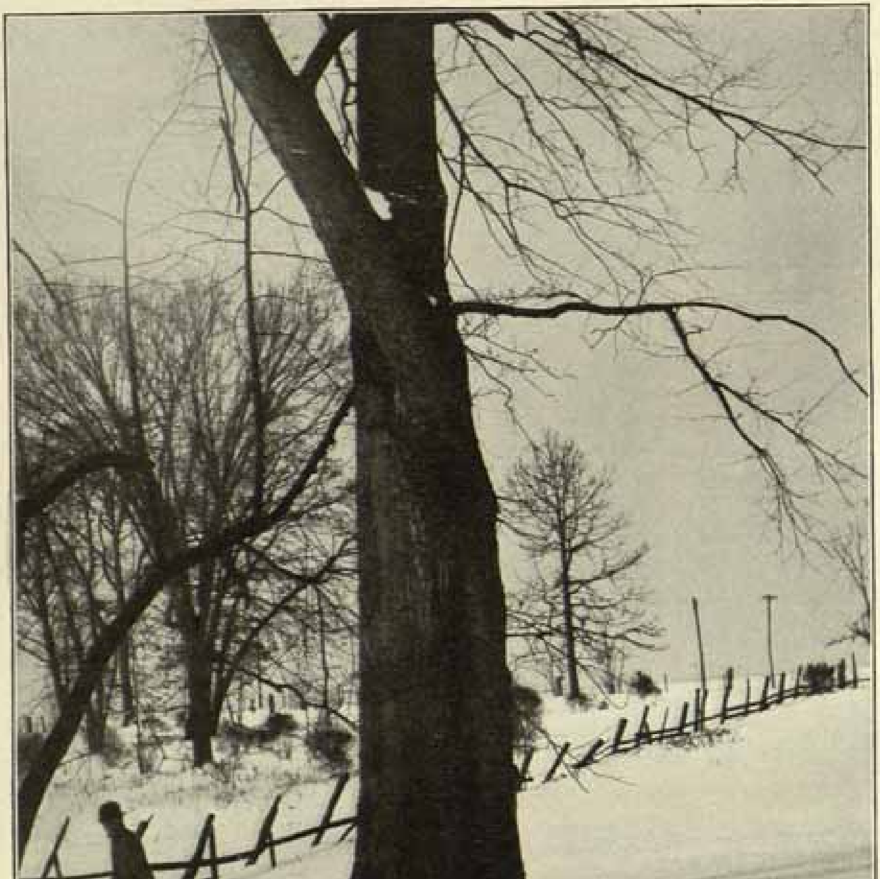


FIG. 2.—THE OLD ELM WITH THE NEST CAVITY IS IN ITSELF A NATURAL CURIOSITY; VIEW NORTHWEST



FEBRUARY 7, 1907; THE GRAY PLUMAGE AND WHITE THROAT PATCH OF THE OLD OWL SITTING ON THE RIM OF THE NEST CAVITY BLEND PERFECTLY WITH THE BARK AND SNOW.

FIG. 1.—MARCH 16, 1907; WHERE THE DEAD ARE MORE IN EVIDENCE THAN THE LIVING; OWLETS 4, 6, AND 8 DAYS OLD.

FIG. 2.—MARCH 30, 1907; OWLETS 18, 20, AND 22 DAYS OLD.

FIG. 1.—APRIL 13, 1907; AGE OF OWLETS, 32, 34, AND 36 DAYS.

FIG. 2.—APRIL 18, 1907; AT THE BASE OF THE OLD NEST TREE; YOUNG 37, 39, AND 41 DAYS OLD.

FIG. 1.—APRIL 22, 1907; DORSAL AND LATERAL VIEWS; AGES 41, 43, AND 45 DAYS.

FIG. 2.—APRIL 22 1907; A FRONTAL VIEW; TWO DAYS LATER ALL WERE IN THE TREE TOPS.

THE OWL HOME OF 1908; A VAIN LOOK ALOFT.

THE PASSENGER PIGEON.

[With 1 colored plate.]

Accounts by PEHR KALM (1759) and JOHN JAMES AUDUBON (1831).

[The former habitat of the passenger pigeon (*Ectopistes migratorius*) as given by the American Ornithologists' Union check list (third edition, 1910) is as follows:

"Bred formerly from middle western Mackenzie, central Keewatin, central Quebec, and Nova Scotia south to Kansas, Mississippi, Pennsylvania, and New York; wintered principally from Arkansas and North Carolina south to central Texas, Louisiana, and Florida; casual in Cuba, eastern Mexico, and Nevada; now probably extinct."

There is one living bird left. This is in the Cincinnati Zoological Gardens.

The causes of the extermination of this pigeon are chiefly the greed of civilized man. The destruction of forests within its range greatly reduced its natural food supply, and the killing (by netting, shooting, clubbing, etc.) of enormous quantities in the end produced the same effect as with the bison. When these pigeons were still numerous great numbers were used in trap shooting.

In a wild state the pigeon became extinct about the year 1900—possibly a few lingered after that date, yet Mershon[1] estimates (p. 92) that a total of 1,000,000,000 were killed in the Michigan "nesting" of 1878.]

I.—A DESCRIPTION OF THE WILD PIGEONS WHICH VISIT THE SOUTHERN ENGLISH COLONIES IN NORTH AMERICA, DURING CERTAIN YEARS, IN INCREDIBLE MULTITUDES.

By PEHR KALM (1759).[2]

In North America there is a species of wild pigeons[3] which, coming from the upper part of the country, visits Pennsylvania and others of the southern English settlements during some years, and in marvelous multitudes.

They have, however, already been described and exceedingly well illustrated in lively colors by the two great ornithologists and match-

[1] Readers wishing to pursue the subject further should consult W. B. Mershon's book, The Passenger Pigeon, 1907, New York, from which the colored plate herewith is reproduced.

[2] Translated by S. M. Gronberger from Kongl. Vetenskaps-Akademiens Handlingar, *för ar* 1759, Vol. 20, Stockholm, 1759. Reprinted by permission from The Auk, Vol. 28, Jan., 1911.

[3] The names given by ornithologists and others to these pigeons are as follows:

Columba (macroura) cauda cuneiformi longa, pectore purpurascente. Linn. Syst. X, T. I, p. 164.

Columba macroura. The long-tailed dove. Edwards's History of Birds, T. I, p. 15, t. 15.

Palumbus migratorius. The pigeon of passage. Catesby's Nat. Hist. of Carolina, Vol. I, p. 23, t. 23.

Dufvor, Villa Dufvor [pigeons, wild pigeons], so called by the Swedes in New Sweden.

Pigeons, wild pigeons, by the English in North America.

Tourtes, by the French in Canada.

less masters of bird drawing, Catesby and Edwards; but as I have had occasion to notice with regard to the description proper and especially as regards the living habits of these pigeons various things which these gentlemen have either left entirely unmentioned, or which at their places of residence they have not been able properly to ascertain, it is my desire to deliver a short account of this subject before the Royal Academy of Sciences, using the notes from my American diary.

Although these pigeons have been splendidly illustrated by ornithologists, they have not been able to reproduce their beautiful colors in true accordance with nature, in one respect, at least; the color indicated on either side of the neck should extend much higher up. [Technical descriptions follow in Latin and are here omitted.]

The size of these pigeons is about that of a ringdove.

Their long tail distinguishes them from other pigeons.

The splendid color which the male and the female have on the sides of the neck and even a little beyond it is also peculiar in that the feathers in that region are as if covered with a finely resplendent copper [color], with a purple tint, which back of the neck shifts more into green, particularly with reference to its position toward the light. Rarely is this color more finely reproduced than in this bird. Mr. Catesby calls it a golden color, but it can hardly be termed that.

In the copy of Mr. Catesby's work which I have seen both the head and the back are of a darker color, and the breast is also of a redder color than the bird actually has. This I could very well see when I laid a recently killed male beside Mr. Catesby's figure, as it is the male which is reproduced in his work. Mr. Edward [sic] has entirely omitted the above-mentioned copper color both in his description and his figure. It may be that some of the young ones do not have it; but it was found on all those which I have handled, and which were killed in the spring.[1]

Quite a number of these pigeons may be seen every summer in the woods of Pennsylvania and New Jersey and the adjoining provinces, in which region they live and nest; and it is very seldom that a greater number of them are not observed there in the spring, during the months of February and March, than in the other seasons of the year. But there are certain years when they come to Pennsylvania and the southern English provinces in such indescribable multitudes as literally to appall the people. I did not, however, have the opportunity of witnessing such personally (although the spring of the year 1749, when I was there, was considered as one of those in which a greater number of these pigeons appeared than had

[1] Edwards's figure represents a distinct species of another genus, namely, the *Columba* (=*Zenaidura*) *macroura*.

been the case for some years previously; yet it was not one of the particular or more unusual ones); but all persons who had observed these happenings and lived long enough to remember several of them recited several incidents connected therewith. Some had even made short notes of various details, of which I will cite the following:

In the spring of 1740, on the 11th, 12th, 15th, 16th, 17th, 18th, and 22d of March (old style), but more especially on the 11th, there came from the north an incredible multitude of these pigeons to Pennsylvania and New Jersey. Their number, while in flight, extended 3 or 4 English miles in length, and more than 1 such mile in breadth, and they flew so closely together that the sky and the sun were obscured by them, the daylight becoming sensibly diminished by their shadow.

The big as well as the little trees in the woods, sometimes covering a distance of 7 English miles, became so filled with them that hardly a twig or a branch could be seen which they did not cover; on the thicker branches they had piled themselves up on one another's backs, quite about a yard high.

When they alighted on the trees their weight was so heavy that not only big limbs and branches of the size of a man's thigh were broken straight off, but less firmly rooted trees broke down completely under the load.

The ground below the trees where they had spent the night was entirely covered with their dung, which lay in great heaps.

As soon as they had devoured the acorns and other seeds which served them as food and which generally lasted only for a day, they moved away to another place.

The Swedes and others not only killed a great number with shotguns, but they also slew a great quantity with sticks, without any particular difficulty; especially at night they could have dispatched as many as their strength would have enabled them to accomplish, as the pigeons then made such a noise in the trees that they could not hear whether anything dangerous to them was going on, or whether there were people about. Several of the old men assured me that in the darkness they did not dare to walk beneath the trees where the pigeons were, because all through the night, owing to their numbers and corresponding weight, one thick and heavy branch after another broke asunder and fell down, and this could easily have injured a human being that had ventured below.

About a week or a little later subsequent to the disappearance of this enormous multitude of pigeons from Pennsylvania and New Jersey, a sea captain by the name of Amies, who had just arrived at Philadelphia, and after him several other seafaring men, stated that they had found localities out at sea where the water, to an extent of over 3 French miles, was entirely covered by dead pigeons of this

species. It was conjectured that the pigeons, whether owing to a storm, mist, or snowfall, had been carried away to the sea, and then on account of the darkness of the following night or from fatigue, had alighted on the water and in that place and manner met their fate. It is said that from that date no such tremendous numbers of this species of pigeon have been seen in Pennsylvania.

In the beginning of the month of February, about the year 1729, according to the stories told by older men, an equally countless multitude of these pigeons as the one just mentioned, if not a still larger number, arrived in Pennsylvania and New Jersey. Even extremely aged men stated that on three, four, five, or several more occasions in their lifetime they had seen such overwhelming multitudes in these places; and even the parents of these people had in their turn told them that the same phenomenon had occurred several times during their own lives; so that 11, 12, or sometimes more years elapse between each such unusual visit of pigeons.

From Lawson's History of Carolina (p. 141), I see that in the winter of 1707, which was the severest known in Carolina since it was settled by Europeans, an equally awe-inspiring number of these pigeons had made an appearance in Carolina and the other southern English settlements, driven thither by causes which I will now mention.

The learned and observant Dr. Colden told me that during his stay in North America, where he had been since the year 1710, at his country place, Coldingham, situated between New York and Albany, he had on two distinct occasions, although at an interval of several years, witnessed the arrival of these pigeons in such great and unusual numbers that during two or three hours, while they flew by his house, the sky was obscured by them, and that they presented the appearance of a thick cloud.

All the old people were of the opinion that the months of February and March is the single season of the year when the pigeons swoop down upon Pennsylvania and the adjacent English provinces in such marvelous quantities; at other seasons of the year they are not to be seen in any great numbers.

The cause of their migrations from the upper part of the country in such great quantities at this season is twofold—first, when there is a failure of the crop of acorns and other fruit in the places where they otherwise generally spend the winter, thus rendering their supply of food insufficient to last until the ensuing summer; and, second, and chiefly, when an unusually severe winter with abundant and long-remaining snow happens to occur in their customary winter haunts, thus covering the ground and making it impossible for them to secure the acorns, beechnuts, and other fruit and seeds on which they otherwise feed at this season; in such cases they are forced to leave these localities and seek their food down along the seacoast, where the winters,

owing to the sea air, are always milder, and the ground more and earlier free from snow. Experience has shown that both of these circumstances have caused their migrations to take place in such great multitudes.

A peculiar fact, and one which older persons have unanimously maintained to be true, is that on all occasions which they could remember, when the pigeons appeared in such great numbers, there had always been during the preceding autumn, in Pennsylvania and adjacent localities, an abundant crop of acorns and other arboreal seeds, excelling that of several previous years; but during their stay the pigeons had so carefully searched and ransacked all possible nooks and corners that after their departure it was almost impossible to find a single acorn in the woods.

Several extremely aged men also declared that during their childhood there were, in summertime, many more of the pigeons in New Sweden than there are now; the cause of this is that the country is at present much more populous and cultivated and the woods more cleared off, and as a result the pigeons have either been killed off or scared away.

As nearly all the inhabitants of Pennsylvania and the English settlements in the South did not quite know whence these numberless swarms of pigeons came from, they entreated me to ascertain, during my journeys in the interior of the country, where so many were to be found in summertime, what their food and other economic requirements were at that time of the year, and so on. During my journey to and within Canada I found the desired occasion of learning all of this, which I will now briefly relate.

When toward the end of June, 1749 (new style), I had left the English colonies and set out for Canada through the wilderness which separates the English and French colonies from each other, and which to a great extent consists of thick and lofty forests, I had an opportunity of seeing these pigeons in countless numbers. Their young had at this time left their nests, and their great numbers darkened the sky when they occasionally rose en masse from the trees into the air. In some places the trees were full of their nests. The Frenchmen whom we met in this place had shot a great number of them, and of this they gave us a goodly share. These pigeons kept up a noisy murmuring and cooing sound all night, during which time the trees were full of them, and it was difficult to obtain peaceful sleep on account of their continuous noise. In this wilderness we could hear in the nighttime, during the calmest weather, big trees collapsing in the forests, which, during the silence of the night, caused tremendous reports; this might in all probability be ascribed to the pigeons, which, according to their custom, had loaded a tree down with their numbers to such an extent that it broke down; although other causes might

also be found, whereof more is mentioned in the third volume of my American Journey. The additional observations which I had occasion to make as to their economy and manner of life during my stay in North America, both in Canada, the wilderness of the English colonies, and in the land of the savages, are as follows:

The birds spend the entire summer in Canada, and particularly do they nest in the vast wild forests and wastes which abound there, where no men are to be found and where seldom any human being ventures. When in summer a person travels through these forests he might easily become terrified by the enormous number of these birds, which in some places almost entirely cover the branches of the trees, and when taking wing obscure the sky. These pigeons have, however, their distinct boundaries, outside of which they do not often venture; as, for example, somewhat south of Bay St. Paul, which is 20 French miles north of Quebec, not very many of them nest in the woods; and the cause of this is said to be that the oak and the beech tree, which supply them with their principal food, are here arrested in their growth, and grow no farther north.

In forests where there are human settlements, or where the country is inhabited, only a few are to be seen; and as the land is being gradually cultivated by man the pigeons move farther away into the wilderness. It is maintained that the cause of this is partly that their nests and young are disturbed by boys, partly their own sense of a lack of safety, and finally that during a great part of the year their food is shared by the swine.

They build their nests in high trees, pine trees as well as deciduous ones; often as many as 40 or 50 nests are to be found in the same tree.

Some maintain that they raise two broods of young every summer.

In places where they nest in abundance the ground is often covered with their droppings to a thickness of 1 to 2 feet.

While these birds are hatching their young, or while the latter are not yet able to fly, the savages or Indians in North America are in the habit of never shooting or killing them, nor of allowing others to do so, pretending that it would be a great pity on their young, which would in that case have to starve to death. Some of the Frenchmen told me that they had set out with the intention of shooting some of them at that season of the year, but that the savages had at first with kindness endeavored to dissuade them from such a purpose, and later added threats to their entreaties when the latter were of no avail.

In Canada it is almost everywhere the custom for young farm hands and boys to investigate where the pigeons have their nests, and as soon as the young are able to fly they are taken from the nest and brought to the farm, where they are afterwards kept in

suitable quarters and industriously fed, whereupon they are killed and eaten. To make doubly sure that they do not escape, one of their wings is generally cut short, so that even in case they do get out they can not fly away. Such nestlings have a good appetite, thrive comfortably, become quite tame, and within a short time, if well taken care of, accumulate so much fat that they afford a most palatable dish.

For food these pigeons select the following fruits, which I will name in the order that they mature:

Seeds of the red-flowered maple (*Acer*); these mature in Pennsylvania at the end of May, but somewhat later farther north.

Seeds of the American elm (*Ulmus americana*); these mature in Pennsylvania in the beginning or middle of June, but farther north somewhat later. When on our journey through the wilds between Albany and Canada we cut up some of the pigeons which the French had shot and given us, their crops were generally found to be full of elm seeds.

Mulberries, which ripen in Pennsylvania in the beginning of June (new style), are relished by these pigeons almost above everything else. During my stay in the last-mentioned locality, in 1750, I noticed that as soon as the mulberries became ripe the pigeons put in their appearance in great numbers. Wherever a mulberry tree grew wild it was at this time generally full of pigeons, which devoured the berries. They often caused me much vexation, because if I had located a mulberry tree in the woods with the intention of securing seeds when the berries became ripe and it should happen that I did not watch out for the proper time, the pigeons had generally, in the meanwhile, been so industrious in their picking that on my arrival scarcely a single berry was left. If some of them were shot the others generally flew away a little distance, but returned within a few minutes to the same mulberry tree; so that a person who owned such trees found no difficulty to obtain daily a sufficient quantity of choice meat as long as the mulberries lasted.

They consume all kinds of grain with the single exception of corn, which is left untouched by them, although it has other enemies. I noticed that they were particularly fond of the following kinds of grain:

They ate rye, although not with particular avidity, but rather as if in the absence of something else more palatable. Some persons assured me that they had seen with their own eyes how these pigeons, during summer time, when they had come to a ripe wheat field, alighted on the fences, vomited up the rye on which they had previously feasted, and then swooped down upon the wheat field, where they gorged their crops with wheat, as being more appetizing.

Wheat is one of their most coveted foods, which may be seen from what has already been stated, as well as from many another experience. As soon as the wheat fields become ripe they swoop down on them in enormous numbers and take considerable toll of them. When the wheat is stacked up in the field they also visit it and devour all too much of it, if they should happen to be in the least hungry. In the fall, when the wheat is recently sown, they alight in full force in the fields and not only pick up the grains which are more or less in broad daylight but also poke up those which the plow has not sunk sufficiently deep. In order to prevent such a damage boys as well as others are seen at this season of the year running around armed with guns and other "contraptions" to kill or scare them away. On such occasions, however, they are not in general particularly timid, especially the young ones, so that when a few of them have been shot at a stack the others oftentimes fly away only a short distance to another stack, and hence the gunner, albeit he has made some lucky shots, generally becomes exhausted before the birds become scared. In Pennsylvania this species of grain, as well as the rye, commonly ripens about midsummer (old style) and sometimes earlier, but farther north it ripens later.

Buckwheat they are also very fond of, and levy considerable tribute on it. The buckwheat matures in Pennsylvania in the middle of September (old style).

The berries of the tupelo or sour-gum tree (*Nyssa*) they also consume with great avidity. In Pennsylvania these ripen in September. This tree does not grow in Canada.

Most forests in North America consist of oak, of which arboreal genus there are several species; of these the greater part have nearly every year a great number of acorns which in the autumn fall off in such quantities that quite often the ground below the oaks is covered by them one hand high and sometimes more. These serve as food for several kinds of animals and birds, as, for instance, squirrels of several species, forest mice, wild pigeons, etc., in addition to which, in places inhabited by Europeans, they serve as the staple food of hogs during the greater part of the year. During certain years the numberless swarms of wild pigeons already described come to Pennsylvania and the other English provinces in search of these acorns. In Pennsylvania and other localities in North America the acorns mature in September and the following months.

They are also very fond of beechnuts. There is a great abundance of beech trees in Canada, but farther south they grow somewhat more sparsely. In Canada the nuts become ripe in the middle of September. These, together with acorns, constitute the principal food of the pigeons during the entire latter part of the fall and throughout the winter.

In addition to the kinds already enumerated, they also consume various other seeds and berries of trees and plants which grow in this country.

The trees above referred to, the seeds and berries of which the pigeons are so fond of, grow in the forests of North America nearly everywhere in great abundance. In a good many places, especially farther inland, oaks, elms, beeches, and the red-flowered maple constitute almost alone, with the addition of the walnut tree, the entire forest tract. Thus it will be seen how the all-wise Creator, even in the case of these birds, has so wisely adapted the size of the food supply to the number of mouths to be fed.

I have also observed that the pigeons have a special fondness for the kind of soil which is much mixed with common salt [alkaline deposits]; this soil serves them as food, as a spice to blend with the food, or for its medical properties, I do not know which. At the salt springs of Onondago [sic], in the tribe of the Iroquois Indians, where the soil is so strongly mixed with salt that the ground during a severe drought becomes entirely covered with it and as white as frost, making it impossible for plants to grow, I noticed with astonishment, in the month of August, 1750, how covetous the pigeons were of this kind of soil. The savages in Onondago had built their huts on the sides of this salt field, and here they had erected sloping nets with a cord attachment leading to the huts where they were sitting; when the pigeons arrived in swarms to eat of this salty soil, the savages pulled the cords, inclosing them in the net, and thus at once secured the entire flock. At certain times, when they came in such numbers that the ground could hardly be seen for them, the savages found it more advisable to use a gun, as by a single discharge of birdshot they could sometimes kill as many as 50 or more; and this proved a splendid source of food supply.

These wild pigeons fly in the same manner as other pigeons; and as soon as they have alighted in a tree or other place they have a habit of making a clapping sound with their wings which, according to some, is a signal for all the others to alight. At times, and when they have had sufficient food, they are quite timid, especially the old birds. Therefore, when one wishes to shoot them it is best to walk to and fro among them, on the ground, as if one did not see them; then they are not so timid, nor do they take wing so soon.

In the vast forests of Canada they remain to the end of August or beginning of September (new style); i. e., until the grain has been stored for the winter. A great number, however, remain until late in the autumn, when the first snow begins to fall, which finally drives them all away. As their food mostly consists of acorns, beechnuts, and the seeds and fruits of other trees which become hidden under the snow, they are obliged to leave these places and

betake themselves farther south, where the ground is bare all winter. Not one of them remains in Canada throughout the winter; but they generally spend this season in the vast forests of the Illinois, who live at about the same latitude as Pennsylvania and Virginia. They do not willingly migrate toward the seaboard, where the country has been extensively cultivated by the English, and the forests are much cut down; partly because they can not there secure a sufficient food supply, and partly to avoid running the risk of getting killed by the number of people and gunners in that section. They prefer the vast and dense forests in the interior of the country, where there are no human habitations for many miles around. But should it happen during a certain year that there is a failure of the crop of acorns or other food suitable for them, or an unusually severe winter with great snowfall sets in, which to some extent covers the ground, then they are forced to leave their usual winter quarters and seek their way to the English settlements down the seaboard. It is on these occasions that they swarm into Pennsylvania in such enormous numbers; but as soon as the weather changes a little and becomes milder, they again retire farther inland. Here they remain until the last snow disappears in the spring.

As the snow gradually melts away in the spring the pigeons migrate farther and farther north and when northern Canada is free from snow, which generally occurs toward the end of April or the beginning of May, the pigeons arrive in their old haunts and commence their mating, nesting, hatching of eggs, and the rearing of their young, etc.

The French in Canada, who annually catch a number of young pigeons alive which they thereafter rear at their homes, have taken much pains to tame these birds, although with but little success. It is very easy, when they are kept in suitable quarters, to make them so tame as to feed from one's hands, in the manner of any other domesticated pigeon; but as soon as they are let out into the open hardly a few days pass before they fly away to the woods, nevermore to return. It was, however, emphatically asserted that some had succeeded in taming them to the same extent as the domesticated pigeons.

As they fly in great flocks and keep close together, whether on the wing, on the ground, or in the trees, so poor a marksman as to fail to make a hit is difficult to find. Several persons told me that a man who lived at Schenectady, between Albany and Col. Johnson's farm, had killed 150 of these birds with two discharges of bird-shot, and in Canada there are said to have been several cases where 130 had been killed in a single shot.

Their flesh is a delight to the epicure, and especially is the meat of the young pigeons scarcely second in delicacy to that of any other bird.

The great French Admiral Marquis de la Galissoniere, who in deep knowledge of various sciences, but especially in natural history and its advancement, has had or has very few equals, and who at the time of my arrival in Canada occupied the office of Governor General of that country, told me that he had once brought with him several of these pigeons from Canada to France, and that he had allowed them to escape in the French forests. At this time he had again collected a great number of live birds which, in the fall of 1749, he brought with him to France, inclosed in large cages, in order to set them free in the woods upon his safe arrival there, with the intention of introducing this handsome as well as useful American bird into Europe.

In addition to the authors referred to above, the following learned men have also mentioned something in their writings concerning these pigeons: P. de Charlevoix, Histoire de la Nouvelle France, vol. 5, pp. 251-252; Salmon's Modern History, vol. 3, p. 440; Williams's Key into the Language of America, p. 91. Others whose works I have not had the opportunity of seeing may also have mentioned something concerning this subject, but they have at least related nothing of any particular value.

II.—THE PASSENGER PIGEON.

By John James Audubon (1831).[1]

The passenger pigeon, or, as it is usually named in America, the wild pigeon, moves with extreme rapidity, propelling itself by quickly repeated flaps of the wings, which it brings more or less near to the body, according to the degree of velocity which is required. Like the domestic pigeon, it often flies, during the love season, in a circling manner, supporting itself with both wings angularly elevated, in which position it keeps them until it is about to alight. Now and then, during these circular flights, the tips of the primary quills of each wing are made to strike against each other, producing a smart rap, which may be heard at a distance of 30 or 40 yards. Before alighting, the wild pigeon, like the Carolina parrot and a few other species of birds, breaks the force of its flight by repeated flappings, as if apprehensive of receiving injury from coming too suddenly into contact with the branch or the spot of ground on which it intends to settle.

I have commenced my description of this species with the above account of its flight, because the most important facts connected with its habits relate to its migrations. These are entirely owing to the necessity of procuring food, and are not performed with the view of escaping the severity of a northern latitude, or of seeking a southern

[1] Ornithological Biography, vol. 1, 1831, pp. 319-327.

one for the purpose of breeding. They consequently do not take place at any fixed period or season of the year. Indeed, it sometimes happens that a continuance of a sufficient supply of food in one district will keep these birds absent from another for years. I know, at least, to a certainty that in Kentucky they remained for several years constantly, and were nowhere else to be found. They all suddenly disappeared one season when the mast was exhausted, and did not return for a long period. Similar facts have been observed in other States.

Their great power of flight enables them to survey and pass over an astonishing extent of country in a very short time. This is proved by facts well known in America. Thus, pigeons have been killed in the neighborhood of New York, with their crops full of rice, which they must have collected in the fields of Georgia and Carolina, these districts being the nearest in which they could possibly have procured a supply of that kind of food. As their power of digestion is so great that they will decompose food entirely in 12 hours, they must in this case have traveled between 300 and 400 miles in 6 hours, which shows their speed to be at an average about 1 mile in a minute. A velocity such as this would enable one of these birds, were it so inclined, to visit the European Continent in less than three days.

This great power of flight is seconded by as great a power of vision, which enables them, as they travel at that swift rate, to inspect the country below, discover their food with facility, and thus attain the object for which their journey has been undertaken. This I have also proved to be the case, by having observed them, when passing over a sterile part of the country, or one scantily furnished with food suited to them, keep high in the air, flying with an extended front, so as to enable them to survey hundreds of acres at once. On the contrary, when the land is richly covered with food, or the trees abundantly hung with mast, they fly low, in order to discover the part most plentifully supplied.

Their body is of an elongated oval form, steered by a long well-plumed tail, and propelled by well-set wings, the muscles of which are very large and powerful for the size of the bird. When an individual is seen gliding through the woods and close to the observer, it passes like a thought, and on trying to see it again, the eye searches in vain; the bird is gone.

The multitudes of wild pigeons in our woods are astonishing. Indeed, after having viewed them so often, and under so many circumstances, I even now feel inclined to pause and assure myself that what I am going to relate is fact. Yet I have seen it all, and that too, in the company of persons who, like myself, were struck with amazement.

In the autumn of 1813, I left my house at Henderson, on the banks of the Ohio, on my way to Louisville. In passing over the Barrens, a few miles beyond Hardinsburg, I observed the pigeons flying from northeast to southwest in greater numbers than I thought I had ever seen them before, and feeling an inclination to count the flocks that might pass within the reach of my eye in one hour, I dismounted, seated myself on an eminence, and began to mark with my pencil, making a dot for every flock that passed. In a short time finding the task which I had undertaken impracticable, as the birds poured in in countless multitudes, I rose, and counting the dots then put down, found that 163 had been made in 21 minutes. I traveled on, and still met more the farther I proceeded. The air was literally filled with pigeons; the light of noonday was obscured as by an eclipse; the dung fell in spots, not unlike melting flakes of snow; and the continued buzz of wings had a tendency to lull my senses to repose.

Whilst waiting for dinner at Young's inn, at the confluence of Salt-River with the Ohio, I saw, at my leisure, immense legions still going by with a front reaching far beyond the Ohio on the west, and the beechwood forests directly on the east of me. Not a single bird alighted; for not a nut or acorn was that year to be seen in the neighborhood. They consequently flew so high, that different trials to reach them with a capital rifle proved ineffectual; nor did the reports disturb them in the least. I can not describe to you the extreme beauty of their aerial evolutions, when a hawk chanced to press upon the rear of a flock. At once, like a torrent, and with a noise like thunder, they rushed into a compact mass, pressing upon each other toward the center. In these almost solid masses, they darted forward in undulating and angular lines, descended and swept close over the earth with inconceivable velocity, mounted perpendicularly so as to resemble a vast column, and, when high, were seen wheeling and twisting within their continued lines, which then resembled the coils of a gigantic serpent.

Before sunset I reached Louisville, distant from Hardinsburg 55 miles. The pigeons were still passing in undiminished numbers, and continued to do so for three days in succession. The people were all in arms. The banks of the Ohio were crowded with men and boys, incessantly shooting at the pilgrims, which there flew lower as they passed the river. Multitudes were thus destroyed. For a week or more, the population fed on no other flesh than that of pigeons, and talked of nothing but pigeons. The atmosphere, during this time, was strongly impregnated with the peculiar odor which emanates from the species.

It is extremely interesting to see flock after flock performing exactly the same evolutions which had been traced, as it were, in the air by a preceding flock. Thus, should a hawk have charged on a group at a certain spot, the angles, curves, and undulations that have been

described by the birds, in their efforts to escape from the dreaded talons of the plunderer, are undeviatingly followed by the next group that comes up. Should the bystander happen to witness one of these affrays, and, struck with the rapidity and elegance of the motions exhibited, feel desirous of seeing them repeated, his wishes will be gratified if he only remain in the place until the next group comes up.

It may not, perhaps, be out of place to attempt an estimate of the number of pigeons contained in one of those mighty flocks, and of the quantity of food daily consumed by its members. The inquiry will tend to show the astonishing bounty of the great Author of Nature in providing for the wants of His creatures. Let us take a column of 1 mile in breadth, which is far below the average size, and suppose it passing over us without interruption for three hours, at the rate mentioned above of 1 mile in the minute. This will give us a parallelogram of 180 miles by 1, covering 180 square miles. Allowing 2 pigeons to the square yard, we have 1,115,136,000 pigeons in one flock. As every pigeon daily consumes fully half a pint of food, the quantity necessary for supplying this vast multitude must be 8,712,000 bushels per day.

As soon as the pigeons discover a sufficiency of food to entice them to alight, they fly round in circles, reviewing the country below. During their evolutions, on such occasions, the dense mass which they form exhibits a beautiful appearance, as it changes its direction, now displaying a glistening sheet of azure, when the backs of the birds come simultaneously into view, and anon, suddenly presenting a mass of rich deep purple. They then pass lower, over the woods, and for a moment are lost among the foliage, but again emerge, and are seen gliding aloft. They now alight, but the next moment, as if suddenly alarmed, they take to wing, producing by the flappings of their wings a noise like the roar of distant thunder, and sweep through the forests to see if danger is near. Hunger, however, soon brings them to the ground. When alighted, they are seen industriously throwing up the withered leaves in quest of the fallen mast. The rear ranks are continually rising, passing over the main body, and alighting in front, in such rapid succession, that the whole flock seems still on the wing. The quantity of ground thus swept is astonishing, and so completely has it been cleared, that the gleaner who might follow in their rear would find his labor completely lost. Whilst feeding, their avidity is at times so great that in attempting to swallow a large acorn or nut they are seen gasping for a long while, as if in the agonies of suffocation.

On such occasions, when the woods are filled with these pigeons, they are killed in immense numbers, although no apparent diminution ensues. About the middle of the day, after their repast is finished,

they settle on the trees, to enjoy rest, and digest their food. On the ground they walk with ease, as well as on the branches, frequently jerking their beautiful tail, and moving the neck backward and forward in the most graceful manner. As the sun begins to sink beneath the horizon, they depart en masse for the roosting place, which not unfrequently is hundreds of miles distant, as has been ascertained by persons who have kept an account of their arrivals and departures.

Let us now, kind reader, inspect their place of nightly rendezvous. One of these curious roosting places, on the banks of the Green River in Kentucky, I repeatedly visited. It was, as is always the case, in a portion of the forest where the trees were of great magnitude, and where there was little underwood. I rode through it upward of 40 miles, and, crossing it in different parts, found its average breadth to be rather more than 3 miles. My first view of it was about a fortnight subsequent to the period when they had made choice of it, and I arrived there nearly two hours before sunset. Few pigeons were then to be seen, but a great number of persons, with horses and wagons, guns and ammunition, had already established encampments on the borders. Two farmers from the vicinity of Russellville, distant more than 100 miles, had driven upward of 300 hogs to be fattened on the pigeons which were to be slaughtered. Here and there, the people employed in plucking and salting what had already been procured, were seen sitting in the midst of large piles of these birds. The dung lay several inches deep, covering the whole extent of the roosting place, like a bed of snow. Many trees 2 feet in diameter, I observed, were broken off at no great distance from the ground, and the branches of many of the largest and tallest had given way, as if the forest had been swept by a tornado. Everything proved to me that the number of birds resorting to this part of the forest must be immense beyond conception. As the period of their arrival approached, their foes anxiously prepared to receive them. Some were furnished with iron pots containing sulphur, others with torches of pine knots, many with poles, and the rest with guns. The sun was lost to our view, yet not a pigeon had arrived. Everything was ready, and all eyes were gazing on the clear sky, which appeared in glimpses amidst the tall trees. Suddenly there burst forth a general cry of "Here they come!" The noise which they made, though yet distant, reminded me of a hard gale at sea passing through the rigging of a close-reefed vessel. As the birds arrived, and passed over me, I felt a current of air that surprised me. Thousands were soon knocked down by the pole men. The birds continued to pour in. The fires were lighted, and a magnificent, as well as wonderful and almost terrifying sight presented itself. The pigeons, arriving by thousands, alighted everywhere, one above another, until solid

masses as large as hogsheads, were formed on the branches all round. Here and there the perches gave way under the weight with a crash, and falling to the ground, destroyed hundreds of the birds beneath, forcing down the dense groups with which every stick was loaded. It was a scene of uproar and confusion. I found it quite useless to speak, or even to shout to those persons who were nearest to me. Even the reports of the guns were seldom heard, and I was made aware of the firing only by seeing the shooters reloading.

No one dared venture within the line of devastation. The hogs had been penned up in due time, the picking up of the dead and wounded being left for the next morning's employment. The pigeons were constantly coming, and it was past midnight before I perceived a decrease in the number of those that arrived. The uproar continued the whole night, and as I was anxious to know to what distance the sound reached, I sent off a man accustomed to perambulate the forest, who, returning two hours afterwards, informed me he had heard it distinctly when 3 miles from the spot. Toward the approach of day, the noise in some measure subsided; long before objects were distinguishable, the pigeons began to move off in a direction quite different from that in which they had arrived the evening before, and at sunrise all that were able to fly had disappeared. The howlings of the wolves now reached our ears, and the foxes, lynxes, cougars, bears, raccoons, opossums and polecats were seen sneaking off, whilst eagles and hawks of different species, accompanied by a crowd of vultures, came to supplant them, and enjoy their share of the spoil.

It was then that the authors of all this devastation began their entry amongst the dead, the dying, and the mangled. The pigeons were picked up and piled in heaps, until each had as many as he could possibly dispose of, when the hogs were let loose to feed on the remainder.

Persons unacquainted with these birds might naturally conclude that such dreadful havoc would soon put an end to the species. But I have satisfied myself, by long observation, that nothing but the gradual diminution of our forests can accomplish their decrease, as they not unfrequently quadruple their numbers yearly, and always at least double it. In 1805 I saw schooners loaded in bulk with pigeons caught up the Hudson River, coming into the wharf at New York, when the birds sold for a cent a piece. I knew a man in Pennsylvania who caught and killed upward of 500 dozens in a clapnet in one day, sweeping sometimes 20 dozens or more at a single haul. In the month of March, 1830, they were so abundant in the markets of New York, that piles of them met the eye in every direction. I have seen the negroes at the United States salines, or salt works of Shawneetown, wearied with killing pigeons, as they alighted to drink the water issuing from the leading pipes, for weeks at a time; and yet, in 1826,

in Louisiana, I saw congregated flocks of these birds as numerous as ever I had seen them before, during a residence of nearly 30 years in the United States.

The breeding of the wild pigeons, and the places chosen for that purpose are points of great interest. The time is not much influenced by season, and the place selected is where food is most plentiful and most attainable, and always at a convenient distance from water. Forest trees of great height are those in which the pigeons form their nests. Thither the countless myriads resort, and prepare to fulfill one of the great laws of nature. At this period the note of the pigeon is a soft coo-coo-coo-coo, much shorter than that of the domestic species. The common notes resemble the monosyllables kee-kee-kee-kee, the first being the loudest, the others gradually diminishing in power. The male assumes a pompous demeanor, and follows the female whether on the ground or on the branches, with spread tail and drooping wings, which it rubs against the part over which it is moving. The body is elevated, the throat swells, the eyes sparkle. He continues his notes and now and then rises on the wing, and flies a few yards to approach the fugitive and timorous female. Like the domestic pigeon and other species, they caress each other by billing, in which action, the bill of the one is introduced transversely into that of the other, and both parties alternately disgorge the contents of their crop by repeated efforts. These preliminary affairs are soon settled, and the pigeons commence their nests in general peace and harmony. They are composed of a few dry twigs, crossing each other, and are supported by forks of the branches. On the same tree from 50 to 100 nests may frequently be seen: I might say a much greater number were I not anxious, kind reader, that however wonderful my account of the wild pigeon is, you may not feel disposed to refer it to the marvelous. The eggs are two [1] in number, of a broadly elliptical form, and pure white. During incubation, the male supplies the female with food. Indeed, the tenderness and affection displayed by these birds toward their mates, are in the highest degree striking. It is a remarkable fact, that each brood generally consists of a male and a female.

Here, again, the tyrant of the creation, man, interferes, disturbing the harmony of this peaceful scene. As the younger birds grow up, their enemies, armed with axes, reach the spot, to seize and destroy all they can. The trees are felled, and made to fall in such a way that the cutting of one causes the overthrow of another, or shakes the neighboring trees so much, that the young pigeons, or squabs, as they are named, are violently hurled to the ground. In this manner also, immense quantities are destroyed.

The young are fed by the parents in the manner described above; in other words, the old bird introduces its bill into the mouth of the

[1] Later observers report that in fully half the nests only one egg was deposited.—Ed.

young one in a transverse manner, or with the back of each mandible opposite the separations of the mandibles of the young bird, and disgorges the contents of its crop. As soon as the young birds are able to shift for themselves, they leave their parents and continue separate until they attain maturity. By the end of six months they are capable of reproducing their species.

The flesh of the wild pigeon is of a dark color, but affords tolerable eating. That of young birds from the nest is much esteemed. The skin is covered with small white, filmy scales. The feathers fall off at the least touch, as has been remarked to be the case in the Carolina turtle.[1] I have only to add that this species, like others of the same genus, immerses its head up to the eyes while drinking.

In March, 1830, I bought about 350 of these birds in the market of New York at 4 cents a piece. Most of these I carried alive to England, and distributed amongst several noblemen, presenting some at the same time to the zoological society.

Adult male: Bill straight, of ordinary length, rather slender, broader than deep at the base, with a tumid fleshy covering above, compressed toward the end, rather obtuse; upper mandible slightly declinate at the tip; edges inflected. Head small, neck slender, body rather full. Legs short and strong; tarsus rather rounded, anteriorly scutellate; toes slightly webbed at the base; claws short, depressed, obtuse.

Plumage blended on the neck and under parts, compact on the back. Wings long, the second quill longest. Tail graduated, of 12 tapering feathers.

Bill black. Iris bright red. Feet carmine purple, claws blackish. Head above and on the sides light blue. Throat, fore neck, breast, and sides light brownish-red, the rest of the under parts white. Lower part of the neck behind, and along the sides, changing to gold, emerald green, and rich crimson. The general color of the upper parts is grayish blue, some of the wing coverts marked with a black spot. Quills and larger wing coverts blackish, the primary quills bluish on the outer web, the larger coverts whitish at the tip. The two middle feathers of the tail black, the rest pale blue at the base, becoming white toward the end.

Length $16\frac{1}{2}$ inches; extent of wings 25; bill along the ridge $\frac{5}{8}$; along the gap $1\frac{1}{12}$; tarsus $1\frac{1}{4}$; middle toe $1\frac{1}{2}$.

The colors of the female are much duller than those of the male, although their distribution is the same. The breast is light grayish-brown, the upper parts pale reddish-brown, tinged with blue. The changeable spot on the neck is of less extent, and the eye of a somewhat duller red, as are the feet.

Length 15 inches; extent of wings 23; bill along the ridge $\frac{3}{4}$; along the gap $\frac{7}{8}$.

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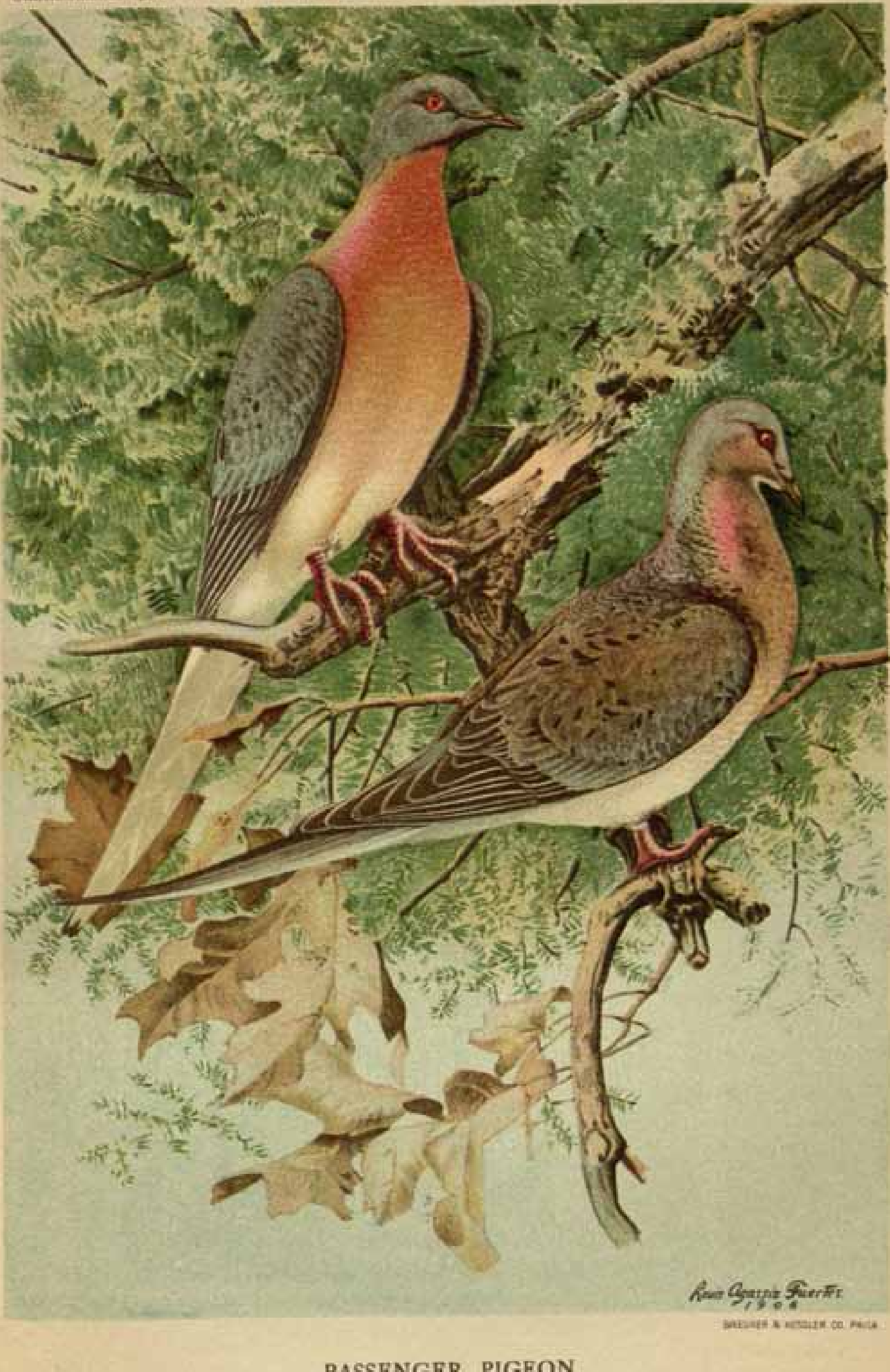
[1] Now called the mourning dove.—Ed.



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PASSENGER PIGEON

(Courtesy of W. B. Mershon)

NOTE ON THE IRIDESCENT COLORS OF BIRDS AND INSECTS.[1]

[With 3 plates.]

By A. MALLOCK, F. R. S.

Considerable interest attaches to the origin of certain forms of brilliant coloring which are of frequent occurrence in the animal world, though hardly represented among plants.[2] The colors in question are those which are not due to ordinary pigment, and which change with the angle of incidence of the light. The most brilliant examples are to be found amongst birds and insects. Fishes, and a few reptiles, exhibit colors of the same kind, but not so conspicuously.

During the last 10 or 12 years I have examined some hundreds of cases of this sort of color production, and quite recently Michelson [3] has published investigations on the same subject, and refers to a somewhat similar paper by Walter, "Oberflächen und Schillerfarben," dated 1895, of the existence of which I was not before aware.

The conclusions of these authors are that the colors in question are, in most cases, due to selective reflection from an intensely opaque material, and, in some few, to diffraction from a finely striated surface. Their reasons for adopting the hypothesis of selective reflection rather than interference are the close similarities as regards the reflection of polarized light found between the natural iridescent colors and dry films of aniline dyes.

In the present note I give some reasons for the belief that in the majority of cases interference of some sort is the active cause, although in others the possibility of selective reflection is not excluded. The question really turns on the size of the "grain" of the color-producing structure. Is it comparable with the wave length of light or of molecular dimensions?

If the colors are due to interference, the first supposition must be true; but if selective reflection is the agent, a comparatively small

[1] Reprinted by permission from Proceedings of The Royal Society, London, Series A, vol.85, No. A 582, Nov. 30, 1911, pp. 598-605. (Received by the society Sept. 12; read Nov. 2, 1911.)

[2] Some Lycopodiums exhibit traces of iridescent color.

[3] "Metallic coloring in birds and insects," Phil. Mag., April, 1911.

group of molecules may cause selective reflection. It seems clear that this property can not belong to individual molecules, at any rate in the case of the aniline dyes, for their solutions absorb impartially all the colors which are not transmitted, and it is only in the solid state that their peculiarities as regards reflected light become apparent; at the same time there is no change in the light transmitted whether the dye is in solution or a dry film.

Before entering in detail into the reasons which seem to point to interference rather than selective reflection as the origin of iridescent colors, some general remarks may be made on the character of the structures examined.

These structures have been either feathers of birds or the scales of insects. There are few orders of birds in which examples of iridescent coloring can not be found, but without doubt the humming birds are the most brilliant, although peacocks, trogons, and many others are not very far inferior. In the insect world the finest examples are to be found amongst butterflies and the day-flying moths of the genus Urania. Some beetles also are provided with vividly colored scales. These belong mostly to the weevils (which include the Brazilian diamond beetle).

Many other insects among the Diptera, Neuroptera, and Hymenoptera show brilliant metallic colors on their integuments, but these are not provided with scales, and in many cases the color fades more or less when the specimens become dry. These I have not examined. Feathers and scales, however, are remarkable for the permanence of their iridescent coloring, and it is to these only that the present observations apply.

Some of the peculiarities of the structures as regards change of color with the point of view depend on the shape of the surface on which the color-producing material lies. If the surfaces are flat or nearly flat, reflection takes place as from a looking glass, and the angle through which the specimen can be turned while still showing the characteristic color is small. Often, however, the surfaces are convex bosses or ridges, and then the angle of incidence and reflection is that contained between the direction of the incident light and the normal to the tangent plane at the point where reflection takes place, and is therefore to a great extent independent of the position in which the specimen is held, since there will always, within wide limits, be tangent planes to the convex surfaces which reflect the incident light in the line of sight. In these cases the colors might at first sight be taken as due to pigment, both on account of their comparatively low intensity and from the small change in tint and intensity which is produced by altering the inclination of the general surface to the direction of the illumination. The

low intensity is of course due to the small area of each convex surface which reflects light in any given direction.

In attempting to investigate the origin of the colors many methods were employed, the first and most obvious being to cut thin sections normal to the color-producing surface and then to examine them with the highest microscopic power available. If the colors are analogous to those of thin plates, it is clear from the high intensity of the reflected light that more than one pair of surfaces must cooperate in the reflection. In general the reflected light is not even approximately monochromatic, and this fact limits the number of surfaces which can be supposed to act, but if the surfaces are supposed to be separated by air and placed at the most favorable intervals their number need not exceed three or four to account for the observed intensity and tints.

The most favorable spacing for the successive layers is that their thickness and the intervals between them should be a multiple of the half wave-length of the mean ray, reckoned in the length of the waves within the material of the layer, and it was thought possible that the thin sections might show a laminated structure.

For the material of feathers and insects' scales, μ is somewhere about 1.5 or 1.6, so that the least thickness for the plates of refractive material would be of the order of one one-hundred-and-fifty-thousandth and the air intervals one one-hundred-thousandth of an inch—both beyond the resolving power of the microscope; but from the composition of the reflected light it seemed likely that the intervals might be two or three half wave-lengths, which would be readily seen as far as adequate separation of the images is concerned. In nearly all the sections examined bands of this order of thickness appeared with some forms of illumination, but it was impossible to be sure that they were not due to diffraction effects from parts of the section slightly out of focus.

There are many difficulties in preparing sections thin enough for the advantageous use of objectives with large angular aperture. When a section is to show a stratified structure its thickness should certainly not be greater than the distance between the successive strata, and may with advantage be much less. It was not difficult to cut sections about one twenty-thousandth of an inch thick, but this is three or four times too thick to show with certainty stratification whose pitch is one sixty-thousandth or less.

Occasionally, by accident, thinner sections (perhaps one forty-thousandth) would be cut, and these showed apparent stratification most plainly, but in no case was the image free from the effect caused by some part of the thickness of the section being out of focus, and, in all probability, what appeared to be stratification was in reality a series

of diffraction bands. Insufficient thinness, however, is by no means the only obstacle to resolving the grain in the structure.

Thin sections are in general very transparent, and the only source of variation of intensity in the image formed by the microscope depends on the varying amount of retardation affecting the waves which traverse their different parts, that is (since the section is of uniform thickness) on differences of refractive index; but, in order to view such sections at all, it is necessary to mount them in some refractive medium, and this greatly reduces the chance of detecting a fine-grained structure.

I have tried washing out the bedding material and examining the sections when dry, but, although great care was taken in keeping the cutting edge of the knife smooth and sharp, striæ always appeared in the direction of the cut, which quite obscured the real structure. The fact is, that there are a very few objects on which the highest microscopic powers can be used with advantage. Even the test diatom, *A. pellucida*, which, of course, has to be mounted dry, or in a medium whose refractive index greatly exceeds that of silica, is too thick to give a satisfactory image, and small solids, whose dimensions are less than a wave length, give images which are not their enlarged geometrical outlines, but phenomena depending on the wave length.

Although the microscope, in my hands, at any rate, has failed to give direct evidence of a "periodic" structure, other tests point strongly to "interference" as the origin of the colors.

In some cases the color-producing film is backed by an extremely opaque layer, and in others the whole of the structure is transparent, and transmits the complementary color with nearly the same intensity as the color reflected. Even where there is an opaque backing, this is often thin enough to allow of examination by strong transmitted light, and the prevailing color is a brown, tinged with the unabsorbed complementary to the color reflected. These opaque backings are present in most feathers and in some insect scales, but in the majority of cases the scales of insects are transparent.

Both theory and observation show that, when the reflected color depends on interference the tint will change toward the blue as the angle of incidence increases, so that reds become yellows, yellows change to greens, and greens to blues, and also that if the color-producing structure is immersed in a refractive fluid instead of air the reflected color will change toward red and have its intensity reduced. Two causes are operative in producing this change: In the first place, if the color-producing film is protected from the fluid by an impermeable outer layer with which it is in optical contact the only effect of the fluid is to diminish the angle of incidence of a ray of given obliquity in air, so that the color reflected is that due to the smaller angle of incidence. Secondly, if the fluid penetrates the layers in

which interference takes place, the interval between the layers, now reckoned in wave lengths in the refractive fluid, is increased, and therefore also the wave length which is reflected for a given angle of incidence. At the same time the intensity of the reflected light is greatly reduced, and if the fluid has the same refractive index as the structure itself, reflection ceases and nearly white light is transmitted.[1]

Observation of reflection from films of aniline dyes, etc., shows that the color changes in the same direction—that is, toward the blue—as the angle of incidence increases, but as regards the character of the change when the film is covered by a refractive fluid there is a great difference.

In some cases (methylene green, for instance) for one particular angle of incidence the color reflected in air is unchanged when the film is covered with cedar oil, for smaller angles of incidence the reflected light is of shorter average wave length, and for greater angles longer than that of the color in air.

For this particular dye the color reflected in air is a very red-purple at small angles of incidence, changing to bluish-green when the angle is large.

Under cedar oil the colors are respectively greenish-yellow and an orange-yellow. The transmitted color, however, does not change perceptibly either with the angle of incidence or with the medium in which reflection takes place, and this applies, as far as my observation goes, to all substances which give selective metallic reflection.

The transparency, or at any rate the vanishing of the characteristic transmitted color in the case of all animal tissues when immersed and permeated by a fluid of the same refractive index, is strongly in favor of interference being the source of the color, but even stronger evidence is given by the behavior of the structure under mechanical pressure.

If the grain or peculiarities which favor the reflection or transmission of particular colors is of molecular size, there is no reason to suppose that pressure insufficient to cause molecular disruption would alter the action of the material on light. On the other hand, if the colors are due to interference—that is, to cavities or strata of different optical properties—compression would alter the spacing of these, and thus give rise either to different colors or, with more than a very slight compression, to the transmission and reflection of white light.

In every experiment of this kind which I have made either on feathers or insect scales the effect of pressure has been to destroy the color altogether.

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[1] The dispersion of the fluid, as well as the refractive index, must be the same as that of the structure if the transmitted light is white.

Where the scales are transparent, white light is transmitted, but with feathers, where the color film is generally backed by dark pigment, the pigment color appears untinged with the complementary to the color naturally reflected.

With many feathers the color returns when the pressure is taken off, but with insect scales the structure seems to be permanently injured by compression, and though when allowed to expand again the material is not colorless the brilliancy which belonged to the uninjured scale is gone, and the color in general changed.

The facts above mentioned seem to offer stronger reasons in favor of interference than the polarization phenomena referred to by Michelson and Walter[1] do against it.

The ellipticity, etc., found in the reflected beams may, although functions of the wave length, accompany the production of color without being necessary to it—that is, they may depend on the molecular, while the colors depend on the mechanical structure.

All Lepidopterous scales, whether colored by pigment or giving metallic reflection, are traversed by a series of fine lines or dots arranged in lines and very evenly spaced, and the universality of these lines on all such scales, whether with or without color, is a good reason for not regarding diffraction as an explanation of the metallic colors.

In many insects these lines are as close as 36,000 to 40,000 per inch, and when light is transmitted through a single scale or a few scales placed side by side very fine diffraction spectra are formed, but no corresponding effect is seen by reflection, what effect there may be being masked by the other form of color production.

The beetle scales which I have examined were, as a rule, without linear markings, and where lines existed they were not very regular. The surface was always mapped out into unequal polygonal areas, and cross sections (pl. 2, figs. 5a, 5b) showed that the scale consisted of a flattened sac of transparent material containing a cellular structure in which the color originated.

When an unbroken scale is immersed in cedar oil, the outer walls prevent the fluid reaching the color-producing layer and but little change results either in the reflected or transmitted light; but when the scale is broken or has a piece cut off the oil penetrates the interior and all trace of color disappears.

Occasionally when a viscous fluid is employed the penetration is not complete and the character of the cellular layer is then indicated by the parts which still show color.

Figures 1 to 4, plates 1, 2, illustrate this. Figure 1 is an unbroken scale of *Entimus imperialis* showing the polygonal areas. Figure 2

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[1] Polarized light should be used for this observation.

shows the same scale partly penetrated by a solution of celluloid in amyl acetate; figure 3, ditto (in which the penetration is not so complete) more highly magnified; figure 4, three scales completely penetrated and quite colorless. Figures 5a and 5b are cross sections of the scale (thickness of section about one twenty-thousandth of an inch).

Feathers are impermeable to most fluids, but when acted on by acid (nitric, acetic, or hydrochloric) they change color toward the red; after washing and drying, however, they regain their original tint.

The subjects from which the above notes have been made include among birds various species of hummingbirds, peacocks and pheasants, sunbirds, trogons, and others; among Lepidoptera, the genera Euplœa, Morpho, Calligo, Argynnis (in which silver markings are common), Vanessa, Callicore, Lycæna, Thecla, Papilio, Ornithoptera, some of the Hesperidæ and moths of the genus Urania. The only beetles examined were *Entimus imperialis* and two species of Cyphus.

To the physicist who is also a naturalist the great variety in the character of the surfaces on which these metallic colors are developed, as well as the beauty and brilliancy of the colors themselves, offers matter of exceptional interest, but it would occupy too much space to enter here into a detailed description of even the typical forms.

A rather curious fact, however, may be mentioned with regard to the scales of Lepidoptera. Nearly all such scales when black or colored by pigment have the free end deeply scalloped and presenting what may be called an ornamental outline, but the scales which show metallic reflections are invariably (as far as my observation goes) merely rounded off or have very slight indentations. Figures 6 and 7, plate 3 (which are respectively colored and black scales from *Ornithoptera Poseidon*), illustrate the difference.

Although all the colors referred to in these notes are probably the result of interference, the ways in which the interference occurs may be very various. Feathers by their behavior suggest an action analogous to that of a Lippmann film, but it is difficult to imagine matter optically dense enough to behave as the silver particles in the film being produced in an organic structure. In most of the scales it seems that the interfering rays are reflected from the surfaces of very thin flat cells, but it is possible that in some cases the effect may be due to reflection from a single dimpled surface. The colored central images sometimes given by diffraction gratings are examples of this sort of interference, but in order that the colors so formed should be as brilliant as possible the depressions or dimples should be closely but irregularly distributed over the surface (if regular much of the light goes in lateral spectra), but of uniform depth and section. I have succeeded in making colored rings of some

brilliancy by holding a piece of glass over the smoke of an arc formed between metal electrodes, iron, nickel, silver, and copper being used. In the most successful trials the rings were brighter than the colors of soap films, and, as might be expected, the intensity of the color increased with the angle of incidence, but the rings did not show with normal reflection nor until the incidence exceeded 30°.

In the spectroscopic examination of the color, it was found convenient to focus the much enlarged image of the surface on the slit of the spectroscope. By this means, and using the sun or an arc lamp, there was sufficient light to show the spectrum from a small part of a single scale.

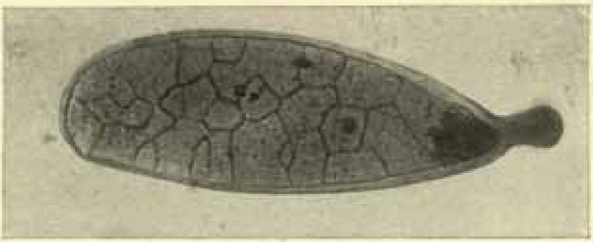
When cutting thin sections of chitin or feathers, it is important that the embedding material should be of the same consistence and hardness as the object to be cut. For this purpose shellac gave the best results. The hardness could be regulated by the time allowed for drying.

The compression tests were carried out by placing the specimens on a slide under a convex lens of about a foot radius. The objects compressed were generally thin enough to allow of the Newton rings of the higher orders being recognized between the lens and slide before any compression occurred, and by centering the object in these the pressure could be applied in the right place.

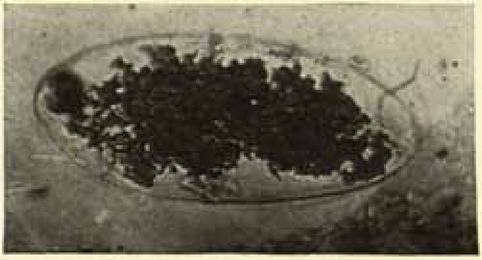
Since writing the above I have examined the colors of some of the iridescent Diptera (chiefly of the genus Lucilia), using the pressure apparatus. It was found that with them, as with the scales and feathers, the color disappeared under compression, and it seems probable, therefore, that interference of one kind or another is the true cause of natural iridescent color in all cases. It may be remarked that the intensity and composition of the light reflected from the integument of the flies is such as would be accounted for by the interference of a single film or pair of surfaces.

DESCRIPTION OF PLATES

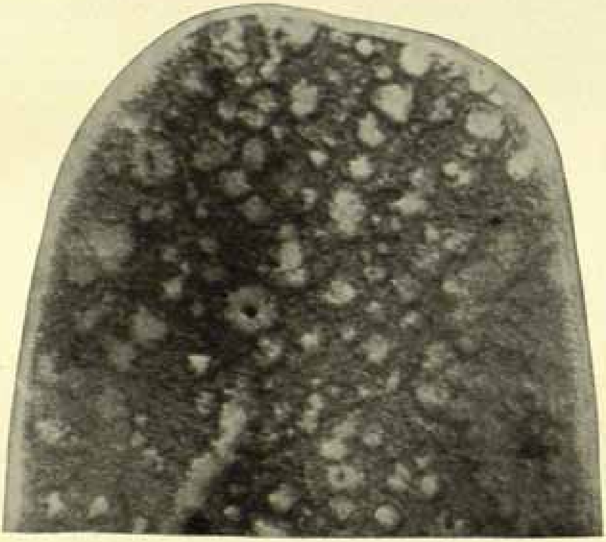
Fig. 1.—Scale of *Entimus imperialis*. × 490.
2.—The same partly permeated with celluloid solution. × 490.
3.—The same. × 1750.
4.—Three scales of same completely permeated. × 490.
5.—Cross section of scale. × 1750.
6.—Iridescent scale of *Ornithoptera Poseidon*. × 1170.
7.—Black scale of same. × 1170.



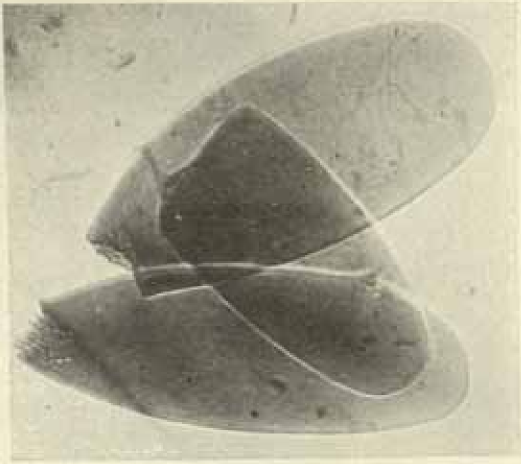
1. SCALE OF ENTIMUS IMPERIALIS, × 490.



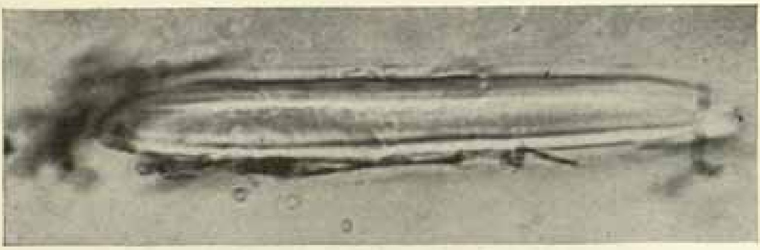
2. THE SAME PARTLY PERMEATED WITH CELLULOID SOLUTION, × 490.



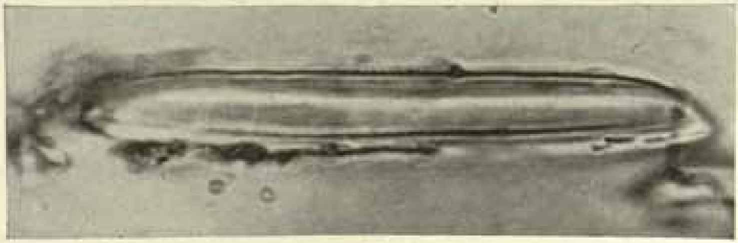
3. THE SAME, × 1750.



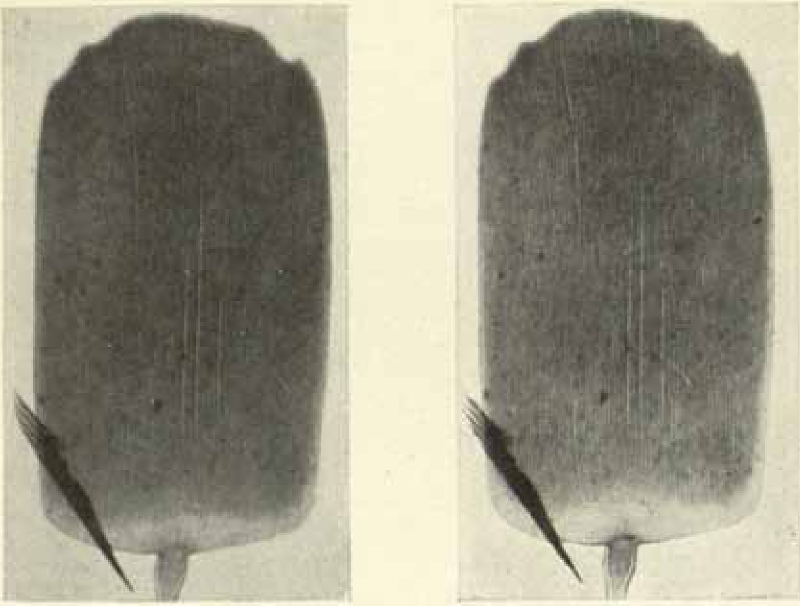
4. THREE SCALES OF ENTIMUS IMPERIALIS COMPLETELY PERMEATED, × 490.



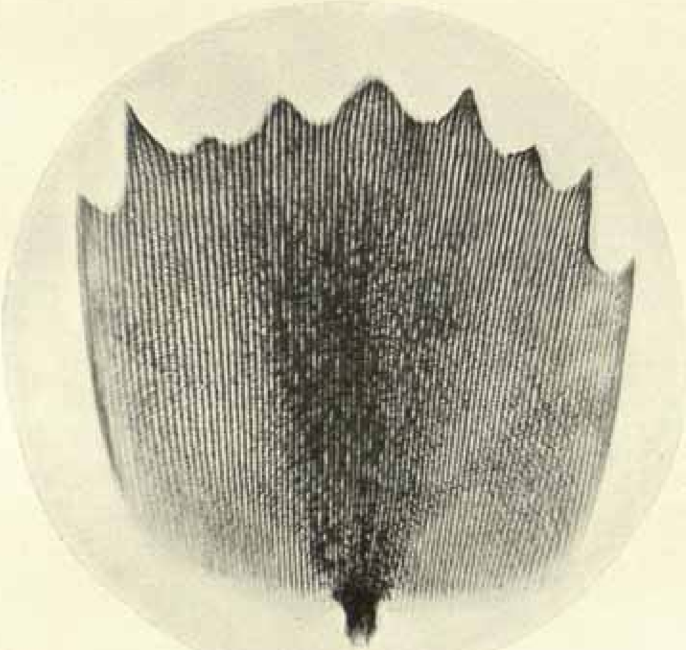
5a. CROSS SECTION OF SCALE, × 1750.



5b. CROSS SECTION OF SCALE, × 1750.



6. IRIDESCENT SCALES OF ORNITHOPTERA POSEIDON, × 1170.



7. BLACK SCALE OF SAME, × 1170.

ON THE POSITIONS ASSUMED BY BIRDS IN FLIGHT.[1]

[With 8 plates.]

By Bentley Beetham, F. Z. S.

I.—STARTING.

The flight of birds must ever remain a source of interest and inspiration to man, for should he eventually master aerial as successfully as he has terrestrial locomotion, birds would, by reason of their inherent sensibility to gauge the varying aircurrents, still remain vastly his superior in the art, if not in actual pace at least in the finer manipulations.

But whether we regard flight from the standpoint of the ornithologist or the aviator, the actions of these naturally equipped performers can not be too closely regarded.

The great difficulty met with in studying the flight of birds is the indefinite and almost inexpressible nature of much of our observation. We see a bird make a sudden turn or falter in its course; a little thing, yet even if we could analyze its actions, which is improbable, it would take a page or two of writing before we could be sure that another would understand the positions and actions as we saw them. In our present lack of intimacy with the subject words are quite inefficient, and we must largely rely on pictures, photographs by preference, wherewith to record our observations.

The slower and individual movements of the wings and tails of such large birds as herons, gulls, or eagles, are easy to perceive, and in many cases their object or result can be appreciated, if only one can get close enough. Unfortunately, however, our near glimpses of large birds on the wing are usually but momentary, and it is only by piecing together little isolated scraps of observation that we can get a consecutive idea of what has taken place. Often the combination of our eyes and brain is far too slow to analyze and follow the different movements, and the only impression the mind receives is one of rapid beating motion, as is so noticeable in the flight of bees and

[1] Reprinted by permission from British Birds, Witherby & Co., London, vol. 4, June, 1910–May, 1911, pp. 162–168, 198–203, 350–356.

other insects. Too often is this the case when trying to follow the flight of some small bird, the beating of the little wings being quite too rapid for our senses. We will here confine ourselves to those birds possessed of ample expanse of wing, for, generally speaking, the larger the wing the less rapid is the beating, and therefore the more easily can we follow its movements.

To gain the velocity in order to create the resistance necessary for the support of all heavier-than-air "machines," some birds run or swim, others simply spring into the air and by the vigor of their flapping achieve the same result; while others, again, launch themselves from some coign of vantage—a tree or rock—and in falling gain the desired resistance. In this article I give some particulars regarding the latter method, illustrated by photographs of the Gannet (*Sula bassana*).

Stepping to the cliff edge, and, if there is no cause for undue haste, having raised and partly unfolded its wings, the bird prepares to dive into space. This dive, it should be noted, is not directed downward, but rather as horizontally outward from the cliff as may be (sometimes it appears to have even an upward tendency). If the bird is one possessed of broad large wings not much altitude is lost, and it skims through the air in much the same fashion as does a piece of cardboard thrown horizontally. If, however, as in the case of auks, the wings are small and narrow and the body heavy, then the bird at first drops nearly vertically, only being able to gain a more horizontal course as its velocity increases.

Sometimes birds of this latter class, presumably through misjudgment of the space they have to work in, do not get the horizontal course in time, and crash into the rocks or sea at the foot of the cliff. This is very noticeable when a group of puffins (*Fratercula arctica*) hurriedly takes flight from a steep bowlder-strewn slope. Under these circumstances I have frequently seen quite a number of birds come to grief on the rocks within 30 yards of starting. Most of these, though somewhat dazed by the impact, flutter and claw their way on to the top of some big bowlder, and after a moment's pause again dive forth, but not infrequently with no better result. The first failure is, I believe, often caused by their paying too much attention to and looking behind at whatever startled them, instead of gauging their proper angle.

The raising and unfolding of the wings is worthy of a little consideration. The former usually takes place not after, but previous to, the diving or springing forward, while generally the whole "foot" is at rest upon the rock. Of course, when suddenly alarmed birds sometimes cast themselves from the cliff without first raising their wings, and in consequence fall rapidly.

In plate 1, figure 1, the gannet has not even risen to its feet prior to lifting the wings, but is sitting on the edge of the nest. The apparent leg supporting it on the near side is a delusion, for instead of being the metatarsus, as it seems, it is really the closed webbed toes hanging downward from the raised and hidden leg, only the claws really touching the nest. The reason for this peculiar position is the newly-hatched chick, hardly discernible, lying in the nest, which would inevitably have been crushed had the bird rested on its expanded foot.

This raising of the wings preparatory to diving forth is perhaps more convincingly shown in figure 2, as the photograph is taken from a point on the same level as the bird, and shows the wings held up far above the bird's head. This picture, as also figure 1, embraces another and more important point—that the unfolding or straightening of the wing takes place, if again there is no extreme haste, subsequent to the raising. This especially refers to the pinion.

It will be noticed that although the humeri are raised almost to meeting above the back (pl. 1, fig. 2) the ulnæ are not fully extended and in line with them, while the pinions are little divergent from the latter, still making an acute angle with them. Casually one might have expected that, had there been any precedence, the pinion being the most important factor, would have been the first to assume the position requisite for flight, but if these two photographs be carefully examined the reverse appears to be the case. In short, it may be said that the unfolding of the units of the wing seems to be sequential, starting with the humerus, and not simultaneous.

This is, I fear, directly at variance with the writings of many leading ornithologists and anatomists, and I can only put forward the photographs in support of my observations. Undoubtedly the arrangement and articulation of the wing-bones appear to indicate that the unfolding will take place mechanically throughout on any one part being extended, but laboratory theories, however much they may be upheld by inanimate evidence, can not pass unchallenged when they are found to be in apparent contradiction to observation of the living action supported by corroborative photographs.

In plate 2, figure 1 shows the bird at the very moment it is diving from the cliff, only the tips of its toes touching the rock, and it will be noticed, as intimated before, that the slope of the body is strongly upward. The wings have not even yet been fully straightened. This final unfolding and stiffening appears, so far as I can ascertain, to take place at the very moment of departure, and had this photograph been taken a minute fraction of a second later it would no

doubt have revealed the wings as fully extended as in figure 2.[1] Here the wings are just beginning to feel the weight of what they are to support and are commencing their first downward beat. And now, though it has only traveled a few inches from the rock and the feet have not yet been tucked away under the tail, the gannet is fairly on the wing, exasperatingly able and wishful to go beyond the range of our lens or even of our observation.

II.—STEERING, SLOWING-UP, AND TURNING.

The old idea that the wings of a bird simply flap up and down, and that by some means the body travels steadily along on a level horizontal course, has long been dispensed with. It is, however, difficult to realize, but none the less true, that at each full wing beat the body is raised as well as propelled. Perhaps this can be more readily appreciated by reference to a photograph, such as that represented in plate 3, figure 2. By good fortune the two gannets shown there so near together exhibit the two extremes of the positions which these birds ordinarily assume in flight. In the top left-hand bird the wings are raised and the body seems to be dependent from them, while in the lower bird the wings are far depressed and the body appears pushed up and supported by them; and this is precisely its position. The wings in their rapid descent found resistance in the air, and as soon as this resistance exceeded the force of gravity acting on the bird the body was elevated at the same time that it was driven forward, only, of course, to sink once again on the wings being raised. Thus the path of a flying bird is a succession of ups and downs, but the movements of the wings being so very much greater in extent cloak those of the body, and so gracefully and smoothly are the actions performed that we do not realize the undulatory nature of the course. The attitude of the right-hand top bird, a kittiwake, in the same photograph (pl. 3, fig. 2), is interesting, as it shows the bird steering by the aid of its feet. The very extensive use some birds make of their feet during flight requires consideration. Not only are they freely used for steering, but they are also often employed as brakes to lessen speed, much in the same way as a drag is used to take way off an incoming vessel. In plate 4, figure 1, the immature gannet there depicted is trailing its partly expanded and lowered feet, thereby causing considerable resistance to its forward progress. To birds which quarter the surface of the ocean for a livelihood, feet have yet another use during flight. As the bird swoops downward to snatch its swimming prey the legs are dropped, and the moment the quarry has been seized, if not before, the feet are plied vigorously to run along the surface of the water and thus not only act as buffers and

[1] The tip of the left wing of the bird in this figure has been retouched, as owing to an accident a portion of the photograph (involving about half of the primaries) had become obliterated. The other photographs have not been retouched in any way and have been chosen to illustrate the various points discussed rather than because they were good photographs.

prevent the body from striking the water, but also help to increase the velocity necessary to enable the bird to rise again. In plate 4, figure 2, although the feet of the kittiwake have ceased to touch the surface, the bird is still running, as it were, in space.

Another method often practiced by birds to lessen speed is that of depressing the tail, and so offering a resistance to the air rushing along the under surface of the body, and this is illustrated in the gannet shown in plate 5, figure 1. This use of the tail is very similar in its purpose and result to the use of the feet as brakes. Steering is also, of course, aided by the tail, it being visibly turned from side to side, raised or depressed, when flight is being executed amid tumultuous currents. But this method of steering by the tail is rather corrective than initiative in its use, being principally employed to compensate for irregularities in the air currents. When a bird is suddenly and deliberately changing the direction of its course—turning an aerial corner, so to speak—the plane of the wings is changed from the horizontal position assumed when gliding to a more or less vertical position, the inclination depending on the abruptness of the turn and the pace at which it is executed. If the turn is to the right, then the left wing is raised and the right depressed, and, of course, vice versa for a turn to the left. When writing here of one wing being raised and the other depressed, I refer to their positions relative to each other, and not to their relation with the body. That is to say, the wings and body may be held rigidly in one plane, the inclination of this as a whole being changed from the horizontal to toward the vertical. This vertical position has been almost reached by the bird, of which, unfortunately, only a portion is shown, in the upper part of plate 5, figure 2. It will be noticed that the left wing is depressed and the right raised; the bird is therefore sweeping around to the left. I have seen birds when thus suddenly altering the direction of their course actually exceed the vertical position, turning the plane of their surface through an angle of about 105°, thus making an angle of about 75° with the horizon, their backs then, of course, being on the underside.

The question of air currents is of paramount importance in flight, though it is probable that owing to their invisibility we have as yet little idea of how extensive and acute these movements are. If, however, we watch small companies of gulls flying leisurely in the same direction, we shall often see them pass through such local air currents, whose existence is plainly indicated by the sudden and harmonious wheeling of the birds. It is often very noticeable, too, how precisely in the same manner all the birds will compensate for the current. This is suggested in plate 6, figure 1, where the four central birds are passing through a disturbance, and it will be noticed how each is "trimming" for it in much the same way, even to the awkward bend in the neck.

III.—ALIGHTING.

The act of alighting appears to be not the least difficult part in the performance of flight; indeed, whether it be regarded from man's standpoint or from the bird's, it may well be accounted the most difficult.

On a boisterous day when a bird wishes to alight at some particular point, its powers are often taxed to the utmost. The obvious signs of this being so are the abrupt and spasmodic turns, and the flapping of the wings, and the jerky, erratic course immediately preceding the alighting; while not infrequently the clumsy and hurried actions on touching the ground, plainly show how comparatively little the flight had been under control the moment before alighting.

That this is a real difficulty of which the birds are fully conscious is, I think, shown by their preparing for alighting long before they actually do so. Their first care is apparently to reduce their speed as much as possible, so as still to leave them sufficient "way" to insure some stability in the air, and some power of guidance. They soar round and round or approach slowly on a long, wavering course, trailing their feet as brakes, or advance in a vertically zigzag course, finding much resistance in short but steep ascents. But even after these and many other preliminary devices have been tried, birds often get sadly knocked about on really boisterous days when alighting on the cliffs. The difficulty lies not so much in the mere act of alighting, as in the settling at some particular spot. A bird must slow up, or the impact would be too great for its leg muscles to cope with; and the difficulty is that when slowing up and almost at a standstill in the air, so to speak, it is greatly at the mercy of the air currents—a swirling gust of wind being able then to carry it this way and that, whereas were it in full flight an equal gust might hardly affect its onward course. I have seen guillemots and puffins when on the point of alighting, and despite their rapidly beating wings, bodily blown over in the air and hurled backwards 30 feet from where they intended to set foot. Frequently, too, a bird, in wild weather or when agitated, will fail to effect a landing, on a cliff for example at the first attempt, perhaps finding it has too much pace to risk a contact with the rocks, or, having too little, a gust of wind will "take hold" of it and bear it past the place it intended to alight upon.

As when dealing with "Taking flight," I illustrated my remarks by photographs of the gannet, it may be well now to continue with the same bird, and to try to follow some of its actions when alighting.

In plate 6, figure 2, the gannet is approaching, intent on alighting. The pace is comparatively slow, and is being continually lessened, and the course of the bird is being steadied by the trailing feet. The position of its home is not indicated in the picture; it was on the

top of the column of rock, the base of which is vaguely suggested at the left-hand side of the print. Each time the bird approached its method was the same. It flew along the cliff-face until it reached a point nearly opposite to the nest, but considerably below it; then it swept round abruptly until it faced the cliff, at the same time giving its course a strong upward tendency, still trailing its feet. Plate 7, figure 1, shows the bird just after it had faced round to the cliff and was sweeping upward. As soon as it arrived directly opposite to its nest, its one thought was to stop the forward and upward impetus produced by the great soaring approach.

Plate 7, figure 2, shows plainly the measures adopted by another bird—which, by the way, advanced in a more direct and horizontal course, and had, therefore, a more direct forward momentum to counteract. It flew straight for its nest, sweeping slightly upward until it found itself almost opposite the place, and perhaps some 5 or 6 yards distant from it. Then by a dexterous turn it threw the plane of its great surface into a vertical position and at right angles to the direction of its course, thus offering the maximum amount of resistance possible. The whole area of the wings, body, and tail is directly opposed and spread out to resist the bird's forward passage through the air, and it is interesting to note how the tail has been extended to the utmost, fan wise, so as to increase as much as possible the effective area. It will be noticed that the feet are thrust forward and the webs extended in anticipation of the coming contact. That a great strain is being placed upon the wings and that therefore a great resistance is being encountered is indicated by the curve of the primaries.

Plate 8, figure 1, shows the position a moment later. The bird has now got its feet upon the rock (or rather one foot, for the other is thrust out horizontally on the nest, having no doubt missed its mark, and can be of little, if any, support), and appears to be almost stationary, but as a matter of fact it has still a forward impetus which the raised wings are trying to counteract. The bird has, indeed, just set foot upon the ledge, and is falling forward in the direction of its approach.

The last photograph (pl. 8, fig. 2) again carries us on a brief moment. Now the bird has pitched forward on to its breast, its wings having failed to find sufficient resistance in the air to counteract the body's momentum, and in consequence the wings have come crashing down upon the rocks at the end of their strenuous beat. The position of the tail is interesting; in plate 7, figure 2, it is seen fully expanded and depressed in order that its ventral surface may oppose the forward progress, and now it is turned upward above the back so that its dorsal surface may find resistance and try to counteract the tendency to pitch forward on to the breast.

FIG. 1.—RAISING THE WINGS PREPARATORY TO GOING.

(Photographed by Bentley Beetham.)

FIG. 2.—ABOUT TO DIVE FORTH.

(Photographed by Bentley Beetham.)

FIG. 1.—GOING.
(Photographed by Bentley Beetham.)

FIG. 2.—GONE.
(Photographed by Bentley Beetham.)

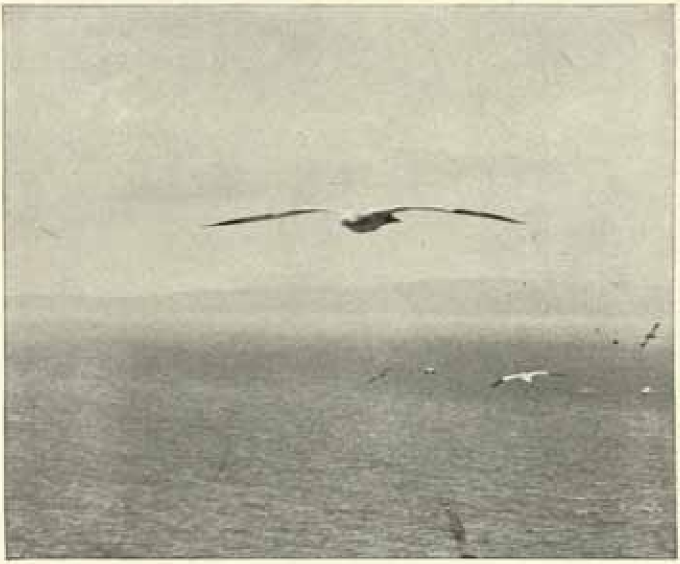


FIG. 1.—FAIRLY ON THE WING.
(Photographed by Bentley Beetham.)

FIG. 2.—THE TWO EXTREMES OF POSITION.
(Photographed by Bentley Beetham.)

FIG. 1.—THE FEET USED AS BRAKES.
(Photographed by Bentley Beetham.)

FIG. 2.—RUNNING, AS IT WERE, IN SPACE.
(Photographed by Bentley Beetham.)

FIG. 1.—THE DEPRESSED TAIL USED AS A BRAKE.

(Photographed by Bentley Beetham.)

FIG. 2.—NEARLY VERTICAL IN POSITION.

(Photographed by Bentley Beetham.)

FIG. 1.—SUDDENLY AND HARMONIOUSLY WHEELING.
(Photographed by Bentley Beetham.)

FIG. 2.—INTENT ON ALIGHTING.
(Photographed by Bentley Beetham.)

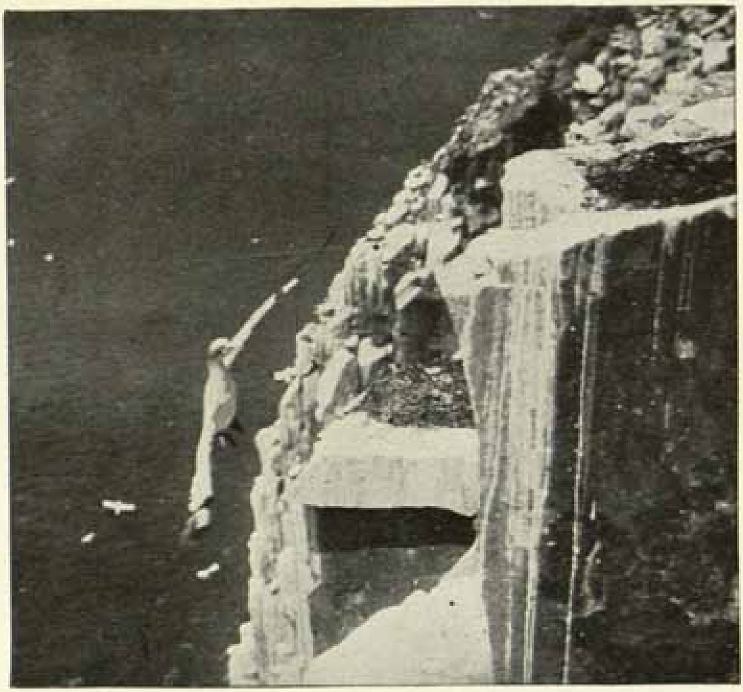


FIG. 1.—SWEEPING UPWARD.
(Photographed by Bentley Beetham.)

FIG. 2.—MAXIMUM OF RESISTANCE.
(Photographed by Bentley Beetham.)

FIG. 1.—JUST SET FOOT UPON THE LEDGE.
(Photographed by Bentley Beetham.)

FIG. 2.—THE WINGS HAVE COME CRASHING DOWN UPON THE ROCKS.
(Photographed by Bentley Beetham.)

THE GARDEN OF SERPENTS, BUTANTAN, BRAZIL.[1]

By Prof. S. Pozzi,

Member of the Academy of Medicine, Paris, in charge of scientific expedition to Brazil and the Argentine Republic.

I passed but 12 days in Brazil on my way back from Buenos Aires to Europe. There is much to be said about the medical institutions of the two large cities where I stopped, Rio de Janeiro and St. Paul. I wish that I could express all the admiration I have for my colleagues, the physicians and surgeons of Brazil, and tell of all I saw and appreciated; but I can cite only a few names: At Rio de Janeiro, Prof. Feijo, jr., head of the faculty; Dr. Aug. Brandao, professor of gynecology; Dr. Daniel d'Almeida, Dr. Magalhaes, Dr. H. de Toledo-Dodsworth, Dr. Antonio Rodriguez Lima, the Drs. Hilario and Nabuco de Govea, Dr. Olympio da Fonseca; the general secretary of the Academy of Medicine, Dr. Aloysio de Castro, and others. At St. Paul, I would mention especially the Drs. Alves de Lima; my excellent pupil, Dr. Arnado Carvalho; Dr. Synesio Rangel Pestana, and Dr. Oliveira Botelho, formerly minister of agriculture and a distinguished gynecologist. Toward all I have a deep feeling of gratitude for my pleasant reception.

But I must limit myself. So I will choose from among my experiences my visit to the antivenom therapeutic institution at Butantan near St. Paul.

This institution has at its disposal incomparable means for this study and work because of its situation in a region where snakes abound. Our eminent compatriot, Prof. Calmette, of Lille, one of the pioneers in the scientific vaccination against snake bites, has been too often impeded and limited in his laboratory work because of the difficulty in procuring the exotic snakes whose venom was necessary for his researches. At Butantan, the country people from all sides bring in their captured snakes, in exchange for which they receive tubes of the beneficial serum.

[1] Abstract of a lecture given by Prof. S. Pozzi, at the Henri de Rothschild Polyclinic, Mar. 29, 1911. Translated by permission from Revue Scientifique, Paris, Apr. 22, 1911. The illustrations in the original paper here omitted.

Brazil may be considered as one of the countries most infested by venomous serpents. Though they have completely disappeared from the most frequented places, they are still extremely numerous in the surrounding country, and their bites are a fearful source of danger to the workmen of the coffee or sugar plantations who go with naked feet.

Two great genera of serpents live in Brazil, the Crotalus and the Bothrops. They are found in the forests, the thickets, and the damp places. Naturally rather timid, they flee as soon as disturbed by a noise, but if by chance one of them is touched it turns upon and angrily bites whoever molests it. So that if a passerby inadvertently puts his foot on one he is at once bitten. This happens very frequently to beasts or horses when they disturb the peace of a snake. Hunters dread them for their dogs when the latter search in the brushwood.

According to statistics, up to 1906 there died annually in the State of St. Paul alone more than 240 persons from the bites of snakes of the Crotalus and Bothrops genera. Since the distribution of serum from the serotherapeutic institution of Butantan, the number of fatal cases has diminished at a rapid rate.

This serotherapeutic institution consists of a large number of buildings separated by courts. They include the laboratory, the cells for the snakes, the stables for the inoculated horses, the storehouses for the manipulation of the serum, and the dwellings of the staff. Everything is perfectly organized.

Many obscure points relative to the physiology of serpents still require study. In order to better know the habits and all the details of the lives of serpents, Dr. Vital Brazil, the eminent director of this institution, conceived a surely novel idea. He has made an inclosure with thick walls, not so high but that one can easily look over them. Within there is a large space, a kind of rustic inclosure, covered in places with luxuriant vegetation, traversed by wide paths, with glades here and there. A large interior ditch, close to the wall and filled with water, forms a second barrier and prevents the escape of the dangerous guests that people these thickets. The most venomous serpents are to be placed here where they are to live at liberty. When I was at Butantan last year the construction of this place was almost complete. At the present time, without doubt, Dr. Vital Brazil and his fellow workers have already made many curious observations while walking to and fro in this frightful paradise, in this garden of snakes.

Before proceeding it will be well to state some theoretical conceptions which will help to explain the importance of the work accomplished by this institution.

The pathological physiology of venom poisoning has become very well known through the researches of Calmette and V. Brazil. The poisoning resulting from the bite of a Bothrops is hemorrhagic in nature. After a bite there occurs a decomposition of the blood which escapes from the capillaries, causing profuse hemorrhage in the subcutaneous and submucous tissues, accompanied by acute congestion of the liver, kidneys, and brain. It is a sort of acute purpura. The Crotalus venom, on the contrary, is a paralyzing poison. It produces bulbar paralysis with disturbances of the respiration, the vision, and the circulation. Local reaction at the seat of the wound is absent or extremely slight. Death of the victim, if a man, results after a variable time, generally about 24 hours.

Vital Brazil has made elaborate studies of the effects of venoms upon animals. The poison of the *Crotalus terrificus* kills a pigeon when one one-thousandth of a milligram is injected into its veins. The fatal doses for other venoms vary slightly.

I will now describe in a few words the preparation of the antivenom serum at Butantan.

The serum prepared at Lille by Dr. Calmette has little efficacy in Brazil. Indeed, he himself says in his remarkable book, Upon Venoms, "For each venom there is a corresponding serum." Since the serum of the institution at Lille is almost wholly prepared with the venom of Asiatic snakes, although excellent for counteracting the bites of European vipers, it is useless against the bites of the Brazilian Bothrops or Crotalus. Accordingly Dr. Vital Brazil has prepared two specific serums, one anticrotalic, the other antibothropic, each having, in small doses, a particular efficacy against the bites of the corresponding snakes. But as it is rare that the kind of snake producing a bite is known, it was important to have also a polyvalent serum, that is one equally active against all venoms. Such a serum Dr. Brazil has made.

The animal used to furnish the antitoxic serum is the horse. A young and healthy animal is taken, free from any disease, and particularly from glanders. Horses are very sensitive to the venom from snakes. At first a minimum does is injected, five one-hundreths of a milligram; then the does is increased. The injections are repeated every five or six days; as soon as the animal seems to suffer or to lose weight the injections are stopped. It is a curious fact that as soon as the immunization is complete the animal seems to thrive from the absorption of the poison; it grows fat, its weight increases. And yet further, a horse in the process of immunization, if the injections are stopped, pines away somewhat as does a morphiomaniac when the latter is deprived of his habitual poison. The horse has become, in fact, a seromaniac.

The immunization lasts about a year, and toward the end enormous doses are given reaching 1 gram. The horse is then ready and the serum from its blood is antitoxic for the venom with which it has been inoculated.

In such manner is prepared at Butantan the anticrotalic, the antibothropic and the polyvalent serums. The last is obtained by alternating the injections, using the venom first from one kind, then from the other kind of snake, and, as its name indicates, it is valuable as a remedy for the bites of all Brazilian snakes. It is therefore of exceptional practical value.

An immunized horse will furnish serum for a very long time, provided that from time to time new injections of the venom are administered. After each bleeding necessary for a supply of serum, the antitoxic power of the horse diminishes rapidly but recovers several days afterwards.

In the case of man, the injection of the serum under the skin should be made during the 12 hours following a bite. If the kind of snake producing the bite is known, the serum specific to that kind is the more efficient toxin to employ in doses of from 10 to 20 c. c., for it works more quickly and with special efficacy. If the kind of snake is not known, as is usually the case, then the polyvalent serum must be injected in doses up to 60 c. c. in serious cases.

The serum is furnished to the public in sealed tubes packed in little wooden boxes. A minimum price is charged. Further, the institute at Butantan distributes the serum free to hospitals, to cities, and to the very poor, together with injection syringes and the necessary directions for its use. The only remuneration asked by Dr. Brazil, at times, in exchange for the serum, is the snakes which are essential to him; and so by bringing a *cascavel* or a *jararaca*, the Brazilian countryman receives a tube of the liquid serum.

I was very curious to visit the institution at Butantán during the few days I stopped at St. Paul near the outskirts of which it is situated. My distinguished colleague and friend, Dr. Alves de Lima, whom I can not thank too much for his generous hospitality, kindly offered to accompany me there. I copy the following account from the note book of my travels:

A powerful 40-horsepower automobile carried us, raising clouds of dust, along the route which traversed a smiling country dotted with trees and exotic shrubs. After a ride of about half an hour we stopped at the gate of a kind of large chalet which belonged to a group of new buildings, the serotherapeutic institution of Butantan. A man of about 40 years of age, tall, energetic, sun burned, wearing a black mustache, with remarkably deep, black eyes, a reserved and deliberate manner in marked contrast with his southern appearance, received us on the threshold. He wore a long white coat, such as surgeons and physiologists wear. Such was Dr. Vital Brazil, director of the institution and a great philanthropist. To him Brazil, and indeed all the other countries of South America, owe the systematic production of the serum

which cures the bites of the numerous snakes of those tropical regions, deadly bites which but lately killed more than 1,000 persons a year.

He commenced his study by himself; he is indeed a "self-made" man; later he continued his studies at Paris with Roux, at Lille with Calmette, and at Berlin with Koch. He speaks French very purely although not very fluently. Indeed he talks very little. It was always necessary to ask for explanations from this modest and somewhat taciturn man.

We at once entered the laboratory, a great hall with rows of jars containing snakes in alcohol. There were snakes of all sizes, of all colors, of all forms, whole and dissected to show their various organs and with some of them (who would have believed it?) full of parasites peculiar to the snakes. In other jars there were horrible, venomous insects, enormous scorpions, and great spider crabs. We had but little time to devote to this visit, we were therefore in a hurry and Dr. Vital Brazil realized it. He knew of a special attraction for us, a snake eater of snakes, the good snake, so to speak, which, inoffensive himself, destroys his venomous confreres whose bites are harmless to him. I asked Dr. Brazil to show us this curiosity. He was prepared for my request and very courteously acquiesced. Only the good serpent had already eaten some eight days ago, and for a snake digestion is very slow and the appetite long in returning; nevertheless he let us see.

And here we saw the good serpent: It was taken from a box by means of a long crooked stick, with a handle, which seized the snake by the middle, like a common sausage, and deposited it on the ground near us. It was a kind of great adder, about a meter long, of a blue color having the sheen of steel, so shiny that it seemed wet. It crawled slowly, erecting its flat head, darting out its tongue, and seemed formidable despite its good reputation. In order to reassure us, Dr. Brazil took it in his hands and twined it about his arms; he told us at the same time the snake's scientific name, *Rachidelus brasili*, locally known as the "Mussurana." The natives and especially the hunters have known it for a long time, but until very recently were ignorant of its habits and its so useful tastes.

With the same crooked stick he took from a box another serpent, this time an exceedingly venomous one, the terrible *Lachesis lanceolatus*, the "Jararaca" of the Indians. Its bite in a few minutes kills man or animal. We recoiled instinctively. He placed it close to the good Mussurana, and, at a respectful distance, we formed a ring about them. I confess I looked back of me to see whether an open door was at hand. The two snakes lay there almost motionless, side by side, and apparently seemed to take no notice of each other. Dr. Brazil thought surely that the Mussurana, having just eaten his fill, would not "make a march," if I may so express myself. Suddenly it made a movement and drew nearer to its formidable victim. The latter, as well as we, had seen the undulation of his adversary; it also stirred. Did it wish to escape or did it rely upon its irresistible fangs? With incredible quickness which told plainly that its apparent torpor was only tactical, the good serpent darted its open mouth upon the neck of its prey, evidently aiming to get hold of the nape of its neck in order to render its opponent helpless. The latter, upon its guard, quickly turned and darted its fangs into the body of the other. The good serpent is, however, immune to the poison by nature. And see, in an instant the Lachesis is enlaced, twisted about in the muscular spiral formed by the body of its adversary; they roll convulsively, one about the other, one within the folds of the other, and I wondered for a minute whether the Mussurana was not trying to choke the Jararaca. Very soon I discovered the purpose of this maneuver; it had seized the enemy lower than it had wished at the first grasp, and little by little was advancing its hold gradually until it had its mouth up close to that of the Jararaca. Now it had a firm grip close to the lower jaw; it had the jaw as in a vice with its little flat head, which looked like an instrument of a surgeon or of a torturer, closed nippers of steel. The venomous head, lamentably open and as if disjointed in the constant effort to escape, extended several centimeters

beyond the coils which enfolded the body and about which they were entwined. The last turns formed a kind of block upon which rested and was thrown back the stretched neck like the cord on a capstan.

The whole body of the wicked serpent had disappeared within the folds of the good serpent; its extremities alone remained visible, the helpless head on one side, the slowly moving tail at the other.

"He is going to dislocate the cervical vertebræ," Dr. Brazil whispered to me, "you will see; it is very curious." Indeed it was very curious and even rather horrible to see. But we were as if fascinated by this spectacle, the contest between the good and the bad reptile, between Ormuzd and Ahriman.

During several minutes, which seemed to me interminable, Ormuzd had stretched the neck of his half-dead adversary, using some of his own entwining coils as a fulcrum, and ingeniously employing the principle of the lever. Then he commenced to twist slowly from right to left, from left to right, the stretched, taut neck.

Was Ahriman dead when I left this spectacle to see the rest of the institution? I would not venture to say that he was entirely dead when Ormuzd, after our departure, commenced to swallow him. An hour later, when we returned, the deed was almost done. The good Mussurana was stretched at full length upon the ground where we had left them rolled up as in a ball. We could distinctly see by the abrupt swelling of the steely armor the point to which the swallowing of the prey had progressed. The latter had disappeared, swallowed up close to the tail; and a detail which struck me and which moved me despite my knowledge of the unconsciousness of reflex movements, that little tail was coiled about one of the legs of a table and clung to it yet with convulsive tremblings.

SOME USEFUL NATIVE PLANTS OF NEW MEXICO.

[With 13 plates.]

By Paul C. Standley.

When the Spanish conquistadores journeyed northward from the mountains and plains of Mexico into what is now the United States, their initial expeditions led them along the narrow valley of the Rio Grande. Near the banks of this stream, or sometimes at some distance from its waters, they found pueblos or Indian villages whose inhabitants supported themselves principally by agriculture. The surrounding regions were peopled by nomadic tribes who derived their sustenance from the untilled resources of an apparently unproductive land.

A not uncommon belief among people who have never visited the far Southwest—that part of the United States consisting of New Mexico, Arizona, western Texas, and the adjacent lands—is that it is a vast desert. By a desert is generally understood a region where the water supply is scanty or lacking and the vegetation sparse. That such a condition is characteristic of large portions of New Mexico must be acknowledged. Not a small proportion of that State consists of sandy plains with but a thin mantle of vegetation, or of barren rocky hills and great malpais—areas invested with comparatively recent lava flows. But there remains a considerable area composed of fertile river valleys artificially watered by the streams which flow through them, and a still larger region of high mountains covered with heavy forests and luxuriant herbage. Among the thickly scattered ranges rise many high peaks upon which snow remains through nearly the entire year.

In the most arid desert regions plant life is abundant, even if inconspicuous, and the variety of species to be found there is greater than one would infer from the number of individual plants. Many among these have proved useful to man and were of the greatest importance in the economy of the early inhabitants. Existence must have been one continuous struggle among the aborigines, situated in a country

where climatic conditions from an ordinary point of view are unfavorable. They had to depend almost wholly upon the natural resources of their homes until the Spaniards introduced domestic animals and improved methods of agriculture, and they were therefore forced to utilize every possible source of food, whether among plants or animals. There have come down to us accounts of the employment for food of many plants which, to the people of to-day, would seem impossible of being thus utilized. The Zuñis, for instance, gathered and ate the inner layer of the bark of the yellow pine, a substance most difficult of digestion and at best very low in nutritive value. Tradition has failed to record the foods to which the people were driven in times of unusual want, but in such periods almost every plant not absolutely poisonous must have been requisitioned. With the advent of civilization, and especially in recent years with the development of the railroads, making it possible to import provisions, the use of many substances which formerly served as food has been discontinued, even by the least civilized tribes. While the earlier inhabitants of New Mexico depended upon dozens or even hundreds of the native plants, present inhabitants disregard all but a few, now that more suitable food can be so easily secured. There are, however, a number of plants which are still used extensively by the natives of the country for different purposes, and some have even attracted the attention of the recent immigrants.

Most important among native economic plants, at least to the original population, were those which furnished food. Not less deserving mention here are some that are or have been employed for fuel, in basketry, as dye plants, and for certain other purposes.

The most interesting, certainly the most remarkable, group of southwestern plants consists of the members of the Cactaceæ or cactus family. These at once attracted the attention of the early explorers, and no stranger visiting this region, whether he be interested in the botanical features of a region or not, fails to remark upon these peculiar forms of vegetation. Over 70 species of this group are known to occur in New Mexico, ranging in size from the small globular Mamillarias or pincushion cactuses, often less than an inch in diameter, to the large branched cholla or cane cactus, frequently 10 feet high or more. Almost all the representatives of this family bristle with spines, which fortify them against the assaults of animals, or possess other adaptations for maintaining themselves amid the most unfavorable surroundings. They are found everywhere in New Mexico except upon the high mountains, but they are by far most numerous in the southern part of the State. Here on a single small calcareous hill no less than 15 species have been collected, each represented by hundreds of individuals.

For the greater part of the year cactuses are little more than masses of spines, of bizarre but scarcely beautiful appearance; but in the spring with the advent of warm weather their buds develop and the plants are transformed into clusters of resplendent flowers. No southwestern plants produce more showy blossoms; hence they are admirably suited for cultivation in arid districts, where it is difficult or impossible to grow the ornamental plants favored elsewhere. The most beautiful of all our native cactuses are the species of the genus Echinocereus. These are characterized by spiny cylindrical stems, seldom more than 1 foot high and 3 or 4 inches in diameter, growing singly or in clumps. Their flowers, borne profusely along the angles of the stems, are very large, often 6 inches long, and of bright and rich hues ranging through yellow, pink, scarlet, salmon, crimson, and purple. At the New Mexico Agricultural College beds of some of the different species have been established, each containing several hundred plants. When in full flower these present a display of color seldom equaled by any of our cultivated plants. Unfortunately they do not bloom all summer, but usually continue in flower several weeks. Other groups of the Cactaceæ are almost equally handsome. The prickly pears are covered in early summer with yellow or whitish flowers. The cane cactus (*Opuntia arborescens*) bears hundreds of large red blossoms. The flowers of the Mamillarias are generally bright pink but too small to be showy, and those of the species of Echinocactus are small and of dull tints.

The most widely distributed of the cactuses are the prickly pears or flat-jointed Opuntias, whose representatives in New Mexico number about 30 species, at least one or two of which occur in every section of the State (pls. 2, 3). This is the group to which the so-called "spineless cactus" belongs. While there are no native species in New Mexico that are completely spineless, at least two are practically so. The spineless sorts which are reputed to have been developed in cultivation are tender and can not endure the winters of even the southern part of the State. The common spiny prickly pears, the nopales of the Spanish-speaking people, are used as food for stock, especially when seasons of drought have depleted the ranges. They are less extensively utilized in New Mexico than in some other parts of the Southwest, chiefly because the stockmen of the State are unacquainted with their possibilities. To prepare them for cattle feed the spines are singed off with a torch, after the plants have been hauled to some central point or while they are standing in the field. Experiments have been made to ascertain the feasibility of growing prickly pear in quantity for stock feed, but these have so far resulted in failure, chiefly because cottontails and jack rabbits eat them as rapidly as they grow and seem to prefer the cultivated plants. When

hard pressed by hunger cattle will eat cactuses, spines and all, even attacking the very spiny chollas. The joints of the chollas are readily detached from the plants and are often seen clinging to the animals' bodies.

In some parts of the Southwest the young pads of the prickly pear are prepared for human food, the tender joints being peeled and cooked in various ways. They are not likely to become a popular vegetable since they are nearly flavorless and their large amount of mucilaginous matter is unpleasant to most people. The joints have been used as poultices and their juice is occasionally employed in sizing rough walls preparatory to the application of paper.

The fruit of the prickly pear, known as the tuna (pl. 4, *B*), is highly prized in Mexico, where it is gathered in great quantities. The kinds growing there have larger and more palatable fruits than any of the New Mexican forms. Some of the northern species produce a dry fruit consisting of little but spines and seeds, and consequently inedible. Others of the tunas are large and juicy and beautifully colored, but even they have large seeds. The fruit has a pleasant flavor and a taste for it does not have to be acquired, as it must for so many of the unusual tropical or semitropical fruits. Some of the other cactuses have still better flavored fruits, best of all being those borne by the different species of Echinocereus. In this genus the seeds are small and can be eaten along with the pulp. In the earlier days, and to some extent at the present time, the different cactus fruits were gathered by the Indians, who ate the fresh ones either raw or cooked, and often dried them in the sun for use in winter. The tunas are covered with very fine spines which must be removed, the Indians resorting to small brushes of dried grass for the purpose. The Echinocereus fruits, besides being much more finely flavored than the tunas, are easier to eat because they are protected only by large spines that are easily removed with the fingers when the fruit is fully ripe.

Tunas have not been utilized extensively in New Mexico by recent immigrants who often eat them when they happen upon ripe fruits but seldom make any definite effort to gather them in quantity. Sometimes they are collected and their juice extracted and used in the preparation of jellies and sirups, the products thus obtained comparing favorably in flavor and appearance with any similar ones from other fruits. It has been discovered that a valuable coloring matter, a rich red similar to that of cochineal, can be extracted from them to be used in tinting candies and pastry. The prickly pear, incidentally, is often a host of the cochineal insect which in spring and early summer often completely covers the plants with its white webs.

In the southern part of New Mexico, on the mesas bordering the Rio Grande, is one of the most remarkable cactuses, known as the fishhook or barrel cactus or viznaga (*Echinocactus wislizeni*, pl. 6, *A*).

This was unknown to botanists until the year 1846, when it was discovered by Dr. Wislizenus who was making a journey of scientific exploration through the Southwest. He first saw the viznaga near the village of Dona Ana at the lower end of the Jornado del Muerto, on August 5, and speaks of it in these words:

> Before reaching Doñana I met on the road with the largest cactus of the kind I have ever seen. It was an oval Echinocactus with enormous fishhook-like prickles, measuring in height 4 feet and in the largest circumference 6 feet 8 inches. It had yellow flowers and at the same time seed, both of which I took along with some of the ribs.

These specimens ultimately reached Dr. George Engelmann of St. Louis, the first botanist to make an extensive study of our North American Cactaceæ, who named the species in honor of its discoverer. This viznaga is seen in cultivation in the Southwest and occasionally in the East. The plants that have been mutliated assume strange forms, and bifurcate or cristate stems are not uncommon.

The barrel cactus is a potential source of water in extreme need. When its top is removed and the juicy white pulp macerated with a club a quantity of a clear watery liquid is extracted from it. While this will serve as a substitute for water in cases of severe thirst its taste is not altogether agreeable, and fortunately in New Mexico water is rarely so scarce as to necessitate such a substitute. The pulp of the viznaga is used more satisfactorily for another purpose. When cut into strips or cubes, boiled several hours until tender, then cooked in a thick sirup which is usually prepared from the crude brown sugar so largely used in Mexico, molded into rough cones known as piloncillos, the resultant product is a candied pulp similar to candied pineapple or citron, of a delicious flavor (pl. 5). Large quantities of it are made every spring by the native people and sold by vendors about the streets of nearly all southwestern towns. It is known as dulce de viznaga. More recently another possible use for the plant has been found. The flesh after being cut into long thin strips and, treated with a glycerin solution forms a sort of vegetable leather which has been manufactured into souvenirs for the tourist trade.

Remarkable among the novel curios to be found in the shops of the towns frequented by tourists are the canes made from the stems of the cholla (*Opuntia arborescens*). These are long narrow cylinders of wood composed of a network of coarse woody bundles with many interstices. They are the woody part of the cholla from which flesh and spines have been removed. Although easy to prepare, to one who is ignorant of the method of manufacture they appear to have been whittled from a solid stick of wood with painstaking care. This tree cactus is another of the plants first made known to science through the explorations of Dr. Wislizenus. Among the Spanish people it is sometimes known as velas de coyote (coyote candles).

Almost as conspicuous as the cactuses are the Yuccas, a group of desert plants whose members are variously known as Spanish dagger, soapweed, Spanish bayonet, palma, palmilla (pl. 1), or datil. There are seven species that grow in New Mexico, at least one of them in every part of the State except the higher mountains, and one species does extend into some of the ranges as high as 9,000 feet. Usually they grow on the plains and mesas or in the foot hills. Most of them are low, consisting of a cluster of long, narrow, more or less rigid, sharp-pointed leaves 2 feet long or shorter, arising from a short stem or caudex. From this mass of leaves appears the inflorescence, which takes the form of a raceme or panicle crowded with nearly white, bell-shaped flowers (pl. 7). In southern New Mexico three species grow much larger, having trunks often 6 or 8 and rarely 15 feet high, surmounted by a cluster of leaves above which are thrust up the panicles to a height of 3 to 5 feet more.

The yucca which is of greatest economic importance, perhaps, is the datil (*Yucca baccata*, pl. 8), which grows in the foothills of the northern part of the State in great abundance, and extends in lessened numbers south to the Mexican border. It is one of the low forms, never more than 2 or 3 feet high, but it is noteworthy from the fact that its fruit, unlike that of other species, is fleshy and edible. In form the fruit is cylindrical or conical and usually 6 inches long, with a smooth skin. When ripe it somewhat suggests a banana, because of its shape and yellow color, and is palatable despite the large black seeds with which it is filled. No use has ever been made of it by the English-speaking people and little by those of Spanish descent, but it was an important food among the Indians, who do not altogether ignore it now. The Navahos made more extensive use of it than any other tribe, possibly because the plant grows so luxuriantly in their territory, where it sometimes covers the foothills with almost unbroken ranks. Regular expeditions were made to gather the fruit when it was ripe. Some of it was eaten fresh, either raw or cooked, but often it was preserved for winter use. The ripe fruits were dried by the fire on flat stones, then ground and kneaded into small cakes, which were laid in the sun and allowed to dry still further. These cakes were stored until wanted, when they were broken up and mixed with water and in this form eaten with bread, meat, or other dishes.

The Zuñis, and probably some of the other Indian peoples, ate the seed capsules of the dry-fruited species after they had been boiled and made into a sort of pickle. These must be very inferior to the fruit of the datil, for they have an unpleasant taste before being cooked, besides being hard and not at all fleshy.

The roots of all yuccas contain a high percentage of saponin and are employed as detergents. After being dug and grated or otherwise

reduced to small particles they are used almost exactly as soap, forming a copious and persistent lather. Both the Indians and the Mexican population use the soap weed in this form, especially for washing the hair. The ground root, amole, is said to be superior to soap for many purposes. In small amounts it has been placed upon the market, where, if its merits were better known, doubtless a profitable sale could be found for it. The soap weeds thrive so well throughout the Southwest that an almost inexhaustible supply of the roots could be depended upon. There are possibilities in the use of saponin from this source for other purposes.

Yucca leaves furnished the Indians with the most satisfactory material for their basketry. The Mescalero Apaches, whose baskets compare favorably with those made by any of the North American Indians, use the leaves of two species (*Yucca radiosa* and *Y. macrocarpa*), obtaining from either of them two colors of fiber with which they usually associate a third derived from another source. From the interior of the yucca leaf is taken the nearly white fiber which forms the groundwork of the basket. The geometrical designs with which these are customarily decorated are worked in with strips from the outer coarser part of the leaf, of a soft greenish-yellow color. With these the weavers combine a few strands of a dark reddish-brown fiber prepared from the bark of the lemita, a kind of sumac (*Schmaltzia trilobata* and related species). Not all Indian baskets made in New Mexico are woven from these materials, but most of them are substantially the same. Some tribes use the bark of the willow or that of other trees and shrubs, while a few prefer the stems of cat-tails, rushes, or sedges. The Apaches also fashion wicker water bottles from the slender willow twigs, waterproofing them with interior and exterior coats of resin from the yellow pine. Anywhere upon the Mescalero Reservation one may come upon dead pines, killed by the removal of the bark from their trunks for several feet above ground so as to produce an exudation of resin for this purpose. Almost all the Indian tribes of the Southwest manufacture similar receptacles for water, although some use earthenware jars.

Because of the prominence and strength of their fibro-vascular bundles Yucca leaves have been considered as a possible source of fiber for cordage, but they are not well suited to such a purpose since their product is coarse and hard. On a small scale the leaves have been made into heavy stable brooms and there is a possibility of a more extensive utilization in this direction.

There are several New Mexican plants that may become fiber producers. The bear grass (*Nolina microcarpa* and other species, pl. 9) furnishes a good quality of fiber, and tests have been made of the sotol (*Dasylirion wheeleri*). Related plants furnish commercial fibers in Mexico and other countries. The lechuguilla (*Agave lechu-*

guilla), a congener of the mescal but a smaller plant, yields a fiber which is twisted into rope and twine in Mexico. It covers many miles of the desert of western Texas, although in that region little effort has been made to utilize it. It barely reaches southern New Mexico and can never be of economic importance here.

Recent advances in the price of rubber, caused by its increased use in manufactures, have stimulated a search all over the world for rubber-yielding plants. A large and profitable industry has been developed in northeastern Mexico in the extraction of rubber from one of the Compositæ known as guayule (*Parthenium argentatum*). It has been reported repeatedly that guayule occurs in New Mexico, but such statements are not supported by investigations. Although the sections of the State where it might be expected to grow have been carefully explored by botanists searching for it, not a single plant has been found. Another species of the genus, mariola (*Parthenium incanum*), from which rubber can be extracted, does occur in New Mexico on the dry limestone hills near the southern border. It is said to yield a fair quality of rubber, but a lower percentage of inferior value to that obtained from guayule. Nowhere in the State is it found in sufficient quantity to be of commercial importance.

Another member of the same family, the Colorado rubber plant (*Hymenoxys floribunda*) is abundant in northern New Mexico, where it covers hundreds of acres on the low foothills or higher up among the pine trees, sometimes to the exclusion of almost all other herbaceous vegetation. By chewing some of the stems for a few minutes a small mass of crude rubber is obtained. A few years ago a company was formed in Colorado to extract rubber from the plant, but the undertaking was not a success. While there is no doubt that rubber can be gotten from this source, it is questionable whether a large enough supply could be relied upon to make extensive operations practicable.

A prominent feature of the desert flora of the Southwest, along the rocky hills or advancing upon the plains, are the stately Agaves, generally known as mescal or century plants, several species of which are at home in New Mexico (pl. 10). Their leaves are broad and short, never more than 18 inches long, succulent, forming a compact rosette. Each is tipped with a sharp dark spine and is armed along the edges with stout hooked prickles. The tall flower stalks of our native species are 10 to 15 feet high or more, surmounted by thick divergent branches bearing hundreds of yellowish flowers. It is a popular belief that the century plant blooms but once, when it has rounded out a hundred years, hence the common name. A possible basis for this reputation is that in cultivation the plants seldom flower, although in their native haunts flowering plants are of common occurrence. They are known to bloom long before they attain the century mark and probably require only a comparatively few years

to reach maturity. Each plant flowers but once, the leaves withering as soon as seed is matured. About each dead plant is usually left a colony of young ones formed from suckers, by which the plant is propagated. The true mescal plant, a native of Mexico, the source of pulque, mescal, tequila, and other drinks, is not rare in cultivation in southern New Mexico, but is not indigenous.

The native Agaves furnished one of the most important items in the diet of the Apaches and other Indian tribes, who used them for making what is known as mescal. It is from the manufacture of this article that the Mescalero Apaches, whose reservation lies in the White and Sacramento Mountains, receive their name.

There are two substances to which the term mescal is applied. It is more generally used to define an intoxicating beverage distilled from the fermented juice of the Agave. This drink is consumed in every part of Mexico, but is probably not manufactured to-day in the United States. After the coming of the Spaniards the natives of the Southwest learned to distill the alcoholic drink and it is not impossible that they had even developed the process independently. This, however, is not the mescal to which the Mescalero Apaches owe their designation.

The Apaches, like others of the southwestern Indians, were wont at certain times of the year to visit the localities where the century plants were most numerous. The favorite season was in early summer when the flower stalks were just starting, but the plants could be used at any time. Pits 10 or 15 feet across and about 3 feet deep were dug and lined with stones, then filled with wood which was fired and kept burning until they were thoroughly heated. The fire was then raked out and the pits filled with the succulent Agave leaves. After being covered with grass or weeds the pits were left for some time, usually about three days, when they were opened and the thoroughly cooked leaves (mescal) were taken out and eaten. The leaves thus cooked contain much sugar and have an agreeable sweet taste. They consist so largely of fiber that they are unfit to be eaten as a whole, but must be chewed until the digestible part is removed, the fiber being then ejected. Large amounts of mescal were prepared after this method and either eaten at once or partly dried and stored for later consumption. Mescal pits are of common occurrence in New Mexico wherever the Agave grows (pl. 6, *B*). The Mescaleros still prepare this food, but not such stores as in earlier days. In the markets of Mexico the same article is everywhere offered for sale. The leaves of the species used there are larger and furnish a greater amount of nutritious matter than the northern kinds.

Another desert plant, more closely related to the Yuccas than to the Agaves, is the sotol (*Dasylirion wheeleri*, pl. 11), which was utilized by the Indians in much the same way as the century plant. Of this

they used only the heart of the plant taken just when the flower stalk was pushing up. The trunks were trimmed and placed in the pits, where they were treated exactly like the mescal. This product must be far less suitable for food, for the stems are hard and woody and only the youngest parts can be easily rendered edible. Sotol has been used in the manufacture of alcohol in a commercial way, the sugars contained in the stems being readily fermentable. With this as a basis reports have been issued of the distillation of alcohol from cactus, but the sugars contained in the different cactuses have so far not proved susceptible of fermentation. All plants that have spines are popularly known as cactus in the Southwest and here may be found the probable source of this erroneous report.

Sotol has proved its utility as feed for stock, especially when continued drought has caused a scarcity of grass. Cattle if starved can eat the plants as they stand in the field but are likely to be injured by the sharp edges of the leaves. When the plants are cut in two, so as to expose their interior, they are greedily consumed. One cattleman in the southern part of the State, while fattening cattle for market, had several carloads of sotol shipped in for feed and used it with profitable results. The plants are very abundant in some localities, closely covering broad slopes along the foothills.

New Mexico is not bountifully provided with wild fruits, but there is a considerable number of native ones, some of which are not particularly palatable but can be eaten. The number that are really useful is small compared with those found in the Central and Eastern States.

The most valuable of all, certainly the most delicious and most frequently gathered, is the red raspberry (*Rubus strigosus*) which is exactly like the plant that bears the same name farther east. Seldom does it grow so luxuriantly as in some localities in New Mexico, where it forms thick patches, often several acres in extent, in the broad open valleys in the higher mountains. Its well flavored fruit is borne in profusion and is often gathered in quantity when accessible. It is a favorite food of bears and many of them frequent the berry patches when the fruit is ripe. A near relative is the thimbleberry (*Rubacer parviflorus*) which also produces a red fruit like the raspberry, but unfortunately the plants are low, never more than 1 or 2 feet high, and each bears but few fruits, so that gathering the berries is a tedious task. Strawberries of excellent quality are found in most of the mountain ranges, sometimes in sufficient abundance to be gathered for the table. In the ranges between Santa Fe and Las Vegas and northward a blueberry (*Vaccinium oreophilum*) is common. It grows in sandy soil high up among the spruces, a low shrub rarely more than a foot high, loaded with small wine-colored berries which are often picked and eaten. On the Plains along the eastern border of

the State are scattered thickets of the sand plum (*Prunus watsoni*) whose fruit is used for jams and jellies. The wild red plum (*Prunus americana*) is known in a few localities in the mountains. It is abundant about the pueblo of Taos whose inhabitants utilize all the fruit produced. In some parts of the State this plum seems to have escaped from cultivation but in places it is almost certainly indigenous.

The buffalo berry (*Lepargyrea argentea*) grows in the San Juan Valley, a large shrub usually about 10 feet high, with silvery white leaves and clusters of very small currant-like berries. The fruit has a flavor not unlike that of the cultivated red currant and is gathered and preserved. Currants and gooseberries are seen everywhere in all the mountain ranges. Unfortunately the fruit of the wild currants is tasteless and insipid and is seldom used for food by the English-speaking people although employed by the Indians formerly and to some extent to-day. The native people used the fruit either fresh, or dried and preserved for winter. From the berries certain of the western tribes prepared an intoxicating beverage, one of the species, *Ribes inebrians*, receiving its specific name from this fact. One of the gooseberries (*Grossularia pinetorum*) is distinguished by having its fruit, while agreeable to the taste, so densely covered by sharp spines that it can not be eaten. Elderberries (*Sambucus microbotrys* and other species) grow in most of the mountains and in the lower Rio Grande Valley. All have edible fruit that is sometimes gathered. The Mexican elderberry (*Sambucus mexicana*), which is frequent in cultivation in the Rio Grande Valley and may be native in some parts of the State, differs from the eastern species in becoming a good-sized tree. It is valuable as an ornamental plant because it is green nearly throughout the year and may put forth its blossoms even in January or February if there are a few days of mild weather. The algerita (*Berberis haematocarpa*), a native of the hills and dry canyons, is a barberry which bears quantities of juicy blood-red berries that are made into jellies. There are several other barberries, including the "Oregon grape" (*Berberis repens*), which grow in New Mexico, but never in sufficient abundance to furnish any considerable amount of fruit. One of the ground cherries (*Physalis neomexicana*), a troublesome weed in cultivated land at higher elevations, makes excellent preserves, besides being prepared in other ways.

The fruits that have been mentioned are nearly all that are used by the English-speaking people of the State, but in former times the Indians were compelled by the general scarcity of food to make use of many others, and some of the more primitive tribes, like the Navahos, still employ some of them. Among those whose fruit has been utilized are the lote bush (*Zizyphus lycioides*) and *Condalia spathulata*, low straggling desert shrubs of the southern mesas, the

wild grape (*Vitis arizonica*), choke cherries (*Padus melanocarpa* and *P. capuli*), the wild rose (the fruit or hips of *Rosa fendleri* and other species), service berries (Amelanchier sp.), mulberries (*Morus microphylla*), hackberries (*Celtis reticulata*), lemita (*Schmaltzia trilobata*), and tomatilla (*Lycium torreyi*, *L. pallidum*, and other species). Of the first two shrubs a Mexican once told the writer that the fruit consists of "mucho hueso y poco carne" (a large seed and little flesh), and this is true of most of those just enumerated. Wild grapes grow in many of the mountains, but their fruit is small and sour. Mulberries are found only in the southern part of the State. The trees, which stand in the drier canyons and on open stony slopes, are small and stunted, and the fruit is undersized and not very juicy. Service berries form thickets in most of the mountains, but the berries are small and insipid. The fruit of some of the species found in the northwestern part of the State is nearly if not quite dry, and so is not edible. The tomatilla, a characteristic shrub of the mesas and river valleys, bears an abundance of bright red juicy fruit which is eaten by the native population, although it does not seem very appetizing.

Besides these fruits—in the popular sense of the word—the seeds of many plants formed part of the food of the Indians. Those of the sunflower, a weed which thrives almost everywhere in the West, were gathered and ground into meal. This is so rich in oil that it was seldom used alone but was mixed with other substances. The seeds of some of the amaranths (Amaranthus spp.) and goosefoots or lamb's quarters (Chenopodium spp.) were collected by the Zuñis and Navahos, as well as those of purslane (*Portulaca oleracea* and *P. retusa*) and of certain grasses. The Apaches depended upon a sort of bread made from the ground legumes and seeds of the mesquite and the tornillo or screw bean (*Strombocarpa pubescens*). The pods of these shrubs are rich in sugar and sweet to the taste. Children are often seen chewing them and they are relished by stock of all kinds. The Zuñis gathered cedar berries and after grinding them formed the meal into cakes. Young fruits of the wild gourd (*Cucurbita foetidissima*) were cooked in various ways.

Besides the seeds of the lamb's quarters the plants themselves, the leaves and young shoots, were cooked as "greens," just as they frequently are in other parts of North America. Additional succulent plants such as the purslane, the Rocky Mountain bee weed (*Peritoma serrulatum*), a small composite (*Pectis angustifolia*), and many others were treated in the same way. All plants used thus are known by the Spanish name of quelite. It seems almost incredible to anyone familiar with the bee weed that it could ever be eaten. It is one of the most common plants of the northern part of the State, covering large extents of mesa land. Its stems and leaves when crushed give off a most offensive odor, but this is said to disappear upon cooking. Only the young shoots are used as food.

While New Mexico furnishes a number of fruits capable of being utilized in different ways, in the matter of nuts the State is not so fortunate, there being only one that is of economic importance. Two species of walnuts (*Juglans rupestris* and *J. major*) grow in the mountains and low foothills. The first bears very small nuts, scarcely large enough to be eaten, and the second has them but little larger and of poor flavor. Indians formerly collected the acorns of the many oaks for food, but it is improbable that they use any at present.

The one kind of nut which New Mexico does produce in quantity is the pinyon (*Pinus edulis*, pl. 12, *A*). This is the seed of a small pine tree, seldom more than 20 feet high and often much lower, which grows almost everywhere in the State at elevations of from 5,000 to 7,000 or 8,000 feet. Where the nut pine is found it is the most conspicuous component of the vegetation and often the only tree or shrub present, although commonly associated with one or two kinds of cedar. The nuts are inclosed in small cones, only a few in each. They are gathered in one of two ways. More frequently, after frost has come and the cones are opening, the nuts are shaken down upon blankets spread beneath the trees. Obviously only a fractional part of them can be secured in this manner, at least at a single shaking. Another method is to pick the cones before they are open and heat them until the nuts fall out or can be removed by the fingers. In either case they are roasted before eating, to the improvement of their flavor. The delicious taste of the roasted nuts is not excelled by that of any of our well-known kinds, and indeed is equaled by few of them. The nuts are small, scarcely more than half an inch long, and oblong in outline (pl. 12, *B*). Their thin shells are easily broken by the teeth and separated from the meat by the aid of the tongue. In the Southwest, at least among the native population, pinyons are much more popular than peanuts, to which they are most comparable, and wherever a crowd assembles on some festive occasion or on market days, the ground and sidewalks are soon covered by the shells. They can not be eaten rapidly, consequently one can eat them almost all day long. Enormous quantities of pinyon nuts are gathered in good seasons, which are said to occur once in every five years. In some localities they are brought into market by the wagonload and have been gathered in large enough amounts to be used in feeding horses. Most of the crop is consumed in the Southwest where the pinyon is known and appreciated, but a part is shipped East and retailed in the fruit stores of the larger cities. Candy manufacturers have used the nuts in sweetmeats and they would become a staple article if the supply were more constant.

The nuts of another New Mexican pine (*Pinus flexilis*) are edible, but they have such thick shells that they can not be easily cracked with the teeth and are seldom gathered. The gum of the pinyon

is sometimes chewed, being similar in flavor and consistency to spruce gum.

Several plants native to New Mexico have roots that serve useful purposes. Two kinds of wild potatoes grow in the State, one of which (*Solanum jamesii*) is a common weed in cultivated lands in the pinyon belt, while the other (*Solanum fendleri*) is not rare in the higher mountains on shaded banks along with pine and spruce trees. The latter is not distantly related to the cultivated potato (*Solanum tuberosum*) and has been referred to that plant as a subspecies. It has small tubers about half an inch in diameter which are sometimes eaten. Wild onions, as well as the roots of certain umbellifers and of wild liquorice (*Glycyrrhiza lepidota*) were used for food by the earlier inhabitants of the region. A member of the Senna family, *Hoffmanseggia densiflora*, found on the lower alkaline land in the western part of the State, is known as camote de raton or rat's sweet potato. It develops along its roots many spherical tubers an inch or less in diameter, which the Indians dig and cook like the common potato.

A near relative of the yellow dock, known as cañaigre (*Rumex hymenosepalus*) is another plant whose root is economically important. This is often the first plant to bloom in the spring on the sandy mesas of southern New Mexico. The flowers appear as early as February in the lower Rio Grande Valley, and by the time most other plants are blooming this has completed its growing season and its fruit stalk and leaves have disappeared. For the rest of the year the plant consists of a large mass of fascicled roots similar in appearance to those of the dahlia and about as large. They are rich in tannin and are employed throughout the Southwest in tanning hides. Most of the cattle, sheep, and goat skins cured within the region are treated with cañaigre roots. Utilization of the plant for commercial purposes has been attempted. Experiments toward this end were successful in demonstrating the efficacy of the roots in tanning.

The problem of fuel in New Mexico has solved itself in much the same way as elsewhere. With the advent of the railroads coal mines were opened and coal is largely used in localities where it is accessible, but wood is still the principal fuel. In the mountains, with the forests of pine, fir, spruce, and other trees to draw upon, firewood is obtained at no great expenditure of labor. Where available oak is preferred to the wood of coniferous trees because of the less amount of soot formed by its combustion. In the foothills of the northwestern and western parts of the State pinyon and cedar are the woods depended upon. The pungent odor of cedar smoke which greets one whenever he approaches a human habitation must always be associated in memory with Indian camps to one who has traveled in the less frequented parts of the Southwest.

In the river valleys, often far removed from forested mountains, or separated by almost impassable country, the fuel question is less easily solved. There is a widely quoted saying that in the Southwest men "dig for wood and climb for water." The first part of this statement is literally true. The people of southern and southwestern New Mexico, like those of the adjacent regions, depend for fuel largely, if not chiefly, upon a low, straggling, spiny shrub, which would certainly be ignored by one not acquainted with its peculiar possibilities. The mesquite (*Prosopis glandulosa*, pl. 13) is a widely distributed and characteristic plant of all the Southwest, being in New Mexico always a low shrub, never more than 3 to 5 feet high, its slender branches seeming even more tenuous by reason of the sparse dissected foliage with which they are invested. The branches are so small that even were they all compressed into a solid block of wood they would still supply but scant fuel. The shrub's value lies not in its branches and trunk, however, but in its roots. When the sand heaped about the stems is pushed away and the roots uncovered it becomes evident that the mesquite can be a source of a large amount of firewood. The roots have been developed more than is common in woody plants, presumably that they may serve as storage organs for water, and thus enable the shrubs to exist in the arid regions where they grow. Many of the native Mexicans earn no inconsiderable part of their livelihood by digging mesquite roots upon the mesas or in the waste land of the valleys. Each bush yields a large amount of wood, but there are no data available from which to determine the amount per acre. While in the form of very thick and gnarled hard roots, extremely difficult to cut or split, when finally prepared for the stove or grate the wood is of unexcelled quality. It can be burned green, but is improved by drying. The tops or branches are usually thrown away. Unimproved land in the valleys is generally covered with mesquite and removal of the bushes and roots must precede cultivation.

A near relative of this shrub is the tornillo (*Strombocarpa pubescens*, pl. 4, *A*) or screw bean, which receives its English name—the exact equivalent of its Spanish one—from the shape of its pods, which are coiled into a long cylinder so as to resemble a screw. In the case of the tornillo the stems, not the roots, furnish fuel. These are little larger than an ordinary broomstick and would appear to be an unsatisfactory source of heat, but thousands of loads of them are cut in the valleys every year. The bushes grow only in the alluvial lands. When cut off near the ground, they sprout up and are soon ready for cutting again.

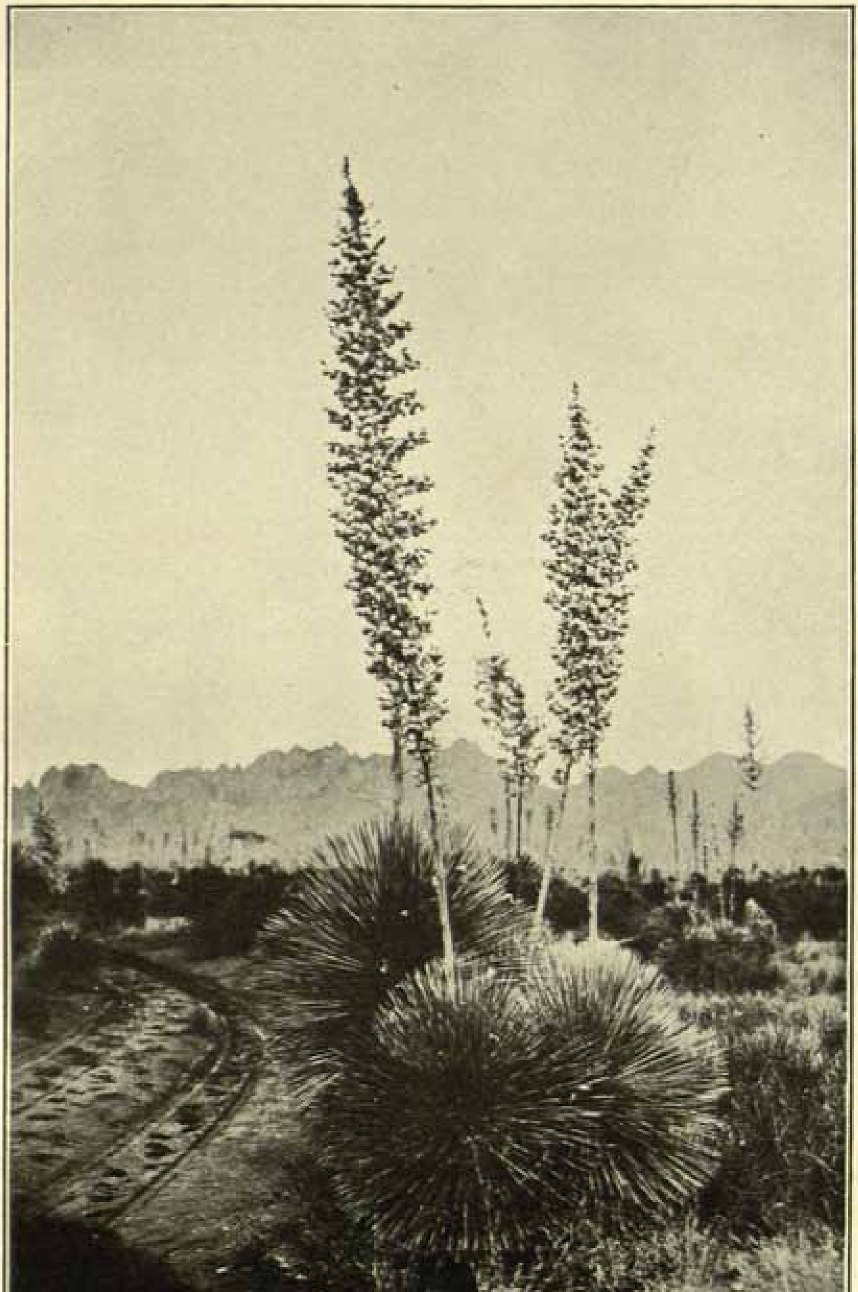
The land immediately bordering the principal streams is nearly always covered with bosques or groves of the valley cottonwood (*Populus wislizeni*) accompanied by a thick undergrowth of small shrubs. The cottonwood, which often reaches a large size, is used

principally in the construction of houses, corrals, and shelters. The wood is so soft that it burns almost as rapidly as paper and produces an intense heat but of short duration. The large trees seem immune to destruction as long as left to the native people, who are apparently baffled by their size. In some localities one sees men going miles to dig mesquite roots, an operation requiring the hardest kind of labor, while along the roads lie huge trunks of fallen cottonwoods, untouched because the people do not know how to cut them up.

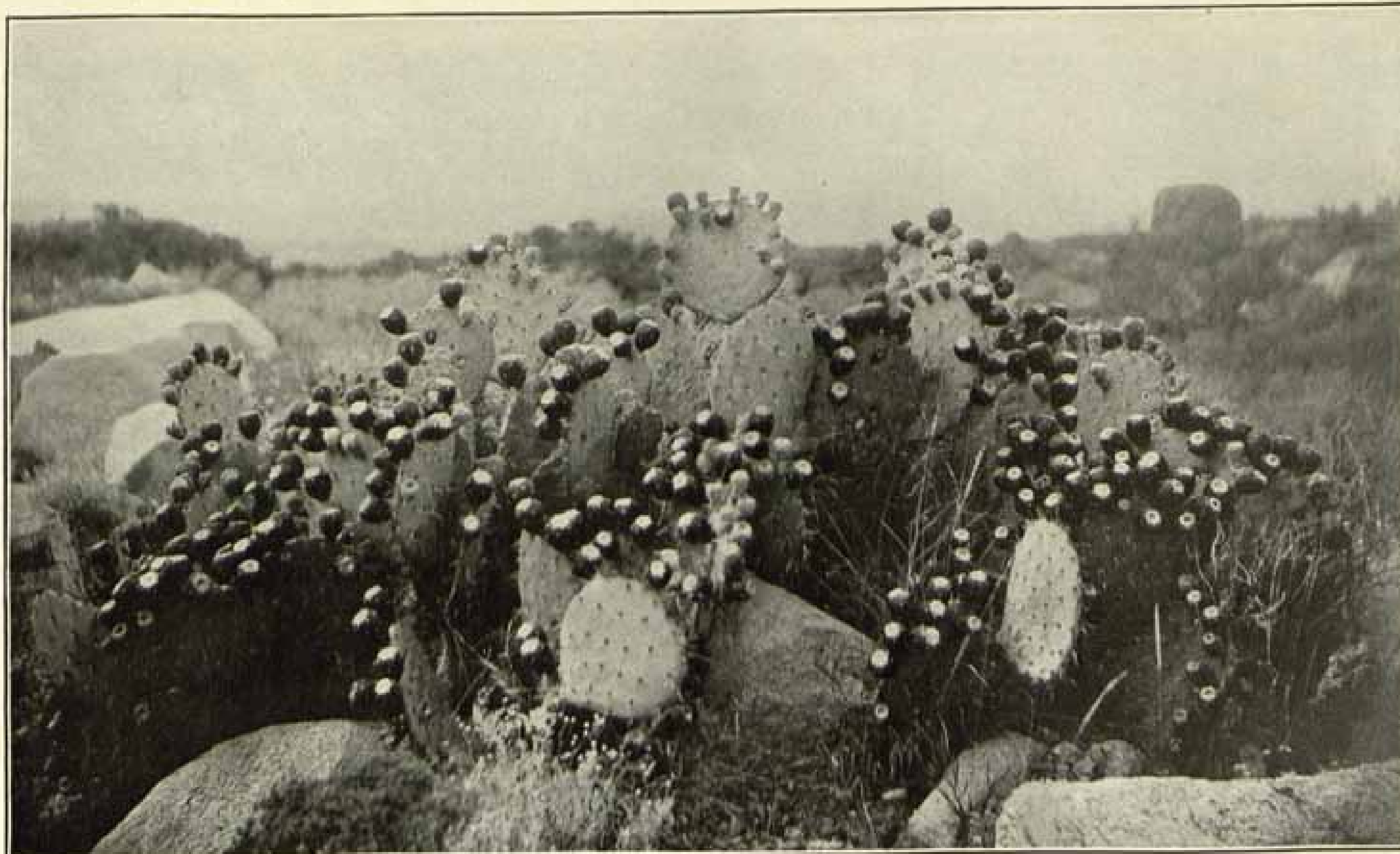
Best known among all the handiwork of the North American Indians are the splendid rugs made by the Navahos, whose reservation occupies the northwest corner of New Mexico. These blankets, whose workmanship would be a credit to any civilized people, notwithstanding the crude methods of their manufacture, are noted for the permanence and harmony of their colors. To-day the raw wool is colored with imported synthetized dyes, but formerly all the colors of the blankets, like those of other similar articles, were obtained from native plants or mineral substances. Red was produced by a decoction of the mountain mahogany (*Cercocarpus parvifolius*), the powdered bark of the alder (*Alnus tenuifolia*), and the ashes of the cedar (*Juniperus monosperma* and *J. utahensis*). Yellow was obtained by rubbing the wool with a paste made from the roots of cañaigre or by using an extract of the flower heads of rabbit brush (Chrysothamnus spp.). Black was produced by a decoction of the leaves and berries of the lemita (*Schmaltzia trilobata*) combined with calcined gum of the pinyon. Other tribes elsewhere in the State used different plants to secure the same results.

There is not space here to enumerate any of the plants used medicinally by the Indians; indeed but little is known or probably ever will be known of this subject. To almost every plant some real or fancied medicinal virtue was assigned. While many of these uses were purely empirical, others doubtless were based on some substratum of fact. There is a common herb which is reputed throughout all the West and Southwest to be a remedy for the bite of the rattlesnake. Others were used to treat the stings of venomous insects and of spiders and scorpions. Nor is there space for the mention of any of the forage plants, in whose variety and abundance consists New Mexico's greatest natural resource, furnishing sustenance to thousands of head of stock each year. A second great asset lies in the extensive forests which cover all the mountains. Those plants which are here briefly noted are but the most conspicuously interesting ones, but there remain many more which are equally or more deserving of mention and may be shown by investigation and exploration to be more useful to man.

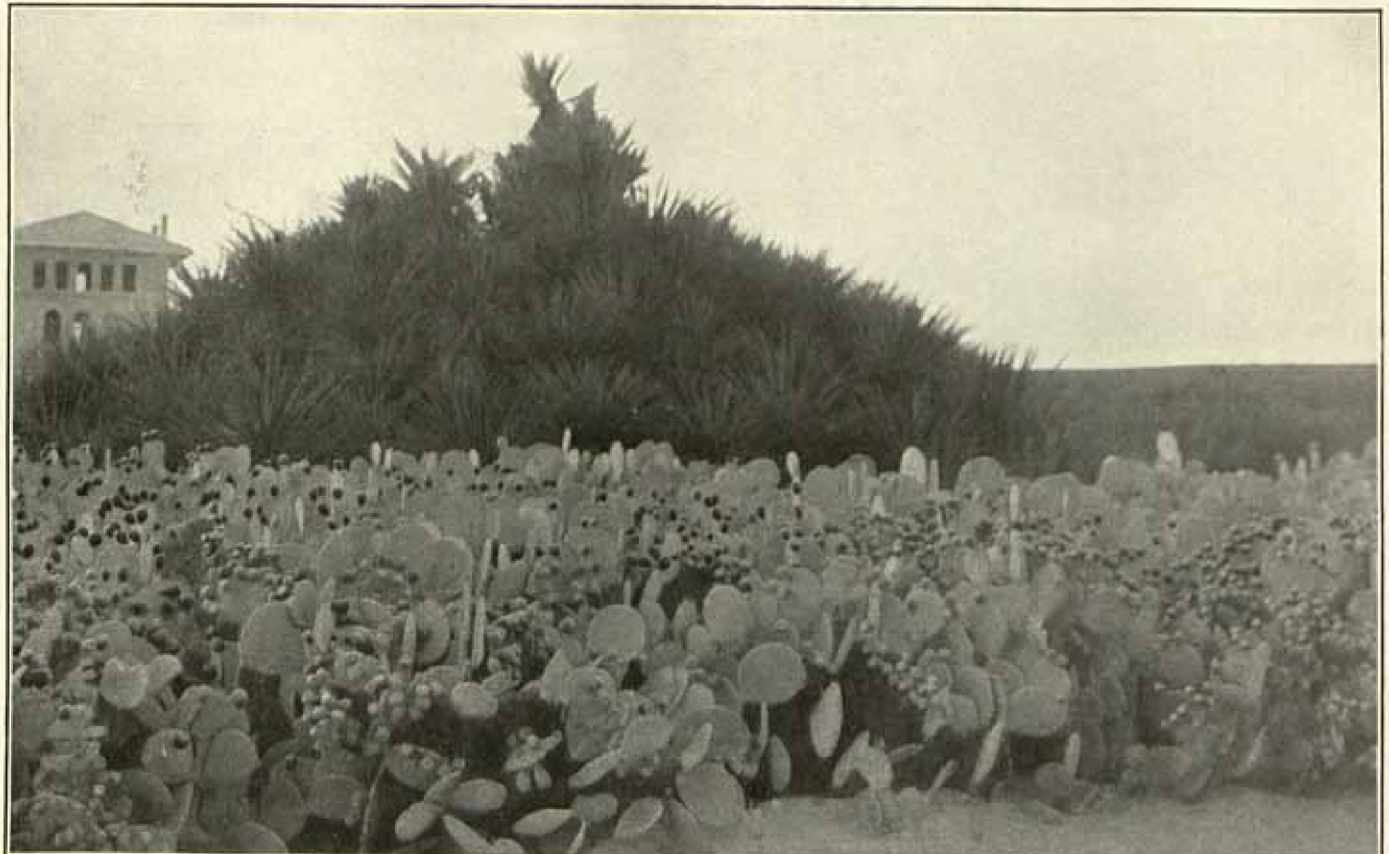
The photographs for plates 4*A*, 6, and 12*A*, were courteously supplied by the Biological Survey, U. S. Department of Agriculture. They were made by Mr. Vernon Bailey.



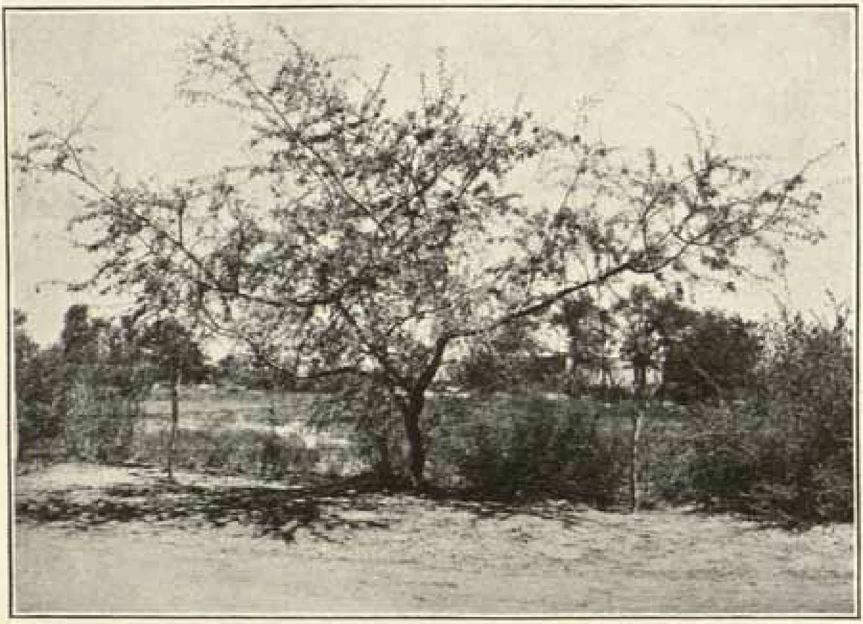
THE PALMILLA (YUCCA RADIOSA) ON THE MESA NEAR THE ORGAN MOUNTAINS, NEW MEXICO.



A PRICKLY PEAR (OPUNTIA ENGELMANNI) IN FRUIT; ORGAN MOUNTAINS, NEW MEXICO.



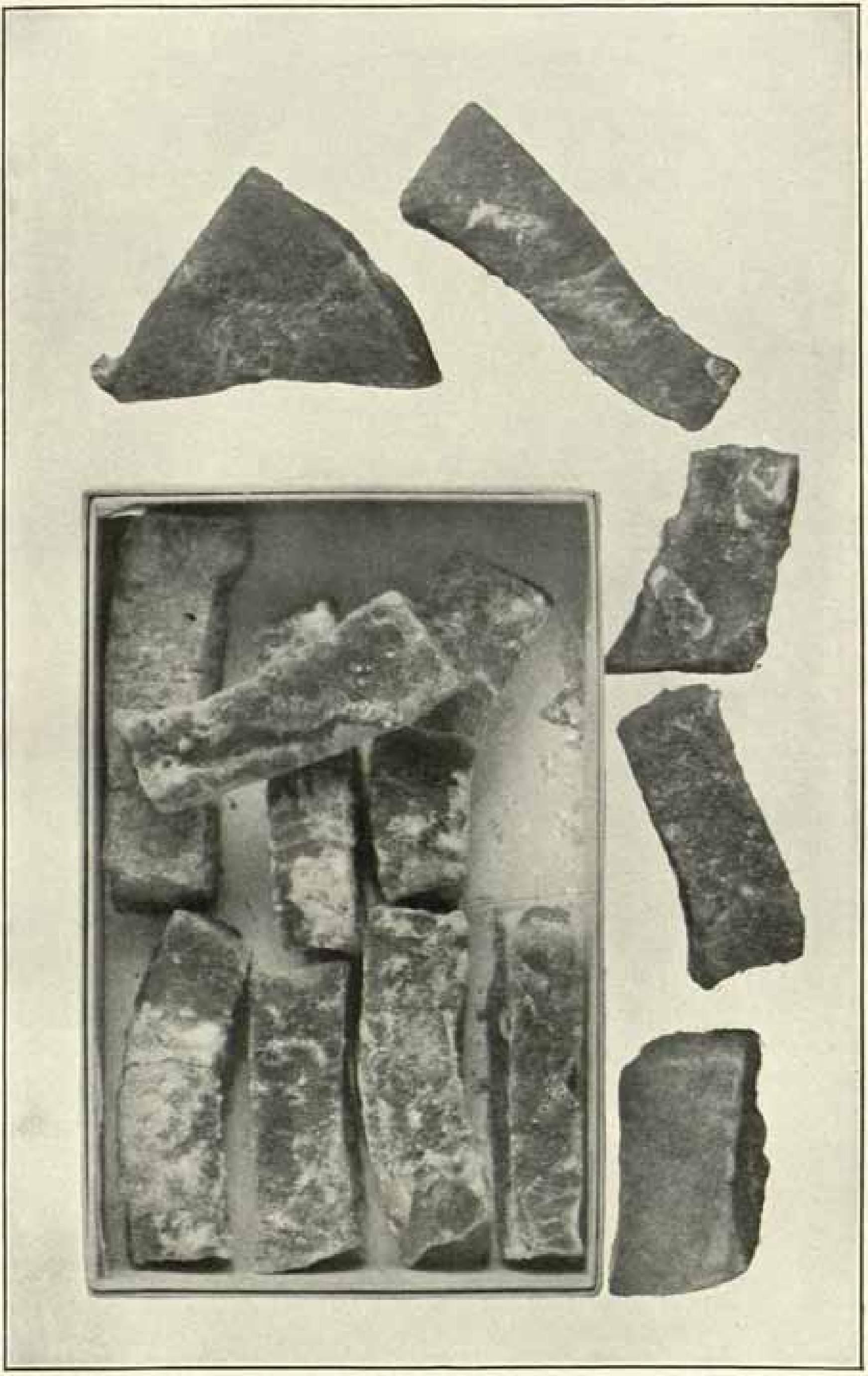
A PRICKLY PEAR (OPUNTIA DULCIS) CULTIVATED AT THE NEW MEXICO AGRICULTURAL COLLEGE. THE PYRAMID IN THE BACKGROUND IS COMPOSED CHIEFLY OF SPANISH BAYONET (YUCCA MACROCARPA).



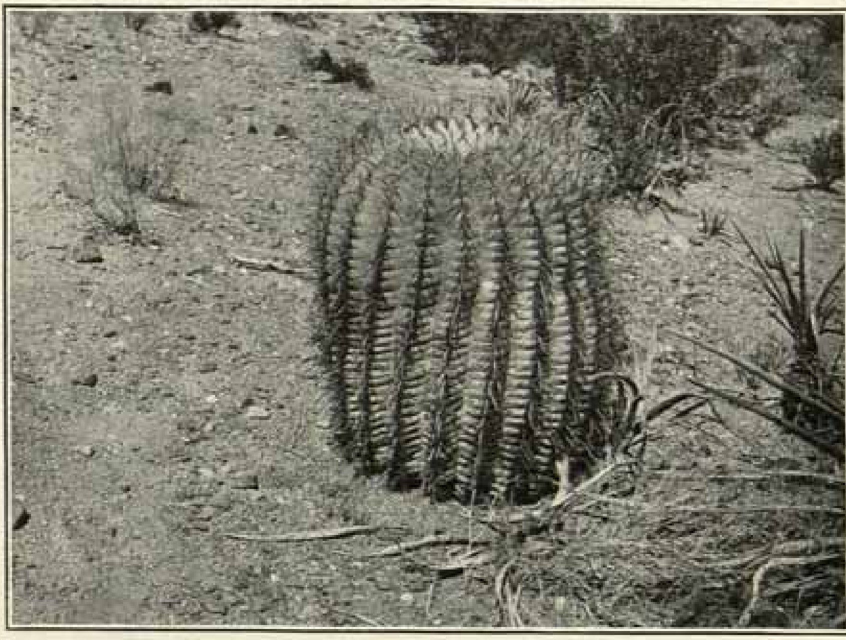
A. TORNILLO (STROMBOCARPA PUBESCENS) IN THE RIO GRANDE VALLEY NEAR EL PASO, TEXAS.

B. FRUIT OF A PRICKLY PEAR (OPUNTIA DULCIS).

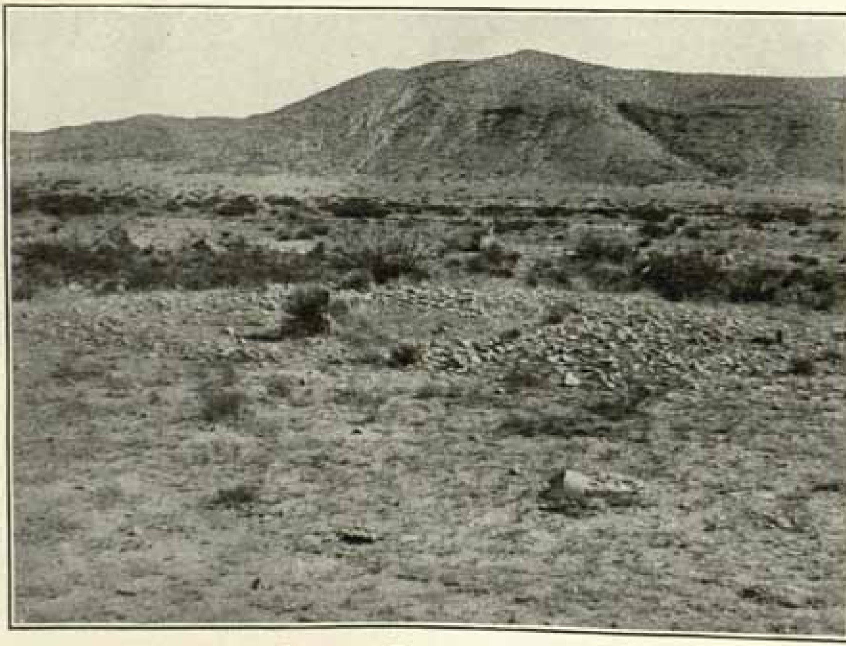
[One-fifth natural size.]



DULCE DE VIZNAGA, CACTUS CANDY, MADE FROM THE PULP OF THE BARREL CACTUS (ECHINOCACTUS WISLIZENI).

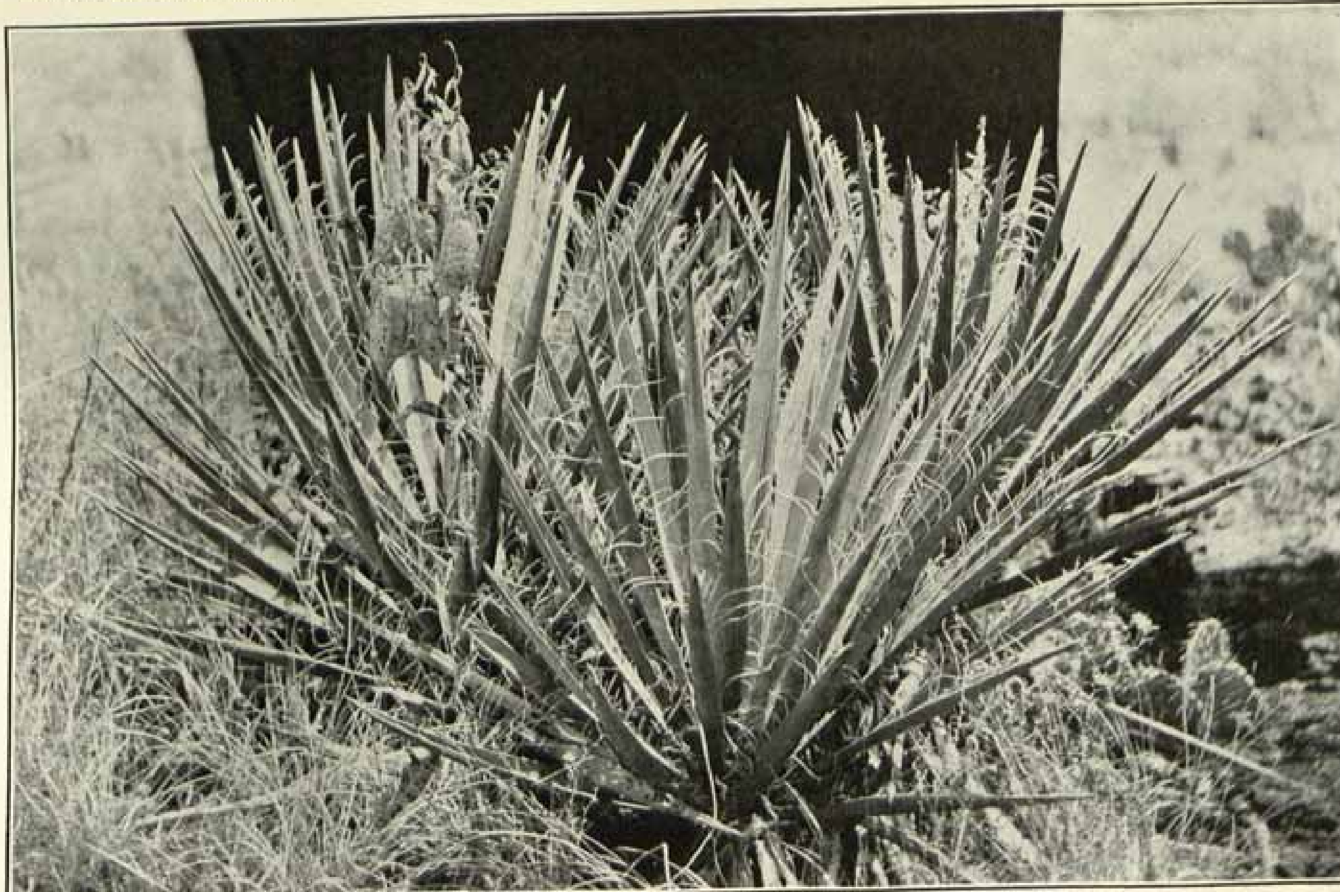


A. VIZNAGA OR BARREL CACTUS (ECHINOCACTUS WISLIZENI).

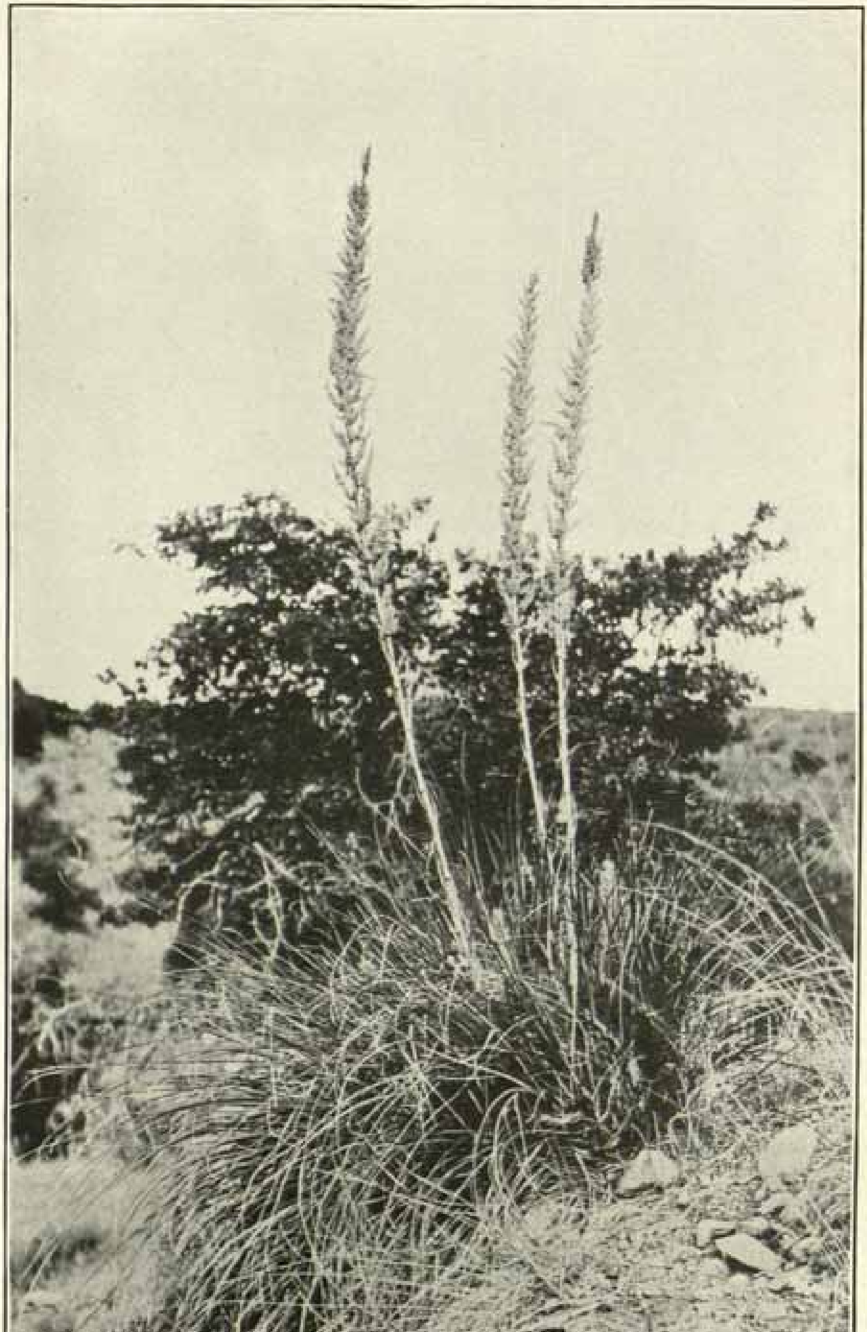


B. OLD MESCAL PIT IN THE GUADALUPE MOUNTAINS NEW MEXICO.

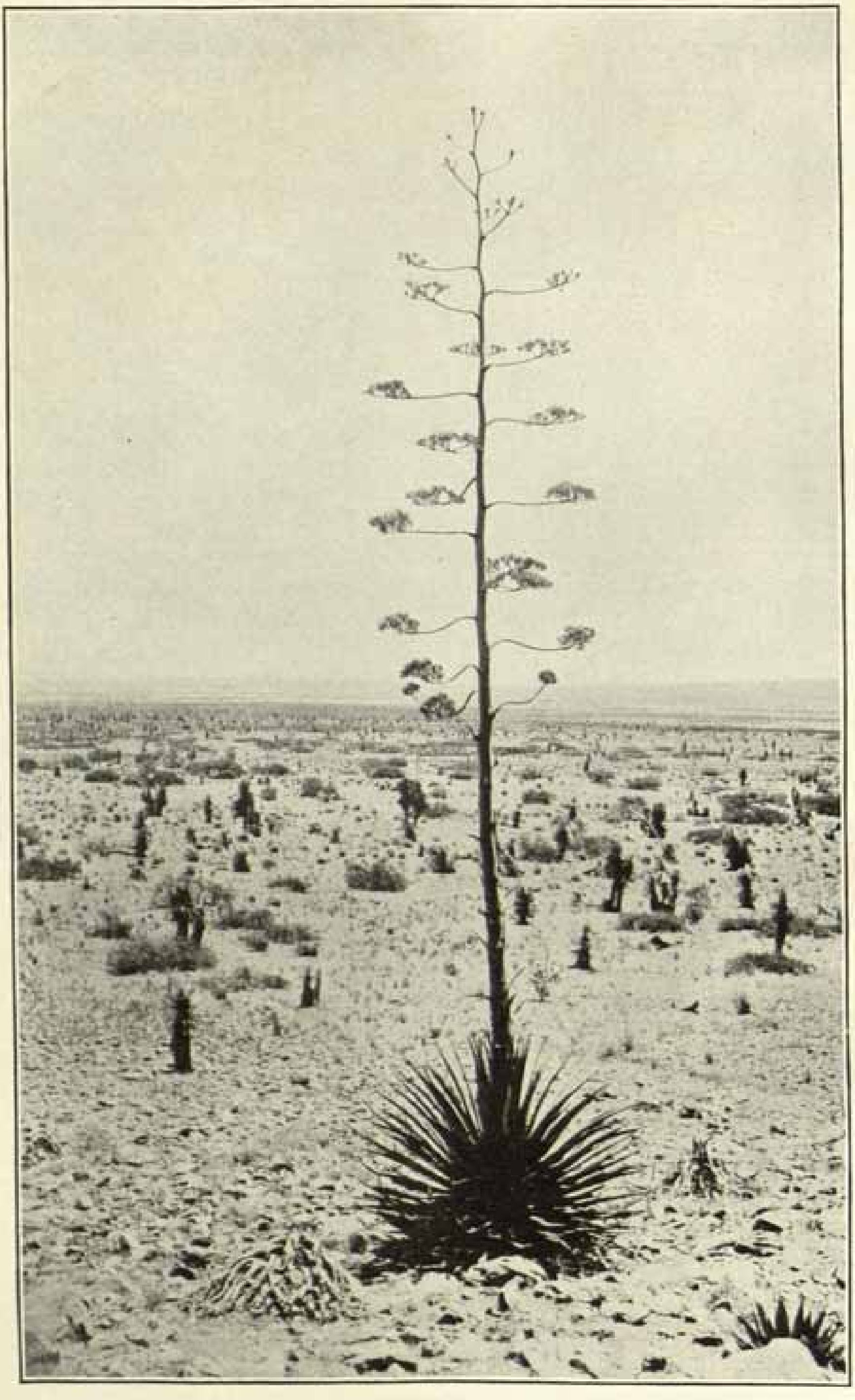
FLOWERING PANICLE OF THE PALMILLA (YUCCA RADIOSA).



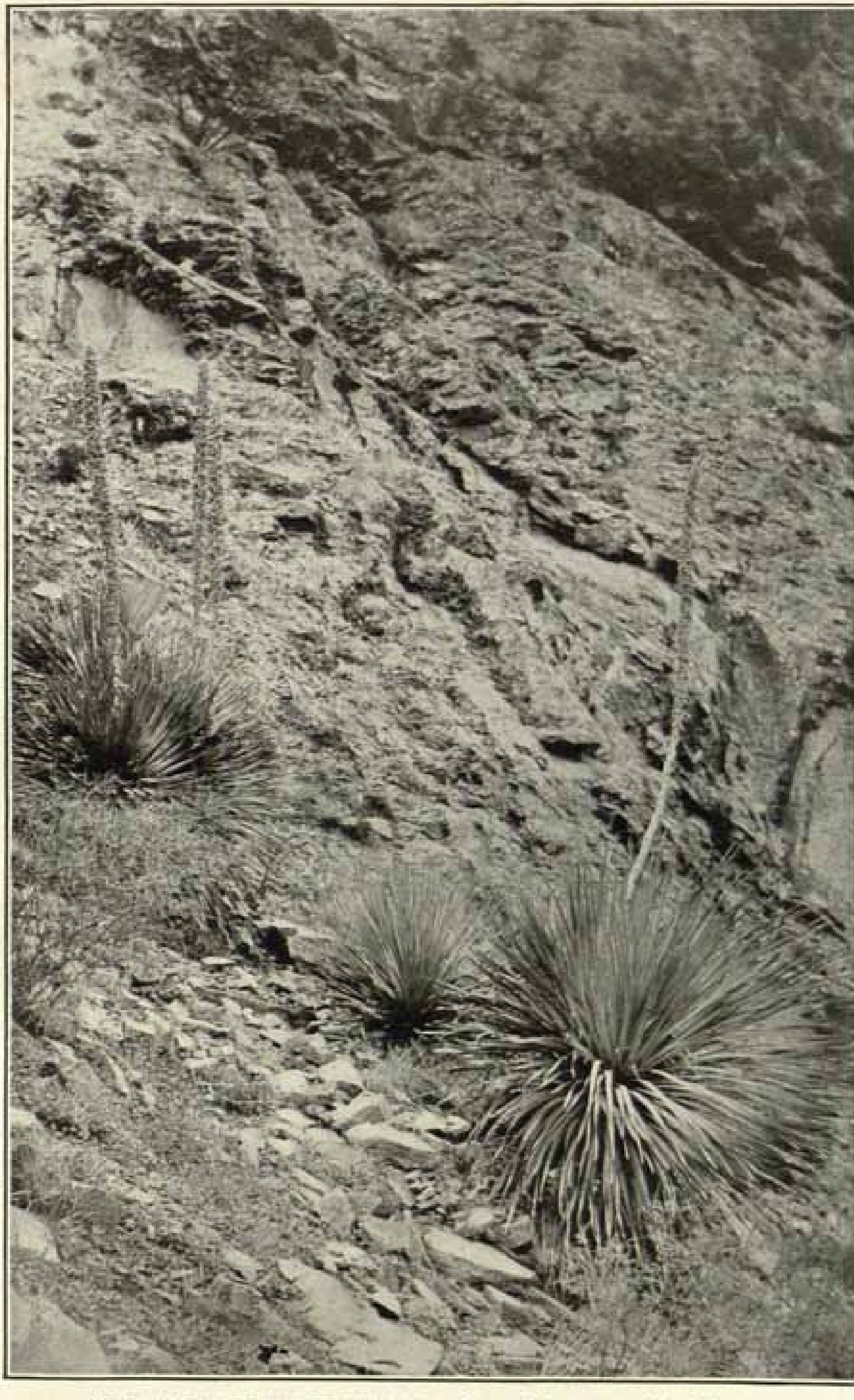
FRUITING PLANT OF THE DATIL (YUCCA BACCATA) IN SOUTHERN NEW MEXICO.



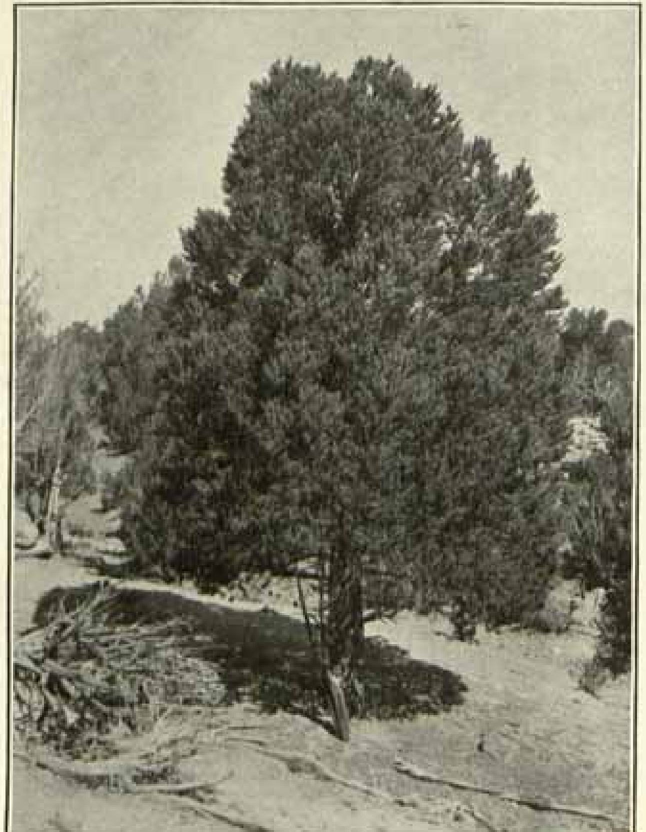
BEAR-GRASS (NOLINA MICROCARPA) AT SAN LUIS PASS, NEW MEXICO.



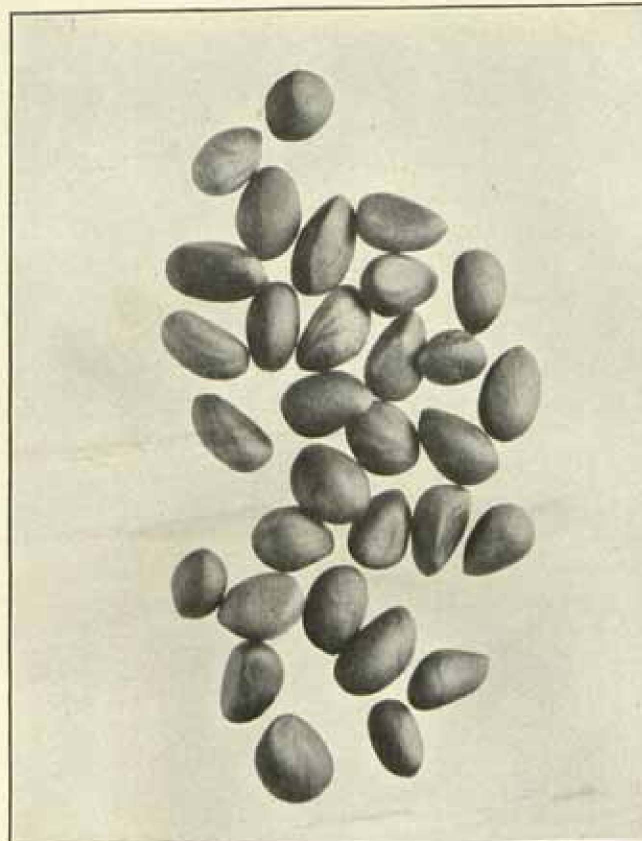
MESCAL OR CENTURY PLANT (AGAVE PARRYI), NEAR THE HATCHET MOUNTAINS, NEW MEXICO.



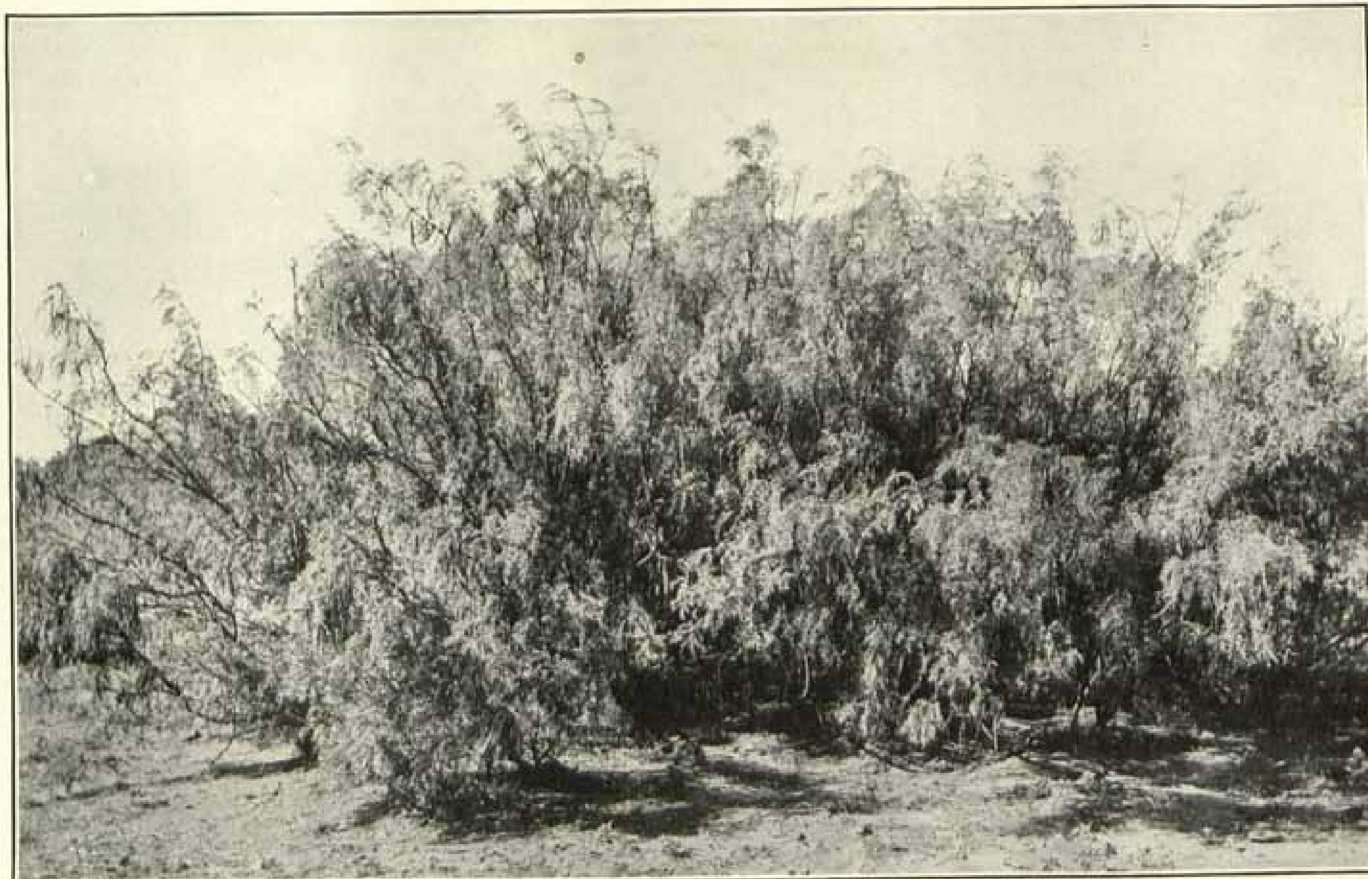
SOTOL (DASYLIRION WHEELERI) IN THE ORGAN MOUNTAINS, NEW MEXICO.



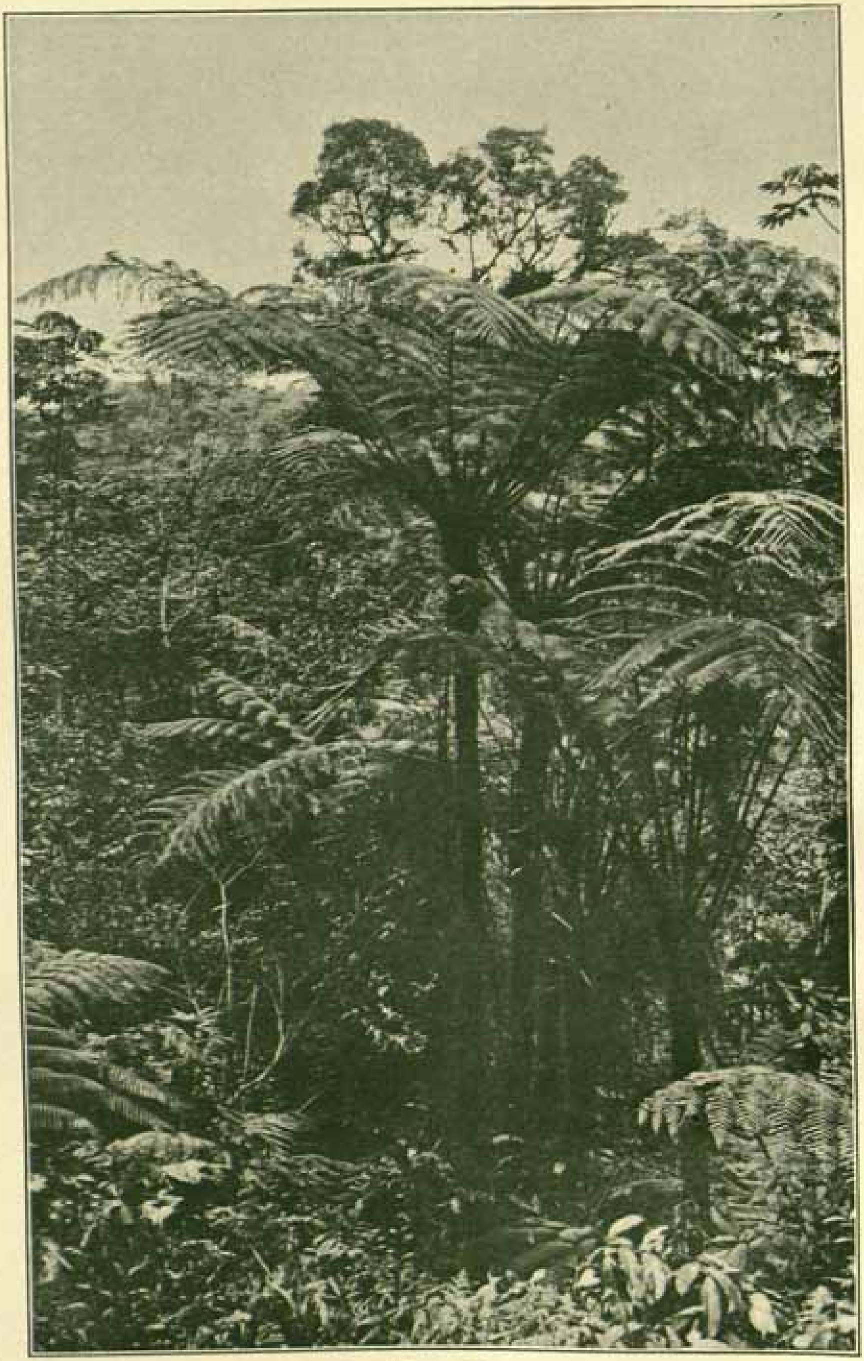
A. PINYON TREE (PINUS EDULIS).



B. PINYON NUTS.
Natural size.



MESQUITE BUSH (PROSOPIS GLANDULOSA) NEAR DEMING, NEW MEXICO.



GROUP OF TREE FERNS (CYATHEA PRINCEPS).

THE TREE FERNS OF NORTH AMERICA.

[With 15 plates.]

By William R. Maxon.

Although the name tree fern is occasionally given to any large fern of treelike form, it has come by common usage to have a definite application to the members of a single family, the Cyatheaceæ, and in so far as any one descriptive term can apply to a large group of world-wide distribution, whose distinctive technical characters are minute and not always very obvious, the expression is a singularly appropriate one. The Cyatheaceæ are known as tree ferns because the great majority of the species are essentially treelike in size and proportion and have strong woody trunks, often attaining a height of 40 feet or more.

One may easily imagine the feeling of surprise with which the early voyagers to the New World, looking upon the wonderful profusion and luxuriance of these enormous plants, contrasted them with the relatively small ferns of Europe. One wonders also at the restraint and rather passive scientific attitude of Sloane, one of the earlier English writers upon the West Indian flora, who, having accompanied the Duke of Albemarle upon his voyage to Jamaica in 1689, thus quaintly describes a common species (*Alsophila aspera*), as he observed it in that island:

> This has a trunc twenty Foot high, as big as ones Leg, (after the manner of Palm-trees) undivided, and covered with the remaining ends of the Foot-Stalks, of the Leaves fallen off, which are dark brown, as big as ones Finger, two or three inches long, thick set with short and sharp prickles. At the top of the trunc stand round about five or six Leaves, about six Foot long, having a purple Foot-Stalk, very thick beset with short, sharp prickles on its backside. At about a Foot distance from the Trunc, each Leaf is divided into Branches set opposite to one another, placed near the bottom, at about six Inches distance from each other.

The ultimate divisions (segments) of the leaf are mentioned as

> about one third of an Inch long, and half as broad, blunt, easily indented about the edges, of a dark green colour above, pale green below, very thin, and so close set to one another that there is no defect or empty space between them.

From this description, brief as it is, several of the most characteristic features of the group as a whole may be noted: The single and simple unbranched trunk or stem, "after the manner of palm trees," the spreading circular crown of ample fronds surmounting the stem, the lighter color of the under surface of the leaf, which may be observed in nearly all Cyatheaceæ, not a few of the species being grayish or even whitish below, and above all the "close-set" divisions, without "defect or empty space between them," a feature which in connection with the enormous size of the fronds of many species lends to tree ferns their greatest charm, that of surpassing leafiness and vigor.

For the benefit of the ignorant or of the superficially minded Sloane adds:

> From these Trees growing on the Mountains of Hispaniola the Spaniards argued the fertility of that Soil, making Ferns grow to such a vast bigness, which in Europe were so inconsiderable, not considering that the Ferns in Europe and here, were quite different kinds one from the other.

Not alone in dimensions, but also in technical characters of structure are the huge ferns of this alliance distinct from those of continental Europe. Sloane calls them "trees," and to this day the term "fern tree" is employed in Australia as commonly as our more familiar "tree fern" for members of the Cyatheaceæ. "Fern-tree gullies" is there a common expression, applied to deep shady ravines of the moister coastal regions having a dense growth of Cyatheaceæ.

ARBORESCENT HABIT.

A typical group of tree ferns of different ages is shown in plate 1, a scene in Guatemala. The species is *Cyathea princeps* (often known as *C. Bourgaei*, and described more recently as *C. Munchii*), a rather uncommon plant which ranges from the moister parts of Mexico to Alta Verapaz, eastern Guatemala. Not all species of Cyathea have their fronds so rigidly ascending. Indeed, *Cyathea arborea*, which is the commonest and perhaps the most graceful North American member of the genus, will be seen (pl. 2) to have them laxly arching or even drooping. The direction of the fronds, however, in many species depends much upon the age of the plant. Thus, the smaller individual at the right in plate 1 owes the upright position of its fronds in part to its quick, vigorous growth and partly, no doubt, to the need the plant has of stretching its leaves up toward the level of the rather dense surrounding undergrowth, where of course the sunlight is much stronger than below.

Tree ferns may in fact be regarded as "standing on tiptoe" in their effort to secure light and air. They are commonest in those moist, densely forested, tropical regions where their struggle for

very existence is sharpest, and where, except for the acquisition of this trait or of some other to give them special advantage, their life would indeed be short. To meet the same conditions ferns of other families and of many tribes and genera have shown wonderful adaptability of different sorts, both in structure and change of habitat, two of the most common instances being the development of the climbing form and epiphytic habit of growth. In the intensely wet and heavily forested mountain region of Chiriqui, for example, probably three-fourths of the ferns are epiphytic. To make best use of the arborescent habit, the growth of the tree-fern stem must be steady and of a permanent character; and we find that moist tropical conditions usually permit this, however slow may be the rate of development from season to season.

Before proceeding, however, to a discussion of the widely different forms assumed by the many species, or of the more minute technical characters which serve to distinguish the genera and species, it may be well to note briefly the general factors which appear to control the distribution of tree ferns in North America.

DISTRIBUTION AND HABITAT.

As already indicated, tree ferns are characteristically inhabitants of wet, forested, tropical and subtropical regions and reach their best development in mountainous districts which are not subject to drought or pronounced seasonal change. In the Greater Antilles they are found mainly upon the northern slopes and summits of the higher mountains, as, for example, the Sierra Luquillo of Porto Rico and the Blue Mountains of Jamaica, where the cool, moisture-laden trade-winds from the northeast bring a constant and ample supply of moisture. The fern vegetation to the south of these mountains is more or less strongly xerophytic, both islands mentioned even having a semiarid region of cactus and scrub growth. Similar conditions were noted in the Sierra Maestra of Cuba. Here on the comparatively dry southern slopes of the peak Torquino at 3,500 feet I found plants of *Cyathea arborea*, a species which in Jamaica and elsewhere in the West Indies rarely ascends to more than 2,000 feet. Associated with it were several polypodiaceous ferns which ordinarily are characteristic of the lowland forests and whose occurrence here so far above their usual limit is in all probability directly correlated with moisture supply. The southern coast in the lee of the Torquino is intensely hot and semiarid, with a dense "chaparal" formation (including cacti), wholly unsuitable not only to tree ferns but to a majority of ferns of other families, as well.

Similar conditions upon a grander scale are observed upon the continent, the tree ferns being practically confined to the humid

Atlantic slopes and to the high mountains. Thus, in the mountainous parts of eastern Guatemala (Alta Verapaz), where according to the native saying "it rains 13 months out of every 12," tree ferns are exceedingly abundant, a few species occurring at and near sea level, but the most of them at from 4,000 to 6,000 feet altitude. West of this region, in the dry interior basin, they are wanting; and only two species, *Cibotium Wendlandi* and *Hemitelia costaricensis*, are reported from the higher region near the Pacific, even the moist forest belts of the volcanoes Fuego and Agua having none, so far as known.

In Costa Rica a relatively small number of tree ferns are found in the moist Atlantic lowlands, but they are elsewhere of very general occurrence, excepting only the half desertlike slopes facing the Pacific and the dry and open portions of the interior table land, which has a temperate and delightfully equable climate. The latter area (meseta central) is relatively small, and one has only to go out a few miles to the lower mountain slopes to find tree ferns in profusion. The greater part of Costa Rica, however, and by far the most interesting, is the exceedingly broken, mountainous region to the northward, from which rise the four great volcanic peaks Turrialba (11,128 feet), Irazú (11,312 feet), Barba (9,412 feet), and Poas (8,786 feet), from east to west. These intercept most of the moisture from the Gulf, and it is here that the Cyatheaceæ reach their highest development, both as to species and size and number of individuals, in any part of North America. Christ, indeed, regards it as "the richest tree fern region of the world." Certainly it is an endemic center of a high order, and when adequately explored is likely to yield many more than the 50 species it is now known to contain. It embraces altitudes above 5,000 feet; and although snows are wanting from all Costa Rican volcanoes, heavy frosts occur more or less regularly from 6,000 feet upward. The extremes of temperature endured by the tree ferns of this region must be very great.

Chiriqui, the westernmost Province of Panama, apparently does not differ greatly from Costa Rica as a tree fern region. Although there are a few coastal species, here also the great majority are found in the high mountains, which form a definite cordillera paralleling the coast line, east and west. Recent exploration has shown that they are mainly those known hitherto only from Costa Rica. The Cordillera gradually decreases eastward, until in the Canal Zone only three or four lowland tree ferns are found. One of these, *Hemitelia petiolata*, first described from Panama, is common in ravines and wet thickets.

In Mexico, also, as might be expected, tree ferns are wanting from the interior, arid, high plateau region, whose flora has been so thoroughly investigated during the past 35 years. Upward of 20 species

of Cyatheaceæ are known from Mexico, but almost the only recent material of these is that secured upon occasional excursions from the table-land into the moist lower regions bordering the *tierra caliente* of Vera Cruz.

In the several regions mentioned a few tree ferns are found to be partial to the lowlands. Among the West Indian species of this class may be noted *Cyathea arborea* which, however, as already explained, exceptionally occurs high up on the southern slopes of the Sierra Maestra, finding there congenial surroundings which are wanting at a lower altitude in this region. Upon the continent *Alsophila microdonta* is found near sea level from Mexico along the Atlantic to South America. *Alsophila myosuroides* shows a similar preference for low altitudes, its known range extending on the mainland from Vera Cruz to Honduras, and including also Cuba and the Isle of Pines. Another and very remarkable species of Alsophila (*A. blechnoides*, described hereafter) ranges along the Atlantic coast from Guatemala to Trinidad. The occurrence of *Hemitelia petiolata* in the moist coastal woods and thickets of the Canal Zone has already been mentioned. Further examples might be cited.

There are still other species which, though occurring commonly at a low elevation, yet show a considerable altitudinal range; for example, *Alsophila aspera*, which in Jamaica extends from about 1,000 to 4,000 feet altitude. A better instance is that of *Hemitelia multiflora* (*Hemitelia nigricans*), which exists mainly as a sea-level species from Guatemala to Panama, along the Atlantic, but nevertheless ascends to nearly 4,000 feet in Costa Rica. There are, doubtless, many tree ferns which are more resistant than others to untoward conditions of environment, or less particular in their requirements of soil, shade, and moisture, which occupy similarly broad belts. In fact, local and hardly appreciable conditions of exposure and air drainage, as well as more obvious differences of humidity and topography, may be supposed to exercise great influence in determining the distribution of tree ferns as of other plants.

Certain tree ferns occur typically as undergrowth in the dense shade of lofty forest trees; for example, *Cyathea gracilis*, a Jamaican species which grows usually in peaty soil in wet, sheltered depressions. The trunks of this, though commonly short, sometimes reach 8 to 12 feet, whereupon, according to Jenman, they "frequently fall and lie procumbent, though this does not much affect the growth." In the mountain ravines of Java and Malaya there occurs also, according to Christ, a definite thicket formation of tree ferns, "over which the crowns of the forest trees form a second forest." A similar "under-forest" formation in which screw pines (Pandanus) are associated with tree ferns is mentioned from Celebes. These dwarf tree-fern associations at high altitudes are believed to fill the impor-

tant rôle of conserving moisture by preventing radiation and the consequent drying out of the forest floor.

Perhaps a majority of tree ferns, however, occur as an integral part of the predominant forest growth, their crowns often reaching nearly or quite to the level of the tree tops, or in not a few species even exceeding it; as, for instance, *Cyathea pubescens*, one of the tallest Jamaican species, which attains a height of 40 feet or more upon the heavily forested higher ridges of the Blue Mountains and easily thrusts its crown above the surrounding deciduous forest. There are also certain species, like *Alsophila parvula*, *Cyathea furfuracea*, and *C. insignis*, which in Jamaica grow indifferently in open and shaded situations, though their occurrence in the open may have followed naturally from the partial and piecemeal clearing of the land, the small cleared patches remaining under cultivation only a year or two before rapidly growing up to bush. It is noticeable that those individuals growing in the open often acquire a condensed or stunted form, as described later.

At least one species, *Cyathea arborea*, flourishes in open situations, commonly in very large colonies. Jenman has described it in Jamaica as "gregarious, often covering acres on fully exposed slopes, everywhere shunning shade." Perhaps on the latter account, and also because of its ubiquity, it is found more commonly than any other about dwellings and plantations, its huge, lacelike fronds lending an unusual decorative charm to scenes already novel and interesting to northern eyes. The formation of groves by this species in relatively dryish, open situations is almost unique for the family, although a few (e. g., *Alsophila armata*) are more or less gregarious in partial shade, and many others of our American species are found in colonies in the deep, wet forest. In New Zealand the social tendency has even resulted in the formation of large groves under intensely humid conditions. One of these, which Colenso came upon in the forest called "Seventy-mile Bush," in North Island, is described by him as follows:

> On a flat in the heart of the forest, in a deep hollow lying between steep hills, the bottom of which for want of drainage was very wet and uneven and contained much vegetable mud and water even in the dryest summer season, I found a large and continuous grove or thicket of very tall tree ferns, chiefly *Dicksonia squarrosa* and *D. fibrosa*, with a few of *Cyathea dealbata* intermixed, with but few forest trees and shrubs growing scattered among them. I suppose they occupied about 3 roods of ground, and I estimated their number to be 800 to 1,000. They were all lofty, from 25 to 35 feet high, and in many places growing so close together that it was impossible to force one's way through them.

Concerning tree-fern formations of this sort in both New Zealand and Australia, Christ has pointed out that they rarely consist of a single species, but are as a rule mixed associations of two or more

species; for example, *Hemitelia Smithii* with *Cyathea medullaris* and *C. dealbata.*

DIMENSIONS AND SHAPE OF TRUNK.

The stem or trunk in the Cyatheaceæ varies greatly in dimensions, shape, and direction, and in most characters of outward appearance and covering, though for a given species these features are, with a few exceptions, fairly constant in mature individuals. The tallest tree fern known is *Alsophila excelsa*, a nearly extinct species occurring upon Norfolk Island, to the east of Australia, whose trunk John Smith has stated to measure from 60 to 80 feet in length. Scarcely inferior to this is *A. MacArthuri*, found upon Lord Howe's Island, which, according to Maiden, attains a height of from 60 to 70 feet. Among American species the nearest approach to these dimensions of length is found, perhaps, in *Alsophila armata*, which Jenman records as sometimes reaching 50 feet in Jamaica, "the head gradually diminishing in size as the stem lengthens."

The smallest member of the family in the world is *Alsophila Kuhnii*, recently described from the Cordillera of Colombia, in which the short rootstock is erect and the leaves (including the leaf stalks) but 8 inches long, the blade less than 1¼ inches broad. The smallest of the North American species is the Jamaican *Cyathea Nockii* (pl. 8), looking most like some coarse bipinnate wood fern (Dryopteris or Polystichum), its relatively stoutish stem 4 to 8 inches long, prostrate upon the ground and rooting underneath, its fronds 1 to 3½ feet long, borne in a crown.

Certain species show, likewise, a slenderness of stem which is astonishing in relation to the enormous spread of crown, while others have remarkably thick trunks which are of very different internal structure. The slenderest North American tree fern known to me is *Cyathea minor* of eastern Cuba, whose trunk measures only 1 to 1½ inches in diameter, though rising to a height of 6 to 12 feet. A Ceylon species, *Cyathea sinuata*, with curious narrow, nearly entire strap-shaped leaves, is even more slender.

Exact data upon the thickness of tree fern trunks are not very abundant. Darwin, in the Voyage of the Beagle, mentions a trunk (the genus and species not stated) in Van Diemen's Land which had a circumference of 6 feet, nearly 2 feet in diameter. Mr. H. W. Henshaw, of the United States Department of Agriculture, measured trunks of Cibotium (supposed to be *C. Menziesii*) in the district of Olaa, Hawaii, many of which (including the dense covering of adventitious roots) were 3 feet in diameter, and a single one 4 feet. These are said to have grown usually as undergrowth in the forest, but also in partial clearings, where they attain a height of 40 feet, large

numbers being from 20 to 30 feet high; the usual shape of the trunk was cylindrical, although many showed a conical form at the enlarged base. Among North American species the largest known is *Cyathea Brunei*, as it occurs on the lower slopes of the Volcano Turrialba in Costa Rica. The trunk of this is nearly cylindrical and very stout, 12 to 15 feet high, 12 to 20 inches in diameter, and clothed with the dead hanging fronds of previous seasons; the fronds measure 12 to 15 feet long and 5 to 6 feet broad—truly a giant among ferns.

It is interesting to note, however, that in addition to the two very small American species previously mentioned a fair number of Cyatheaceæ have failed to develop a pronounced upright habit, and that several of these are among the largest-fronded species of the family; for instance, *Alsophila quadripinnata* (*A. pruinata*) and several species of Hemitelia, section Cnemidaria. The former, which in one state or another ranges through the West Indies and from Mexico to Chile, has enormous fronds, 9 to 15 feet long, borne in a spreading crown from a short erect stem which is rarely more than 3 feet high and usually much less, averaging perhaps 1 foot high, with a diameter of 3 to 5 inches. Jenman has called attention to the fact that the stem of this commonly "buds and throws up from the base a number of minor stems about half the size of the primary one," a condition which is comparable to the development of the fasciculate or multicipital crown in the male fern (*Dryopteris filix-mas*) and other common northern species, but which is not found in many Cyatheaceæ. The Cnemidaria species mentioned show a wide amount of variation in length of trunk. One or two South American members of this small and exceedingly interesting section have tall slender trunks, but most of the North American representatives have the stem either short (1 to 3 feet high), thick, and erect, as in *Hemitelia* (Cnemidaria) *horrida* (pl. 11), or a little longer, and weakly ascending, rarely attaining the dignity of a trunk.

TYPES OF UPRIGHT TRUNKS.

Two main types of upright trunks may be distinguished readily among the American Cyatheaceæ: The first, in which the fronds, like those of *Cyathea arborea*, fall completely from the trunk in old age, leaving clean-cut scars; a second type, in which the fronds are imperfectly jointed to the trunk and thus are slowly deciduous, commonly hanging for several years after dying, and even when fallen leaving parts of their bases as a rough outer covering to the trunk. More species have trunks of the first sort than of the second; but the latter condition is not at all uncommon, and is apparently the rule for species of Dicksonia. It is common also to many species of Cyathea, among which may be mentioned *C. nigrescens* in Jamaica and *C. araneosa* in Cuba. Some species are intermediate in this respect; and many (e.g.,

the West Indian *Cyathea elegans* and *Alsophila aquilina* and the Costa Rican *A. crassifolia*), which exhibit this character to a marked degree in their young state, in age develop clean trunks, with definite even-surfaced scars.[1] The appearance of a trunk sheathed with broken or hanging fronds is much less attractive than that of stems from which the leaves are freely deciduous; yet a few, like *Cyathea Brunei*, more than make up in sheer massiveness whatever they may lack in elegance and graceful proportion.

The arrangement of the leaves upon the stem may be observed best in species which have smoothish trunks, as in the common form of *Cyathea arborea*, shown in plate 3, figure A. In these the leaf scars may be either widely spaced or rather compactly set together, forming a rough but regular mosaic pattern; if the latter, the trunk is said to be tesselate. In most there may be noted a definite spiral arrangement, which differs according to the species and, exceptionally, among individuals of the species. In *Cyathea aureonitens*, however, and probably in others, the scars are not spirally arranged nor closely set, but uniformly appear in distinct horizontal zones, the six to eight leaf scars of each forming a separate distinct girdle about the trunk, 8 to 12 inches from the one above or below.

RESTING PERIODS.

Cyathea aureonitens has also another unusual feature, that of shedding all its fronds, after maturity, at one time, seasonally, a trait which it shares with several other species of the same genus, *Cyathea concinna* and *C. Tussacii* of Jamaica and *C. insignis* of Jamaica and Cuba. Concerning the first of these Jenman remarks that "like *C. Tussacii*, in the resting season, in late spring or toward midsummer, it drops all its fronds, the large stout trunk, a uniform diameter from top to bottom, standing, postlike, till growth begins again." With respect to *C. Tussacii* he writes, "In some instances, late in the resting season, about May or June, the fronds all drop away, leaving the bare trunk. When vegetation begins again a whorl is thrown up together." *Cyathea insignis*, also, "like the two preceding, makes its growth periodically, throwing out a tier of fronds at once and then resting for an interval." In *Cyathea aureonitens*, as I have observed it in western Panama and Costa Rica, not only the large tripinnatifid fronds themselves but also their component leafy parts, the pinnæ and pinnules, are sometimes freely deciduous; the latter were even observed to fall first, leaving the leaf stalks and nearly bare midribs of the huge leaves standing out temporarily like stout whip stalks before they also should fall.

[1] A similar tendency toward bushy growth from long-persistent leaves is noted in young plants of certain palms, as, for example, the common "coroho" of Jamaica (*Acrocomia fusiformis*).

Other species show this trait to a lesser extent; and while a few seem to maintain always their full complement of leaves, it is doubtless true that most tree ferns bear their greatest number of leaves during the moister, vegetative season, and a smaller number while resting between active growing periods. An accentuation of this tendency might easily lead, and doubtless has led, to the complete seasonal shedding of fronds in the several species mentioned. This conclusion is strengthened by our knowledge of the development of the habit by different species upon widely separated areas, and is not invalidated by the fact that these are associated with other species, apparently under identical conditions of environment, in which this trait is not in evidence.

VARIABILITY IN RATE OF GROWTH—AGE.

Of the species which under humid forest conditions ordinarily produce lofty trunks, certain individuals growing in more open situations will often be found much reduced in stature. One of the best illustrations of this to come under my observation is that of *Cyathea furfuracea*, a species which is very common in the forests of the Blue Mountains of Jamaica, occupying a broad belt between 4,000 and 6,000 feet, and occasionally attaining a height of 40 feet or more. Dwarfed specimens upon partially cleared slopes, although often only 3 or 4 feet high, still retain their erect arborescent character, however slow the development of the trunk may be, and differ from the more luxuriant individuals growing in moist shade mainly in their smaller fronds and more closely set leaf scars, the last a definite mark of the plants of slow growth. The same species as I met with it upon the shrubby open slopes of the Gran Piedra in eastern Cuba, at 4,000 feet elevation, is even more reduced, its trunk measuring from 1 to 2 inches in thickness, its fronds one-third to one-half their usual size. This phenomenon of reduction in size as a result of excessive insolation, and consequent drying out of the substratum, is commonly observed in most groups of ferns whenever plants normally shade inhabiting are thrust into the open. Johow has stated that the great tree ferns of Juan Fernandez develop as well in the sun as in shade; but such a condition, we must believe, is exceptional.

Another excellent example of the variability in rate of growth is found in *Cyathea arborea*, as evidenced by two trunks, both of this species (shown at one-half natural size in pl. 3), which I collected upon the southern slope of the Sierra Maestra of eastern Cuba in March, 1907. The plants of which figure A represents a typical trunk section were about 35 feet high and slender, with a compact crown of medium-sized leaves spreading widely from the trunk,

their attachment being nearly at right angles. The plants of which figure B represents a trunk section were rather shorter and more robust, with an immense crown of larger fronds rising from the trunk like a huge funnel, their leaf stalks being suberect and in attachment extending from the apex a distance of several inches down the trunk. At the time these plants were collected they were believed to represent two very different species. Nevertheless, upon careful study subsequently it was found that they possessed no technical differences whatever by which they might be recognized as distinct, aside from the difference in shape and size of leaf scars, even the scales of the trunk and leaf bases being exactly alike except as to size; and the conclusion was forced that these were forms assumed by a single species, the differences noted in the trunks being dependent upon the age and vegetative vigor of the plants. This conclusion was substantiated later by an examination of several living West Indian plants of this species in the conservatories of the New York Botanical Garden, in which both kinds of scars were found to occur upon the same individual, each in a separate zone. In one cultivated plant in particular it was clear that a period of rapid vigorous growth, as indicated by a sequence of long-elliptical distant scars, had been followed by a period of diminished growth, during which the elongation of the stem had proceeded but slowly. The record of the latter period was plainly written in the zone of closely set, rounded to subhexagonal scars, the shape and position of these obviously having resulted from the crowding of the leaves at the apex of the very slowly lengthening stem. I have noticed a similar variation in the rate of growth in other arborescent species of Cyatheaceæ, but none so pronounced as in *Cyathea arborea*.

The age of the larger tree ferns is difficult to determine, and I am not aware that any authentic data are available. Certain specimens in Jamaica have been reckoned 200 years old, which probably is too high an estimate, although many individuals doubtless attain an age of at least 100 years, if we may judge from the apparent rate of elongation of the upper stem. Growth, however, is more or less periodic at some stage in the life history of most large tree ferns, depending upon favorable or unfavorable seasons and upon various factors of environment; and the only reliable means of arriving at the probable age of such individuals is from an extended series of observations, over a long period, of plants growing in their native environment.

BRANCHING OF TRUNKS—ADVENTITIOUS GROWTH.

The upright stems of tree ferns are usually simple, but there have been put on record several instances of occasional forking of the trunk, and in a few species the tendency is rather pronounced.

Jenman cites *Alsophila armata* and *Cyathea furfuracea* in Jamaica as occasionally branched and having two or more crowns, and *Alsophila aspera* as having produced in one instance several stems from a single base. The peculiar *Dicksonia Berteroana* of Juan Fernandez is said to divide at the base, having branches up to 18 feet long and "thick as one's leg." A notable instance also is that of a New Zealand species, *Hemitelia Smithii*, as described and figured by Buchanon, in which a specimen 16 feet high had no less than 16 branches. In *Alsophila quadripinnata*, previously mentioned, the branching is at or near the ground, as in *Dicksonia Berteroana*.

Christ has also mentioned on Werckle's authority a remarkable example of adventitious growth in a Costa Rican tree fern (*Cyathea* sp.) which is worthy of further investigation. In this plant buds are said to have been borne in all the axils of the leaves, their position therefore being at the upper side of the leaf scar after the fronds were fallen from the trunk. Although a comparatively small number of these developed, yet the stem was several times branched at a height of 5 feet, and the larger of the branches formed a beautiful crown of more than 25 branches.

In a large number of Cyatheaceæ having treelike stems one of the most conspicuous features is the development of adventitious roots, which encircle the older portions of the trunk in a hard, wiry, closely interwoven mass, very much like bark. These roots are commonly produced in great abundance, often wholly obscuring the original proportions of the stem, which may, indeed, appear in cross section merely as a core, measuring but one-fourth to one-half the total diameter. Toward the bottom of the trunk they are especially abundant, as might be expected, and frequently occur in such quantity as to form a massive conical base, which undoubtedly serves to give stability to the lofty stem, as in *Cyathea suprastrigosa* (*C. conspicua*), a species inhabiting the upper slopes of several Costa Rican volcanoes, whose huge base is said to measure a full 5 feet in diameter. There can be little doubt also that the formation of the dense indurated covering of the lower and middle portions of the trunk proper gives great strength and rigidity to the otherwise slender stem, which better enable it to support the weight of the upper part, including the great spreading crown of succulent leaves. The production of these aerial roots is apparently continuous, the diameter of the complete "trunk" (stem and aerial roots combined) thus roughly keeping pace with the elongation of the trunk.

Tree fern trunks of this sort are the favorite home of many filmy ferns (Hymenophyllaceæ), a few of which, like *Trichomanes capillaceum* (*T. trichoideum*), are not often found in other places. The sight of a huge fern trunk, its rough surface clothed on all sides in a lacelike mantle of this most delicate of all ferns, each of their hair-

like divisions with its tiny drop of moisture sparkling in the soft half light of the cool forest, and the unbroken silence of the forest itself create an impression not readily to be forgotten.

In Hawaii and elsewhere aerial root masses are cut from the stem and fashioned into hanging baskets for the cultivation of ferns, orchids, and various epiphytes. They are admirably suited to this purpose, the interstices among the closely interwoven roots affording a ready outlet for excess water.

TREE FERN TRUNKS AS TIMBER.

The illustration shown in plate 4 is of a building at Sepacuité, Alta Verapaz, Guatemala, whose outer upright timbers are mostly tree fern trunks, roughly squared and set on end close together. The country immediately surrounding Sepacuité is for the most part heavily forested, except in the areas cleared for coffee planting, and since many species of tree ferns still abound, the use of their trunks in building is not remarkable. I am informed, however, by Mr. O. F. Cook, of the United States Department of Agriculture, who has traveled extensively in this region, that elsewhere, even under conditions of considerable difficulty, a similar use of these timbers is made, indicating the high value placed upon them. Mr. Cook writes as follows:

> Though Guatemala is naturally a country of heavy forests, wood for building purposes, or even for fuel, is a scarce and expensive article in most of the larger towns, all of the neighboring forests having been cut long since and burned to make room for cornfields. Everything in the way of wood has to be brought down from the mountains on the backs of men.
>
> During a visit to Coban, the capital of the Department of Alta Verapaz, in 1904, many Indians were seen carrying tree fern trunks through the streets. On inquiry it was learned that the fern logs command a higher price than any other kind of wood, and are looked upon as the best of building material. The special value of the fern wood lies in the fact that it withstands the attacks of the termites and does not decay. The termites, or so-called white ants, are wood-boring insects that are very destructive to buildings in tropical countries.
>
> The fern trunks have a diameter of 6 or 7 inches. They are usually flattened on two sides or roughly squared and are set upright to support the framework of the native houses. The walls are filled with clay or loose rubble of clay and stones. The surface receives a coating of plaster in the interest of appearances and as a protection against the weather.
>
> The fern timbers are entirely black in color, like wood charred in fire. The texture appears rather loose and open, the outer layer being mainly a compact mass of small roots; but the elements have a glassy hardness that makes it easy to understand their resistance to all forms of decay or insect injury. When houses become dilapidated with age the fern trunks are taken out and used over again and are considered quite imperishable.

Jenman mentions a somewhat similar use of the trunks of *Cyathea arborea* by the blacks in certain parts of Jamaica as posts for their houses, stating that no other species is there applied to this purpose.

According to Christ *Alsophila elongata* is thus utilized in Colombia, and the trunks of *Dicksonia Sellowiana* in Brazil by planters in making inclosures for their farms. In Colombia Mr. Frank M. Chapman has observed the occasional use of tree fern trunks "possibly 14 feet in height above the surface of the ground" as telegraph poles, although as a rule bamboos are ordinarily there used for this purpose.

Still another use is made in Hawaii of Cibotium trunks, which, as mentioned above, there grow to such enormous proportions. Mr. Henshaw states that it is a common practice to make trails, 1 to 5 miles long, leading through the woods to the coffee plantations in the mountains, entirely out of Cibotium trunks, either whole or split in halves. He adds that the coarse thick covering of adventitious roots provides a springy, well-drained surface for walking, and that trails thus constructed, by the convenient use of these trunks as a rough and nearly indestructible planking, afford ready access to plantations through wet forests which otherwise would prove almost impassable.

THE LEAVES.

Considerable attention has been devoted thus far to a consideration of the rhizome, which has been found to assume different forms of growth and to vary greatly in nearly all respects. A similar diversity is exhibited also by the leaves or, as they are commonly called, the fronds. Of the two tribes between which the North American species are divided, the Cyatheæ and Dicksonieæ, the former presents not only a far greater variety in vegetative form, but also a much higher differentiation of special structures. It will, therefore, be desirable to consider the two tribes separately, though it is impossible in the present paper to do more than indicate briefly some of the more typical structural and vegetative features of each.

LEAVES OF THE CYATHEÆ.

The leaves of the Cyatheæ vary in length from 1 foot to 15 feet, the two examples previously cited being *Alsophila Kuhnii* and *Cyathea Brunei*, respectively. In position they have been mentioned as arching in a semierect crown, spreading, or even drooping, their attachment (in arborescent species) varying from nearly vertical to horizontal, and thus determining, in connection with the rate of growth, the shape, size, and relative position of the leaf scars. In addition to the general shape and cutting of the leaf blades there remain now to be noticed especially the thornlike armature of the stipes (leaf stalks) and rachises (primary and secondary midribs of the blades), the covering of the growing crown, and the production of minute scales and hairs of many different kinds not only upon the vascular parts of

the blades, but also upon the leaf tissue. In these characters the members of the tribe Cyatheæ show almost infinite diversity.

In many species of Cyathea and Alsophila, and less commonly of Hemitelia, the trunks are more or less completely covered with spines, a fact which no one who has reached out hastily and grasped one in a futile effort to stay his rapid descent down some steep, slippery, forest-clad slope, is likely to deny. As a rule, however, the trunks are spiny simply from the partial persistence of the broken stipe bases, which indisputably are spiny. Two stipe bases thus armed are shown in plate 5; of these figure B represents *Cyathea onusta*, and figure C, *C. aureonitens*, both species of Costa Rica and western Panama. The last mentioned is one of those which really produce spines upon the trunk also, and these, like those of the stipe, of needlelike sharpness. In certain species the spines are long, straight, columnar, and blunt; in others low and broadly conical, with a hooked point; in still others slender and sharp, but very short and closely set. The conical, more or less curved form is the commonest one among North American species. In *Cyathea arborea* (pl. 5, fig. A) they are evident only as low tubercles, and in not a few others they are altogether lacking. They are usually produced only upon the underside of the stipe, in some species extending in lessened size and number along the rachis well toward the apex of the blade, as may be seen in *Alsophila aspera* (pl. 7). In color spines range from yellow to brown, purple and black, usually taking the color of the stipe or presenting a darker and highly polished surface. They have been said to be poisonous, though the truth of this is certainly open to doubt.

The stipe is otherwise furnished with large protective scales which, however varied in character, are as distinctive for each species as are the spines of each. These scales closely invest the apex of the crown in a thick, upright, brushlike mass. The young fronds, like those of all ferns, as they unroll from the bud carry with them their scaly covering. (Plate 6 represents at natural size a young expanding frond of *Cyathea arborea*.) The great majority of the large scales which develop upon the frond as it increases in size are, however, readily deciduous; and as a rule only those of the lower stipe, and more especially those which are seated in the deep axils of the stipe bases, persist until the frond attains maturity. The latter are precisely like those of the crown, of which, in fact, they are really an integral part. Thus constituted, the cap or head of the crown consists ordinarily of scales so closely packed together that they serve as a very effective, impervious, protective covering, not only against excessive moisture and consequent infection from without, but also as a safeguard, enabling the plant to maintain without interruption its vital activities at the one essential point, the apex, despite unusual extremes of dryness, heat, and cold. The utility of the chaffy cap is

thus obvious; for it is inconceivable that without this or some similar protective feature individuals of such slow continuous growth could attain their great size and age. Tree ferns with trunks 20 to 80 feet high do not grow in a day.

As offering diagnostic marks to assist in the recognition of the species also the scales are of the greatest interest, since however various their form, color, and structure these features are usually constant and distinctive for each species. The largest scales I have seen are those which densely clothe the 2-inch thick stipes of *Cyathea Brunei*. In this species the large outer scales are of a silky texture, yellowish-brown, up to 2½ inches long, in shape very narrowly lanceolate and long pointed, borne in great profusion and widely spreading, and underlaid by successively smaller scales, the innermost of which are comparatively minute, slender, stiff, dark brown, and have minutely spiny margins. Very few species show so great variation in this particular. The prevailing color of the scales is some shade of brown, ranging in different species from yellowish or reddish-brown to chestnut-colored, or purplish-brown; a few are white, others almost coal black; and in certain species two colors are strikingly combined. In shape there is nearly every variation between the rounded-ovate and slender almost needlelike form, and in texture from delicately membranous to very thick. As a rule, the thickest scales are the most highly colored, as in most other ferns. The margins of the scales may be entire or irregularly lacerate, minutely saw toothed, or, as already noted, even beset with stiff, bristlelike teeth.

Of the North American members of the tribe Cyatheæ a few are bipinnatifid, though most are either very deeply tripinnatifid or tripinnate, and a very few quadripinnate or nearly so; none are simple. In outline their blades range from lanceolate to broadly ovate. An example of the tripinnatifid type is shown in plate 7, representing pinnæ of *Alsophila aspera*, the plant mentioned by Sloane. A peculiar, low-growing, bipinnatifid species, *Cyathea Nockii*, of Jamaica, is figured at about two-fifths natural size in plate 8. Upon the rachises and midveins of most species, and also upon the ultimate veinlets and upon the leaf tissue of many of these, occur various small, even minute, scales of varied form and color. They may be flattish or convex, thick or exceedingly thin and delicate, roundish, linear, deeply cleft, fringed, or either reduced to the form of minute stellate bristles; but whatever their character and position upon the several parts of the blade they will be found, within certain limits, to be very constant and, like the spines and scales of the stipe, to serve as definite recognition marks for the species. Hairs, some composed of several cells, others unicellular and glandlike, are also borne similarly. Like the scales, they also in their structure and dispo-

sition contribute excellent diagnostic characters by which the species may be distinguished.

LEAVES OF THE DICKSONIEÆ.

Of the three genera which comprise the tribe Dicksonieæ, two (Dicksonia and Cibotium) are usually arborescent and have numerous large leaves borne in erect-arching crowns, as in most species of the Cyatheæ, while the third (Culcita) is very much smaller, never develops an upright trunk, and might readily be taken for a member of the family Polypodiaceæ. There is evident among them not only a pronounced difference in size, but also in shape and cutting of the blades, as mentioned hereafter. They have, however, one very distinct feature in common, namely, the development of great masses of delicate, limp, threadlike scales, of a type not found in many species of the tribe Cyatheæ. These are produced in great abundance upon the growing crown of the plant and extend freely along the stipes and rachises, from which, however, they are readily deciduous. They are usually yellowish or yellowish-brown and glistening, either straight or matted together, fragile, each composed of a single series of thin, elongate, flattish cells set on end. Apparently scales of no other types are produced in this tribe. The collection of this soft woollike substance from the crowns of several species of Cibotium occurring in the Hawaiian Islands was long a commercial industry, the material (there called "pulu") being used mainly as a stuffing for small pillows. The wool of the Asiatic *Cibotium Baronetz*, the fabled "Scythian lamb," and of a species of Culcita has been similarily used, and in a limited way also for stopping bleeding of wounds in surgery.

CLASSIFICATION.

The recognition of the Cyatheaceæ as a distinct family of ferns is based for the most part upon minute microscopical characters of the sporangia, the "spore-cases," which form the sori or "fruit dots." The division of the family into tribes rests in part upon similar characters, but also very largely upon more apparent differences in the form of the indusia, special outer structures which more or less completely inclose and protect the sporangia during their period of development. As already stated the North American species are associated in two tribes, the Cyatheæ and the Dicksonieæ, whose main diagnostic characters may be readily recognized.

The tribe Cyatheæ is distinguished by having the sori borne directly upon the ultimate veins of the segment and never at the ends of the veins, which extend nearly to the margin. The sorus may in different genera be either naked (without a special protective outer structure) or either partially or wholly surrounded by such an organ,

the indusium. If an indusium of any sort be present, it is never formed of any portion of the leaf margin, but is developed separately, being attached at the base of the receptacle—the raised conical, globose, or club-shaped structure upon which the sporangia are borne.

The tribe Dicksonieæ, on the other hand, has all the sori produced upon the ends of the veins; that is, they are truly terminal and marginal. In this tribe the sorus is invariably provided with a bilobed or bivalvate indusium of a wholly different character from that of the Cyatheæ, since it is formed in part by the more or less modified and concave margin of small lobes of the leaf segment, these facing inward. A similarly fashioned concave inner lip, facing outward, arises from the base of the receptacle. Thus the two lips together constitute the "double" (i. e., bilobed or bivalvate) indusium mentioned above, within which the sporangia are contained. At maturity the lips are thrust widely apart by the expanding sporangia.

These are the more obvious technical characters by which the two tribes may be distinguished. Without entering very far into the subject it may be well to indicate briefly the grounds for recognizing the several genera constituting these. Recourse will be had to illustrations showing the parts upon a greatly enlarged scale, which will serve far better than description alone to indicate the position of the sori and to emphasize distinctions in form and structure of the indusia.

THE TRIBE CYATHEÆ.

The tribe Cyatheæ was divided long ago into three genera, Cyathea, Alsophila, and Hemitelia, mainly upon characters of the indusium; and this conception has prevailed generally down to the present time. It happens, however, that within the limits of this tribe there is found nearly every intermediate stage between a complete hollow sphere wholly inclosing the sporangia and the absence of any indusium whatever. Because of this, the justification for laying great weight, as a basis of generic classification, upon structures of such an ephemeral and variable nature has been seriously challenged by nearly every recent writer upon ferns; and also because in many other groups of ferns the indusia are now looked upon as really of such secondary importance as often to preclude their use for more than minor taxonomic distinctions, though they may be very serviceable in distinguishing species or for associating them in minor groups below the rank of a genus. The proposition again put forward, of late, to merge Cyathea, Alsophila, and Hemitelia under a single generic name (Cyathea) is thus not without merit. Yet, considering our present incomplete knowledge and the extent of data still to be derived from a thorough study of the group as a whole, it seems desirable to hold to the established classification until a better one

can be devised, and to frankly recognize it as one merely of convenience. To the objection that the recognition only of the three genera above mentioned is scarcely logical, since each of these is susceptible of division into two or more fairly distinct groups, it may be answered that at least the treatment here followed has the sanction of long usage and on this account will incur neither confusion of old names nor the substitution of new ones. The species constituting the tribe Cyatheæ may be grouped, then, under the three genera Cyatheæ, Alsophila, and Hemitelia.

THE GENUS CYATHEA.

The North American representatives of the genus Cyathea fall readily into two sections, based upon characters of the indusium; in the first of these the indusium is cup-shaped or saucerlike; in the second it is like a complete hollow sphere. Of the 50 species occurring in North America about 30 fall under the latter section.

An excellent example of the cup-shaped or hemispherical type of indusium is seen in *Cyathea elegans*, of Jamaica, a species with large tripinnatifid fronds. Plate 9, figure A represents the young sori of this species at a stage when the sporangia are just reaching maturity and are beginning to crowd upward and outward, thus widening into a broad mouth the opening above them which is first evident merely as an apical pore. In plate 9, figure B is shown a later condition, in which the sporangia have reached maturity and have mostly disappeared. Another example of similar but less pronounced form is shown in plate 10, figure A, representing the sori of *Cyathea arborea*. In this the indusium is saucer shaped, and the sporangia are seen to have been heaped high above its low even margins. In all species of the section of which these two species are illustrative, the indusia are firm, have perfectly entire margins, and almost invariably are persistent long after the spores have been shed and the sporangia dropped. The central position of the elevated receptacles may also be noted in the figures cited, as well as details of venation and pubescence. The sori are seen to be borne near the midrib (costule) of the segment, being seated at or just below the forking of the slender lateral veins. This section of the genus is known as Eucyathea or true Cyathea, since it contains those species which in general form and structure of the indusium agree with *C. arborea*, the type species of the genus. Of the 20 North American species all are confined to the West Indies, excepting only *C. arborea*, which occurs sparingly also on the continent from Mexico southward.

A very different type of indusium characterizes the second section of Cyathea, which having once been regarded as generically distinct

from Eucyathea was given the name Eatoniopteris, in honor of the late Prof. Daniel Cady Eaton, of Yale University. The numerous species of this group are distinguished by having the indusium globose and wholly inclosing the sporangia, until at maturity these distend the indusium beyond the bursting point; whereupon, having no sutures or definite lines of cleavage, it ruptures irregularly, its ragged divisions being thrust outward. A species having this type of indusium (*Cyathea Brunei*, of Costa Rica and Panama) is illustrated in plate 9, figures C and D. The first of these shows the firm, white, unbroken indusia in a condition approaching maturity, and the midribs of the segments still clothed with dark slender scales. In figure D is shown an older state of the same species, in which it will be noticed that the sori have burst and appear more or less confluent, and that the indusia, though irregularly broken, have partially resumed their original position. In this and several other species having thick or firm indusia it will be found that the divisions commonly persist or, at least, tend to disappear only with age, sometimes spreading apart hardly more than enough to allow the spores to escape freely, then drawing in nearly to their original form and appearing valvelike. But in many other species the indusia are thin or even of such extreme delicacy that they appear merely as a slight, translucent membranous film. In these the indusium is too delicate to withstand the explosive hygroscopic action of the sporangia, so that after the spores have been shed there will be found only traces of the broken indusium, a few half-detached fragments appearing among the mass of confluent sporangia, or sometimes only a small basal portion persisting in the form of a thin flattish scale, which may be wholly concealed by the sporangia, at the base of the receptacle. During the process of spore shedding, or it may be merely with age, the scaly covering of the midribs of the underside of the segments often will either have disappeared or have become so mixed with broken sporangia, spores, and fragments of the indusia as to be almost indistinguishable. On this account it is essential in collecting material to secure, in addition to fully mature pinnæ, pinnæ from other fronds in which the sori are so young that they will not burst in drying but will retain their original form. The very general failure of collectors to observe this precaution is responsible for much of the confusion which will always result from the study of carelessly selected and imperfectly prepared herbarium material in so critical a group.

Of the section Eucyathea, some of the more interesting species are: *Cyathea Nockii*, already briefly described (pl. 8); *C. Brooksii*, a Cuban species with a short, horizontal, mostly subterranean rhizome and several long-stalked bipinnate fronds about 4 feet high; *C. minor* and *C. pubescens*, the former with a very slender, clean trunk, the

latter with a huge thick trunk that is utterly disproportionate to the crown of narrow, lanceolate, bipinnate fronds; *C. arborea*, previously mentioned and figured (pls. 2 and 3; pl. 10, fig. A); *C. elegans* (pl. 9, figs. A and B); *C. Tussacii*, a Jamaican species with coarse, tripinnate fronds, everywhere shaggy with slender tawny or grayish scales; *C. nigrescens* and *C. araneosa*, very much alike in their harsh, exceedingly coriaceous, tripinnate blades and densely spiny trunks and stipes; and *C. portoricensis*, a species with dark, lustrous, purplish-brown vascular parts and large, nearly tripinnate blades. The last species is apparently unique in having the outer surface of the deeply cup-shaped indusia rather densely clothed with simple yellowish hairs.

Only a few species of the section Eatoniopteris may be mentioned. Perhaps the most interesting are *C. Brunei* and *C. aureonitens*, already referred to in the preceding pages. The Costa Rican forms, *C. Werkleana*, *C. hemiotis* and *C. hastulata*, constitute a natural group in having the ultimate segments of the tripinnate fronds constricted at the base, or even sessile. Three other species, *C. Tuerckheimii*, *C. gracilis*, and *C. divergens* are unusual in having the larger pinnules (divisions of the primary pinnæ) mostly long-stalked. *Cyathea insignis* and *C. princeps* have the primary and secondary rachises unarmed as to spines, but yet conspicuously rough from the presence of the broken-off bases of the slender spiny-margined scales which at first thickly invest them. At least one species, *C. patellaris*, has both veins and leaf tissue glabrous, while its nearest ally, *C. mexicana*, has the similar parts very minutely but distinctly glandular-setulose, and in addition many of the veins simple, an unusual feature in this genus.

As to the characters which distinguish the species, it may again be mentioned that although minute they are usually constant, if due allowance be made always for minor variations which may be correlated mostly with known differences of habitat, altitude, and geographic position; and that if a sufficient amount of well-prepared material be brought together the recognition of the species will not prove especially difficult. Indeed, the most surprising feature of all is that species so similar in details of leaf form have been able to develop such marked diversity in the general form, structure, and disposition of minute scales and hairs and that these differences are so nearly constant. An attempt has recently been made to give to these structures some part of the weight in classification to which they appear to be entitled. To this treatment [1] the reader is referred for full descriptions of the North American species of this interesting genus.

[1] North American Flora, vol. 16, part 1, pp. 65-88, 1909.

THE GENUS HEMITELIA.

In the section Eucyathea of the genus Cyathea the indusium has been shown to be inferior in attachment and to partially envelop the base of the sorus upon all sides within its cup-like walls. The indusium of Hemitelia is not unlike an indusium of this sort cut vertically in half; that is, it is deeply concave or hood-shaped when young, and from its point of attachment at the base of the receptacle bulges outward, surrounding the sporangia of at least one-half of the sorus upon one side. When the sporangia expand at maturity the indusium is borne back against the leaf surface and forced to assume a flattish, semicircular form. In so doing it usually splits part way to the base into several irregular spreading lobes. These are commonly short and rounded, two to four in number, and slightly concave; but in a very few species (for example, *Hemitelia muricata* of the Lesser Antilles) the indusium becomes sharply cleft into several elongated, acute segments, which stand out obliquely from the leaf surface, mixed among the sporangia, and are not very readily observed, more especially since they are deciduous. Nearly all species of the genus, however, have indusia of the former sort; and this without regard to differences of leaf form. The receptacles are similar to those of Cyathea.

Hemitelia is generally accepted at present as consisting of two sections, Euhemitelia and Cnemidaria, distinguished by differences in habit, leaf cutting, and venation. The first section, typified by *Hemitelia multiflora*, embraces mainly plants with upright trunks and large tripinnatifid fronds, similar in form to those of most species of Cyathea, the segments or ultimate divisions being relatively small. Also in free venation, scales, and minute characters other than those of the indusia, the half dozen or more North American species of Euhemitelia are precisely like those of Cyathea. The usual form of the indusia is shown in plate 10, figure B, representing *H. multiflora*.

Of far greater interest is the section Cnemidaria, composed of plants which are rarely arborescent and whose leafy fronds are of very simple form. The typical and best known species of this group is *Hemitelia horrida*, which is nearly confined to the Greater Antilles. An unusually well-developed plant of this is shown in plate 11, affording an excellent idea of the broad and relatively large divisions of the deeply bipinnatifid, nearly bipinnate fronds. Other species have smaller and simply pinnate leaves, with the margins of the pinnæ entire, undulate, crenate, or marked by regular rounded or angular lobes; and a few are even larger than *H. horrida*, with the margins similarly variable in form. In some species the lobes are sharply acute; in others regularly rounded. There are marked dif-

ferences in venation, too, certain species having the veins and veinlets entirely free, others having the midveins of the segments regularly united near their base by a short transverse veinlet; differences which have been largely overlooked in recent years, but which, especially in connection with the position of the sori, are of primary importance in the recognition of the species. Only a few species, of which *H. horrida* is one, have the stipes noticeably spiny. The scales of the rhizome and stipe also are unusual in their broadly oval to ovate form, blunt (or at least never long-attenuate) tips, and usually thin lax texture; and many of the species are nearly or quite devoid of any scales upon the under surface of the segments, probably because these are not needed as a protective covering. Indeed, in many respects this group, which is wholly tropical American, is one of unusual interest, although the recognition of the 20 North American species is by no means easy, largely because of their complicated taxonomic history. A somewhat detailed descriptive account of these has recently been published.[1]

The lateral position and hoodlike form of the indusium common to the species of this section is shown in plate 12, which represents part of a segment of *H. horrida* at eight times natural size. The lax cobwebby covering of the veinlets here noticed may be observed in several other species in their young state; with age it disappears.

THE GENUS ALSOPHILA.

As Hemitelia differs from Eucyathea in having but "half an indusium," so Alsophila departs still further in having no indusium whatever, or in a few species only a rudimentary or vestigial one, lying as a minute thin scale at the base of the receptacle, beneath the sporangia and concealed by them. Taking the place of indusia as a protective feature, however, there is noticed an increased development of paraphyses, variously shaped and colored, elongate, simple hairs, mixed among the sporangia and often exceeding them. Similar hairs are present in Cyathea and Hemitelia, but are mostly shorter and not very obvious.

The North American species of Alsophila, about 30 in number, are divided among the sections Eualsophila, Trichipteris, Lophosoria, and Amphidesmium (Metaxya). Eualsophila contains mostly arborescent species similar to Cyathea in everything save sori; the others are represented within our area by a single species each. Of Eualsophila may be mentioned the following more interesting or better-known species: *Alsophila aspera*, a common West Indian species, two pinnæ of which are shown in plate 7; *A. elongata*, a species ranging from Costa Rica to the Andes of South America, well marked by its huge, broad, nearly tripinnate fronds, its stiff, yellowish pin-

[1] Contributions from the U. S. National Herbarium, vol. 16, part 2, pp. 25-62, pls. 18-34, 1912.

nules all drawn out to long, slender, nearly linear points, thus suggesting the species name; *A. microdonta*, a lowland species already mentioned, easily distinguished by the remarkably large, strong, narrowly conical spines which occur at irregular intervals the whole length of its stipe and primary rachis; *A. stipularis*, a plant of the mountains of Costa Rica and western Panama, with a trunk 30 to 40 feet high and enormous spreading, nearly tripinnate fronds which show the very interesting adaptation of having the primary pinnæ (particularly in the basal part of the blade) directed backward from their insertion upon the rachis at an acute angle; *A. armata*, which, with several related species, has the stipes and rachises densely soft-hairy; *A. myosuroides*, previously mentioned, with very minute, thickly set spines closely associated with an abundant covering of glossy brown, slender scales at the base of the stipe, and the pinnules of the deeply tripinnatifid fronds ending in narrow greatly elongate tips, "mouse-taillike," as the specific name implies; *A. Schiedeana*, a much more leafy plant of Mexico and Guatemala, with broader and larger rounded segments; and *A. Salvinii* of Chiapas and Guatemala, a species with leaf blades fully tripinnate, the elongate, crenate, leathery segments sessile or short stalked, the rachises firm and woody and of a polished, dark purplish-brown color. The naked (nonindusiate) sorus of this group is indicated in plate 10, figure C, representing a portion of a very young pinnule of *A. myosuroides*, in which the sporangia are all in place. In figure D, of the same plate, is shown a similar portion of *A. Schiedeana* at a later stage, in which the sporangia are nearly all fallen away from the roundish elevated receptacle.

The section Lophosoria contains a single species, *Alsophila quadripinnata*, which offers several peculiar structural characters, possibly warranting its separation as a distinct generic type; the trunk and fronds have already been described.

The section Amphidesmium likewise contains a solitary species, *Alsophila blechnoides*, which is unique among American tree ferns in the production of more than one sorus upon the veinlets of its large simply pinnate fronds. A partial section of one of the long slender pinnæ of this species is shown in plate 13, figure A. Both this and the preceding species are peculiar in the silky hairlike scales of the rhizome and stipe, their form and structure being that of the tribe Dicksonieæ and very different from the usual flat scales of the Cyatheæ. The fourth section, Trichipteris, which is essentially a group of fully bipinnate South American species, with sessile or stalked pinnules and sori borne in a dense row, is represented in North America by a single species, *Alsophila marginalis*, first described from British Guiana but gathered once since in Mexico. The scales in this section are like those of Eualsophila.

THE TRIBE DICKSONIEÆ.

Differences in habit and size of the plants and in the general shape and dissection of the leaves offer more obvious marks for the recognition of the three genera of Dicksonieæ than do the indusia, which are alike in position and of very similar structure. Thus, the several species of Culcita are small plants, none of them ever treelike, having short rootstocks only a few inches high and a spreading crown of broad, skeletonlike, greatly dissected leaves rarely more than 3 or 4 feet high, including the stipe; while Cibotium and Dicksonia are mostly if not altogether arborescent, plants at least of huge growth. In distinguishing the latter genera it will be noted that the blades of Dicksonia are elongate and either lanceolate or oblanceolate in outline, and that those of Cibotium are very much more ample and broadly ovate or even triangular. Coupled with these differences, however, are characters afforded by the sori, which, when once made out, are unmistakable. The position of the sori and the general structure of the double indusium has already been touched upon; the generic distinctions follow.

THE GENUS DICKSONIA.

In Dicksonia the outer concave lip of the indusium consists of the greenish leaf tissue of a small marginal lobule of the leaf segment which is slightly if at all modified by its function as a partial covering for the sporangia. The shape but not the texture of this outer lip is shown in plate 13, figure B, representing *Dicksonia navarrensis*, of Costa Rica and Panama. The inner lip, or true indusium, is seen to be of similar form, almost hemispherical, its hollow inner or under surface embracing the sporangia upon the side opposite to the outer lobe. It is yellowish and rigidly cartilaginous, thus conspicuously different in texture from the outer lip, and is attached along the base of the receptacle, upon which the sporangia are borne.

But one other species of Dicksonia has been described from North America, the closely related *D. lobulata* of Costa Rica. This and the other members of the genus have like indusia. A section of a primary pinna of *D. navarrensis* is shown in plate 14 at natural size. The leaf tissue is rigidly coriaceous and of a yellowish green color. The trunks of this species, as I have seen them, are about 9 to 12 feet high and always roughly clothed with the very stout smooth bases of old fronds, a feature which seems to be characteristic of the genus as a whole.

THE GENUS CULCITA.

Although the indusia of Culcita are very similar to those of Dicksonia, the plants are so different in habit, in their smaller size, and in the nondevelopment of an upright trunk, and bear quadripinnate

leaf blades of such distinctive form and cutting, that their recognition as a genus seems justified. There are about half a dozen species, mostly of the South Sea Islands and Malaya, one, however, occurring in the Azores, Madeira, and Teneriffe, and another (*Culcita coniifolia*) inhabiting the high mountain forests of Jamaica and Santo Domingo, and extending on the continent from Mexico to Ecuador and Brazil. A pinnule (tertiary division) of the last is shown in plate 12, figure C.

THE GENUS CIBOTIUM.

The most highly differentiated indusium structure of any of the Dicksonieæ is exhibited in Cibotium; for in this genus the outer lip, like the inner, is manifestly cartilaginous, and the two valves fit together like a box and its lid, offering complete protection to the sporangia until maturity. Plate 12, figure D, represents at four times natural size a section of a pinnule of *Cibotium Schiedei*, of Mexico and Guatemala, in which may be noticed both closed and open indusia; as also in plate 15, which shows part of a primary pinna of the same species, at natural size. Three other species, all with deeply tripinnatifid or tripinnate leaves of similar form are known from Mexico and Guatemala. In these, as in most foreign members of the genus, the double indusia after maturity are bent back in a close row upon the leaf tissue of the underside of the segments, their position (i. e., whether oblique or parallel to the midvein of the segment) at this stage varying according to the species. Their shape also is diagnostic, some of them having the valves sprung widely apart, like gaping jaws. In all but two or three of the species, both American and foreign, the under surfaces of the blades are whitish or even bluish pruinose, from a dense covering of very minute and closely set whitish papillæ which are of a waxy nature. Not a few species of the tribe Cyatheæ also have a similar development, whose function must be to guard against excessive transpiration.

Cibotium has never been collected in South America, and is certainly not common in the North American Tropics, judging from the small amount of material collected. We have also only scant and and conflicting data as to habit, from which it appears doubtful if the four American species normally attain a pronounced arborescent form, similar to that of the Hawaiian species, for example. A brief critical account of these, with notes on their rather involved taxonomic history and with illustrations of each, has recently appeared.[1]

DIFFICULTIES OF STUDY.

From the foregoing it will be evident that tree ferns are more than ordinarily difficult of study on account of their enormous size. Even for the most commonplace data as to dimensions of trunk and shape

[1] Contributions from the U. S. National Herbarium, vol. 16, part 2, pp. 25-62, pls. 18-34. 1912.

and size of leaves, fern students up to a comparatively recent time have been dependent mainly upon the chance and often inexact observations of collectors, who as a rule have not been well acquainted with the group, and upon the characters offered by conservatory specimens. As has been pointed out, excellent distinguishing characters are afforded by the trunk and by the vascular parts of the frond, especially by the stipe bases, which are mostly armed with spines of different kinds for different species and clothed with equally characteristic scales. Yet these are the very parts usually omitted from collections, which are likely to consist only of a small section of the blade, often a single pinna. To know from such scant material the real characters of plants with stems 10 to 50 feet high and leaves 5 to 15 feet long is obviously impossible; and many have been the complaints of fern writers from Sir William Hooker's time almost to the present upon the inadequateness of herbarium specimens. Within the past two or three decades, however, and with the development of more convenient and ready means of travel, the practice of sending investigators to collect material of their own special groups has become general. Very full and valuable data are being obtained in this way, in marked contrast to the incomplete and piecemeal information conveyed under the old method; and it has been found feasible to collect and dry characteristic sections of the trunk of most species, in addition to the stipes and the lower, middle and upper pinnae of the fronds. It is upon the basis of carefully selected and complete herbarium material of this sort, supplemented by photographs and by exact field data as to size, form, structure, and color of the various parts, that an adequate knowledge of tree ferns will finally be built up.

EXPLANATION OF PLATES.

Plate 1.

Group of tree ferns (*Cyathea princeps*), near Sepacuité, Alta Verapaz, Guatemala. Photographed by Mr. G. N. Collins, April 16, 1904.

Plate 2.

View from the Adjuntas Road, Porto Rico, showing plants of *Cyathea arborea*. Photographed by Mr. G. N. Collins, July 11, 1901.

Plate 3.

Two forms of trunk of *Cyathea arborea* (see p. 472), collected in the valley of the Rio Bayamita, southern slopes of the Sierra Maestra, eastern Cuba, altitude 2,000 to 3,500 feet, April, 1907; fig. *a*, *Maxon* 3909; fig. *b*, *Maxon* 3906. Both one-half natural size.

Plate 4.

Coffee warehouse at Sepacuité, Guatemala; excepting the five heavy supporting timbers the upright sides are entirely of tree fern trunks. Photographed by Mr. G. N. Collins.

PLATE 5.

Stipe bases of three species of Cyathea, showing different kinds of spines and scales. Fig. A, *C. arborea*, valley of the Rio Bayamita, Cuba, *Maxon* 3909; fig. B, *C. onusta*, vicinity of Coliblanco, Costa Rica, altitude 6,500 feet, May 1, 1906, *Maxon* 318; fig. C, *C. aureonitens*, forest along the upper Caldera River, western Chiriqui, Panama, altitude about 4,800 feet, March 24, 1911, *Maxon* 5575. All natural size.

PLATE 6.

Young unrolling frond of *Cyathea arborea*. Photographed at Caguas, Porto Rico, June 20, 1901, by Mr. G. N. Collins. Natural size.

PLATE 7.

Two pinnæ of *Alsophila aspera*, from the vicinity of Mansfield, near Bath, Jamaica, altitude 900 to 1,200 feet, June 2, 1904, *Maxon* 2405. Two-fifths natural size.

PLATE 8.

A nearly complete plant of the smallest North American tree fern, *Cyathea Nockii*, from the vicinity of Vinegar Hill, Jamaica, altitude 3,600 feet, June 23, 1904, *Maxon* 2791. About two-fifths natural size.

PLATE 9.

FIG. A. Cup-shaped indusia of *Cyathea elegans* in a very young condition. Specimen from the Blue Mountains, Jamaica, *Hart* 175.

B. A later stage of the same species, the indusia empty of sporangia and partially collapsed. Specimen from Hollymount, Jamaica, altitude 2,500 feet, May 8, 1903, *Maxon* 1945.

C and D. Entire and ruptured globular indusia, respectively, of *Cyathea Brunei*. Specimen from Coliblanco, Costa Rica, altitude 6,500 feet, May 1, 1906, *Maxon* 332.

PLATE 10.

FIG. A. Mature sori and shallow saucerlike indusia of *Cyathea arborea*. Specimen from valley of the Rio Bayamita, eastern Cuba, *Maxon* 3909.

B. Sori of *Hemitelia multiflora*, showing the semicircular reflexed, scalelike indusia. Specimen from Port Livingston, Guatemala, at sea level, February 18, 1905, *Deam* 483.

C. Young sori of *Alsophila myosuroides*, with sporangia all in place, an indusium wanting. Specimen from mountains near El Guama, Province of Pinar del Rio, Cuba, March 9, 1900, *Palmer & Riley* 198.

D. Old sori of *Alsophila Schiedeana*, showing the nearly bare receptacles, the sporangia having fallen. Specimen from vicinity of Cacao (between Panzos and Senahú), Alta Verapaz, Guatemala, April 23, 1906, *Barber* 164.

All at four times natural size.

PLATE 11.

A plant of *Hemitelia horrida* in cultivation at the New York Botanical Garden. Specimen from Dollwood, near Silver Hill Gap, Jamaica, altitude 3,000 feet, 1909.

PLATE 12.

Segment of *Hemitelia horrida*, showing the ample, hood-shaped, laterally attached indusia which protect the young sporangia. Specimen from the upper slopes of the Gran Piedra, eastern Cuba, altitude about 3,000 feet, April 14, 1907, *Maxon* 4034. Eight times natural size.

PLATE 13.

FIG. A. *Alsophila blechnoides*, the only American tree fern having more than one sorus upon a veinlet. Specimen from hilly forest above Las Cascadas, Canal Zone, Panama, altitude about 500 feet, February 19, 1911, *Maxon* 4887.

B. Sori and indusia of *Dicksonia navarrensis*. Specimen from mountains 5 miles south of Cartago, Costa Rica, altitude 5,500 feet, May 12, 1906, *Maxon* 513.

C. Sori and indusia of *Culcita coniifolia*. Specimen from humid forested slopes near Cerro de la Horqueta, western Chiriqui, Panama, altitude 6,500 feet, March 18, 1911, *Maxon* 5459.

D. Sori and indusia of *Cibotium Schiedei*. Specimen from Zacuapan, Vera Cruz, Mexico, November, 1908, *Purpus* 1976a.

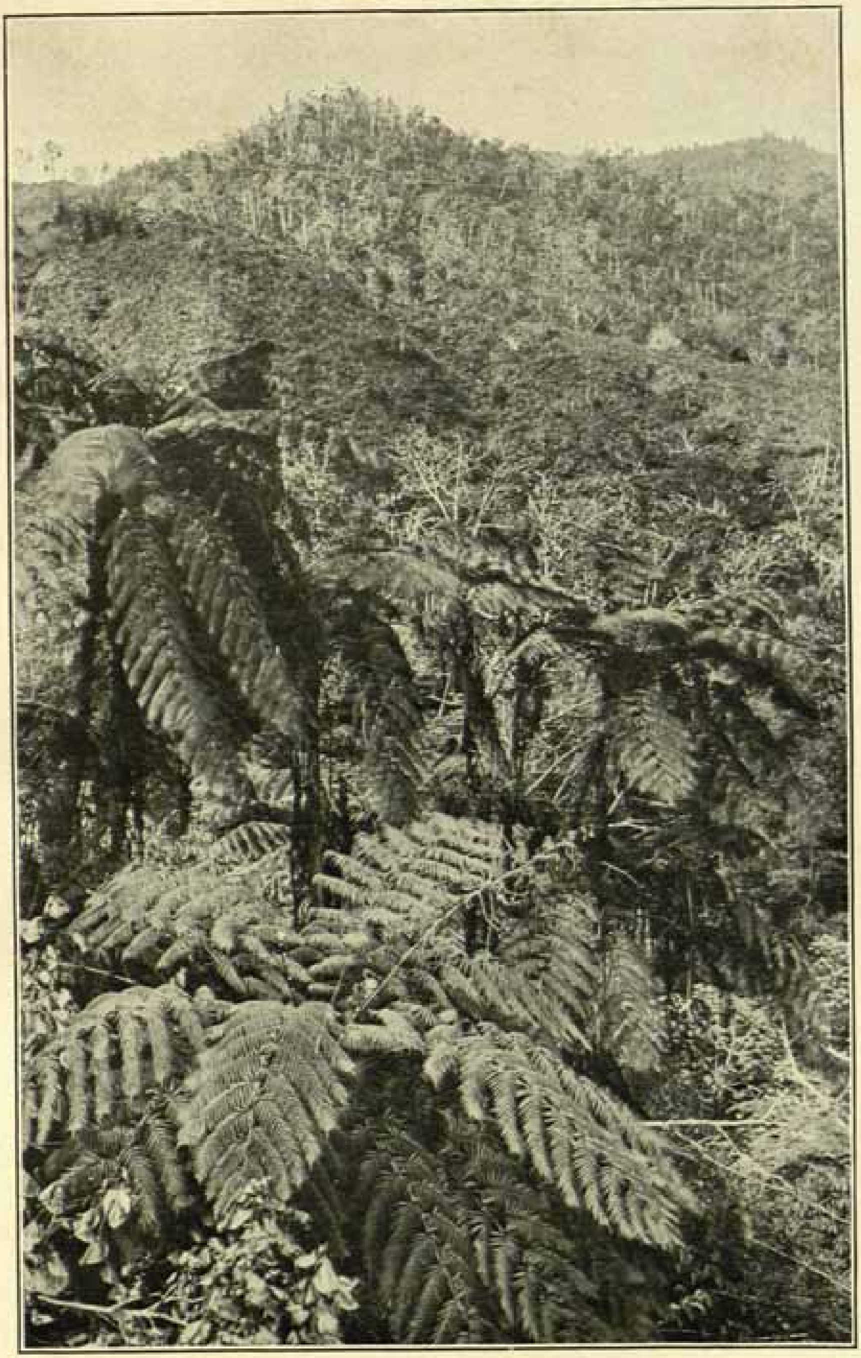
All at four times natural size.

PLATE 14.

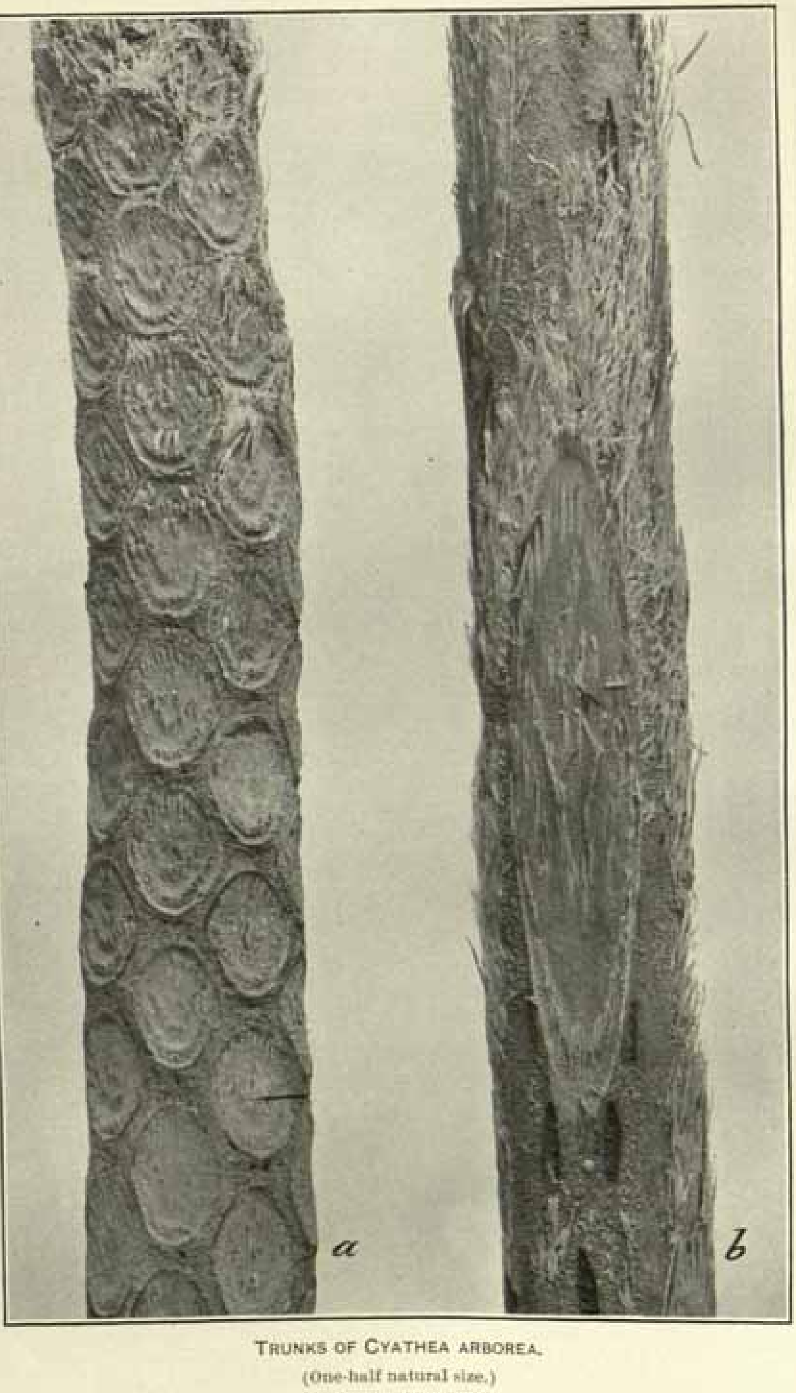
Section of a pinnæ of *Dicksonia navarrensis* at natural size. Specimen from mountains 5 miles south of Cartago, Costa Rica, altitude 6,500 feet, May 12, 1906, *Maxon* 513.

PLATE 15.

Section of a pinna of *Cibotium Schiedei* at natural size. Specimen from Zacuapan, Vera Cruz, Mexico, November, 1908, *Purpus* 1976a.

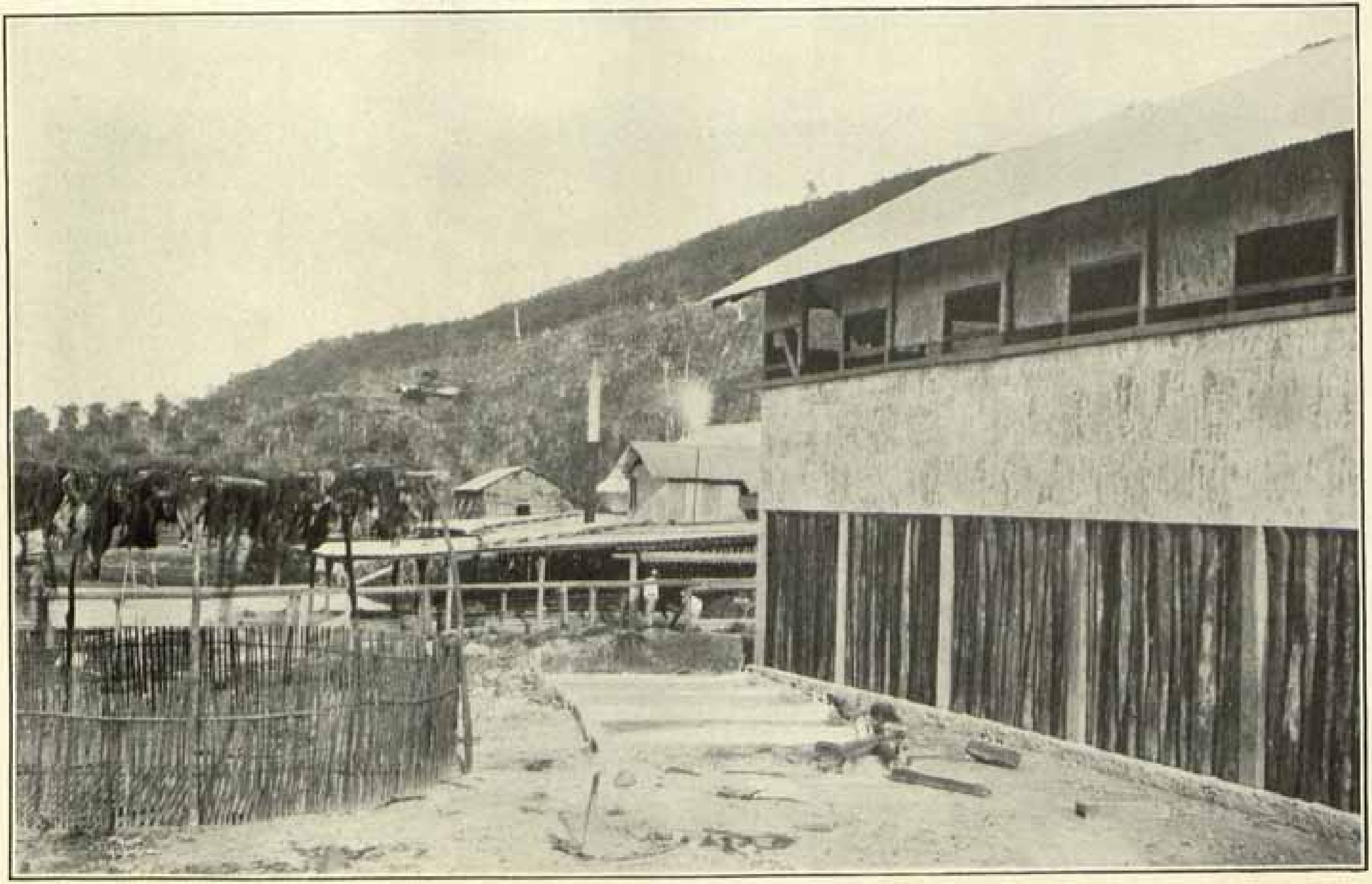


CYATHEA ARBOREA IN PORTO RICO.

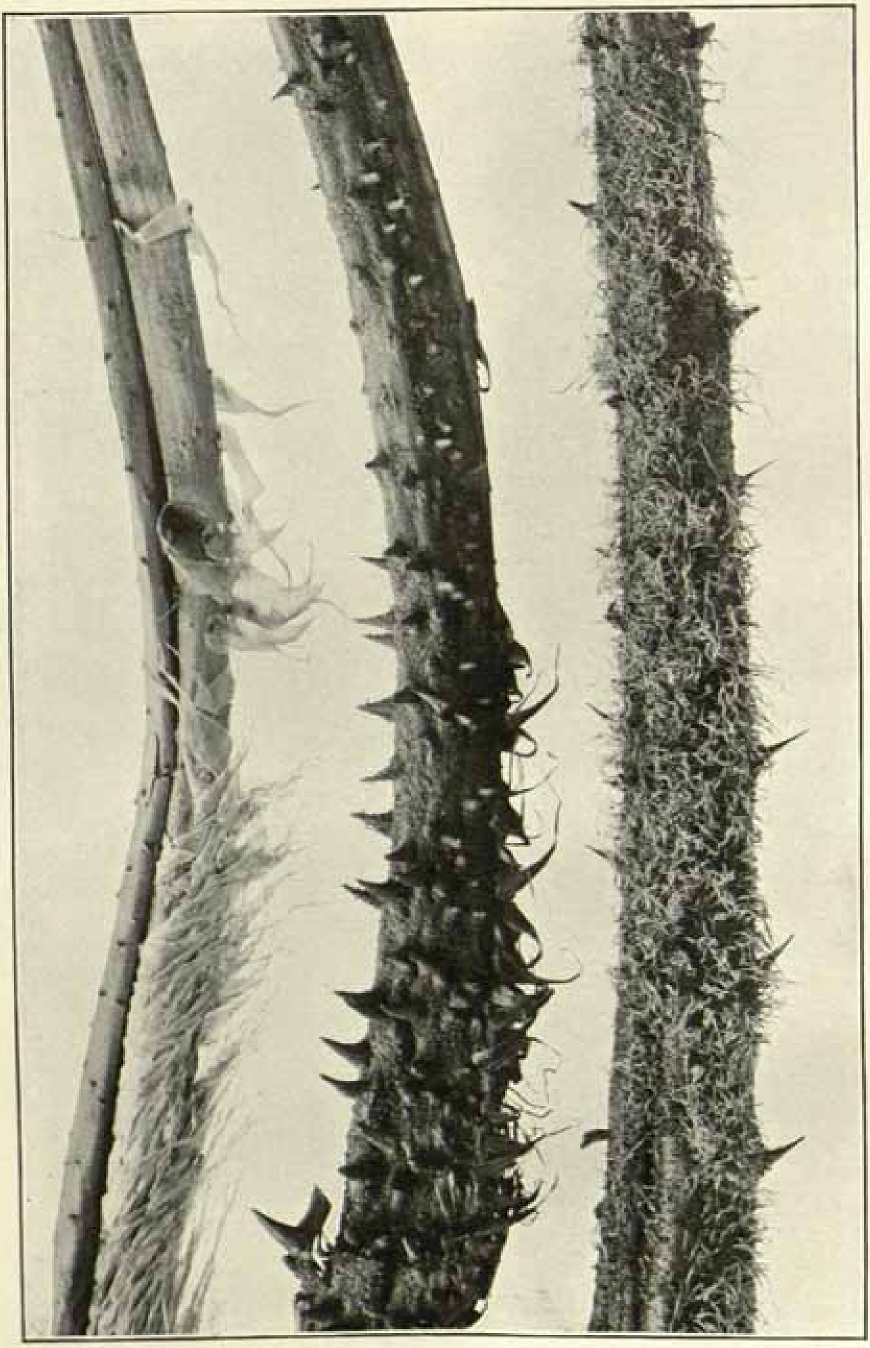


TRUNKS OF CYATHEA ARBOREA.

(One-half natural size.)



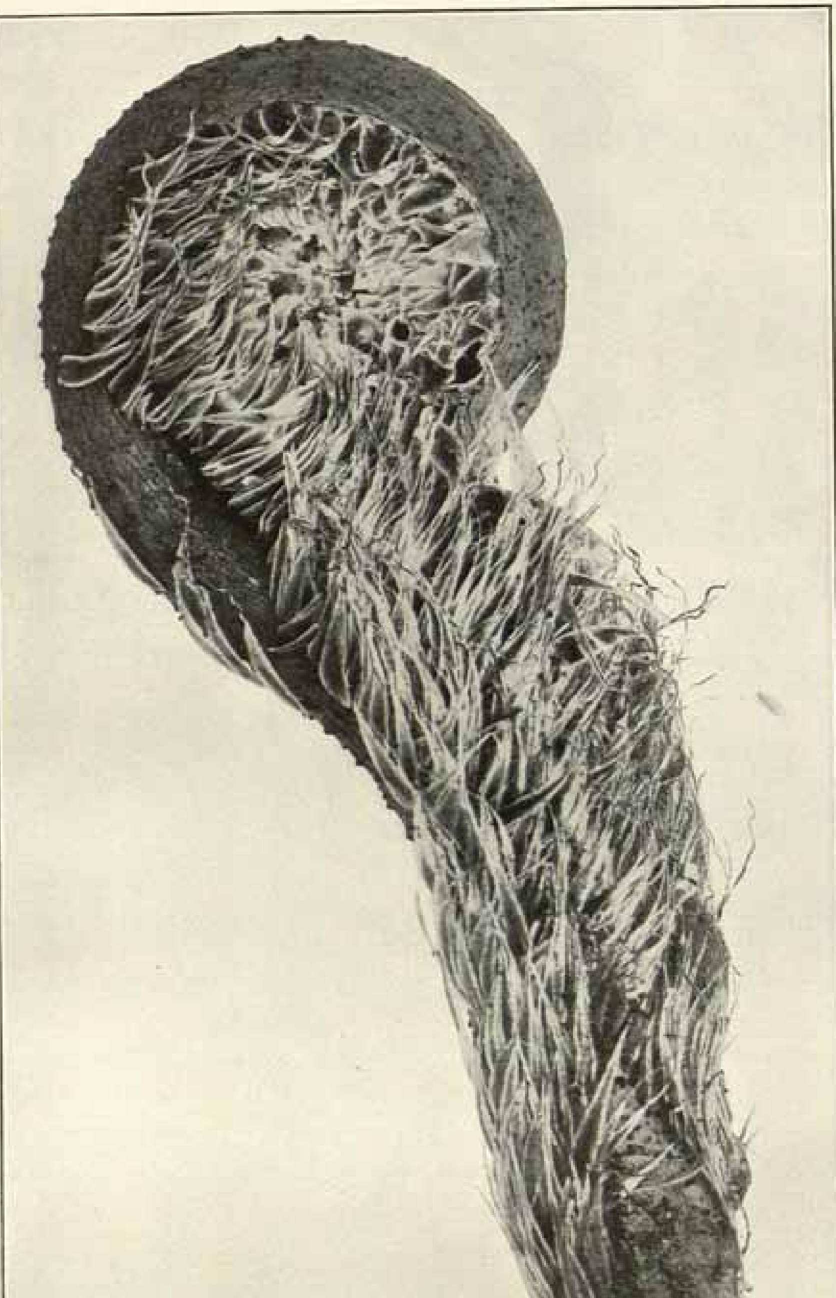
TREE FERN TRUNKS USED IN A BUILDING.



A B C

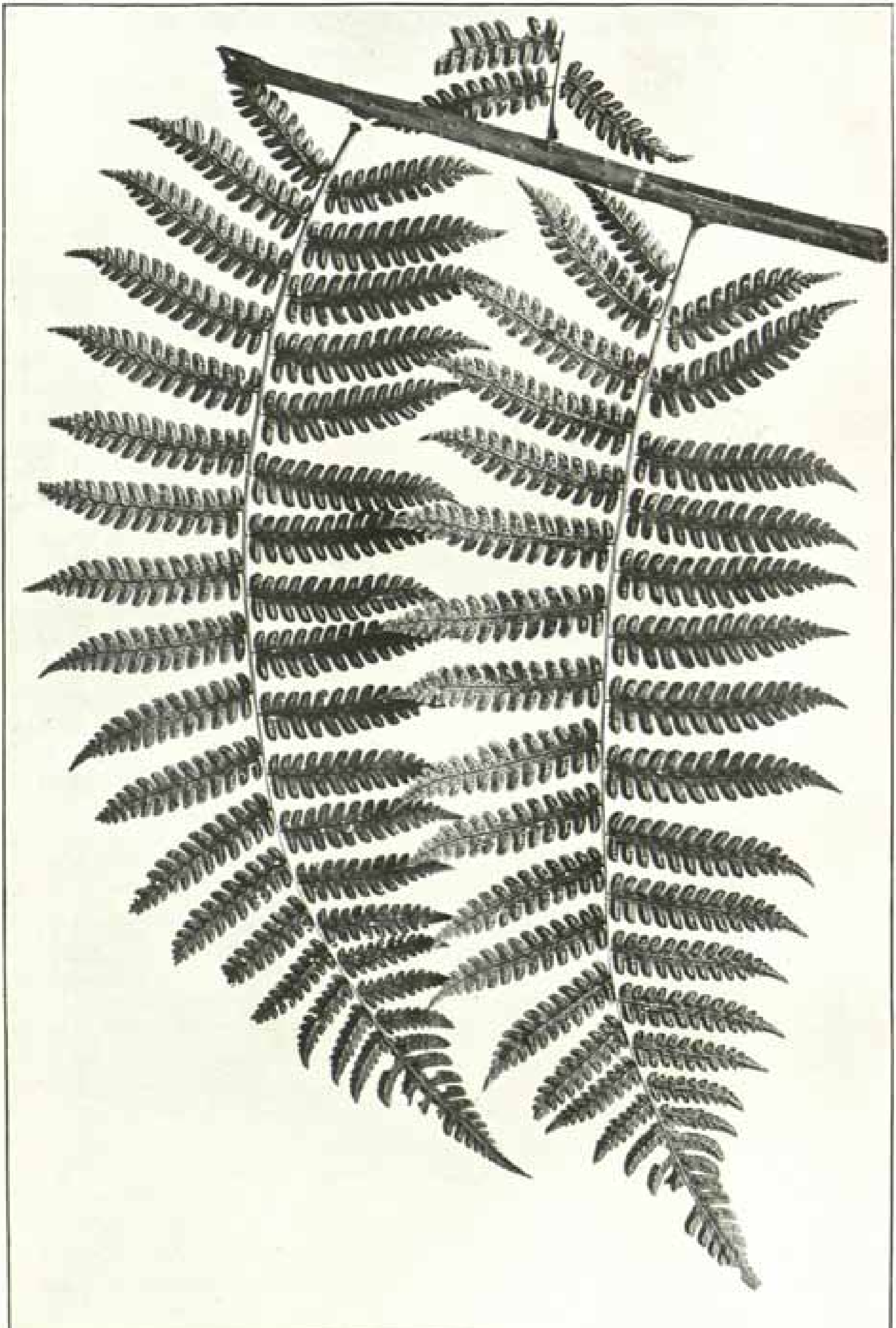
STIPE BASES OF CYATHEA.

(Natural size.)

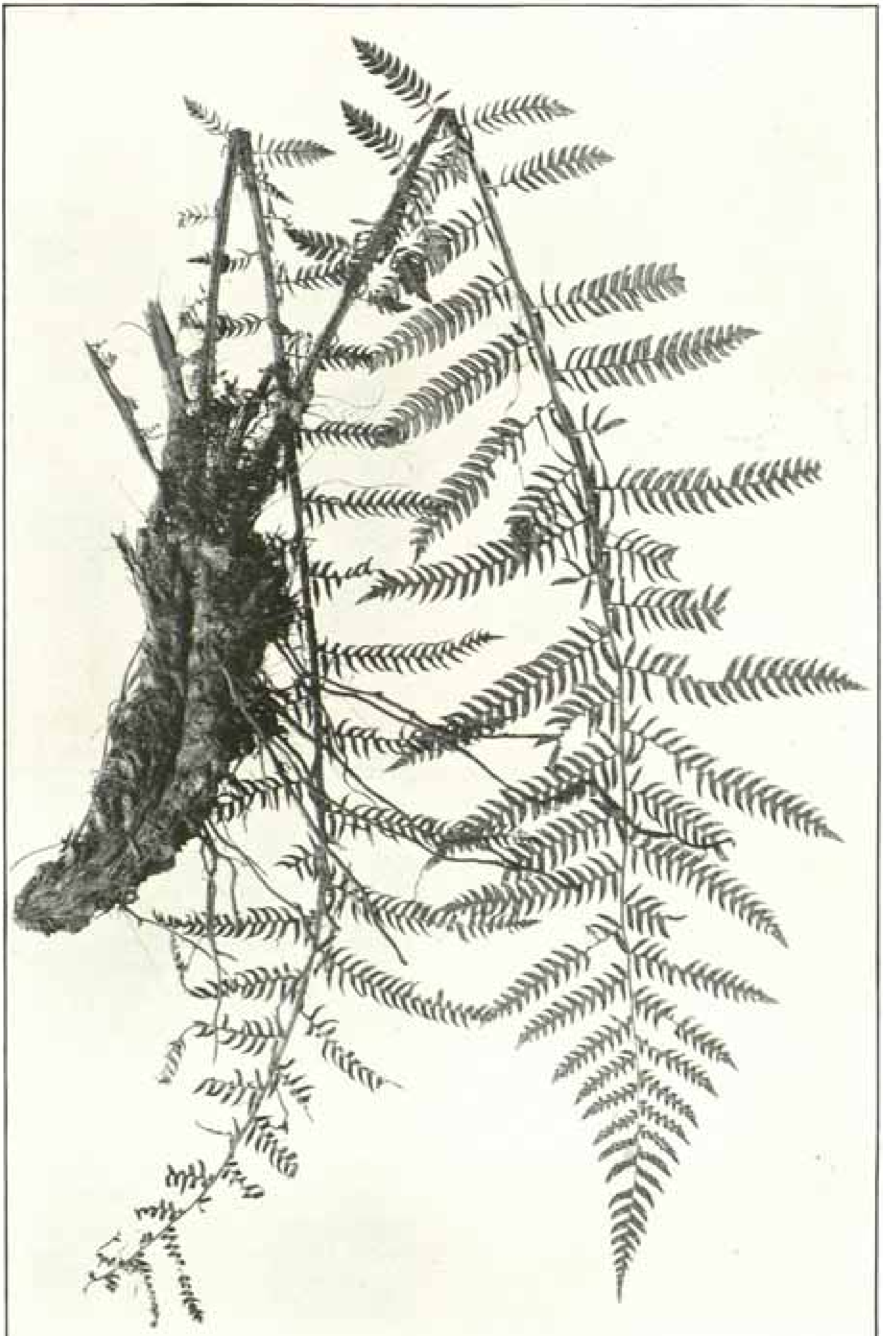


UNROLLING FROND OF CYATHEA ARBOREA.

(Natural size.)

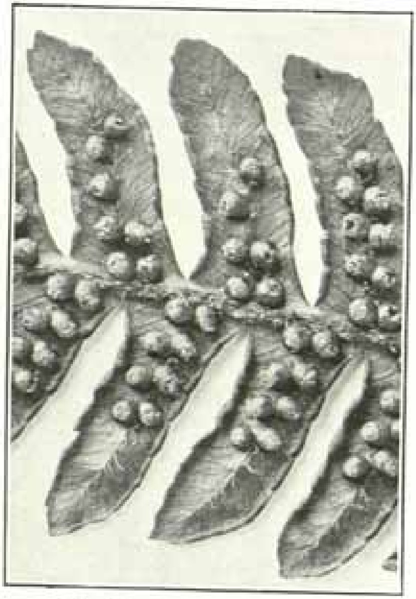


PINNAE OF ALSOPHILA ASPERA.



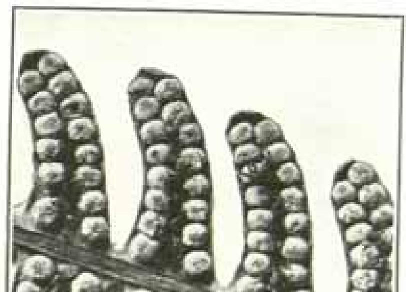
CYATHEA NOCKII.

(About two-fifths natural size.)

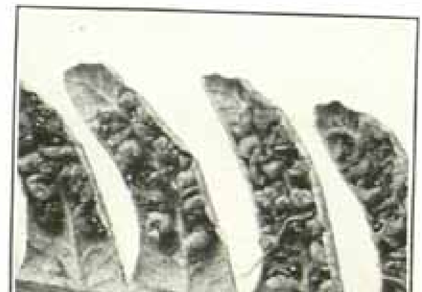


A. CYATHEA ELEGANS (× 4).

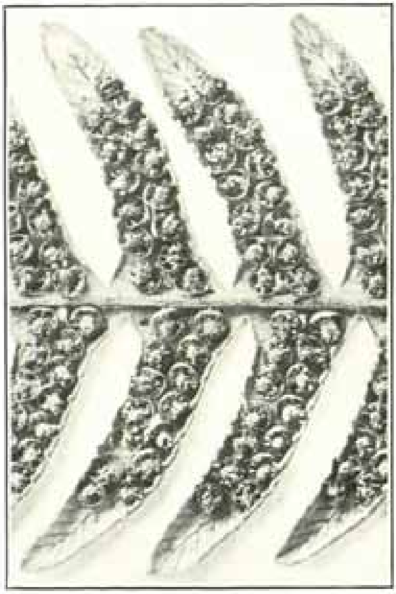
B. CYATHEA ELEGANS (× 4).



C. CYATHEA BRUNEI (× 4).

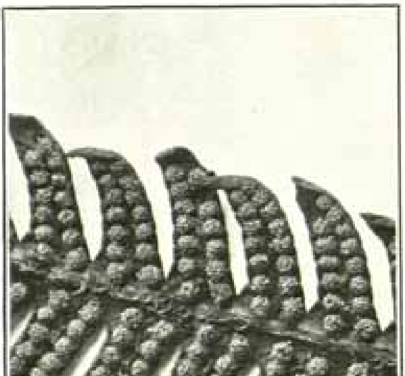


D. CYATHEA BRUNEI (× 4).

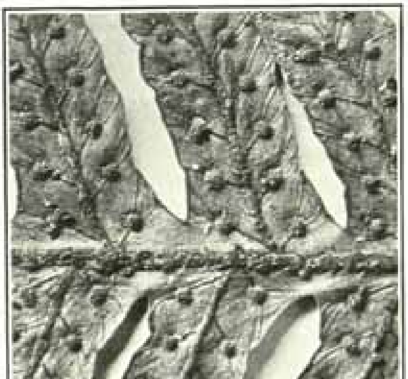


A. CYATHEA ARBOREA (X 4).

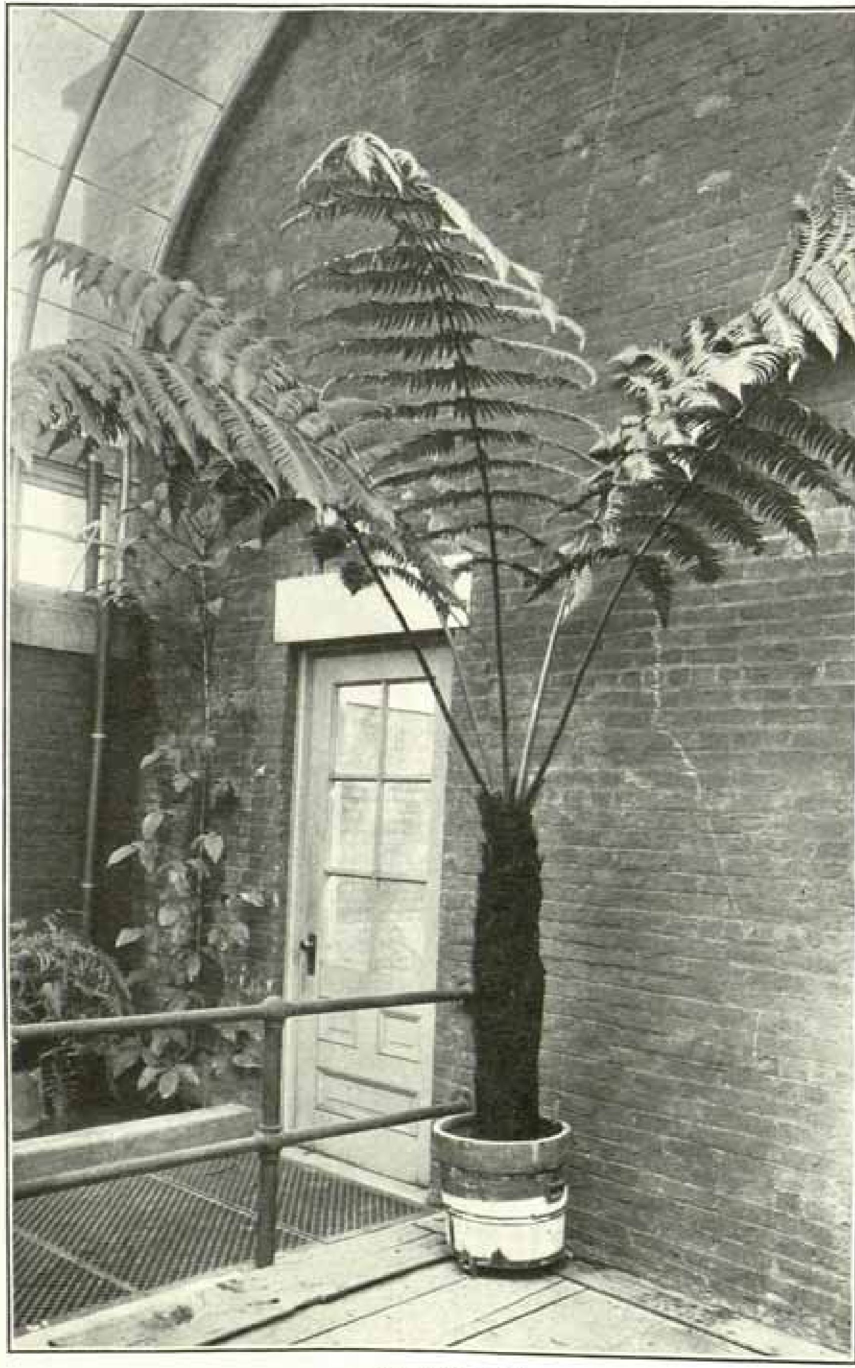
B. HEMITELIA MULTIFLORA (X 4).



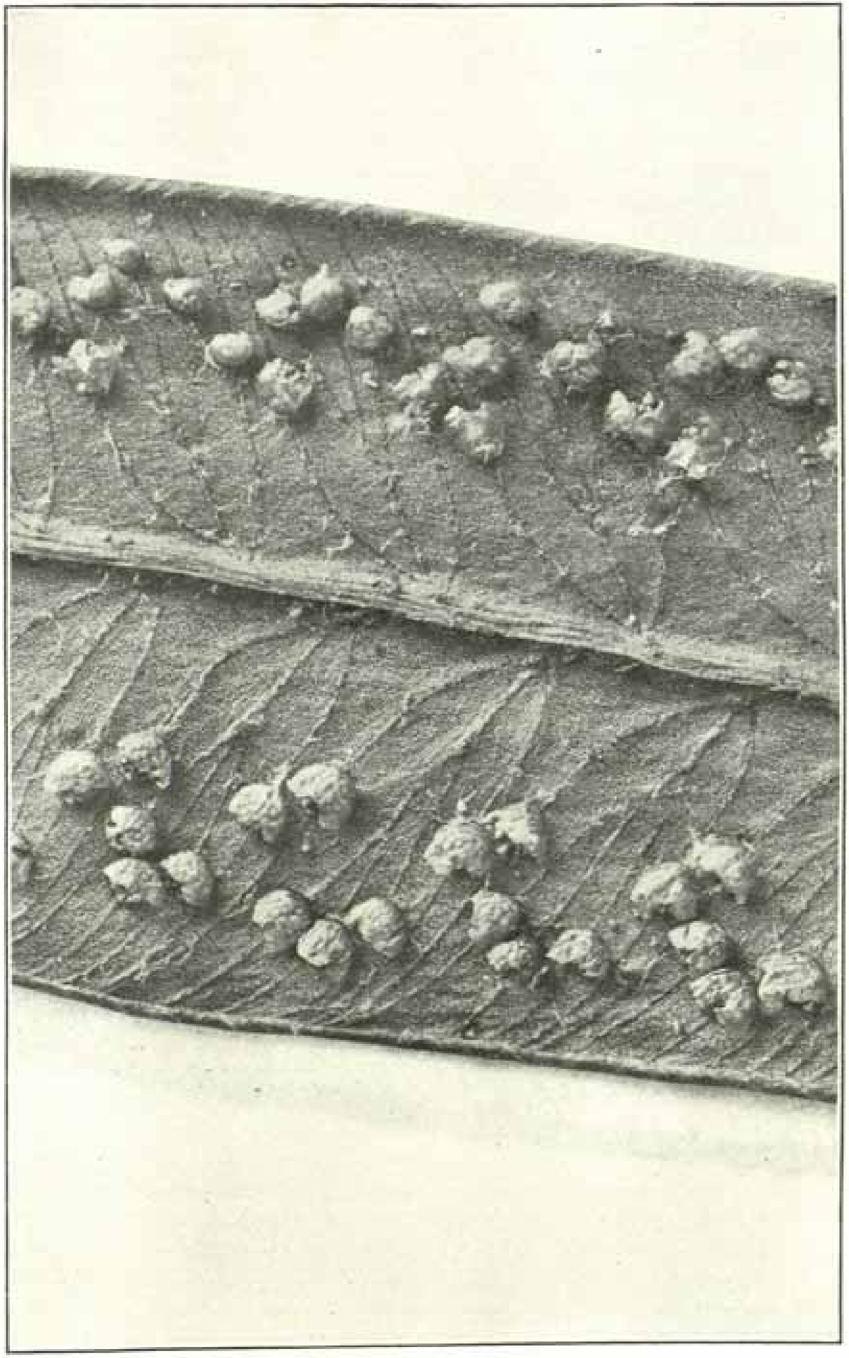
C. ALSOPHILA MYOSUROIDES (X 4).



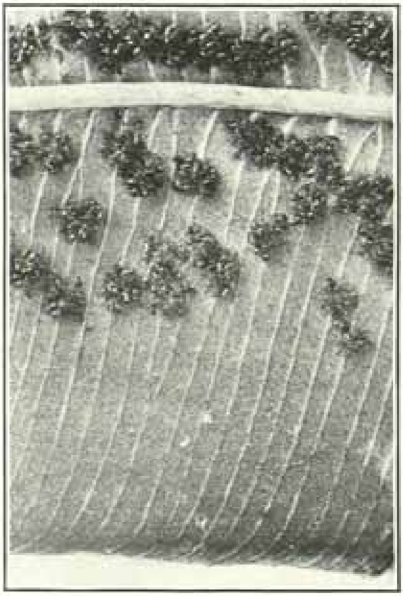
D. ALSOPHILA SCHIEDEANA (X 4).



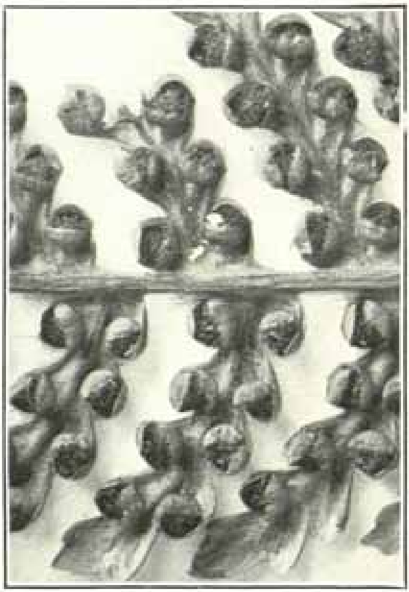
HEMITELIA HORRIDA.



INDUSIA OF HEMITELIA HORRIDA (X 8).

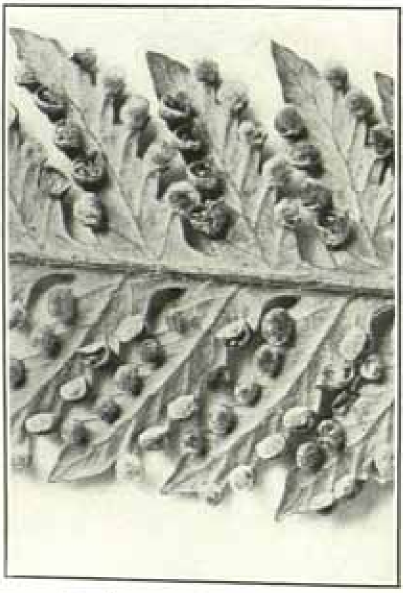


A. ALSOPHILA BLECHNOIDES (× 4).

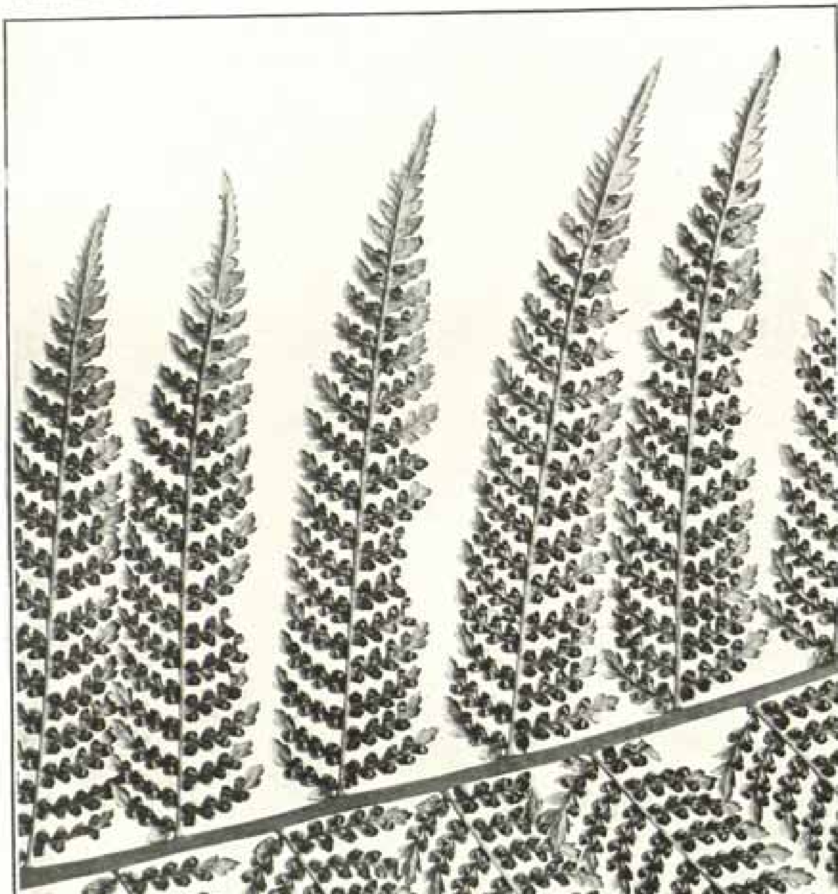


B. DICKSONIA NAVARRENSIS (× 4).

C. CULCITA CONIIFOLIA (× 4).



D. CIBOTIUM SCHIEDEI (× 4).



DICKSONIA NAVARRENSIS.

(Natural size.)

CIBOTIUM SCHIEDEI.

(Natural size.)

THE VALUE OF ANCIENT MEXICAN MANUSCRIPTS IN THE STUDY OF THE GENERAL DEVELOPMENT OF WRITING.[1]

[With 5 plates.]

By Alfred M. Tozzer.
Harvard University, Cambridge, Mass.

The successive stages through which writing has passed have been fairly generally accepted and I do not intend at this time to add anything new in regard to this development of writing.[2] Illustrative examples have usually been drawn from various sources in point of time and place. It is possible, however, to find in the Mexican manuscripts illustrations of all the steps in the early history of writing.[3]

Mexico is the only part of the new world where there are any appreciable data on the prehistoric life of a people outside of the monuments and objects found in connection with them. In Mexico and Central America we approach even if we do not, by any means, reach that fortunate situation in the old world where the documentary evidence of an ancient culture, a literature, is present as an important aid in the study of the life of a people.

The manuscripts of Mexico and Central America have, for the most part, been neglected by all except the specialists in this field. These documents furnish important examples of primitive ideas of art and illustration together with minute details of ethnological interest.

The Mexican manuscripts may be divided into two obvious classes, those written before the advent of the Spaniards at the beginning of the sixteenth century and those written during the early days of the Spanish occupation. Another classification might be based on the distinct localities where the manuscripts are supposed to have been written and the nationality of their authors. The codices of the

[1] Reprinted by permission from the proceedings of the American Antiquarian Society for April, 1911, Worcester, Mass., published by the society.

[2] For a short account of the development of writing see Clodd, 1907.

[3] A portion of this paper was presented at the Toronto meeting of the Archæological Institute of America, Dec. 28-31, 1908. A brief abstract is published in the American Journal of Archæology (second series), vol. 13, pp. 65-66, 1909.

Nahuas or Aztecs of the plateau of Mexico are to be distinguished from those of the Nahuas of the tierra caliente region and these in turn from those of the Zapotecs in the State of Oaxaca, and these, again, from the manuscripts of the Mayas of Yucatan, southern Mexico, and Guatemala. The many minor differences do not prevent one from seeing a great similarity both in subject-matter and treatment running through them all. The calendar, together with other features of the life of the different peoples of Mexico and Central America, shows a common origin and, to a certain point at least, a parallel development.

The number of manuscripts is limited. The Maya documents form the smallest class with three. There are more than a score of available codices from the Mixtec-Zapotec region, a great part of which show a strong Nahua influence, and about half as many from the Nahuas proper, in addition to a large number of single maps and other manuscript material from Mexico.[1]

The Spanish priests in their attempts to Christianize the natives aimed especially to destroy all that pertained to the ancient teaching. Accounts tell of the large number of manuscripts burned, and all owing to the misdirected zeal of these Spanish missionaries. The greater part of the documents still in existence are in European libraries, although a few still remain in public or private collections in Mexico.

The manuscripts are usually written either on long strips of deerskin, fastened together end to end, or on strips of paper made of bark or of maguey fiber. The whole strip is, in most cases, folded up like a screen. The two sides of the sheet are often covered with a thin layer of fine plaster, on which the characters are painted. Those dating from post-Columbian times are often written on European paper.

The greater part of these early manuscripts have been published. Lord Kingsborough in the first quarter of the last century was the first to recognize the importance of reproducing the codices for study. The Duc de Loubat has been instrumental in bringing out in exact facsimile several of the most important ones. There is therefore a considerable amount of available material for a study of the writing of Mexico and Central America.

Both the pre-Columbian and the post-Columbian manuscripts contain records of an historical nature, accounts of migrations, the succession of rulers, campaigns, and lists of tribute. Different phases of the ancient religion and the calendar are also shown, the secular and the sacred calendar, astronomical calculations, the methods of divination of the lucky and unlucky days, and the religious ceremonials.

[1] For the names of the most important codices from Mexico and Central America, see Saville (1901), Lejeal (1902), and Lehmann (1905).

It is not, however, the ideas expressed in these documents but the methods used in expressing them, not what is written, but how it is written, not the content, but the means employed that the present paper aims to consider. The manuscripts form only a part of the available material for the study of the writing of the peoples of Mexico and Central America. The extensive use of stone carving on the façades of buildings, on altars and stelæ, and on the lintels opens up another extensive source from which examples might be drawn. It is only in one case, however, that an illustration will be taken from the stone bas-reliefs.

The early history of writing has been curiously alike over the greater part of the world. The preliminary step is in the use of reminders or mnemonics. These signs convey no message in themselves, but serve only as an aid in bringing to mind some event. They are not universally useful as are many specimens of picture writing. They can usually be employed only by those who possess the previous knowledge which the reminders serve to recall. Notched sticks and tallies of various kinds are well-known examples of this class. The Roman rosary immediately suggests itself as belonging to the same type. The Peruvian *quipu* or knotted string is usually cited as the best representative of the class of reminders. Boturini (1746) in his "Idea de una nueva historia general" states that the natives of Mexico used a knotted string for recording events before the invention of a hieroglyphic writing. Its native name was *nepohual tzitzin*, "*cordon de cuenta y numero.*"[1] Lumholtz (1902, vol. 2, p. 128) states that the Huichols of north-central Mexico in setting out on a journey prepare two strings of bark fiber and tie as many knots in them as there are days in the journey. One string is left behind in the temple with one of the principal men and the other is carried on the trip. A knot is untied in each string each day. As the travelers always camp in the same places, they are protected from accidents in each place by the prayers of those at home. Lumholtz cites a second instance of the use of the knotted string as a reminder. In the *Hikuli* rite there is a general confession made by the women. "In order to help their memories each one prepares a string made out of strips of palm leaves in which she has tied as many knots as she has had lovers. This twine she brings to the temple and standing before the fire she mentions aloud all the men she has scored on her string, name after name. Having finished, she throws her list into the fire and when the god has

[1] Boturini, 1746, p. 85: "Nació assimismo en esta Edad un raro modo de historiar y fuè con unos Cordones largos, en los quales se entretexian otros delgados, que pendian de el Cordon principal con nudos de diferentes colores. Llamabanse estas Historias Funiculares en los Réynos del Perù *Quipu*, y en los de la Nueva España *Nepohualtzitzin*, derivando su denominacion de el adverbio *Nepohualli*, que quiere decir *Ochenta*, ò como si dixeramos, *Cordon de cuenta, y numero*, en que se referian y numeraban las cosas dignas de memoria, assi Divinas, como Humanas."

accepted and consumed it in his flame, all is forgotten." The men have a similar custom.

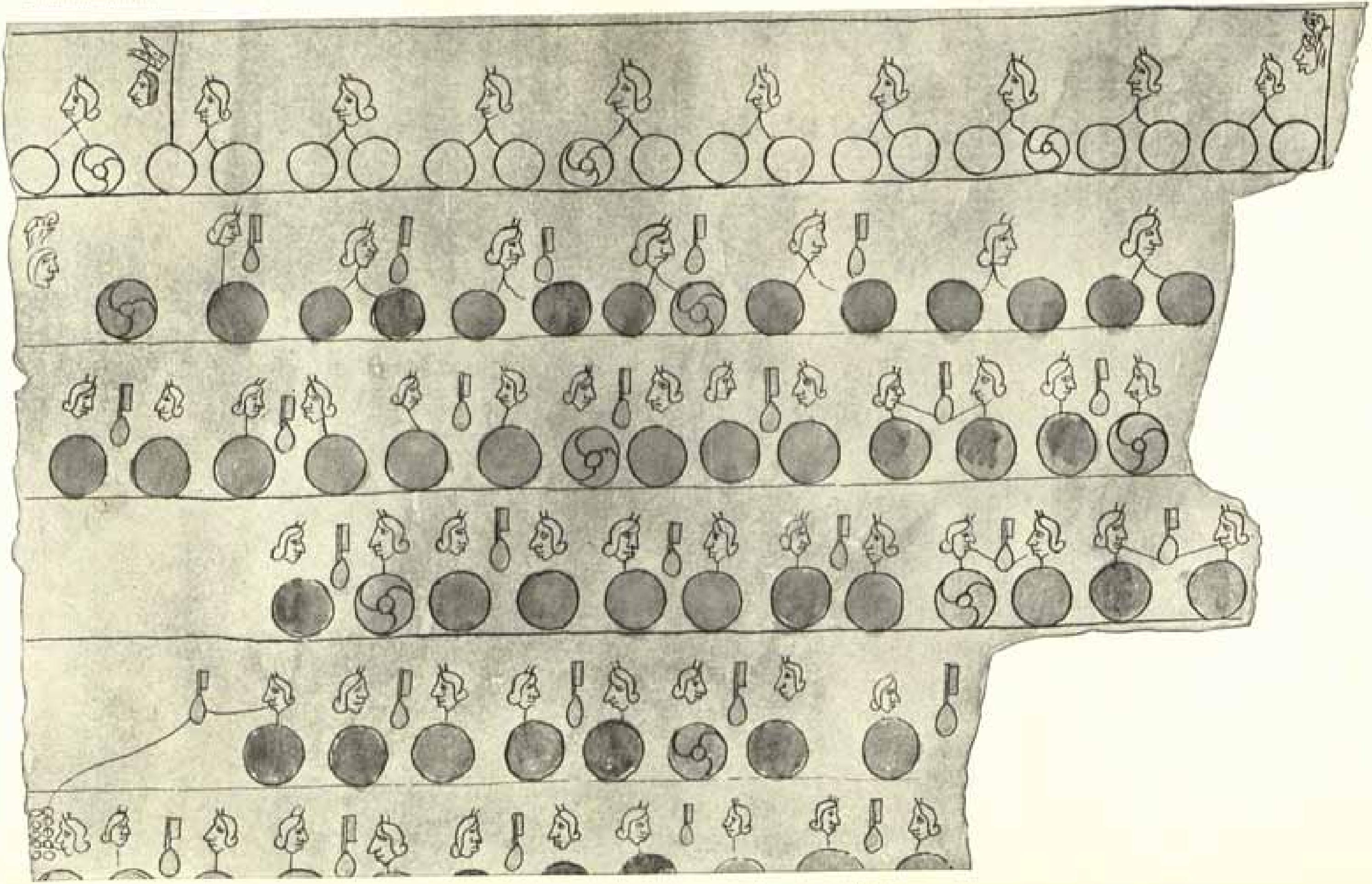
A single manuscript leaf of the Humboldt Collection, dated 1569 (pl. 1), shows the same idea of reminders together with true picture writing.[1] It is a baker's account. Just as the baker in many countries notched a stick in keeping his record, so here he employs much the same principle. The circles are tallies, the reminders of the number of tortillas or perhaps loaves of bread baked each day by the women. The sign of the flag over several of the circles is a symbol for 20. The circles containing the curved lines show the feast days, the Sundays, coming six days apart. The Spanish method of keeping time has been adopted in this case.

The first step in the development of writing after the preliminary stage of reminders is that of pure pictures. There is no lack of illustrations of this step in the manuscripts. Pictures are used simply as pictures with no idea of sound entering into the meaning. They are used not as symbols or signs of something else, but simply in their objective sense. There is no trace of mysticism. The objects represented can not be treated as ciphers or cryptograms in any attempt at their interpretation. A good example is found in a series of pages (pls. 2–5) from a post-Columbian manuscript in the Mendoza Collection, now in the Bodleian Library and published in Kingsborough (1831–1848, vol. 1, pls. 59–62).[2] The pictures give a clear account of the education of the Mexican boy and girl from the age of 3 to the age of 15. The boy and his father are shown on the left and the girl and her mother on the right. The years are indicated by circles, and the daily allotment of bread appears in front of each child. At the age of 3 a half cake or *tortilla* is the daily ration, whereas at 4 it is increased to a whole one.

Plate 2 shows the education from the ages of 3 to 6. Plate 3 indicates the tasks imposed and the punishments given to children from the ages of 7 to 10. Plate 4 continues the punishments for the eleventh and twelfth years and shows the tasks from the thirteenth and fourteenth years. Plate 5, at the top, indicates that at the age of 15 the boy is turned over to an outside authority to continue his education. The lower half of the same plate shows clearly by means of pictures the marriage ceremony. The groom carries his bride on his back into an inclosure and is accompanied by four women carrying torches. The marriage rite consists of tying the corners of the mantles of the two together. The marriage feast is also indicated. The Spanish accounts of the ancient marriage customs are no clearer

[1] This manuscript is called Fragment XIII of the Humboldt Collection and is described in Seler, 1893, and also in his collected works, vol. 1, pp. 27?–283. This is translated in Bureau of Ethnology, Bulletin 28, pp. 212–217, pl. 18.

[2] This series of pages is also published in Mallory, 1888–89, pls. 35–38. I am indebted for this series of pictures (pls. 2–5) and also for pl. 1 to Mr. F. W. Hodge, chief of the Bureau of American Ethnology.



Humboldt Manuscripts. Fragment XIII.

than the pictures shown in this manuscript. Every detail recorded in the picture is described in the Spanish texts covering these points.

It is not possible in the present paper to enter into a discussion of the different uses of picture writing among the Mexicans. From our point of view much that appears as mere decoration, as ornament, on the sculptured façades of the buildings and on the bas-reliefs are far more than decorative designs. There is in every case a meaning, however hidden it may be by the complication of the design.

Picture writing may develop along two lines, the first to a form of conventionalized pictures and the second to one characterized by symbolic forms, which in turn may become conventionalized. Conventionalization shows itself often in stereotyped forms used over and over again to express the same idea. The mountain almost always appears as shown in figures 3–5. All the top part is painted green, the bottom yellow with a line of red above. The color of the original drawings is a great aid in identifying the pictures.

The usual form of house is shown in figure 3, water as in figure 4 at the top of the mountain. The water is usually colored blue.

Symbolism may appear in the use of the part for the whole, the

Fig. 1.

picture of the whole body of a jaguar may give way to a representation of the head, or, still further, the idea of the animal may be expressed by the spotting of the skin. The road traveled is shown by footprints, as in figure 1. Night is pictured by the stars in a circular field, as seen in the Mendoza manuscript (pl. 4, *n*). Death is often shown by a skull.

Symbolism and conventionalism may appear in the same figure. Speech and song are usually expressed by a commalike form in front of the mouth, as shown before the parents instructing their children (pls. 2–5). These speech forms sometimes go so far as to indicate the actual character of the speech. An example taken from a stone bas-relief in Yucatan[1] illustrates this point (fig. 2). The whole design, of which that shown in figure 2 is only a small part, centers around an altar, behind which is shown the feathered serpent. Speech scrolls are indicated before the mouths of all the personages. The warrior above is bringing his offering of weapons. He has before his mouth, separated only by his breast ornament, the con-

[1] This bas-relief forms the back of the lower chamber of the Temple of the Tigers at Chichen Itza. For a drawing of the whole design, see Maudslay, 1895–1902, vol. 3, pl. 49. An explanation of the design is given in Seler, 1898.

ventionalized head of a serpent with open jaws, the nose plug, the eye, and teeth. This evidently is the representation of a prayer or speech in behalf of the serpent god. Below, to the left of the altar, the figure is possibly an idol; to the right of the altar a civilian is shown bringing his gifts, possibly bags of feathers. Before the mouth of this figure a most elaborate speech is indicated with buds, blossoms, and leaves.[1] In each case the conventionalization and symbolism are marked.

This development of writing from realistic pictures to those of a symbolic or conventionalized nature has its parallel in a develop-

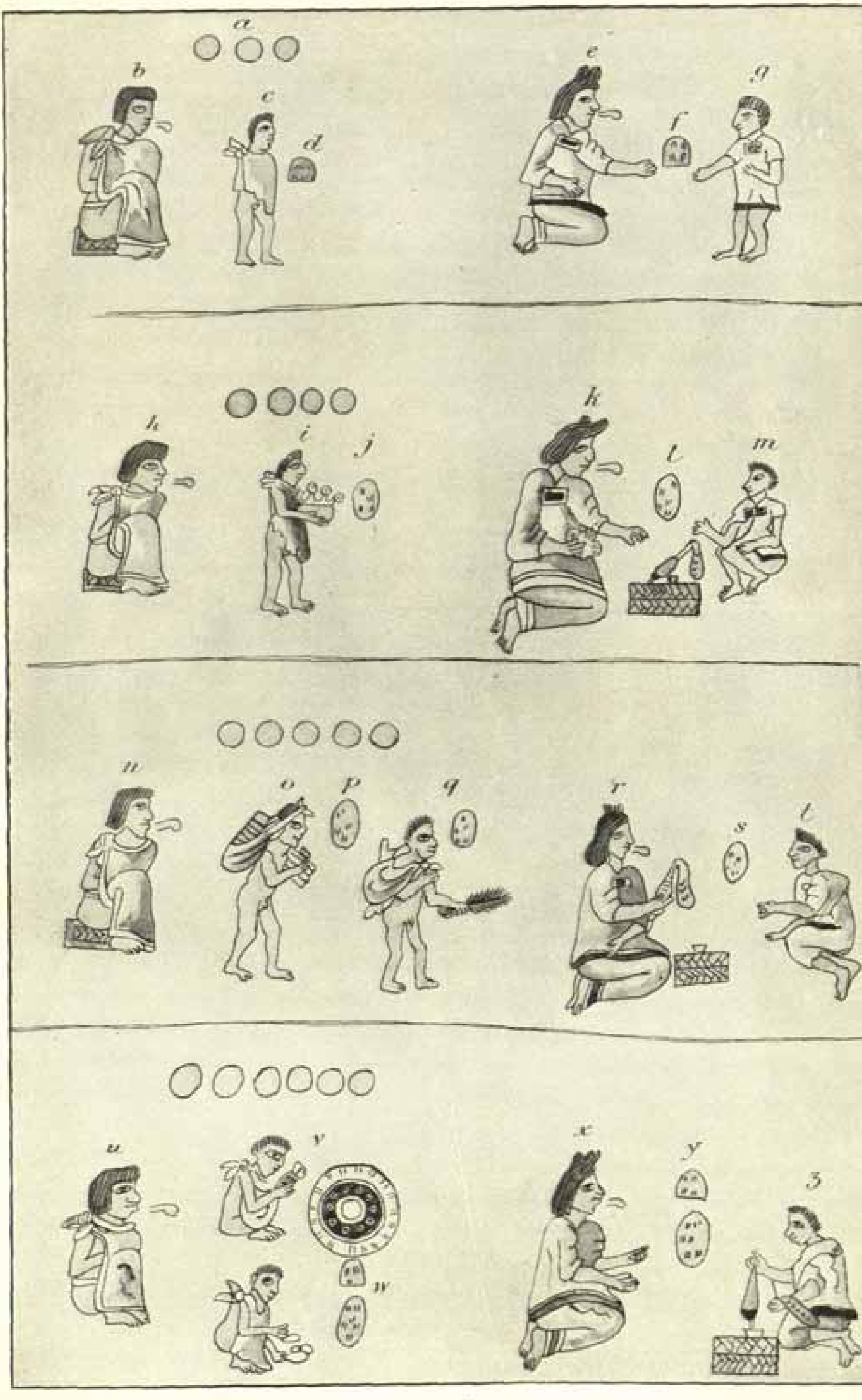
FIG. 2.

ment of ornamental art.[2] That the reverse process from certain more or less geometric forms to those of a realistic character may sometimes be present in primitive art should also be noted.

The "ideographic" stage in writing is reached when suggestions take the place of representation. The idea rather than the picture is the important factor. The Spanish priests realized very early the

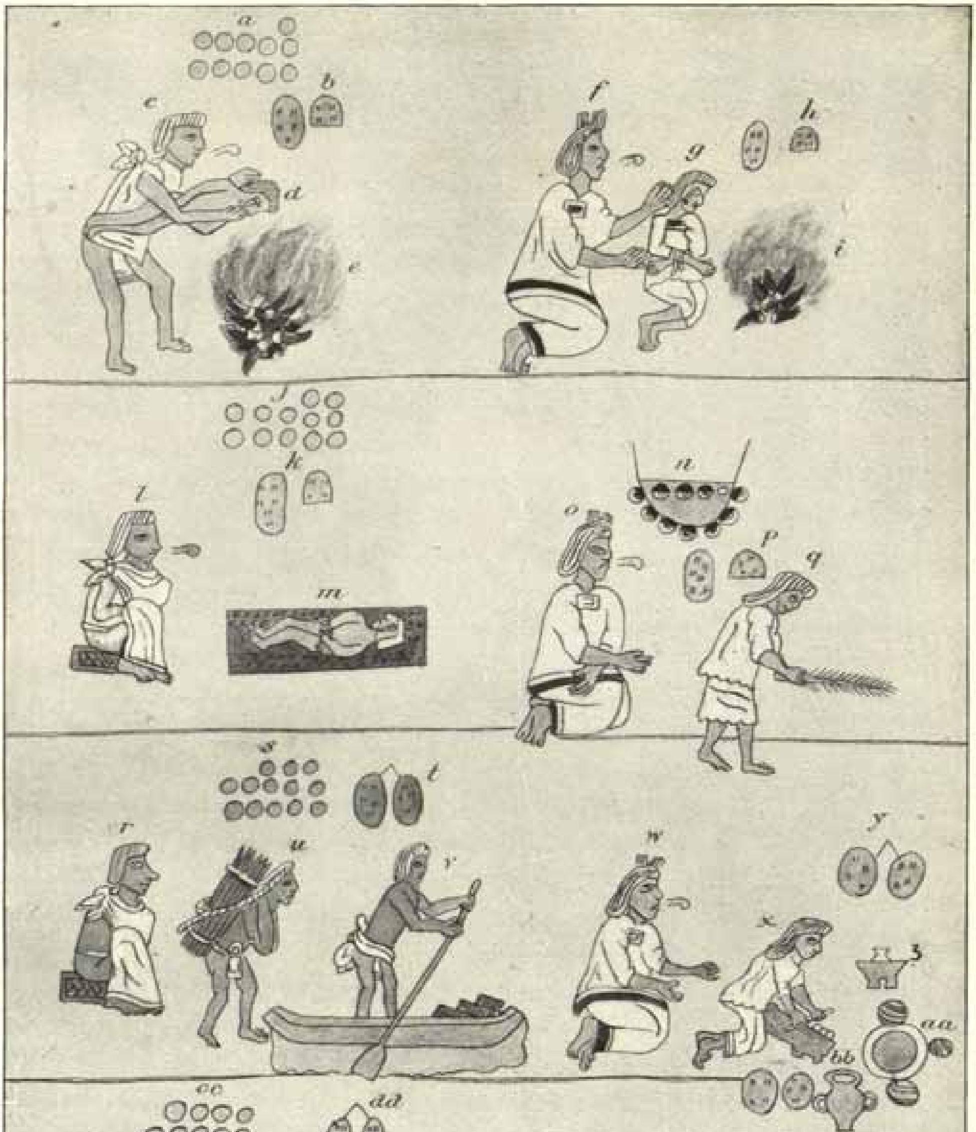
[1] For other designs expressing speech and song, see Orozco y Berra, 1880, vol. 1, p. 479 and pl. 7, figs. 321-346.

[2] Prof. Putnam (1887) was the first to point this out in connection with American art. See also his paper on "Symbolism in ancient American art" (1896).

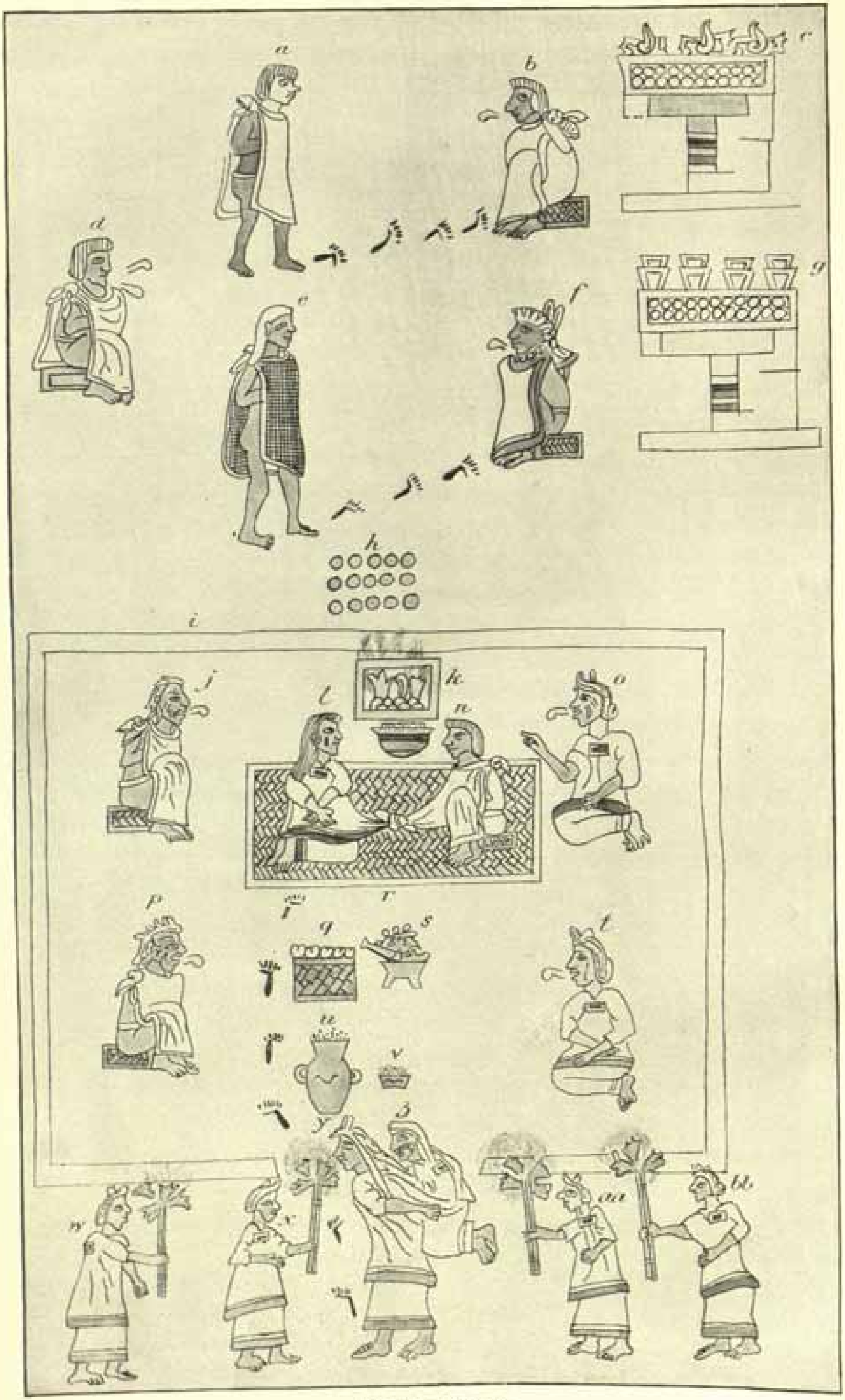


MENDOZA CODEX.

MENDOZA CODEX.



MENDOZA CODEX.



MENDOZA CODEX.

great ability possessed by the natives of Mexico to read by means of pictures. They took advantage of this in several ways in order to disseminate the teachings of the Roman religion. The entire catechism was shown by means of pictures. No question of sound entered into this sort of picture writing. These pictures were painted upon great cloths and hung up before the people. A page of Velades,[1] a Latin account of the activities of the priesthood, dated 1579, shows some of the ways taken by the priests to introduce the new religion into Mexico. * * * Torqumada (1723)[2] and other early writers describe these charts or "*lienzos.*" I know of none of these charts still in existence, but there are several manuscripts which contain the same class of pictures. Leon (1900) illustrates and describes this kind of document. The Peabody Museum has a manuscript which is slightly more elaborate in its figures than that pictured by Leon, but in all essential particulars they are identical. Both may be considered copies of earlier charts. * * *

In all these illustrations we have seen pure "thought writing,"[3] ideas expressed by pictures, conventionalized pictures, symbols, or conventionalized symbols. Up to this time there has been no suggestion of the name, or, more exactly, the sound of the name. Ideas have been expressed, but ideas regardless of the sounds which the names would signify.

The next step to be illustrated by Mexican examples is where sound comes in for the first time as a factor. It is not the object now that is the desired thing, but the name of the object. This marks an intermediate stage between picture writing on the one hand and phonetic writing on the other. It employs the well-known principle of the rebus. It is this step which is illustrated with special clearness in the Nahua manuscripts, perhaps better than in the writing of any other people.

Much has been written in various places on this phase of the writing of the Mexicans. The phonetic character of the greater part of the various pictures has been known for some time.[4] Brinton (1886 and 1886, a) has discussed this method of writing and gives it the term "ikonomatic," the "name of the figure or image," referring to the sound of the name rather than to any objective significance as a

[1] Velades, 1579, chap. xxviii, gives a pictorial alphabet which is of no importance. Valentine, 1880, p. 74, gives a reproduction of it.

[2] Book xv, chap. xxv, "Tuvieron estos Benitos Padres, un modo de Predicar, no menos trabajoso, que artificioso, y mui provechoso, para estos Indios, por ser conforme al uso, que ellos tenian, de tratar todas las cosas por Pinturas, y era desta manera. Hacian Pintar en un Lienço, los Articulos de la Fè, y en otro, los diez Mandamientos de Dios, y en otro, los siete Sacramentos, y lo demàs que querian, de la Doctrina Christiana; y quando el Predicador, queria Predicar de los Mandamientos colgavan junto, de donde se ponia à Predicar el Lienço de los Mandamientos en distancia que podia, con una Vara señalar la parte del Lienço, quequeria. * * * " For further references to this custom, see Leon, 1900.

[3] Seler, 1888, uses the term "Gedankenrebus" for this kind of writing.

[4] Peñafiel, 1885, gives an atlas of the place-names found in the tribute lists in the Codex Mendocino.

picture. Phonetic picture writing is perhaps a term more easily understood.

The simplest names are those compounded of two nouns expressed directly by two pictures:

Cal-tepec, the house on the mountain (fig. 3):
Cal from *calli*, house;
Tepec from *tepetl*, mountain.

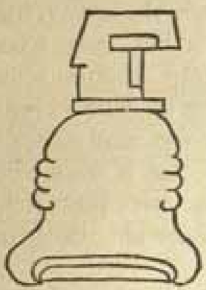


FIG. 3.

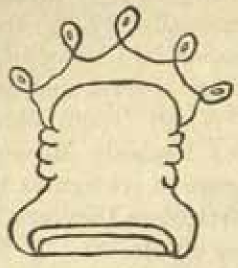


FIG. 4.

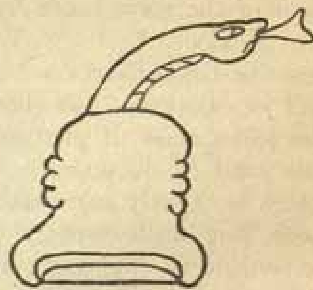


FIG. 5

A-tepec, the water on the mountain (fig. 4):
A from *atl*, water;
Tepec from *tepetl*, mountain.

Coa-tepec, the mountain of the serpent (fig. 5):
Coa from *coatl*, serpent;
Tepec from *tepetl*, mountain.

The verbal idea is expressed as one of the factors in some of the proper names, giving a compound of a verb and a noun, both ideas being expressed by pictures:

Toli-man, the place where the rushes are cut (fig. 6):
Toli from *tollin*, rushes;
Ma, the root of the verb meaning "to take something with the hand."

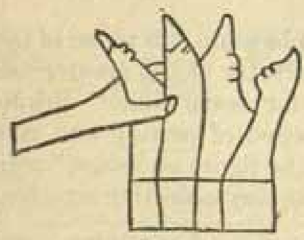


FIG. 6.

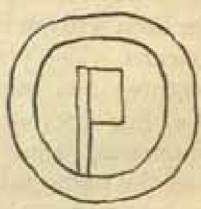


FIG. 7.

There are various ways of expressing the same combination of sounds. The syllable *pan* may be shown in three different ways, as follows:

(1) By the picture of a flag, *pantli* (fig. 7).
Chimal-pan, the shield of the flag:
Chimal, from *chimalli*, a shield;
Pan from *pantli*, a flag.

(2) By means of the representation of a river or canal, *apantli* (fig. 8).

Coapan, the river of the serpent:

Coa, from *coatl*, serpent;

Pan, from *apantli*, a river or canal.

FIG. 8.

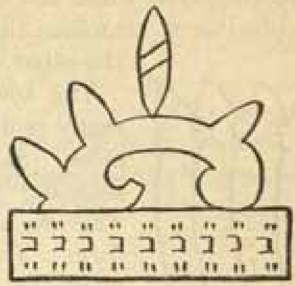


FIG. 9.

(3) By means of position, the syllable *pani* meaning "over" or "in" (fig. 9).

Itz-mi-quil-pan, the obsidian knife over the verdure of the cultivated field:

Itz, from *itztli*, obsidian knife;

Mi from *milli*, a cultivated field;

Quil from *quilitl*, verdure;

Pan from *pani*, over.

The color of the picture also has a phonetic significance in some cases, as (fig. 10)—

A-co-coz-pan, the canal of the very yellow water:

A from *atl*, water;

Co-coz, the intensified form from *coztic*, yellow; [1]

Pan from *apan*, river or canal.

In all these examples the meaning of the picture is conveyed at the same time as the sound.[2] The name is not made up of signs used simply for their phonetic value alone, but the meaning is expressed

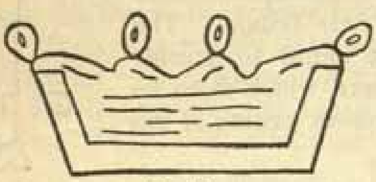


FIG. 10.

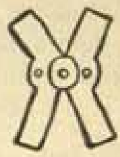


FIG. 11.

by the signs as well. The town of the "very yellow water" undoubtedly derived its name from the fact that it was situated on the bank of a muddy stream. We note the river and the yellow water in the original drawing, as well as the sides of the stream.

The true phonetic stage is not reached until signs are used without regard to their meaning as pictures but simply for their phonetic

[1] In the original manuscripts the water is colored yellow.

[2] Another interesting development of the use of a sign where the essential feature is its name rather its significance as a picture is seen in the character for the day *Ollin* (fig. 11). The word means "rolling motion" and is used not only to designate this day in the series of 20 days, but is found again and again in the historical records to indicate the occurrence of an earthquake.

value. In all the examples of place names given the different syllables of the term have been expressed directly by pictures of objects or acts, by position, or by color. Some other method has to be employed when one desires to bring out a meaning where it is not possible to translate the idea directly by a picture or by any of the other means we have noted.

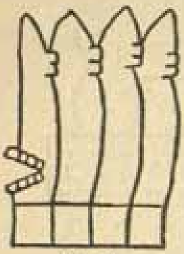


Fig. 12.

The town *Tollan*, "the place of the rushes," is easily represented by a picture of a cluster of reeds, *tollin*. Supposing, however, a town called *Toltitlan*, meaning "near *Tollan*," was the one to be written. This would be more difficult to express in picture form. The use of the homophone comes in here, words of a similar sound but with different meanings. The word *tetlan* means "near something" and the second syllable, *tlan*, is also found in *tlantli*, meaning "teeth." Thus if the picture of some teeth (fig. 12) is shown, the sound *tlan* would be expressed, suggesting in this case the meaning, not of teeth, but of nearness.

There is another word for "near" or "near by," *nauac*. A place named *Quauhnauac* has the meaning, "in or near the forest." *Quauh* is the root of the word *quauitl*, tree. The termination *nauac* is supplied by the sign of "clear speech" (fig. 13), which is a second meaning of *nauac*. A variant of this place name is shown in the Aubin manuscript (fig. 14). Here there is an animal head with the leaves of the tree shown on top. Speech is represented as in the preceding form.

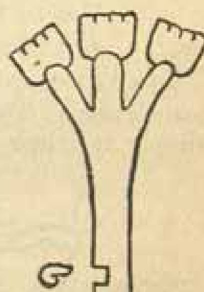


Fig. 13.

An interesting class of diminutives is formed in the same way by the use of the homophone *zinco* as in *Tollanzinco*, meaning "Little Tollan." The use of determinatives is not found to express the special meaning of the word which is to be used as is the case in the Egyptian writing of the same class.

We find in the place names we have been considering the beginning of a syllabary, certain characters always used for certain combinations of sounds. These signs not only express single syllables but in a few cases, as in *tepec* and *nauac*, double syllables, and, *a* from *atl*, single sounds.

The adoption of certain definite signs to express certain combinations of sounds is a step far in advance of the stage of pure picture writing and it is well on its way toward the adoption of an alphabet where the signs no longer express combinations of sounds but single sounds. It might be possible to go a step farther in the case of the

Mexican writing and say that the Nahuas had reached, to a slight degree, this final stage in their writing. We have seen how an *a* sound in the place names is always expressed in their writing by the sign for water, *atl.* So other signs which formerly stood for entire syllables seem in some cases to have been used to express the initial sound of the syllable. The sign of a flag, *pantli*, came in time to be used for the initial sound *p*, the sign for *etl*, bean, was worn down to express the initial *e* sound, and the sign *otli*, for road, to be used for an *o* sound. I am inclined to think, however, that the Nahuas in pre-Columbian times did not realize the importance of the step which they were about to take, the use of signs for single sounds, an alphabet. In the few cases where this seems to be found we have the idea of a syllabary rather than an alphabet as the *tl* of *atl*, *etl*, and *otli*, is a nominal ending and the word in composition can stand without this suffix. The signs for *a*, *e*, and *o* are really signs for syllables composed of single sounds rather than for single letters as distinguished from syllables.

The Nahuas in the pre-Columbian period did not develop the syllabary to the point shown in later times. There are no early texts in the true sense of the word written in the Nahua characters. The Spaniards were the ones to realize the importance of the syllabary and it is undoubtedly owing to their influence that certain signs are found used in later manuscripts to express certain syllables absolutely for their phonetic value and entirely divorced from the signification of the signs as pictures. Moreover, the Spaniards seem to have used to some extent at least the signs of the Nahuas to express single sounds.

We have already noted the work of the Spanish priests in their endeavor to teach the natives the creed of the Roman Church. In this case the ideas are expressed quite apart from the sounds of the words. The pictures could be understood quite as well by one people as by another. The missionaries were not content with this. They desired the Nahuas to learn the actual sounds of the words of the catechism. They took advantage of the ability of the natives to read in signs denoting syllables. The priests selected native words which had the same initial sounds as the Latin or Spanish words which they wished the Nahuas to commit to memory. The signs for these native words were then written in the native manner. The Lord's Prayer is usually given as an example of this kind of writing.[1]

[1] Torquemada, 1723. Book xv, chap. xxxvi, writes: "El Vocablo, que ellos tienen, y que mas tira à la pronunciacion de *Pater*, es Pantli, que significa una como *Banderita*, con que cuentan el numero de veinte; pues para acordarse del Vocablo *Pater*, ponen aquella Banderita, que significa Pantli, y en ella dicen *Pater*. Para la segunda, que dice *Noster*, el Vocablo, que ellos tienen mas parecido à esta pronunciacion, es Nuchtli, que es el Nombre de la que los nuestros llaman Tuna, y en España Higo de las Indias pues para acordarse del Vocablo *Noster*, pintan consecutivamente tras de la Banderita, una Tuna, que ellos llaman Nochtli; y de esta manera vàn proosiguiendo, hasta acabar su Oracion; y por semejante manera hallavan otros semejantes Carectères, y modos, por donde ellos se entendian, para hacer Memoria de lo

A flag (fig. 15) *pantli* suggests *pa*. A picture of a stone, *tetl*, highly conventionalized, stood for *ter*, making *Pater*. A prickly pear, *nochtli*, the fig of the *castus opuntia*, was used for recalling the syllable *nos* and another stone, *tetl*, the *ter*, making *noster*. In the same way (fig. 16) water, *atl*, stood for an *a* sound and *agave*, *metl*, for *men* making *amen*.

The attempt made by Bishop Diego de Landa[1] to furnish an alphabet for the interpretation of the Maya hieroglyphics, as shown by Valentini (1880), is a "Spanish fabrication" and entirely unworkable when applied to the decipherment of the hieroglyphic writing. The "alphabet" illustrates exactly the same method as that just pointed out. Here Landa chose a native word beginning with the initial sound he desired to write. A picture or symbol was then drawn to represent this word and this came to stand for the initial sound of the word. The picture of a man's footprint stood for one of the sounds for *b*, the Maya word for road being *be*.

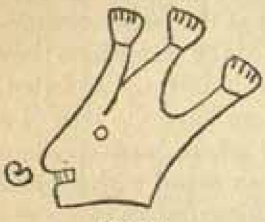


Fig. 14.

The hieroglyphic writing of the Mayas, however, does not serve as well as that of the Nahuas to illustrate the various steps in the development of writing as a whole. There is far less known in regard to the phonetic components of the Maya glyphs.

In view of the higher development of the calendar system found among the Mayas, we might naturally presuppose a corresponding higher development of the art of writing and yet Förstemann (1886, p. 2), Schellhas (1886, p. 77), Brinton (1886, a), and Seler (1888) all seem to agree that the Maya hieroglyphics are essentially ideographic, with a number of constant phonetic elements which are used only to a comparatively slight extent. Up to the present time a corresponding development among the Mayas of the rebus form of writing

Fig. 15.

que avian de tomar de Coro, y lo mismo usavan algunos, que no confiavan de su Memoria en las Confesiones para acordarse de sus Pecados, llevandolos pintados con sus Caractêres (como los que de nosotros se confiesan por escrito) que era cosa de vèr, y para alabar à Dios, las invenciones, que para efecto, de las cosas de su salvacion buscaban, y usaban."

Las Casas in his Apologetica Historia de las Indias, a new edition of which is available (1909), chap. CCXXXV, writes: "Y no sabiendo leer nuestra escritura, escribir todo la doctrina ellos por sus figuras y caracteres muy ingeniosamente, poniendo la figura que corresponderá en la voz y sonidaá nuestro vocablo; asi como dijésemos amen, ponian pintada una como fuente, y luego y un maguey, que en su lengua frisaba con amen, porque llámanlo ametl, y asi de todo lo demás; yo he visto mucha parte de la doctrina cristiana escripta por sus figuras e imágines que la leian por ellas como yo la leia per nuestra letra en una carta, y esto no es artificio de ingenio poco admirable.

[1] See Landa, 1864, p. 320.

of the Mexicans has not been found. Various elaborate attempts to read the Maya hieroglyphics phonetically have met with failure. Mr. Bowditch (1910, pp. 254–255) sums up the whole question when he writes:

> While I subscribe in general to these words (that the wrting is chiefly ideographic) of the eminent Americanist (Dr. Brinton), I do not think that the Aztec picture writing is on the same plane as that of the Mayas. As far as I am aware, the use of this kind of writing was confined, among the Aztecs, to the names of persons and places, while the Mayas, if they used the rebus form at all, used it also for expressing common nouns and possibly abstract ideas. The Mayas surely used picture writing and the ideographic system, but I feel confident that a large part of their hieroglyphs will be found to be made up of rebus forms and that the true line of research will be found to lie in this direction. If this is a correct view of the case, it is very important, indispensable indeed, that the student of the Maya hieroglyphs should become a thorough Maya linguist. I am also of the opinion that the consonantal sound of a syllable was of far greater importance than the vowel sound, so that a form could be used to represent a syllable, even if the vowel and consonant sounds were reversed.

A further discussion of the hieroglyphic writing of the Mayas would lead us too far away from our subject.

I have not attempted to elucidate any new problems or to add to the knowledge of the writing of the Mexicans, but to coordinate and systematize the various forms and employ them as examples of the general development of writing. There is found in Mexico, perhaps to a greater degree than in any other one place in the world, examples of all the different kinds of writing, as we have seen, starting with a preliminary stage of reminders and passing to pure pictures which are used simply in their objective sense as pictures, thence to the more or less conventionalized and symbolic pictures or ideographs and finally to characters expressing sounds as well as ideas, and the beginning of a syllabary, the first step in the development of a phonetic writing, and a step beyond which the Nahuas did not go. The Spanish priests made the last advance toward the goal, the formation of an alphabet, by selecting a few syllabic characters which they used to express the initial sounds. The first credit belongs, however, to the ancient Nahuas, who arrived, quite independently, at the idea of the possibility of a phonetic writing, and it is not difficult to imagine a further development into a true alphabet had they been left to develop their culture in their own way.

Fig. 16.

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THE DISCOVERERS OF THE ART OF IRON MANUFACTURE.[1]

By W. Belck.

About three years ago I again brought before our society the question as to the age and origin of the art of ironworking.[2] I can now state with satisfaction that the discussion and study of this problem has not, as in similar cases, after a sudden burst of enthusiasm, well nigh exhausted itself, but it continues, here and elsewhere, to engage the earnest attention of scholars.

If it be said that by this time we should have reached some conclusions, I may say that in a measure we really have arrived at somewhat definite results, due chiefly to the present manner of stating the problem, and to a restriction and limitation of the question, which I claim as my modest contribution in the treatment of the subject.

In the course of my studies, untrammeled by methods and aims of other investigators, and constantly guided by entirely different viewpoints, I was soon convinced that there was a very long interval between what may be called the accidental and the intentional production of iron implements, an interval that probably covered many milleniums. The question as to when prehistoric man first held in his hand an iron object made by himself is very interesting to us all, the more so because of the apparent impossibility of finding a satisfactory answer. But this question as to incidental ironworking is unimportant beside the query as to whom we are indebted for the intentional production of iron, its manufacture, and for the industry thus made possible. In a word, who gave this industrial art to ancient and modern civilization, when and where was it first practiced? And since the superiority of iron over all other metals known to the ancients is not at all based upon the qualities of wrought iron, which because of its softness and pliability is for many uses considerably inferior to the hard bronze of antiquity, but is due mainly to the excellent qualities of hardened steel, the question as to who were the originators, the time and place, of the first manufactures of steel, becomes of preponderating interest to the historians of civilization.

[1] Translated by permission from the German of W. Belck, Die Erfinder der Eisentechnik in Zeitschrift für Ethnologie, vol. 42, 1910, part 1, pp. 15–30. Berlin: Behrend & Co., 1910.

[2] Zeitschr. Ethnol., 1907, pp. 334–381. Compare also Zeitschr. Ethnol., 1908, pp. 45–69 and 241–253.

It will not be amiss to glance first at the results of the discussion and researches of scholars during the last three years. First of all, as to the age and origin of steelmaking, the most important stage in the history of the working of iron—it is unfortunate that nobody has attempted to solve this difficult problem. And, indeed, our sources here fail us completely, for the process of making and working fine steel was guarded by the ancients as a most profound secret known only to members of the same sect. The evil repute in which ironworkers were held by some peoples—apparently also by the earliest of the Israelites—must certainly in not a small measure be connected with the superstition of their neighbors, who ascribed skill in the making of fine steel weapons to the aid of evil spirits and demons. And it is self-evident that the masters of this art, the prosperous sword-cutlers of the time, would not themselves divulge, much less write, upon the secrets of their trade. On the contrary, it was in their interest to foster popular belief in the supernatural origin of their workmanship, and thus to put a stop to all inquiry as to the real methods of their trade. The steel makers and workers were therefore looked upon either as artists by the grace of God, or as malignant sorcerers and wizards, and were treated accordingly. In either case the result was the same, the methods of steelworkers remained the secret of the sect and was under no condition betrayed. We can thus understand why such a learned man as Pliny could offer no definite data on the history of the steel industry, although he was well acquainted with the makers of fine steel.

The oldest written direct information now known on the employment and working of steel is the Biblical passage in I Samuel xiii, 19–22.

> Now there was no smith found throughout all the land of Israel: for the Philistines said, Lest the Hebrews make them swords or spears: But all the Israelites went down to the Philistines, to sharpen every man his share, and his coulter, and his axe, and his mattock. Yet they had a file for the mattocks, and for the coulters, and for the forks, and for the axes, and to sharpen the goads. So it came to pass in the day of battle, that there was neither sword nor spear found in the hand of any of the people that were with Saul and Jonathan: but with Saul and Jonathan his son was there found.

The implements mentioned above, according to my conception, can not possibly mean anything other than those of steel. And so also very probably in the following Biblical passages in Joshua xvii, 16 and 18, by "chariots of iron" we should understand "chariots of steel:"

> And the children of Joseph said, The hill is not enough for us: and all the Canaanites that dwell in the land of the valley have chariots of iron, both they who are of Beth-shean and her towns, and they who are of the valley of Jezreel.
>
> But the mountain shall be thine; for it is a wood, and thou shalt cut it down: and the outgoings of it shall be thine; for thou shalt drive out the Canaanites, though they have iron chariots, and though they be strong.

And in Judges i, 19, and iv, 3:

And the Lord was with Judah; and he drove out the inhabitants of the mountain; but could not drive out the inhabitants of the valley, because they had chariots of iron.

And the children of Israel cried unto the Lord: for he had nine hundred chariots of iron; and twenty years he mightily oppressed the children of Israel.

It affords me satisfaction to state that investigators generally have tacitly adopted my interpretation of these passages.

But it should also be pointed out that there is hardly any prospect that older written evidence will be discovered, for the peoples who have left ample written monuments older than those of the Hebrew, the Assyro-Babylonians and the Egyptians, are not to be considered in our problem. The former, because without question they became acquainted with iron at a much later period; the latter, because—even assuming that they had known wrought iron in earlier times—they never employed steel. But even if we must confine ourselves to Biblical passages and to accounts of the conquest of Palestine by the invading Habiri (Hebrews) hordes as resting on good tradition and therefore reliable, we obtain quite an early date, about the thirteenth pre-Christian century, for the first mention of steel. At the same time it should be borne in mind that we must postulate for that period a quite well advanced workmanship, so that the ironsmiths were able to turn out scythes at least 1 meter long and correspondingly wide for the scythe chariots. It is self-evident that the making of such steel scythes was attempted only after long practice in making swords, daggers, arrows, and other weapons of steel. If these steel scythes were fixed to the axles and poles of war chariots, it may be assumed that in time of peace they were used for purposes of agriculture. In short, the reference to the scythe chariots of the Canaanites introduces us at once into a period of a highly developed steel industry. In the face of this undeniable fact it appears the more strange and incomprehensible that the Egyptians as well as the Assyro-Babylonians, as also the Hittites and all the other great nations of western Asia, had no knowledge whatever of this steel industry which certainly must then have been several hundred years old. For even if the ancient armorers most carefully guarded and practiced their art as a secret, they could hardly have prevented its products from becoming generally known and used by neighboring nations. This condition can be accounted for only by assuming that the actual development of the steel industry, which must have required many years, did not take place in Palestine but elsewhere, and that it was introduced into Palestine shortly before the immigration of the Israelites. These data fully accord with our knowledge of the Philistines, who are assumed by scholars generally to have immigrated

to Palestine at a comparatively late date; some even claim that they came later than the Jews.[1]

If it is assumed that the weakening of the Egyptian supremacy in Syria and Canaan, in consequence of the repeated wars with the great Hittite kings, was taken advantage of by the island Philistines for carrying out their invasion and the establishment of the five Philistine principalities, and that some five decades later the influx of the Israelitish hordes followed, it may be clearly explained that in the meantime the products of the Philistine iron and steel industry were introduced and spread among their nearest neighbors, the Canaanites. The Israelites would therefore have learned to know, to admire, and to fear their weapons, while at the same time the more distant peoples, such as the Babylonians and Assyrians and the Egyptians, who carried on scarcely any foreign trade, must have remained in ignorance of them.

Sober and intelligent research in this subject will certainly result in revealing many a grain of truth in the débris of the milleniums, and some important facts may even now be pointed out. Since the effectiveness of the scythe chariot, so much employed in ancient wars, depended upon the continued keenness of the blades, which could hardly be attained in bronze scythes, it seems to me scarcely subject to doubt that the inventors and propagators of the steel industry in Palestine were also the inventors and earliest constructors of the scythe chariot. The possession and employment of such deadly chariots must have materially aided the invading Philistines in the conquest of the coast land, for the Jews could hardly have been the only ones to be horror-stricken by these terrible slaughtering machines, so that, as they themselves often admit, they did not even venture into the valleys occupied by the Philistines, where alone could these scythe chariots be used to advantage. Among the Egyptian troops similar fear must have prevailed. We may therefore conclude that the Philistines at the period of the invasion of Palestine, in the thirteenth or fourteenth centuries B. C., introduced there a steel industry whose higher development must also have gone on for several centuries in their former settlements, probably on the island of Crete. On this assumption the beginnings of the steel industry would reach back into the first half of the second pre-Christian millenium, or to the period from 1800 to 1600 B. C. Moreover, it may be implied from this that the beginnings of the manufacture of wrought-iron objects among the Philistines must at least be set in the second half of the third millenium B. C.; that is, that the working of iron was developed among the Philistines during a period considerably earlier than hitherto we have been inclined to assume.

[1] Thus M. Mueller, Asien and Europa, p. 388, lets them immigrate as late as about 1100 B. C., which is, however, probably by 200 to 300 years too low.

My propositions on the history of the wrought-iron industry[1] as far as the several peoples are considered, have in part received prompt and unconditional assent, and in part they have been disputed.

In this way a welcome clearing of the disputed points was effected which will materially facilitate further investigation.

The Assyriologists admitted that only the very late Assyrian and Babylonian inscribed monuments mention iron, and also that in the excavations iron objects make their appearance at a comparatively late period (ninth to eighth century B. C.). Assyria and Babylonia, and with them the entire Assyro-Babylonian culture sphere (especially also Elam), are thus definitely eliminated from the circle of peoples who might be considered as inventors of the working of iron.

As regards the Jews, there was at first some opposition. Not that they were suspected to have been inventors of ironworking, but rather as concerns the age and source of their knowledge of iron, which there was a strong inclination to derive from their sojourn in Egypt. Heretofore I could produce only indirect proofs in support of my views that it was in Canaan that the Jews first learned of iron, and the fact that this metal is not mentioned during their wandering in the wilderness, or even in the detailed description of the construction of the Tabernacle. In the meantime I came across a Biblical passage which seems to be direct corroboration of my views, namely, in Joshua vi, 19–24:

> But all the silver, and gold, and vessels of brass and iron, are consecrated unto the Lord: they shall come unto the treasury of the Lord. So the people shouted when the priests blew with the trumpets: and it came to pass, when the people heard the sound of the trumpet, and the people shouted with a great shout, that the wall fell down flat, so that the people went up into the city, every man straight before him, and they took the city. And they utterly destroyed all that was in the city, both man and woman, young and old, and ox, and sheep, and ass, with the edge of the sword. But Joshua had said unto the two men that had spied out the country, Go into the harlot's house, and bring out thence the woman, and all that she hath, as ye sware unto her. And the young men that were spies went in, and brought out Rahab, and her father, and her mother, and her brethren, and all that she had; and they brought out all her kindred and left them without the camp of Israel. And they burnt the city with fire, and all that was therein: only the silver, and the gold, and the vessels of brass and of iron, they put into the treasury of the house of the Lord.

Joshua here gives his commands to the Jews, how they should, after the conquest of Jericho, deal with the peoples and dispose of the captured booty: All living beings, except the family of Rahab, should be killed; all the silver and gold, together with the brass and iron vessels, should be appropriated to the treasury of the Lord in the Tabernacle. This last ordinance is, according to verse 24, punctually carried out. Now, the ordinance with regard to the gold and silver objects is easily understood, in a measure also that for the

[1] Compare especially Zeitschr. Ethnql., 1907, pp. 341-362; ib., 1908, pp. 46-69.

valuable bronze vessels. But what would the Tabernacle and the Temple treasury do with iron vessels if they were in general use and therefore to be had in large quantities and at a small price? No; this regulation made by Joshua is intelligible only if we assume that at that time iron was to the Jews something rare and precious which they would consecrate along with the other valuable things to the Temple treasury. Likewise the passage in Joshua xxii, 8, in which Joshua says to the two tribes and a half, who were returning to Bashan and Gilead:

> Return with much riches unto your tents, and with very much cattle, with silver, and with gold, and with brass, and with iron, and with very much raiment:

clearly proves that iron objects were then classed as valuable booty, even as was the case with the Assyrians in 800 B. C.; that is, about 300 years later.

If this view, that iron and iron vessels were then both by the Jews and probably also by peoples living still farther away from the Philistines considered as something rare and costly, the following tradition of the iron bedstead of King Og of Bashan, contained in Deuteronomy iii, 11, presents an entirely different aspect:

> For only Og king of Bashan remained of the remnant of the giants; behold, his bedstead was a bedstead of iron; is it not in Rabbath of the children of Ammon? nine cubits was the length thereof, and four cubits the breadth of it, after the cubit of a man.

It has been recently assumed that it was not a real bedstead, but a sarcophagus of basalt,[1] which may also have appeared to the Jews as something unusual. Whether, even so, the Jews, who devote scarcely a word to the coffins, tombs, and interments of their own kings, even the most famous and favored ones, would consider it worth mentioning in their sacred writings, seems to me very questionable. Besides, it has been entirely overlooked that this iron "bedstead" was still at a much later time preserved and shown as a curiosity (compare Deuteronomy iii, 11), though not, as would be expected, in Bashan, but in Rabbath-Ammon—that is, among a people hostile to the Jews. This fact is difficult to understand if it were a sarcophagus, which with its enormous weight could not, like some piece of war booty, be carried from one place to another.

But if, on the other hand, it is remembered that according to the Assyrian cuneiform accounts couches of state of pure gold for the princes of that time were very common, it can be easily understood, on the assumption that at the time of the Israelitish invasion in Palestine iron was a rare and costly article, that a rich prince had himself, for the sake of variety, made a bedstead of the costly iron. And there will be nothing strange that the Jews in the account of their victory

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[1] Compare Blanckenhorn, Zeitschr. Ethnol., 1907, p. 365.

especially mention such an extravagantly expensive object, or that this valuable and easily transportable article was carried away by a host of the Ammonites who sometime afterwards may have invaded Bashan (compare Judges iii, 13, where soon after Joshua's death—that is, at a time when iron could certainly not have become much cheaper—there is given an account of a victorious campaign of the Ammonites, Amalekites, and Moabites against the trans-Jordan Jews).

So much as to the relation of the Jews to our problem.

Serious objections, though there was also partial agreement, were made to my statements relating to the Egyptians. This is not strange concerning a people like the Egyptians, about whom opinions are so divided. While some investigators allow to the Egyptians a knowledge of iron only since about the fifteenth century B. C. and a more extensive employment of the metal only since the beginning of the Ptolemaic period, denying them any independence in iron manufactures in the pre-Ptolemaic period, as also the quarrying of iron ores or iron casting, others hold almost an entirely opposite view, supported by the sporadic finds of iron in the pyramids and temple ruins on supposedly untouched sites. These investigators speak of the Egyptians' knowledge of iron metal during the fourth or even earlier dynasties, and less cautious scholars have claimed these pretended hoary finds as proof not only that the Egyptians knew the value of iron, but as evidence of a veritable iron industry in those very ancient times.

However, this last bold assertion, supported by Herr Blanckenhorn and others, has found few adherents.

There seems to be no real evidence of the existence of a very ancient iron industry among the Egyptians, but on the contrary all circumstances pronounce against it. Serious investigators, such as von Luschan, Olshausen, and others, are therefore content to emphasize the importance of those very ancient iron finds, whose genuineness and age they energetically defend against skeptics, and to merely call attention to the frequent representation of iron objects on old Egyptian mural paintings, in which the blue-colored objects are assumed to be made of iron. From these observations they conclude not that there existed a native iron industry among Egyptians, but that it indicates an intermediary rôle in the spread of metallurgic knowledge of iron among other peoples. In the latter class von Luschan particularly includes the Negroes[1] settled in the south of Egypt, and recounts many, at first sight seemingly plausible, circumstances to show that the iron industry of Europe had its origin among those Negro peoples, from whom it spread to other peoples through the medium of the Egyptians.

[1] Compare Zeitschr. Ethnol., 1907, pp. 379-381; and more in detail, ib., 1909, pp. 22-53.

Von Luschan thus does not consider that the Egyptians themselves were the inventors of ironworking, but rather attributes to them a secondary rôle, and in so far I agree with him as against that group of scholars who, notwithstanding all the proofs brought forth, still maintain that the origin of the iron industry is to be sought in Egypt.

If von Luschan's view be correct, the following conditions must first of all be fulfilled:

1. There must be proof of the existence of an iron industry among the Negroes in the very ancient period assumed by von Luschan.

2. It must be proven that ironworking was in very ancient time imported from the Negro territories into Egypt, and there practically employed.

3. It must be proven that, and the manner how, the industry spread from Egypt to Asia and Europe.

As to the first proposition, Schweinfurth, like von Luschan, also considers the iron industry of the Negro peoples as native (not imported) and of probably considerable antiquity, although he hardly seems to be inclined with von Luschan to ascribe to it an age of from 4,000 to 5,000 years or even more. Von Luschan offers no proof for such a high antiquity of that industry among the Negroes, and we may concede to him that on this question conclusive proofs can scarcely be expected. Von Luschan therefore tries verisimilar proof, pointing out:

> On the old Egyptian mural paintings are often seen dark people presenting to the Pharaoh blue-colored objects (weapons, knives, etc.). I assume with many other investigators that the dark people represent Negroes, and the blue-colored weapons are iron ones, hence the Negroes were then in possession of an iron industry.

This method of proof involves some serious errors; for, on the one hand, it assumes two premises which are by no means generally conceded, and on the other hand, the derived conclusion is false.

(*a*) There is thus far no proof that the dark people represented Negroes, African Negroes, and if one should wish to recognize them as the likewise dark inhabitants of the Arabian west coast and of part of the Sinaitic peninsula, he could scarcely be convinced of being wrong. We may call to mind the tradition of the ancients (compare Herodotus i, 1, and vii, 89), according to which the Punt-Punians-Phenicians had, previous to their immigration into Phenicia, lived at the Red Sea, and they received their name from the dark-reddish color of their skin. In my opinion we have in the relation by Herodotus an historic account of great importance which, very agreeably, is supported and corroborated by Biblical data, for this same statement is indirectly but distinctly made. I refer, in the first place, to I Kings ix, 26–28, where it reads:

> And King Solomon made a navy of ships in Eziongeber, which is beside Eloth, on the shore of the Red Sea, in the land of Edom. And Hiram sent in the navy his

servants, shipmen that had knowledge of the sea, with the servants of Solomon. And they came to Ophir, and fetched from thence gold, four hundred and twenty talents and brought it to king Solomon.

This Jewish-Phenician sea voyage is also mentioned in I Kings x, 11:

And the navy also of Hiram, that brought gold from Ophir, brought in from Ophir great plenty of almug trees, and precious stones.

Further, ib., verse 22:

For the King had at sea a navy of Tharshish with the navy of Hiram: once in three years came the navy of Tharshish, bringing gold, and silver, ivory, and apes, and peacocks.

The same is read in II Chronicles ix, 21:

For the king's ships went to Tarshish with the servants of Hiram: every three years once came the ships of Tarshish bringing gold, and silver, ivory, and apes, and peacocks.

In full agreement with this Josephus relates in his Jewish Antiquities, viii, 6, §4:

Then the King (Solomon) had built himself many ships in the Egyptian bay, in a place called Gasiongabel, situated on the Red Sea, not far from the city of Aelana, which is now called Berenice. For this entire region at that time belonged to the Jews. For the construction of this navy, too, he received abundant support from the liberality of Hiram, King of the Tyrians. For Hiram sent him a number of steersmates and experienced seamen. Solomon ordered them, together with his own officials, to sail to Sophira in India, the present so-called gold land, and to bring him gold from there. They gathered about four hundred talents of it and then returned home to the King.[1]

The statement in these accounts that Solomon's people had built the ships at Eziongeber (=Gasiongabel) is improbable, for whence could the inland Jews have acquired the professional knowledge and skill necessary for such work? Had they really attempted to build ships on their own initiative, they would have had the same experience as that of Jehoshaphat, King of Judah, later on, of whom it is related in II Chronicles xx, 35–37:

And after this did Jehoshaphat king of Judah join himself with Ahaziah king of Israel, who did very wickedly: And he joined himself with him to make ships to go to Tarshish: and they made the ships in Eziongaber. Then Eliezer the son of Dodavah of Mareshah prophesied against Jehoshaphat, saying, Because thou hast joined

[1] In connection with this historically so important account I wish to make the following remarks:

1. Josephus was certainly in position to establish without difficulty or uncertainty where the land of Ophir or Sophira was located. In the face of his clear statement that it was India it remains incomprehensible that Ophir was ever seriously sought for in Africa on the Zambesi. Ophir is also mentioned in the genealogical table of Genesis (x, 29) as a descendant of the Semite Joktan; and Josephus, Jewish Antiquities, i, 6, §4, makes Opheires, as he calls him, together with other descendants of Joktan, dwell on the Indian River Kophene and in adjacent Ariane.

2. I can not believe in the supposed "voluntary" aid given by Hiram of Tyre to Solomon (and likewise to David); probably Tyre at the time of David and Solomon stood to the rising and flourishing Jewish state in a relation of suzerainty similar to that of Damascus and Hamath.

3. The visit of homage paid by the Queen of Sheba to Solomon seems to have been a direct result, not so much of the fact that Jewish rule in David's time extended to the coast of the Red Sea, but rather of the Jewish-Phenician sea voyages on the Red Sea to Ophir along the Arabian coast.

thyself with Ahaziah, the Lord hath broken thy works. And the ships were broken, that they were not able to go to Tarshish.

And similarly we read in I Kings xxii, 48, 49:

Jehoshaphat made ships of Tharshish to go to Ophir for gold: but they went not; for the ships were broken at Eziongeber. Then said Ahaziah the son of Ahab unto Jehoshaphat, Let my servants go with thy servants in the ships. But Jehoshaphat would not.

The Bible is silent about the cause of the failure of this first and only attempt of the Jews at independent seafaring, but it is found in Josephus, Jewish Antiquities, ix, 1, §4:

He (Jehoshaphat) also kept friendship with Ahab's son (Ahaziah), King of the Israelites, and entered into an agreement with him to equip ships which should sail to the Pontus and the trading places of Thrace. But as the vessels were too big and therefore perished, he gave up building other ships.

Here it is unmistakably stated that the Jews indeed made an attempt at independent shipbuilding, without the assistance of the Phenicians, but—as would naturally be expected—made a complete failure of it.

Another apparently improbable statement in the Biblical account about Solomon is that his people carried on seafaring independently. Here, too, Josephus doubtless gives the correct statement when he writes that Solomon sent along his own officials with the Tyrian seamen to Ophir, obviously chiefly as superintendents of the entire rather costly undertaking. For it is evident that the building of ships at Eziongeber must have been very expensive on account of the necessity of transporting the requisite timber from the Lebanon to the Red Sea.

Considering these several definite accounts, there can be no doubt that Solomon's officials had really undertaken, on ships built at the Red Sea with the aid of Tyrian craftsmen and manned with Tyrian sailors, one or more for that time very important sea voyages of three years' duration to Ophir-India. How came the Tyrian seafarers to undertake such a distant and perilous voyage to an unknown gold land, from which they were separated not only by many thousands of miles of sea but also by a broad tract of land? There is no suggestion that the ships had been sent out haphazard to an unknown goal, but, on the contrary, as indicating the difficulties of such a voyage, it is stated that it consumed three years, probably the normal duration of such a trip. We may therefore conclude that this sea route was nothing new to the Phenicians, but something they had long known. But it is absurd to assume that the Phenicians inhabiting the Syrian coast had reached the Red Sea overland before the times of David and Solomon, and there at random had built ships with timber brought along by them, and that they set out at haphazard and accidentally discovered India. The statement of Herodotus that

the Phenicians had previously been settled at the Red Sea will have to be given credence; for in this case an extensive sea voyage along the Arabian coast, and on such an occasion a chance discovery of India by them, would be nothing strange. And even after the subsequent partial migration northward into Syria the enterprising Tyrian merchants would equip expeditions to the Sinaitic peninsula and thence, in common with the members of their tribe who remained behind, would barter with India. And the Jews, as long as their kingdom extended in the south only to Beer-Sheba, could hardly have had any knowledge of this Tyrian commerce. This condition changed when David routed the Edomites in the battle of the valley of salt, killing 18,000 men (II Samuel, viii, 13, 14; I Chronicles, xviii, 12, 13; Psalms, lx, 2, 10, 11; compare also Josephus, Jewish Antiquities, vii, 5, § 4), subjecting entire Edom, in which he placed garrisons, and imposing ground taxes and poll taxes. In consequence of this not only did access to the Mediterranean Sea, or the caravan route from Elath, but also the harbor of Elath, fall into the hands of the Jewish King, without whose permission the Tyrian merchants could not undertake their trading voyages to Ophir. Obviously they had to pay some toll to the new sovereign, which, besides gold, must have consisted in merchandise which they brought back from India and Arabia. If our deduction that the Phenicians continued their voyages to Ophir before their immigration to the Syrian coast as well as after is correct, then it stands to reason that this was also the case under David's long reign, to whom they would, after the conquest of Edom, pay tribute in gold and other valuables. And, as a matter of fact, the Bible tells of Ophir gold in the treasury of David, for in I Chronicles, xxix, 4, there are, among other valuables consecrated by David for the building of the temple, also enumerated "3,000 talents of gold from Ophir."

According to Herodotus, ii, 44, the Phenicians came to Tyre, or founded this city, 2,300 years before his time—that is, about 2800 B. C.—so that the continuous seafaring of the Phenicians from the west coast of Arabia to Ophir-India may thus be followed back to at least 3000 B. C. At the same time it may be assumed with great probability that they sailed not only along the Arabian coast but also that of Africa southward (at least by way of trial), and thus were, in comparatively high antiquity, also acquainted with the east coast of Africa. We have thus in our investigations as to the age of iron-working gained two important data on the seafaring customs of the ancients.

Assuming, for instance, that the Phenicians had, as early as the fourth pre-Christian millenium, either themselves manufactured iron or imported the industry into the Sinaitic peninsula from southern Arabia or from Crete, then the dark men with the supposed iron

weapons appearing before the Pharaoh, as represented on the Egyptian mural paintings, could readily have come from the eastern shore of the Red Sea—that is, have been Phenicians; von Luschan's hypothesis would thus lose one of its main supports.

The assertion that the dark people carrying blue-colored objects were Negroes may thus perchance be right, but not necessarily so.

(*b*) The same is the case as regards the assertion that the blue-painted objects can only be iron ones, for eminent scholars, among whom I may again mention Schweinfurth, absolutely deny that blue designates iron exclusively. Schweinfurth, who points to the blue-painted beards of men,[1] thinks, with Maspero, that blue may also designate gray,[2] and when it is recalled that arsenical bronze, which because of its hardness was much used in high antiquity, is of a pronounced gray color, there is no reason why those blue-colored objects presented by the dark men may not have been made of arsenical bronze. This assertion, therefore, lacks conclusive proof.

(*c*) Even if the assumptions under (*a*) and (*b*) were admitted, the conclusion that the dark men (Negroes) carrying the blue, or supposedly iron, objects must also be the makers of these utensils is unwarranted. Such may be the case, but it is not necessarily so. It would be about the same as if one should assert that the Phenicians, who presented to the Pharaoh gold ornaments obtained by them in India, had themselves produced the gold and worked it into ornaments.

From the preceding it clearly follows that from our present knowledge the old-Egyptian mural paintings should not be adduced as proof of a very early iron industry developed by the African Negroes.

I do not, however, mean to deny an early native iron industry among the Negroes, but to express my astonishment that these peoples could have remained through many milleniums with that industry in its most primitive stage, while all other peoples have advanced and developed the art to a higher degree of perfection.

Thus the first proof required from von Luschan, namely, that iron working existed in high antiquity among the Negro peoples, may be considered as not having been furnished by him. As to the second proposition, that the assumed ancient iron industry of the Negroes was in high antiquity imported into Egypt, the evidence can not be considered as adequate and conclusive. But even von Luschan himself does not maintain, much less try to prove, that this supposed imported industry from the Negro lands was in any way practically exploited in ancient Egypt, so that there were old-Egyptian black-

[1] Compare Zeitschr. Ethnol., 1908, pp. 63, 64.

[2] Von Luschan himself, in Zeitschr. Ethnol., 1909, p. 48, points out that the god Amon is painted blue, which he declares himself to be unable to explain; but this does not prevent him from categorically designating as iron ones other blue-painted objects on the same painting.

smiths and locksmiths, armorers, etc.[1] He merely maintains that the ancient Egyptians had a knowledge of iron.

And here we come at last to the core of the whole discussion. It is entirely unimportant in the development of the iron industry among the peoples of ancient civilizations, whether the Egyptians had occasionally or often seen, or even sometimes used an iron instrument. The main question is rather, whether they knew how to manufacture iron objects and actually spread this knowledge in a practical manner among other peoples. For a knowledge which one neither himself practically employs, nor communicates to other people for practical use, but rather keeps "under a bushel," is of no value in the cultural development of mankind. And this would be the case with the ancient Egyptians if they really had obtained a knowledge of iron-working from their southern Negro neighbors, for it has not yet been proven, and is strongly disputed by Schweinfurth and others, that there were early Egyptian iron makers and workers. And that they did not communicate to other peoples a knowledge of ironworking, which is falsely ascribed to them, can be shown by two instances. On the one hand, the Jews bring no knowledge of iron from Egypt, nor do they designate the Egyptians as the masters and inventors of bronze-work and ironwork, but rather the Canaanite Tubal-cain (Genesis iv, 22). On the other hand, the Greeks, likewise, who gratefully enumerate the benefits the Egyptians have bestowed on mankind and themselves, are absolutely silent about the Egyptians as propagators of a knowledge of ironworking and rather name the Cretans as the oldest iron manufacturers and mechanics.

Thus it is seen that all the asserted proofs as to the mediatorship of the Egyptians in the spread of a knowledge of the iron industry fail when put to the test of a keen scrutiny. In the face of this main result of our investigatior it is of little importance, whether or not the Egyptians in hoary antiquity came across an iron object which was the product of a chance manufacture. The question raised by me was as to the actual "inventors of ironworking," and the isolated appearance of such iron objects as owe their existence to a chance production, are not to be considered. Ironworking begins with the purposeful manufacture of articles of iron, whose inventors we endeavor to discover. It would be very encouraging if other investigators would follow up the traces pointing to Crete, as indicated by me—especially by careful excavations—which in the meantime have been most auspiciously corroborated by the traditions of the Greeks and Romans.

Let us consider the Hindus a moment longer.

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[1] Schweinfurth, however, very energetically disputes such an hypothesis; compare Zeitschr. Ethnol., 1908, pp. 61-62.

Blanckenhorn maintained (Zeitschr. Ethnol., 1907, p. 368) that iron was generally known in India at least as early as 1500 B. C., but he was unable to produce proofs for this assertion, and as little was G. Oppert able conclusively to prove that it was known as early as 1000 B. C.[1] It was merely a conviction of Oppert which he could argue with probable reasons, but not support with positive proofs. Hence I would emphasize the statement that iron finds made in strata of old East India ruins of the tenth to fifteenth pre-Christian centuries do not justify the conclusion that there existed a native iron industry among the Hindus. Such objects only prove that the ancient Hindus were acquainted with iron utensils, but not that they actually made them. We have few accounts of the use of iron by the Hindus, and these scarcely favor the assumption of a native iron industry, but rather suggest that the Hindu iron utensils of the tenth to fifteenth centuries B. C. were foreign importations, and the Phenicians will probably have to be considered as the importers of such iron manufactures. For in my opinion it has been proven above that the Phenicians at least as early as 3000 B. C. had regular commercial relations with India which they carried on from Eloth-Aelana on the Red Sea. If, then, at the period 1300 B. C., iron and steel utensils were practically unknown to the Hindus, as may well be assumed, while among the Phenicians they were objects of common barter, it seems natural that the latter carried such articles to India to use for barter. It is therefore not only not impossible but very probable that in excavations in India, especially on the sites of harbors, such solated imported Phenician iron and steel articles will be found.

As regards an iron industry among the Chinese, I have thus far not come across any views of sinologues on our problem. This indifference of the students of Chinese history is regrettable for the progress of this investigation, the more so since China is probably to be looked upon as a second independent source of a native iron industry and so also of independent inventors of iron implements.

Such contributions as anthropologists, ethnologists, historians, and naturalists could make to the elucidation of our problem have to a great extent been presented, but as to the cooperation of philologians, there is much left to be desired from them. A great desideratum is an examination of the cuneiform texts for the first mention of iron, and of possibly still greater importance is a study of the Egyptian inscribed monuments for the same purpose. On the other hand, comparative philology could in many cases indicate the way in which different peoples became acquainted with the metal and at the same time received and adopted its name. It is probable that the name

[1] Zeitschr. Ethnol., 1908, p. 60.

given the metal by the inventors of ironworking migrated along with the metal to very many peoples, and philologians could therefore render valuable help in the search for the earliest iron industry.

I can not close this discussion without referring with special satisfaction to von Luschan's lucid and thorough treatise on African ironworking and the furnace apparatus and blowing apparatus employed by the Negroes.[1] A continued comparison of these utensils with those in use among peoples of other continents, will doubtless yield some important conclusions as to the age and peculiarity of ironworking among the Negroes as well as among other peoples. Similarly, we gratefully hail the investigations of Olshausen, Grosse, Busse, Krause, and Giebeler[2] of the quarrying of iron in prehistoric time, especially in Germany, which are valuable contributions to our question. Although I can not agree with these investigators on every point, I am glad to state that on the principal questions there is general agreement. In the near future I hope to present a separate study on the chemico-technological side of the quarrying of iron and of metals in general in antiquity.

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[1] Zeitschr. Ethnol., 1909, pp. 22-53.

[2] Zeitschr. Ethnol., 1909, pp. 60-101.

THE KABYLES OF NORTH AFRICA.

[With 12 plates.]

By A. Lissauer.[1]

While traveling in Algeria a year ago for recreation the only object I had in view, like all tourists, was to receive the passing impressions of landscape and art as they offered themselves along the road. Soon, however, there was pressed upon my attention many interesting questions about the historic and prehistoric periods of the country. I could not resist their fascination, and thus I became more and more engaged in studying the archeological and anthropological problems which the natives of Algeria and the surrounding countries, the home of the Kabyles, offer to the investigator. I pass over the numerous beautiful monuments of historic time, for they are described in every guidebook.

But besides these memorials of the ten invasions of various peoples of historic time, from the Phenicians to the French, there exist in north Africa thousands of megalithic tomb structures about which history has nothing to say. Some of them fully resemble those of Europe; others are peculiar to that region.

These megalithic monuments may be divided into two classes:

I. DOLMEN, MENHIR, AND CROMLECH, AS THEY ALSO OCCUR IN EUROPE.

1. In Morocco there were still, in 1876, about 70 dolmens preserved in five groups between the Straits of Gibraltar and the River Loukhos (the Lixus of the ancients), and at Beni Snassen, on the frontier of Algeria. A group of about 40 menhirs, which as late as 1830 numbered 90, was also in Mzora, south of Tangier; finally, there were then still in existence, west of Fez, a number of cromlechs. The tombs are hidden in a hill so that only the stone covers are exposed on the surface. They contain crouching skeletons and coarse, poorly

[1] Translated, by permission, from the German: Archäologische und anthropologische Studien ueber die Kabylen. Von A. Lissauer, Zeitschrift für Ethnologie, vol. 40, part 4, 1908. Berlin, 1908, pp. 501–529.

made potsherds, intermingled with coal. Alongside of a dolmen lay three silex axes and a crude figure of reddish sandstone.

2. In Guyotville, near Algiers, only nine out of several hundred dolmens, which in the middle of the last century were still standing upright and since then carried off by inhabitants for house building, are now preserved in perfect condition. These were saved through the interest of the late German professor, Kuester, an instructor at the Lyceum, in Algiers, who acquired these remnants, together with a vineyard. One dolmen contained two crouching skeletons, the bones of a child, a bronze bracelet, and potsherds.

3. At Bou Nouara, near Constantine, on the road to Guelma, there is a large number of dolmens, mostly surrounded by stone circles (pl. 1); as also at Sigus (pl. 2 and pl. 3, fig. 1), Ksar Mahidjiba (pl. 3, fig. 2), and El Kheneg, all in the neighborhood of Constantine.

4. At Bou Merzoug, near Oulad Rahmoun, there are about 1,000 dolmens, inclosed by one or more stone circles. Their contents consisted of cowering skeletons, accompanied by copper rings, pots, bowls, and horse bones. One tomb contained iron rings, copper rings, and plates, fragments of worked flint, potsherds of very fine clay, and a bronze medal of Faustina.

5. At Roknia, on the road from Guelma to Hammon Meskoutine, there are several thousand dolmens, with contents similar to the preceding.

6. At Henchir el Hadjar, in the territory of Enfida, in the regency of Tunis, there were still preserved in 1904 about 400 dolmens, mostly passage graves, often surrounded with cromlechs or stone circles. The tombs are often built entirely in the ground, so that only the flat stone cover on the surface indicates the tomb. They comprise up to six stone chambers, each with a threshold stone, and contain crouching skeletons of both sexes with platyknemic tibia and potsherds.

7. Still farther south the existence of megalithic monuments has been discovered; as a cromlech of the expedition Choisy at Ain Messine, between Laghouat and El Golea, and a dolmen of Johnston in Uganda.

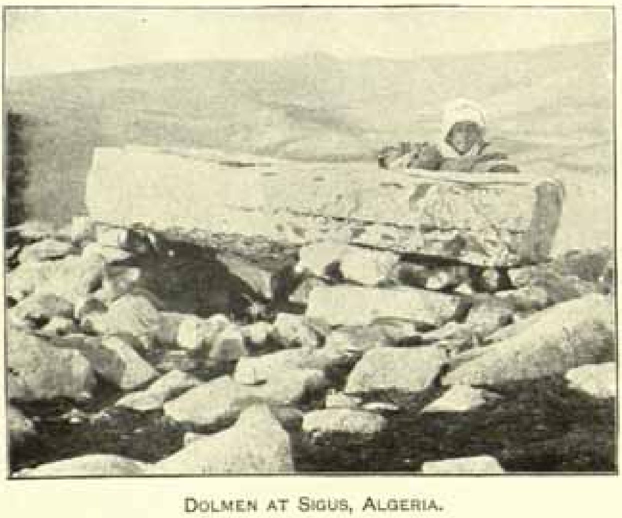
II. MEGALITHIC MONUMENTS PECULIAR TO THE LAND OF THE KABYLES.

Only the most important will be mentioned here.

1. Quadrangular gigantic chambers at Ellez, in the neighborhood of Le Kef in Tunis. They are chambers of four large stone plates, with doors and small windows in the doorplates. Two rows of five such chambers each are separated by a passage and covered with stone plates in form of a gable roof. The general entrance to the cemetery is closed with four large stone plates.

DOLMEN AT BOU NOUARA, ALGERIA.

DOLMEN AT SIGUS, ALGERIA.



DOLMEN AT SIGUS, ALGERIA.

2. Oven-shaped tombs of large stone plates, forming a vault whose upper keystone is supported by two very large stone plates at the entrance. These tombs are seen at Hammam-Soukhra, in the region of Ellez.

3. Cone-shaped tombs, the largest megalithic monuments in the country, are found at Henchir-el-Assel, in the territory of Enfida, Tunis. They consist of two concentric circles of large stone plates 1.5 meters apart and are covered with a cone-shaped roof in such a way that the top of the roof is a flat cone whose apex is formed by the large stone cover of the grave chamber. Hamy found here 106 such tombs, in various states of preservation, the largest of which measured 19 meters in diameter. These prehistoric structures are evidently the prototypes of the beautiful Mauretanian royal tombs of Medracen near Batna and of the so-called Tombeau de la Chretienne near Algeria, the models of which have been set up in the Trocadero at Paris and in the museum of Algiers.

4. "Senam"—that is, stone circles with a niche-shaped entrance—have been investigated by Maciver and Wilkin[1] at Msila in Algeria, where about 100 can still be seen, although the Arabs have been for a long time carrying away the stone plates for building purposes.

Besides those named above there is still a series of other megalithic monuments which have been described by Letourneux,[2] and will be here merely mentioned. They are the "Bazina," which appear to resemble the Senam; then the "chouchet," tower-shaped structures, which have especially become known in the Aurès and Hodna, and finally the "Hanouat" or rock tombs, as they are known in Sicily.

On the question as to what period these monuments belong, only excavations can give an answer. Unfortunately till now only a few tombs in proportion to their great number have been explored. Only this much is fully known concerning them, namely, that they contain sitting crouching skeletons, accompanied with potsherds and rings of "copper" and of genuine bronze. Near one dolmen lay also three silex axes and a crude stone figure. On the other hand, one dolmen contained rings, a bridle, a bit of iron, and a coin of Faustina. While thus the larger number of dolmens containing accompaniments (12) must be ascribed to the stone or bronze age, one at least belongs to the Roman period. It is true that further investigations may show that a great many of these megaliths were still in use during the iron age—but the conclusion that they were already in vogue in the bronze age can no longer be disputed.

[1] Randall-Maciver and Wilkin, Libyan Notes, p. 78 ff.

[2] Archiv für Anthropologie, ii, p. 307 ff.

The study of the skulls from the dolmens in Rocknia (20) and Guyotville (2), in two of which the greatest width could not be accurately measured, resulted, according to the German division, in 60 per cent dolichocephalic skulls, 30 per cent mesocephalic and 10 per cent brachycephalic, thus indicating a preponderance of dolicho- and mesocephalic people.

The significance of this result will be dwelt upon further on.

Besides these megalithic monuments there are also numerous remains of a paleolithic and neolithic people in north Africa. That Africa had a stone age was proved in 1882 by Andree,[1] and since then this fact has been frequently confirmed. Through the well-known expedition of Foureau-Lamy, as also through Pallary, Ferrand, and Flamand, large collections of the earlier and later stone age became known, part of which is preserved in the museum at Algiers. An excellent survey of the latter is given by Flamand.[2] These finds come chiefly from the highland in southern Oran and the Sahara as far as the regions of the Tooarceks and consist of celt axes, moustier points and scrapers, and laurel-leaf-shaped arrow points; further, polished stone axes of the common sort and of the double obconic form (hache en boudin); then, especially at Ouargla, in southern Algeria, numerous arrow points of the known forms as well as also of a peculiar shield-shaped kind, with long point and handle (pointes à écusson), also points with transverse edges and a kind of harpun (hameçon double), finally large spearheads—all of silex or siliceous limestone; besides pearls made of shells and ostrich eggs, polishing stones, millstones, and other objects.

Flamand also discovered anew in south Oran a large number of stone engravings and published an instructive survey of these monuments in north Africa, of which those with Kabyle inscriptions and representations of extinct animals are especially important.[3]

Hamy likewise came across many neolithic finds in southern Tunis. Among these, remnants of earthenware are rare though very instructive because they were built up or molded in baskets, so that they retain an impression of the texture as an ornament. In the pursuit of his investigations he found that only the baskets of the Somalis continue to bear the same ornament as the vessels of the neolithic stations in the Sahara and in southern Tunis.

If we inquire what people left all these remains of their existence we are confronted by great difficulties. This much is clear, it must have been a settled people, spread over all of northern Africa from Tripolis, or certainly from the Gulf of Gabes, to the Atlantic Ocean. As evidence of this the great number of monuments still surviving speaks in clear and unmistakable language.

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[1] Globus, 1882, p. 196 ff.

[2] Revue Africaine, 1906, No. 261, 262, p. 204 ff.

[3] In the publications of the Société d'Anthropologie de Lyon, 1901, p. 5 ff.

Herodotus (i, iv, especially 168) relates in legendary manner that north Africa, from Egypt to the Pillars of Hercules, was originally inhabited by the Libyans, who, however, were divided into many tribes whose names can not now be positively identified. Sallust (De bello Jugurtino, 18), who drew from the lost writings of King Hiempsal II of Numidia, relates that the aborigines of north Africa near the seacoast consisted of Libyans, while south of these were the Gaetules. Later, however, Armenian, Median, and Persian immigrants from western Asia, who supposedly had gone with Hercules to Spain and after his death were scattered, invaded north Africa and were entirely absorbed by the natives. The Persians amalgamated with the Gaetules and called themselves Nomads, whence the name Numidians originated; the Armenians and Medians united with the Libyans, who corrupted the name Medians into Moors. Later, however, the Numidians subjected all the other tribes and formed a people under one name. Thus the region was found by the first historic invasion of the Phenicians.

From this people descended the modern Berbers, who according to the genealogical tribe legends of the Berani, a Berber tribe of fair complexion, were called in antiquity Barbari,[1] they themselves, however, being designated as Kabyles, after the native word "Kabila," that is, "a union of several Gurbi (small huts) on one point."

Without discussing the legendary etymology of the name of the people, we may conclude from this account that even before the invasion of the Phenicians there was an invasion from western Asia, and that the aborigines of the Libyans and of the Gaetules did not represent a pure stock. If it is now recalled that after the Phenicians there immigrated Greeks, Romans, Jews, Vandals, Byzantines, Arabs, Turks, Spaniards, and French, who more or less intermixed with the natives, it seems impossible to distinguish and anthropologically determine the aborigines from the present inhabitants.

Fortunately some Kabyle tribes have from ancient times protected themselves by their love of freedom from subjection, and through their pride, from any intermixture. Retreating to the highest points of the Atlas, whither enemies could not pursue them, they preserved their independence, the purity of their race, and their old language, the "Tamazirt," although they exchanged their own original script, the "Tifinagh," for the Arabic, and their original religion for the Islam.

The language of the Kabyles, the Tamazirt, which has been thoroughly studied by Basset, belongs to the great Libyan family, of which already 40 dialects are known, among which is included the ancient language of the Guanches in Teneriffe. It extends from

[1] Cles, Sallust, Der Krieggegen Jugurtha. Berlin, Langenscheldt, p. 112 ff.

Senegal to north Africa, and certainly from Morocco to Tunis, but the peculiar script is in present use only among the Tooarceks.

Tamazirt is closely related to the language of the Copts, the Nubians, and the Somalis. It thus belongs to the Hamitic language group and also exhibits a certain relationship with the Semitic, but absolutely none with the Indo-German language group.

These pure Kabyles are found only upon the highest points of the inhabited Atlas, in the Rif of Morocco, in the great Kabylia of Algeria, in the Aurès and in Enfida in Tunis. Those in the Rif have been studied by Tissot[1] and Quedenfeld[2]; those of the Aurès, where they call themselves Shania, by Laritique[3] and Maciver-Wilkin[4]; and those of Tunis by Collignon[5] and Hamy[6]. To obtain a closer personal knowledge of them, I made a trip to the great Kabylia, as I had the good fortune to secure as a guide a native Kabyle, a servant at my hotel, who was very intelligent and, besides his mother tongue, was well versed in Arabic and French.

The country of the great Kabylia—that is, that part of the Atlas which attains its highest point in the Jurjura, extends from Haussonville, on the railroad from Algiers to Tizi-Ouzon, and Bougie in the north, and Beni Mansour in the south[7] (pl. 4, fig. 1).

The Jurjura, rising to a height of 3,208 meters, and till far into the summer covered with ice and snow, forms an imposing, picturesque, connected chain of mountains, separated from one another by deep ravines. Around, and partly parallel with them, run other ranges of high mountains likewise cut by deep ravines. All the waters from the Jurjura are gathered in the Sebaou, which at Dellis falls into the sea. The deep precipices, which rise steeply to a height of 180 to 2,000 meters, are closely planted clear to the top with vines, figs, olive trees, wheat or barley, ash, oak, and eucalyptus, and the ridges and adjoining slopes are so closely settled with villages that the population attains here a density of 172 to 190 to the square kilometer, which surpasses even that of Holland, the second most densely populated country in Europe, with only 149 to the square kilometer (pl. 4, fig. 2).

The center of this entire country is Fort National (pl. 4, fig. 1), a fortress established in 1857, through which the French Government dominates the entire Kabylia—it is therefore also called by the peo-

[1] Revue d'Anthropologie, v. 1876, p. 390 ff.

[2] Zeitschrift fuer Ethnologie, 1888–9.

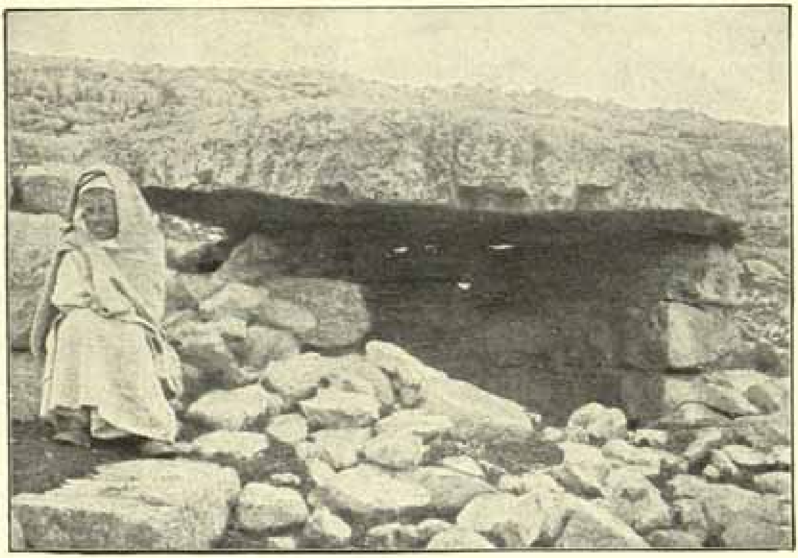
[3] Theobald Fischer, Mittelmeerbilder. N. F. 1908, p. 390.

[4] Wilkin, Among the Berbers of Algeria, p. 57 ff. and Maciver-Wilkin, Libyan Notes, p. 23 ff.

[5] Materiaux pour l'histoire de l'Homme, 1887, p. 172 ff.

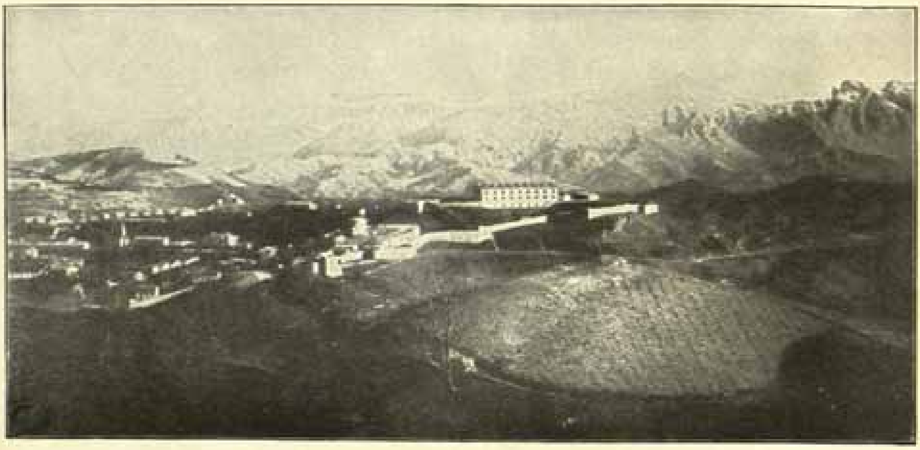
[6] La Tunisie au début du XXme siècle, 1904, p. 1 ff.

[7] I am indebted for the following cuts with one exception to the photographs taken by M. Achard in Fort National, in whose store I bought them.



DOLMEN AT SIGUS, ALGERIA.

DOLMEN AT KSAR MAHIDJIBA, ALGERIA.



THE COUNTRY OF THE GREAT KABYLIA.

DENSITY OF KABYLE VILLAGES.

ple "a thorn in the eye of the Kabylia." Modern cities are unknown to the Kabyles, who live only in villages of varying size. The French started establishing cities in the neighborhood of the larger village settlements in order to create appropriate residences for the military and civil officials, thus in Tizi-Ouzon, Fort National, Michelet and others.

The Kabyle villages consist merely of low, stablelike huts, whose walls were originally constructed of poles of about the thickness of an arm, and rude branches of olive trees, eucalyptus, and ash were then intertwined with their ramage, plastered and made tight with clay, all being erected without any rule or system. The walls support a slanting roof with coping made of branches and straw, with no outlet for the smoke (pl. 5, fig. 1). A wooden door opening into the dwelling does service likewise for window and chimney. These "brushwood huts" are low and small, about 3 meters in breadth and length and 2 to 2.5 meters high, and are commonly designated by the French as "gurbi," while in Kabyle they are called "acham."

In the interior the floor of clay is without covering. More or less in the center is the fireplace, a small depression of about 0.5 meter in diameter, on whose edge lay three stones on which rest the pots for cooking.

Within the hut, usually at the entrance, are stalls for the cattle (mule or sheep). At the opposite side of the room is a kind of clay bench, which serves as a sleeping place (in Kabyle, "tirarrard") for the family, being covered for the night with any suitable material. Above the bed for the cattle agricultural implements and tools are stored, and on the other walls are places for holding household utensils, clothing, ornaments, and other objects.

This primitive style of architecture has been steadily disappearing since the French occupation. But there are still many villages that consist only of such "brushwood" huts. The walls of the houses are now generally constructed of stones (pl. 5, fig. 2; pl. 6, fig. 1), the roof is covered with tiles, and in single rare cases supplied with a chimney. In the interior of the houses, however, the arrangement and furnishings have not changed.

So also the barns for drying of hay and straw are still built like the old achams (pl. 6, fig. 2), only that they are round, the roof umbrella-shaped, and the walls not so carefully made tight as in the dwellings.

The homes of the richest Kabyles, like those of the French, are now constructed in Moorish style, so that it may be expected that by another generation the primitive brush huts will entirely disappear.

Coffee houses are very numerous and are built in the same manner as the private dwellings, only of larger size.

The village streets are generally nothing more than gutters washed out by the rain, without repair or improvement. In the center of the village, however, there is a large free space or square where the old men crouch or lie down and indulge in story telling. Here also stands the communal house, the "taasest," its construction the same as other buildings.

The Kabyle men (pl. 7) are sturdy and are exceedingly hardy in withstanding privations and the influences of the weather. Herodotus says (i. 4, 187): "The Libyans are in fact the healthiest men that I know." They are slender and of medium height, although persons over 180 centimeters tall are not very rare, yet undersized and weak ones are hardly ever seen. Prengrueber[1] gives the results of measurements of 294 pure Kabyles as follows: 28.9 per cent, 161–163 centimeters; 46.6 per cent, 164–170 centimeters; 24.5 per cent, 171–175 centimeters; minimum, 150 centimeters; maximum, 185 centimeters.

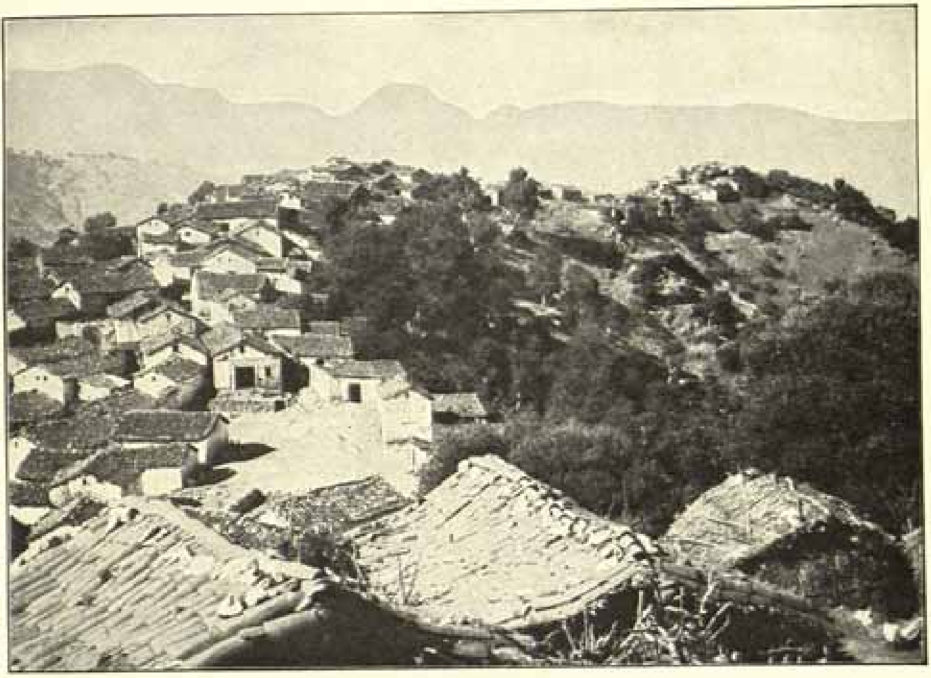
The Kabyles have a dignified carriage, but are not conceited or haughty like the Turks and Arabs. The color of their skin on the uncovered parts of the body, as the face, hands, and feet, which are exposed to the sun, is brown, and often, among the field workers, dark brown, but on the covered parts it is white, as with the Europeans. They are, therefore, as regards their bodily characteristics, wrongly counted among the Hamites, who are brown over the entire body, and transmit this character to their children, as I learned by observing a new-born Somali child.[2] The eyes are generally brown (88.6 per cent,[3] of which 41.3 per cent are dark brown, 47.3 per cent light brown); the hair is black (74.2 per cent, 59.7 per cent deep black, 14.5 per cent black brown). The face is handsomely oval, orthognathic, the forehead high, the nose straight and well-proportioned, the mouth generally small. The ear is not large, and frequently without lobes. The growth of the beard is thick, but a long beard is rarely worn; so also the hair of the head is kept short. The expression of the face is intelligent and benevolent.

The head formation occasionally exhibits a strongly prominent occiput; rarely is the region of the temples vaulted. Narrow heads, inclining to dolichocephaly, are very common, and brachycephal heads are never seen. Prengrueber gives the following indices of 182 measurements: of 72.2 per cent, 36.4 per cent were dolichocephalic up to 75 and 35.8 per cent subdolichocephalic up to 77.7; 15.7 per

[1] Dr. Prengrueber has been for many years government and colonial physician in the great Kabylia with his residence at Palestro, and has improved the opportunity for the anthropological study of the Kabyles to write a comprehensive treatise, which was awarded the prize by the Paris Anthropological Society, but up to the present has not been published. At my request he readily placed the manuscript at my disposal with permission to use the data contained in it for my studies. I here express to him my warmest thanks for this courtesy.

[2] Zeitschrift für Ethnologie, 1906, p. 159.

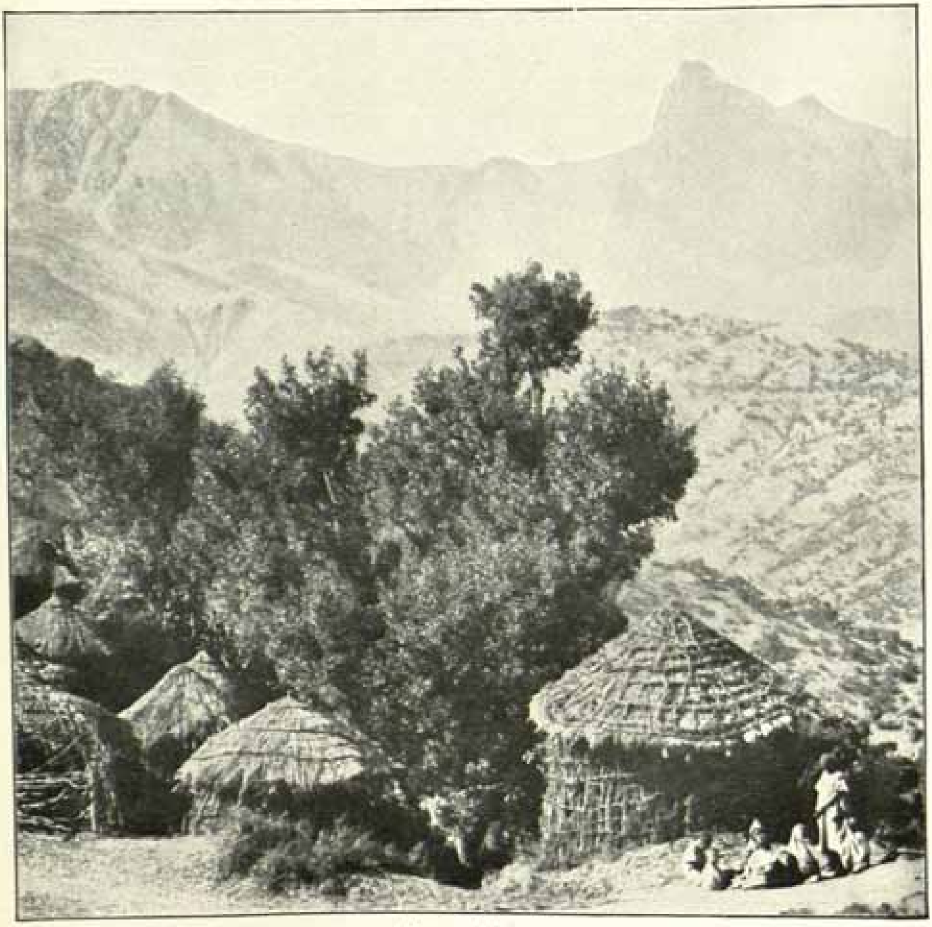
[3] These statistics are everywhere taken from Prengrueber's treatise.



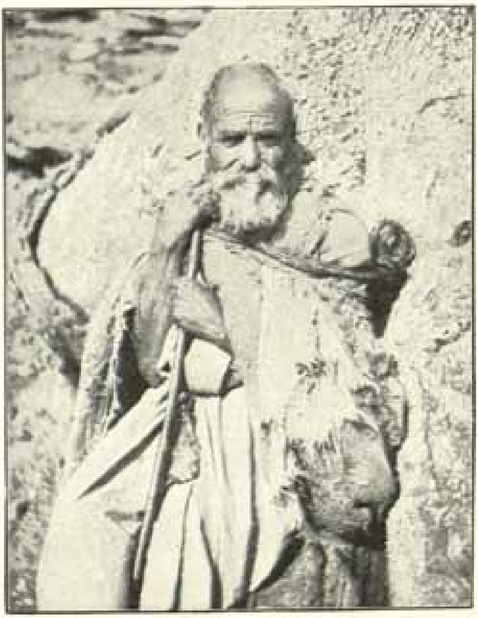
KABYLE HOUSES.

KABYLE HOUSES.

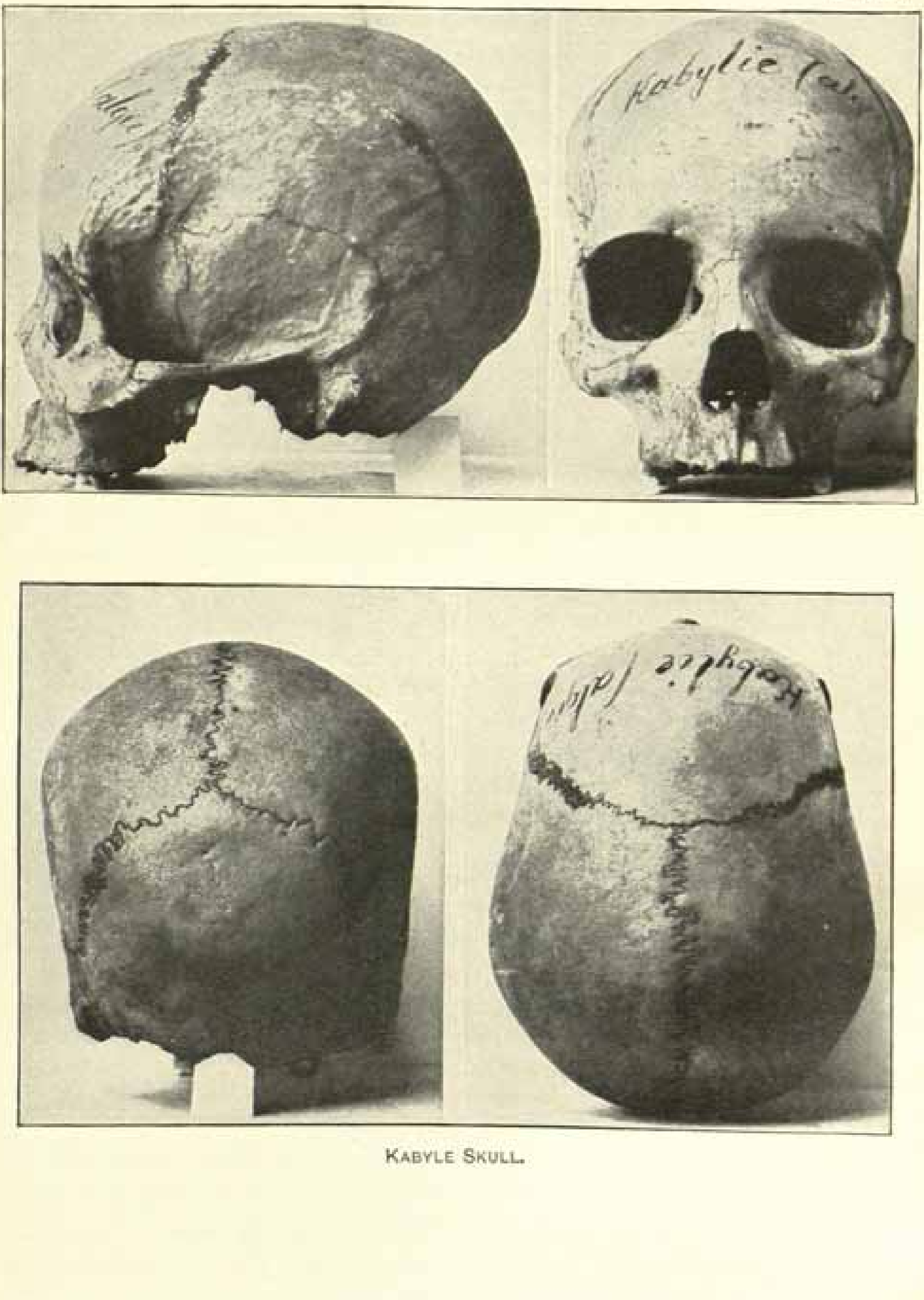
KABYLE HOUSES.



KABYLE BARNS.



KABYLE MEN.



KABYLE SKULL.

cent were mesaticephalic up to 80; 8.2 per cent subbrachycephalic up to 83.3; and 2.7 per cent brachycephalic above 83.3; minimum, 65; maximum, 85.

The Kabyle skull (pl. 8) in the geological collection of the college at Algiers, the fine photograph of which I owe to the kindness of Profs. Fischer and Savornin, has an index at 76.6, and is as well formed as the heads of most of the Kabyles.

On the whole these people make the same impression as the southern Europeans and might readily be regarded as Spaniards or southern Italians if they were correspondingly dressed.

But besides these black-haired and brown-eyed people there are also many blond persons with blue eyes who make the exact impression of European northerners. Occasionally the color of the hair is rather reddish.

Prengrueber found the hair in 3.34 per cent light brown, 1.67 per cent very light brown, 5.20 per cent blond, 1 per cent ashy blond, 2.23 per cent more white (13.44 per cent); while the eyes in 3.85 per cent blue, only with blond or slightly red hair; 8.35 per cent light green, with blond or black or light brown hair.

Divergent are the data of Faidherbe,[1] who observed in Constantine 10 per cent blond Kabyles, and of Maciver and Wilkin,[2] who in the Aures likewise noted 10 per cent, while Tissot,[3] who was for a long time French ambassador in Morocco, estimated the number of blonds among the Kabyles of the Rif, of Tangier, and Tetouan at at least one-third of the population, and Quedenfeld[4] even at two-fifths. On the other hand, according to Rohlfs and Quedenfeld no blonds occur south of Morocco among the Shlöh.

These blond Kabyles so much resemble our northern Europeans that according to Quedenfeld they would be simply taken for north Germans, or according to Maciver and Wilken for Scotchmen if they dressed the same.

Black individuals, genuine negroes, are rare, but mulattoes, prognathic and with gross faces, which indicate an admixture of negro blood, are frequent.

Persons with somewhat curved nose are often met with, so that many children and adults remind one of the Jewish type.

The women are distinguished for their beauty (pl. 11, fig. 1). As they do not veil their faces nor wrap their forms, as the Arab women do, one has opportunity to admire them in their entire beauty. They are slender and of medium height. The hair is not cut and is worn rather loosely. Large, bony figures are seen only among the negresses, who live among them as servants, or, though rarely, as wives.

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[1] After Reclus, Nouvelle Géographie Universelle, 1886, xi, p. 380ff.

[2] Libyan Notes, l. c., p. 97.

[3] Revue d'Anthropologie, 1876, p. 390.

[4] Zeitschrift für Ethnologie, 1888, p. 115ff.

Boys are circumcised at the age of 3 years. At the age of 15 boys, as well as girls, marry.

The dress of the Kabyles is very simple and, in Algeria, is alike for rich and poor (pls. 9 and 10). A cotton shirt is worn next to the skin and over it is a second shirt-like dress which reaches to the knees, and over this, for men, a white woolen mantle, a kind of burnus, which likewise leaves the lower parts of the thighs free, and in walking is so draped that the left arm rests as in a sling, while the right arm from the elbow remains free. The women usually wear only the two shirts and a kind of shawl wound as a belt around the hips; the fore arms and lower thighs are entirely free, usually also the feet. Trousers and stockings are used neither by the men nor the women, but the wearing of shoes is frequently noticed.

Upon the head the men usually wear a red fez, the shashiya, round which a piece of cloth is wound in form of a turban. Old men sometimes wear a black, and the poor often a white fez, over which the head part of the mantle is drawn in form of a capouch.

Their entire clothing is often very dirty and ragged so that the men look as if they had pulled an old long sack over their heads for their walking dress. Occasionally they wear discarded European vests or torn trousers that obviously produce a ludicrous impression on Europeans.

In contrast to this the higher judges or Kadis, who were installed by the French Government, wearing red burnuses often decorated with many orders, and the police officers in their black ones, high stockings, and shoes, make a dignified appearance in their picturesque costumes.

With the women the second shirt is often dyed red, blue, or striped, so also the head handkerchief, which they wind around the head so that the hair streams out somewhat wildly from beneath it. Their personal ornaments consist of simple pendants of silver filigree, corals, and glass pearls, which are worn on the head, around the neck, and on the breast; or earrings, bracelets, and anklets of silver; rarely, for display at festivals, are the ornaments of a richer combination. Children often wear a whole row of amulets suspended from the neck. The women love finery but are generally modest and industrious.

The main occupation of the Kabyles consists in tilling the soil. Stock raising as an industry is comparatively insignificant. The mule performs all the work of the horse or ass in other regions—but there is no lack of small flocks of sheep and cattle. Men and women are seen diligently at work in the fields.

The tilling of the soil is chiefly carried on for the winning of barley, wheat, grapes, figs, and olives, which are all in great demand

KABYLE DRESS.

KABYLE DRESS.

KABYLE WOMAN.

KABYLE WOMAN WEAVING.

KABYLE WOMAN MAKING KUSKUS.

KABYLE WOMAN MAKING POTTERY.

as articles of trade. Wine and oil especially are exported in large quantities.

The women also perform all the domestic labor, as cooking and weaving, in the well-known primitive manner (pl. 11, fig. 2, and pl. 12, fig. 2). Pottery making is also the special task of the women. The vessels are burnt and often handsomely painted in yellow and red colors.

The men make the filigree ornaments of silver, the agricultural implements, and all the things required for house building.

The food consists principally of bread, butter, oranges, figs, dates, and rarely meat. Peculiar is the kuskus (in Kabyle, soksa), the preparation of which is somewhat complicated. Into a large dish are put meat, a great deal of pepper, salt, some vegetables, and water. Over this is a second dish with a sieve-like bottom, into which flour—mostly barley flour—is placed. The whole is then closed with a cover and put on the fire. The steam from the lower dish pervading the flour effects the formation of small balls (pl. 12, fig. 1), which are then served in a separate plate from the meat soup, but which for a European palate is too strongly peppered.

Many men and children loaf all day in the streets and coffeehouses, the children, in particular, begging. But this will soon change. The Government has, besides the building of excellent roads, undertaken a second most important civilizing work in educational lines which has already produced good results. Beginning in 1893 primary schools have been established in which French and Kabyle children are commonly instructed. Each school has two classes and two teachers, a Kabyle and a Frenchman, who are trained in a large seminary at Bouzaria, near Algiers, in both languages. As the Kabyle children are very docile they soon learn to read and write French, arithmetic, and also the elements of the natural sciences in order to combat the widely spread superstition. The Government grants each school a subsidy of 80 per cent, the rest is borne by the municipality. Up to the present, 80 such schools have been established, which are obviously too few for such a dense population; but the children, who in some cases have to walk three kilometers to school, come gladly and by their mannered behavior and knowledge of languages distinguish themselves very notably from those who have grown up wildly. There are also said to be in the larger places Kabyle physicians and lawyers who have studied alongside the French. One can observe the rapid progress of the beneficent influence that French civilization has exercised in this country. At the same time the Kabyle language is spared and at present as far as possible preserved. Under the leadership of a well-known authority on the Kabyles, Prof. Basset, the Government sends out scientific missions for the study of the various dialects. They have no literature, nor historical

traditions; they only know that before the invasion of Islam they were Roman—further back their recollection does not go. On the other hand, they have many Kabyle legends and tales.

As to whether the ancestors of the modern Kabyles were also the builders of the dolmens, the only means of determining are the few excavated dolmen skulls. It has been seen, it is true, that the pure Kabyles are predominately dolichocephalic or mesocephalic, and that the 20 skulls which were taken from the dolmens of Roknia and Guyotville show approachingly the same form. Still, aside from the fact that the craniological character alone is not decisive, we can not determine at present whether the apparent relation of the skull forms to one another will not be changed after hundreds of dolmens have been explored. The most that we can now say is that the investigations thus far carried on are not opposed to the assumption that the explored dolmens were erected by the ancestors of the modern Kabyles. The question of the introduction of this custom will be discussed later on.

No less difficult is the answer to the question as to whether the rich remains from the stone age came from the Kabyles. According to the investigation of Hamy, quoted above, certain pots of the stone age (corrugated pottery) show that they were in the form of baskets, such as are at present exclusively in use among the Somalis. This observation would certainly support Hamy's assumption that the people of the stone age in north Africa were related to the Hamitic Somalis, if a conclusion from the similarity of culture forms to that of this race were summarily permitted.

Summing up the result of all these investigations, the following proposition can be maintained:

All pure Kabyles in the Rif of Morocco, in the great Kabylia, in the Aurès and in Enfida in Tunis belong to the white Mediterranean race, and are more or less strongly intermixed with blond, blue-eyed individuals of northern European character. They all speak a dialect of Hamitic language belonging to the "Tamazirt."

There arise four new problems which are of much interest for general anthropology.

1. Whence came the blond Kabyles? It is easily comprehensible that the strange appearance of so many blonds amidst such a sunburnt population with black hair excited the attention of many investigators, particularly the French. Already in 1876 Faidherbe and Broca[1] taught that the blonds were the descendants of the Tamahu or northlanders, who, according to the famous inscription of Karnak, at about 1400 B. C., advanced into northern Africa as far as Egypt after Celtic tribes had already, in the fifteenth or sixteenth

[1] Revue d'Anthropologie, 1876, p. 393 ff.

century, immigrated as far as Andalusia. These northlanders had also introduced from Europe into northern Africa the custom of megalithic structures, as was also maintained by Bertrand.

On the other hand, Shaw[1] declared that the blonds, it is true, immigrated from Europe, but only in historic time, that they were the descendants of the Vandals whom Genseric, in 429 A. D., led over from Gibraltar to northern Africa. This view was afterwards taken up by other investigators, especially Quedenfeld.[2] But Broca, on the basis of information of Procop, rightly points out that most of the 50,000 Vandals whom Genseric brought over, perished in the struggles with the native Moors, Numidians, and later with the Byzantines, so that in 544 A. D. only 420 men remained who were partly killed with their last leader Gontharis and partly transferred to Constantinople. Since then the Vandals have entirely disappeared from northern Africa.

Besides, the ancient authors of the third century B. C. and the third century A. D. assert that there were among the native Berbers many fair and blond ones.[3]

Finally, Sergi,[4] on the basis of his craniological investigations, maintained that the blonds did not immigrate but were native in northern Africa, especially on the heights of the Moroccan Atlas, under the influence of the altitude climate. He refers for this to Livi's results of anthropometry, according to which in the population of Italy dwelling at above 400 meters altitude the blonds predominate; below 400 meters, the brown. Against this Quedenfeld[5] points out that among the Shlöh in southern Morocco not a single blond is to be found notwithstanding that the people partly live on still higher mountains on the great Atlas.

Still other hypotheses have been set up to explain the strange appearance of blonds among the Kabyles. They are said to be descendants of Roman mercenaries from the north, or to have come from the East, after the explusion of the Hyksos from Egypt. The former view seems to be contradicted by the numerically and geographically great diffusion of the blonds, while the latter view lacks any record of the existence of blonds among the Hyksos.

If it is asked which view is most probable on the basis of our present knowledge, I can only say that as long as we are ignorant of all the conditions on which the distribution of the pigment among the various races of mankind depends we must be guided by actual observations. Now we know that only in northern Europe, and

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[1] Revue d'Anthropologie, 1876, p. 398 ff.
[2] Zeitschrift für Ethnologie, 1888, p. 115.
[3] Th. Fischer, Mittelmeerbilder, N. F., 1908, p. 390.
[4] Sergi, The Mediterranean race. London, 1901, p. 73 ff.
[5] Zeitschrift für Ethnologie, 1888, p. 115.

nowhere else upon earth, is there a zone in which a large contiguous blond population is autochthonous, and we are therefore compelled to assume that wherever else on earth blonds emerge island-like, they are derived from the north European zone. The opponents of this view would not take it seriously if one maintained that the Negro population in Haiti or in North America were there autochthonous—and yet commit the same error as regards the blonds.

We can, therefore, only assent to the view that the ancestors of the present blonds among the Kabyles must have at some time emigrated from northern Europe into north Africa and this view would account for the occurrence of numerous blonds in the Rif in Morocco, in the Jurjura, in the Aurès, and in Enfida, where in high altitudes, in a climate similar to that of their home, they felt most comfortable.

If in opposition to this view it is contended that at present the immigrant French do not propagate in northern Africa, it may be said that the time of occupation is still too short to definitely settle this question. I, myself, have made there the acquaintance of families living in Algiers in the fourth generation, who have propagated and are comfortable. It is, moreover, evident that the colder climate on the north coast and especially on the heights of the Atlas must be very favorable for the thriving of northlanders.

Since the Vandals, as has been seen, can not have been the ancestors of the blonds in northern Africa, and since other northern European immigrants are not known in historic times, we must assume that already in prehistoric time a considerable host of blond north Europeans entered it—that a kind of migration took place similar to the migration of nations in later times.

2. The second question is: Whence came the white Kabyles, with black hair and brown eyes?

This questión is even more difficult to answer. Since all the peoples of the Mediterranean coasts possess identical somatic characteristics, and we have no point of vantage from whence to scan the cradle of this Mediterranean race, the Homo mediterraneus, we are also unable to decide whether it immigrated from the north African coast to southern Europe, or the reverse. All that can be said with certainty is that the Kabyles are neither Negroes nor Hamites.

But if we consider that no other people of the white race besides the Kabyle speak an Hamitic language, it results that they adopted the Hamitic language on north African soil and that they are there not autochthonous, but immigrants, and for anthropological reasons, as well as on account of their resemblance to the Spaniards, they probably immigrated from the Iberian Peninsula.

It must be further concluded that in north Africa they found an Hamitic population, which they drove away, but adopted its lan-

guage without amalgamating with it. It has been often observed in historic time that the victorious immigrants adopted the language of the conquered. Thus the Waragians adopted the Russian language, the Normans first the French, then the English and Italian languages. The Longobards likewise adopted the Italian language, notwithstanding they dominated these several countries as conquerors. If all these were absorbed by the native peoples, it was due to the relationship of race, which was not the case with the Kabyles.

3. The third problem: Who, then, were the autochthons, can accordingly be answered only by a conjecture. That they were Hamites—that is, people of brown skin—is made probable by the language, and in conjunction with it Hamy's observation, cited above, that the corrugated pottery from the stone age in the Sahara exhibits a decisive relationship with the industry of the Somalis, gains a greater significance.

4. Finally, the fourth problem: Whence comes the custom of the megalithic tomb structures in north Africa, has already been answered above. Bertrand and Broca think that with the immigration of the blonds from northern Europe was also thence introduced the custom of the megaliths. It has been stated above that only a craniological investigation can decide whether the ancestors of the Kabyles have used the dolmens, but not whether they introduced them. If it is now considered that megaliths occur not only in Europe and in north Africa and as far as Uganda, but also in Palestine, Syria, India, and Japan, and that we do not know whence this custom first started, we must herein agree with Montelius that the erection of dolmens is a general phenomenon of civilization that makes its appearance from Japan to Europe, but whether it spread from Africa to Europe (Montelius) or the reverse (Bertrand and Broca) can not at present be decided. Only when we shall have come to know the period of the erection of the megaliths in the various countries shall we be able to draw a safe conclusion as to the starting point of this custom. But if it is considered that upon the highest points of the Atlas, the Rif, the Jurjura, the Aurès, where the blond Kabyles are most numerous and purest, no dolmens whatever exist, it seems improbable that the custom of dolmen tombs should have been carried to north Africa by the blonds of northern Europe.

If we would draw a picture of the various invasions which in the course of time took place in north Africa it would be as follows:

1. As autochthons we must assume an Hamitic people, related to the Somalis, that lived there in the stone age and spoke Tamazirt.

2. Then followed the invasion of the Kabyles from the Iberian Peninsula who pushed the autochthons toward the south, erected dolmens, and changed their language for the Tamazirt.

3. Thereupon followed the invasion of the blonds from northern Europe who, though completely assimilating with the Kabyles, settled chiefly upon the heights of the Atlas, where they have preserved the purity of their race to the present day.

4. There followed then the invasions of historic times: The Phenician, Greek, Roman, Jewish, Vandal, Byzantine, Arabic, Turkish, Spanish, and French.

In the face of all these invasions, the Kabyles on the heights of the Rif, the Jurjura, the Aurès, and in Enfida have preserved the purity of their race to the present day.

CHINESE ARCHITECTURE AND ITS RELATION TO CHINESE CULTURE.[1]

[With 10 plates.]

By Ernst Boerschmann.

I left Germany in August, 1906, to make an extended exploration in China. The route was via Paris, London, and America, where I saw treasures of Chinese art in the museums, thence via Japan, to acquire a fleeting impression of that branch of oriental culture; and finally I arrived at Peking early in December. In the summer of 1909, upon completing my work in China, I returned, via the Siberian Railroad, to Germany, after an absence of exactly three years.

Dr. Bachem had discussed the importance of a study of the Chinese before the Reichstag in 1905, and the late Baron von Richthofen, then secretary of the foreign office, as well as a large number of other high officials, so interested themselves in the proposed journey that the German Imperial Government, with the approval of the Reichstag, provided the necessary means.

I owe profound thanks to all who aided this exploration, first for the effectual development of the idea of endeavoring to solve the important problems of the Far East from a purely scientific point of view, and also personally for their confidence in assigning me this important duty.

My commission bore the title: "An investigation of Chinese architecture and its relation to Chinese culture." I could not have desired a more comprehensive designation of this task for such a country as China, with its 18 Provinces, covering an area seven times greater than Germany, and with remarkable coincidence exactly seven times its population.

A solution of the problem appeared to be possible by confining myself to the northern part, especially around Peking, which, from a previous residence there for two years, I knew to be the center of

[1] Reprinted by permission from Zeitschrift für Ethnologie. Organ der Berliner Gesellschaft für Anthropologie, Ethnologie und Urgeschichte, Berlin. 1910. 42d year, parts 3 and 4, pp. 390–426.

a specific culture, and which would also serve in many respects as typical for all China. I gradually, however, extended my travels to cover a large part of the entire country.

I spent the first months in Peking in making preparatory studies of China. As soon as the weather permitted I made short excursions to the imperial tombs of the Ming dynasty, and to the eastern imperial tombs of the present dynasty, two days' journey from Peking, where the late Empress-Dowager was recently buried. I then visited the ancient summer residence at Jehol, five days' journey from Peking, where in the midst of a wild mountainous region a number of important Lama monasteries are scattered around a famous imperial hunting park.

The summer was passed in the charming neighborhood of Peking, especially among the western hills, with its numerous magnificent temples, of which Pi-yün-sze, the temple of the Blue-black Clouds, is regarded as one of the most beautiful in all China.

Then followed a seven months' trip to the western imperial tombs of the present dynasty, where the remains of the deceased Emperor will be buried. Thence to Wut'aishan, the sacred mountain, which is visited chiefly by the Mongolians. On this occasion, the only one during all my travels in China, I was for some weeks accompanied by a friend. At all other times I traveled alone with my Chinese followers, that at times numbered 30, including the burden bearers.

The train carried us south over the bridge across the dangerous Yellow River to K'aifêngfu, the capital of Honan; thence a four days' trip down the Yellow River, at a time when the dam had just been broken and when the river in places was so broad that the farther bank could not be seen. In Shantung I visited the sacred mountain T'aishan, then K'üfu, the birthplace of Confucius and the site of his tomb. The winter drove me southward. I spent Christmas in Ningpo and in January, 1908, I dwelt alone, remote from the world, on the island Pu̇-tȯ-shan, the sacred island of Kuanyin, the goddess of mercy.

Upon returning to Peking by sea, I prepared for a long 12 months' journey, to extreme western and southern China, that carried me overland across the whole of China; first to T'aiyüanfu, capital of Shansi, then diagonally across that Province to Lu ts'un, where there is a large salt marsh, that provides salt for the four northwestern Provinces.

Shansi, like Shensi, is a dry Province. In some years there is almost no rain at all. A mild famine is expected with considerable certainty every 5 years and a serious one at 10 year periods. This aridity favors the manufacture of salt, which is accomplished by simple evaporation in the bright sunshine. This ceases in rainy weather. Wheat is then grown. The salt Mandarin expressed the conditions

impressively by comparing Shensi to a balance, with salt in one scale and wheat in the other. As one rose the other fell. It was best when they balanced. Perfection lies between these two extremes.

I entered the Province of Shensi at the bend of the Yellow River, visited the sacred mountain Huashan, the capital Hsinganfu, crossed the Tsin ling mountains, and then descended to the exceedingly luxurious, charming, and fertile Szech'uan. This Province has an area and population somewhat larger than Germany. As a whole it is a poem, and its perfect beauty has been accomplished by gods and men.

From the capital, Ch'êngtu, I pushed on to the most western point as far as Yachoufu, and before me to the westward and northward lay the snow-capped mountains that magically lure the traveler to Tibet. It is an imposing mountain panorama whose sublimity is already realized in its spurs near Ch'êngtu. The Viceroy Chao Êrhfêng just then set out with a military force en route to Lhassa; but unfortunately my plans did not permit an acceptance of his cordial invitation to accompany him. I spent three weeks on the sacred mountain Omeishan. The Chinese say that one here feels the pulse of K'un-lun. Then I went down the Min River in a small boat. I made a short excursion to the salt district of Tze-liu-tsing, where are the self-spouting wells, over 4,000 in number, with an average depth of 1,000 meters. From these are extracted salt essences that are boiled and evaporated with natural gas from underground. This district furnishes salt for all the Provinces as far as the mid-Yangtze. The frameworks of the wells are 20 to 30 meters high. As natural gas is used, there is no smoke in this industrial region where 700,000 people are employed. The salt is transported with ease by boats through the numerous canals of this charming Province. The hidden and mysterious force and the benefit thus derived from the interior of the earth gave the Chinese the motive for the development of their peculiar religious ideas. In China one observes everywhere that industry and trade serve to strengthen and deepen the religious sentiment, because everything is brought into relation with the forces of Nature which are then personified as gods.

My little boat carried me farther down the Yangtze River, and then for several days I had the pleasure of traveling in our German river gunboat, the *Vaterland*. We passed by lovely and then again by mighty banks on either side, often at high speed, then by many densely populated cities, over famous rapids, and through romantic gorges, where the echoing voices of the sailors made the great solitude the more impressive. The Yangtze gorges, as they are generally known, are most imposing at the entrance to the Province of Hupeh. From the Tungt'ing Lake one reaches, by way of the Hsiang River in the Province of Hunan, the capital, Ch'angshafu. With a short excursion into the Province of Kiangsi I spent the Christmas festi-

val of 1908 in the company of the German engineers who superintended a Chinese coal mine.

I passed the first days of the year 1909 on the sacred mountain Hêngshan, then journeyed overland to Kueilinfu, the capital of Kuangsi, and down the Kuei River, passing over 300 rapids in 10 days, to the West River, by which I reached Canton, the imposing, populous, and gay city. Going by sea I reached Fuchow, the capital of the Province of Fukien. I celebrated Easter in Hangchow, the capital of Chekiang, on the much celebrated beautiful West Lake. Then I hastened back to Peking, where I arrived after an absence of over one year, on May 1, at the time of the funeral of the deceased Emperor.

In all my travels, which took me through 14 of the 18 Provinces of China, I followed the main highways, the ancient, much-traveled roads, and was constantly in the midst of Chinese life in densely populated and mostly the richest regions. The sacred mountains, annually visited by millions of pious pilgrims, belong to these regions, as also do the imposing industrial and cultural centers and great cities where an enormous commerce is carried on through the countless waterways and lakes where boats constantly follow each other in rapid succession, and the seacoast with its busy traffic from harbor to harbor. Industry, contentment, and order everywhere prevail among this 400,000,000 people, whose joy of living and contentment is apparent in their art. Nothing is more erroneous than to speak of China as fossilized and ready to fall to pieces mentally, morally, or even politically. The unity of the culture of yesterday and yet of to-day has welded the people and keeps the nation strong.

This observation may account for the fact that no problems of archeology, art, religion, or general history will be discussed here, interesting as they may be, but the China as it is to-day will be described. The means should not be given greater importance than the end.

To introduce our subject: We stand in China contemplating a unity of culture which can only be dreamed of in the days of ancient Greece or of some other ideal period. One imposing conception of the universe is the mainspring of all Chinamen, a conception so comprehensive that it is the key defining all expressions in life—trade, intercourse, customs, religion, poetry, and especially fine arts and architecture. They exhibit in nearly every work of art the universe and its idea. The visible forms are the reflex of the divine. They behold the divine in the various forms which they fashion to express it; in short, in the microcosm is recognized and revealed the macrocosm.

This method of thinking and acting on a grand scale gave rise, and rightly so, to the favorite expression "China, the land of great

bounds." Since the most ancient periods the extent of this vast Empire has been enormous. Long before the birth of Christ the Chinese carried their policies to far distant Turkestan, and even to the shores of the Black Sea, and sent large armies thither. The conquest of these regions required time, engendered patience and consideration of resistance, and developed political tact and wisdom.

Lao tze, the reputed wisest man of China, recognized that the relationships are stronger than mankind.

These characteristics guaranteed an orderly government in China proper, the land of the present 18 Provinces. It was here always necessary, and still is so, to reckon with great distances and to plan months and years ahead. Imperial orders and the reports of officials are long en route. The constant changes of officials oblige them to travel for months, thereby acquiring a knowledge of their country that few of us have in the same degree of our own land. In thus traveling, the varied topographical features of the country slowly but surely make their deep impression. They may journey for days across plains, then along a river, then for 10 days over mountains and hills, and finally over fields and plains for 6 days—always in intimate contact with the varying population, high and low, thus becoming acquainted with the advantages and disadvantages of each region.

The Chinese are thereby well acquainted with the conceptions of time and space. This manifests itself in their architecture. They have developed an architecture which in its ground plans and landscape is unknown to us. The most significant structure in all the world is the well-known Great Wall of China. It must be regarded as a whole, a unit, which shuts off the entire north against Mongolia and Manchuria. All the famous Egyptian Pyramids combined can not compare with this work, which is the most skillful, the most monumental, and at the same time in the most picturesque manner adapts itself to ragged precipices along the mountain ranges and presents a view of the grandest outlines.

The imperial palace in Peking is the most extensive in the world. Scarcely a temple has ever been built as large as the Temple of Heaven in Peking, or as large as some of the other numerous important temples in China. The palaces of the nobility and the wealthy, even the dwellings of the middle classes, are extravagantly spacious and roomy. The buildings of the imperial tombs and the temples at Jehol are of most imposing magnificence. The Chinese playfully bring points into correlation and features of nature, rivers and mountains, separated from one another by miles, to unite them in the expression of some definite idea.

One of the most definite expressions of this prevailing Chinese idea of unity is given by their groupings of all buildings symmetrically around the axis of the meridian, the north and south line. This is

invariable whenever possible. The main hall in which the prince sits in state, or the host entertains his guest, or the god in his temple, is invariably aligned to face the south. The lord faces the midday sun. The cities are likewise laid out along the meridian line accurately, and, where natural obstacles intervene, such as a mountain, a river, or where other special considerations require the city walls to deviate and take some other direction, yet the axial line is always maintained in the meridian in all the temples, government buildings, and dwellings.

China has often changed its capital. The Empire has been ruled from the Yangtze, from Honan, and Shensi; but for long ages, even before the Mongolian dynasty, they have always returned to Peking, which lies in the extreme north. This was, of course, mainly due to political considerations. But knowing the ideal importance which is attributed to the line of the axis, we can appreciate the exalted notion of conceiving the Emperor as seated on the dragon throne in Peking and turning his gaze southward along the meridian of Peking over the entire Empire, when at the New Year festival, or on the Emperor's birthday, all officials and many of the people assemble at the same hour in all the cities and villages to kneel before his altars throughout the Empire and offer their homage, looking north toward him, the Son of Heaven. Claims of nature, the political development, and the ideal all agree and assist in demanding and deepening this sentiment. Thus natural conditions, political evolution, and ideal conceptions answer one another and form a combination. The world of phenomena is merely a mirror of the infinite which in our world conception and religion we try to give a definite, and yet how changeable, formula.

Before considering the details of China's idealistic culture it is necessary first to refer briefly to certain external conditions and relations which have contributed to those grand conceptions of the unity.

The population of China is constantly fluctuating, and it has always been so. Allusion was made to the wars that carried great masses of men and women as far as Turkestan. These wars prevailed for long periods and were repeated at certain intervals. At times, as during the Mongolian sway, intercourse with the western countries reached a certain climax, but it was constantly lively. The Chinese have a tendency to emigration, probably greater than we of to-day. For ages they have been colonizing and invading foreign countries for peace or war. The south was colonized in historic times, while northern Chihli has ony been colonized during the past two centuries in a methodical manner. During the past five years the Chinese have been systematically settling in Tibet, and since the European press has only recently sounded an alarm over this proceeding, it goes to show how news is really only relatively new.

Domestic wars and insurrections have repeatedly mixed the people of different parts in Chinese history, which in its vicissitudes equals our own. The migratory instinct has also contributed to this unification. According to Chinese records, the Province of Szech'uan was decimated at the beginning of the present dynasty to such an extent that only 1 in 10 survived, and it is now inhabited for the most part by settlers of other Provinces. Here one finds a greater variety in the styles of club buildings than anywhere else, with the possible exception of the Province of Kuangsi, in the capital of which, Kueilinfu, nearly all the inhabitants are foreigners. During the period immediately before the New Year festival I daily passed small merchants, mechanics, and day laborers traveling to their homes in Hunan for the festival weeks. This custom prevails throughout China, and similar scenes are witnessed everywhere. In Shantung the people constantly travel to and from the Liaotung Peninsula, along the seacoasts and on interior highways. The trains on the recently built railroads are always overcrowded, and the two small steamers which ply between Shanghai and Ningpo daily transport several thousand Chinese.

The merchants of the Shensi Province have a monopoly of banking silver and copper throughout a greater part of the Empire. They travel everywhere and finally in their old age return to their homes with their acquired wealth. One particular city in Chekiang usually furnishes the subaltern officials for the mandarins of several Provinces. Other well-known towns, often inconsiderable in size, furnish, in addition, singers, actors, certain classes of artisans, and tradesmen. These all leave their homes to travel and usually return later.

The ancient decree forbidding the appointment of higher officials to offices in their native Provinces, not to mention their native cities, was for the purpose of making the Government independent of personal influence and of attaining uniformity.

Traveling is habitual in China. Car drivers, muleteers, boatmen, and carriers readily contract to start immediately on long journeys requiring months of travel. A journey to remote Turkestan or Tibet is regarded as a most commonplace undertaking. The Government requires this readiness to travel of all officials. A high official in Ch'êngtu received orders to proceed to Tibet for a long period of years and departed within five days.

The ancient classical examinations, which have now ceased, probably forever, also contributed to this traveling instinct. Hundreds of thousands of students annually traveled to the examination halls of their districts and the capital cities, while thousands of them went on to Peking. In weary journeys they learned the country; they acquired strange customs here and there and diffused them abroad.

Priests and pilgrims, Buddhists and Taoists, are met on the road throughout the empire. They wander from temple to temple, staying for a time here and there, and there is scarcely an old and experienced priest who has not visited all or at least most of the holy mountains and the famous religious places. Finally, scholars, poets, painters, and other artists (frequently combined in one individual) all travel. There is no one among the famous men of China of the past or present who has not traveled over the whole country. This is still the case. On Omeishan, 3,300 meters high, I met a certain Han-lin, who had climbed up there to meditate, study, and compose poetry. In Szech'uan I visited the memorial temples of the most famous poets of the T'ang dynasty in the eighth century, Li T'ai-po and Su Tung-po. I was shown the place where the former of these had lain drunk on the road, and later I sailed on the Tungt'ing Lake and the Yangtze River, where the latter poet had sailed alone and fished and composed poems. The memory of these great men of the past is as fresh as ever. The smallest boy learns their stories in school. Stories in regard to them are recited at home and among friends. Professional story tellers choose their deeds for their themes. In the theaters the known pieces are acted. In this way the tales and events become the common property of the nation, from the coolie to the highest personage. The classics are learned by everyone who goes to school almost by heart. The paintings represent well-known things. The temples and houses teem with carvings and inscriptions which refer to famous deeds, men, and thoughts; and everybody feels everywhere at home.

An important item is the fact that until quite recently the daily newspaper was unknown in China. Almost all information was communicated orally. In comparison with us, the Chinese seem to talk incessantly. A rumor or report spreads most rapidly in everybody's mouth, and he who is convinced that the spoken word is more alive than the written word will appreciate the culture of this folk in their lively intercourse, in contrast to ours, which more and more emanates from the study desk.

China has thus been developed to that uniform individuality in which we find it to-day, not that there is a dead uniformity in all parts of the Empire. There is a proverb: "Go a mile and speech changes; go 10 miles and the customs change." These changes are first noticed in the styles of buildings, then in the dispositions of the people, their mode of life, their agriculture, clothing, and food. Differences in culture are found prevailing in different regions, the north with six Provinces, the Yangtze Valley with five, and the south with six, including the seacoast Provinces of Fukien and Chekiang. Szech'uan is in a class by itself. This Province is by nature divided off by mountains, and has developed its own peculiar culture, imaginative as the in-

tensified elegance of China. It is proverbial that poets originate here, and truly the beauty of the landscape and of art is such that one almost must verily become a poet. A proverb says, "Soldiers come from the north, and scholars from Hunan," with reference to the ancient school in the capital, Ch'angshafu. For many reasons two cities are special centers of culture; one of these is Peking, in the north, the other Canton, in the south—the two poles, as it were, of China.

Thus there is enough of variety, even in going from Province to Province. This also holds good for certain districts within the Provinces. But there is a common trait everywhere, and it is not only unity that meets us, but there is prominent the broad view, the wide outlook in appraising all relations which for the Chinese resulted from the nature of the country and its history. This feeling finds expression also in their conception of the universe, in their religion, which can be read in all their works of art and all other forms, and which constitutes the common inheritance of the people, the soul of their culture, their even at present still classical art.


FIG. 1.—The drawing of the dual principles and the eight trigrams.

Only in China and in no other country one sees a world conception, a philosophy, embodied in visible form. One sees an architecture that is a direct expression of this conception, a conception formed of the universe and its moving forces. Thus they have found it possible to express the idea in a visible concrete form.

In the year 600 before Christ, Lao tze, the older contemporary of Confucius, taught: "From one come out the two, from the two come out the three, and from the three the ten thousand things—the whole of the physical world." This is illustrated in the diagram which already in his time belonged to hoary antiquity. The center consists of two fish-shaped forms that represent the male and female principles. But besides these two there is a third, the surrounding circle itself. This is the highest, the Tao, the eternal way leading to perfect virtue, the pole of the entire visible and ethical world, the comprehension of existence, the eternal, which prevails in all phenomena—unity. How the various philosophers have designated it in their systems is immaterial. It is everywhere postulated as the Eternal

Truth and as the essence of things. It is after all nothing else than our conception of God.

In this unfathomable first cause two forces are acting, equal and opposite, above and below, white and black, but supplementing one another to establish that unity which they constitute and are, being inseparable from it and from one another. This is the male and female principle. It is the active, creative energy, conceived as two and subsequently embodied as the dragon. Thus, from one we have two, and from three, the triad, the trinity.

The masculine is distinguished by one stroke as odd and the feminine by two strokes as even. The combination constitutes an element, to which another stroke is added, to designate the divine existence of the Tao, so that a triad arises. These strokes are varied, interchanged, and repeated to give eight variations, the masculine or the feminine predominate in each of the variations, they never balance. This number 8 forms the harmonic basal number for all further philosophical investigations. The entire universe is represented by the eight elements. By mathematical means the world of phenomena is thus delineated in its fundamental constituents. There are no more either on the surface or in the theory of numbers. The multitude of the other phenomea is formed by the combinations of the elements. When doubled to six elements the resultant is the number 64 as in the accompany illustration (fig. 2).

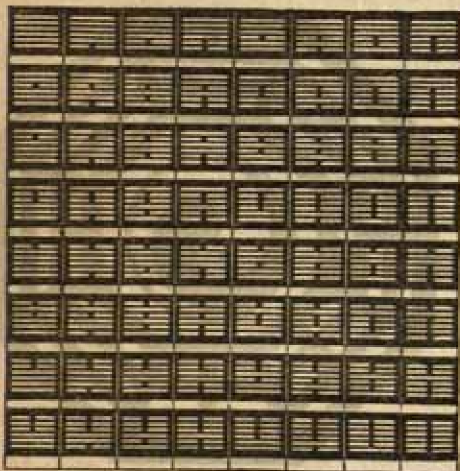
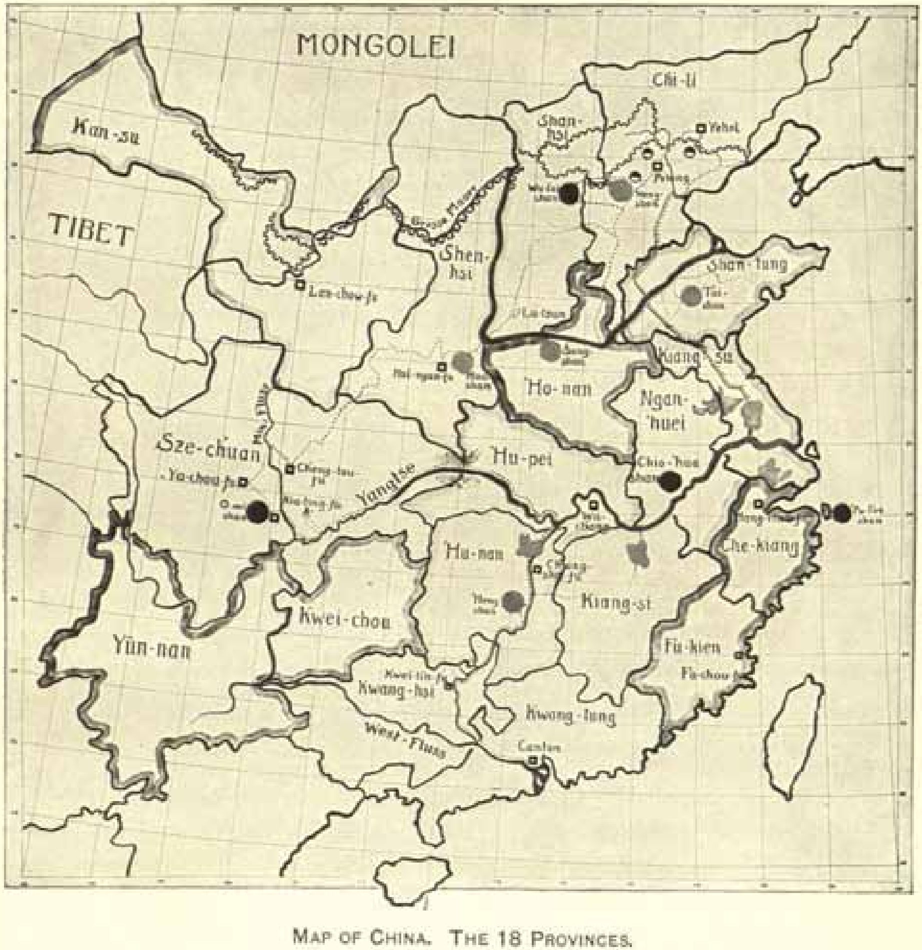


FIG. 2.—The 64 trigrams.

One must closely study this cogent metaphysical interpretation of the number 64 to comprehend the profundity of chess, by which we also endeavor to find the eternal truth, that round central figure which gives the solution of the riddle. But as every chess player knows that a perfect game does not exist, likewise everyone knows that this ideal, perfect truth, is forever unattainable in this life but is always effective in the various endeavors to attain it.

The Buddhist conception here accords with that of the Chinese.

The Buddhist triad shows Buddha between the two main radiations of his being. To the Chinese mind this trinity signifies, in the center, merely a personification of the essence of things and on the sides, the



MAP OF CHINA. THE 18 PROVINCES.

(Itinerary shown by dotted line.)

THE GOD OF LONG LIFE, SHOU-HSING, WITH THE EIGHT TRIGRAMS.

two forces, there active, which rule the world; thereby closely approximating the thought in the round central figure of the trigrams. And when one is convinced that in life as well as in nature, in the conflict of two forces, absolute wisdom and truth are forever unattainable, then this triad represents the commonplace but profound expression, "Truth is in the middle." The reality is only the reflex of the Divine. The chief priest in the temples loves to be depicted with two other priests, fully aware that this will convey a living impression of the triad. I saw this in many temples, one, for instance, in that of the southern sacred mountain Hêngshan in Hunan, which is 900 meters high.

From another point of view, that of the four cardinal points, north, south, east, and west, the world is divided into four parts, and by subdividing we got the number 8, the number which in the preceding was obtained in another way, and, further, the number 16. These rhythmic numbers were known to Buddhism, too, which at the time of the birth of Christ penetrated China and amalgamated with Chinese thought. Besides Buddha there are 4 great Bodhisatvas, making together 5; and we find 5 great Buddhas during one period. The Chinese not only reckon with the 4 cardinal directions but also include the center; that is, they reckon with 5. In the diagram of 8, if we include the center, we have 9. The Chinese have embodied this number 9 in their god of eternal life, Shouhsing and his 8 genii, the Pa Hsien.

A famous statue of this god of longevity represents the symbol of eternity by the well-known 8 trigrams in the center of a plate which he holds in his hands.

The well-known 8 trigrams are also displayed on the wall behind the statue, together with the sacred numbers 1–8. The symbol is called T'ai-chi-t'u, the drawing of the high majestic pole of life. This image of the god in its composition is of a very special style; the massive cranium indicates the mass of wisdom concentrated in the high forehead of the hoary god. The white hair, beard, eyebrows, and mustache express the great age of the god, who is practically identified with the wise Lao-tze.

The statue is placed in one of the most beautiful temples in China, at Kuan-hsien in Szech'uan. The temple is dedicated to Li Ping, an eminent hydraulic engineer, who by his clever skill, at about the time of the birth of Christ, corrected the mighty Min River, by conducting it through hundreds of canals over the plains near the capital Ch'êngtu, by which he converted a dangerous swampy region, that was overflowed, into the most fruitful and richest land in China. The temple is built on a slope close by the river. The main hall shows Li Ping deified, with the statue of the god of longevity farther back, to signify that this great man emanated from him and had

grasped his profound wisdom, by which he was enabled to perform the great deeds for which he was entitled to the perpetual gratitude of the people.

The god of longevity and his eight genii are everywhere represented throughout China and play an important part in the daily life (pl. 2). A table with eight seats is designated as "the table of the eight genii" (fig. 3).

Reception halls are furnished with four tables, each with two seats; that is, again, eight in all. At the end of the hall there is a handsome broad sofa, for the two most distinguished guests, representing the two principles, male and female, which are inclosed in the circle. As symbolical of eternity, purity, highest wisdom, and truth some handsome article is placed in the axis of the room; a vase, a piece of mystic carving, or a mirror, a handsome picture, or written sentence is hung on the wall. These make an exact representation of the sacred number 9=8 plus 1. Ancient China had 9 Provinces, that are represented by bronze vases. Present China has 2×9=18 Provinces, that are often identified with the 18 Lohan, the disciples of Buddha. This ancient symbolical number 9 constantly recurs in their architecture; for example, the altar of Heaven at Peking is so constructed that the two uppermost platforms consist of rings of free-stones, each divisible by 9 (9, 18, 27, etc., fig. 5).

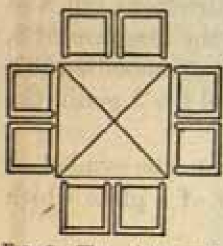


Fig. 3.—The eight genii table.

Besides this, one is constantly finding combinations of 3 and 9, 3×3=9 is very much used in the temple plans illustrated in figure 6, that shows the ground plan of a temple in the center of which the sanctuary is placed. The reverential approach and adoration before the gods in the temples consist of a kowtow repeated 3×3=9 times. The numbers 10 and 12 are easily deducted from the ground number. Five doubled equals 10, combined with the male and female. The four quadrants, each divided into three parts, combining the energetic system of 3 with the harmonic system of 4, as 3×4=12; by further multiplication and combination we have 24, 60, and 360, the degrees of the circle, which was known to the Chinese ages ago. By such division of the numbers there results from the diagram of 8 the countless variety of phenomena that are personified as gods and placed in the temples and houses to represent ideas.

This is a wide, special field, and here attention is invited only to the rhythm that is derived from the theory of numbers.

These numbers that may be said to be derived purely mathematically (the Chinese are great mathematicians) are confirmed in nature as duality of sex, two eyes, ten fingers, and their relation to the visible order of the universe, the months, the zodiac, stars, etc., that introduce the lacking numbers 6 and 7 with their cosmic significance. This

consideration is necessary to understand the rhythm of Chinese culture. We are reminded of the system of Pythagoras, in which numbers represent the intelligence of the world. His system may be explained and understood by the Chinese system which I shall designate as the cosmogonic numbers.

The pagodas, that stand out as isolated columns, are well adapted to represent the number 4 of the gods, or that of 8 or 16. Their interior always contains an image of a Buddha or a sacred memorial of him that embodies the conception of the world, and around which the other gods are merely grouped.

A marble pagoda in Canton, erected about the middle of the eighteenth century, has four sides, on each of which, indicating the four cardinal directions, there are the great Bodhisatvas riding a lion, an elephant, or other symbolical animal.

Another beautiful pagoda is on the island of Pů-tó-shan. It was built at the latest during the Ming dynasty, and it is a clear, vigorous presentation of the rhythmic number of Buddhas on its four sides.

The octagonal great pagoda in T'ien-ning-sze at Peking, dating from the Mongolian period, is covered with large reliefs in stucco, and is highly ornamented with elaborately sculptured tiles. The small entablature carriers are very natural, carrying cornices after the manner of Atlants.

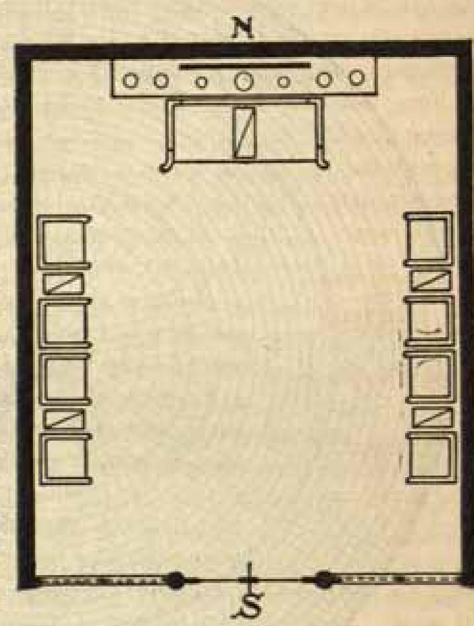


FIG. 4.—Reception hall, with large sofa, four tables, and eight seats.

Sometimes four pagodas surround a central pagoda. The Emperor K'ien-lung in 1793 built an imposing group in memory of Panchen Erdeni Lama, who died while on a visit in Peking. It is entirely of marble and very elaborately covered with ornamentations and sculpture. The central structure is on a high terrace surrounded by four small octagonal columns. The rhythm of the numbers is repeatedly represented in its relation to religion. The most important of these marble pagodas is that at the temple of Pi-yün-sze, previously mentioned as one of the most beautiful temples in China. It is situated near Peking, in the western hills, with numerous other temples that

form, as it were, a glorious crown for the capital of the Empire. The approaches to the pagoda, which were also built by K'ien-lung, lead through a marble gate. The spires of the pagoda then appear visible in the distance behind a second gate. The marble structure stands upon a high platform and is most elaborately covered with ornamentations and Buddha reliefs, and carries on top five four-sided pagodas. Here there is a cypress tree, with nine sacred branches,

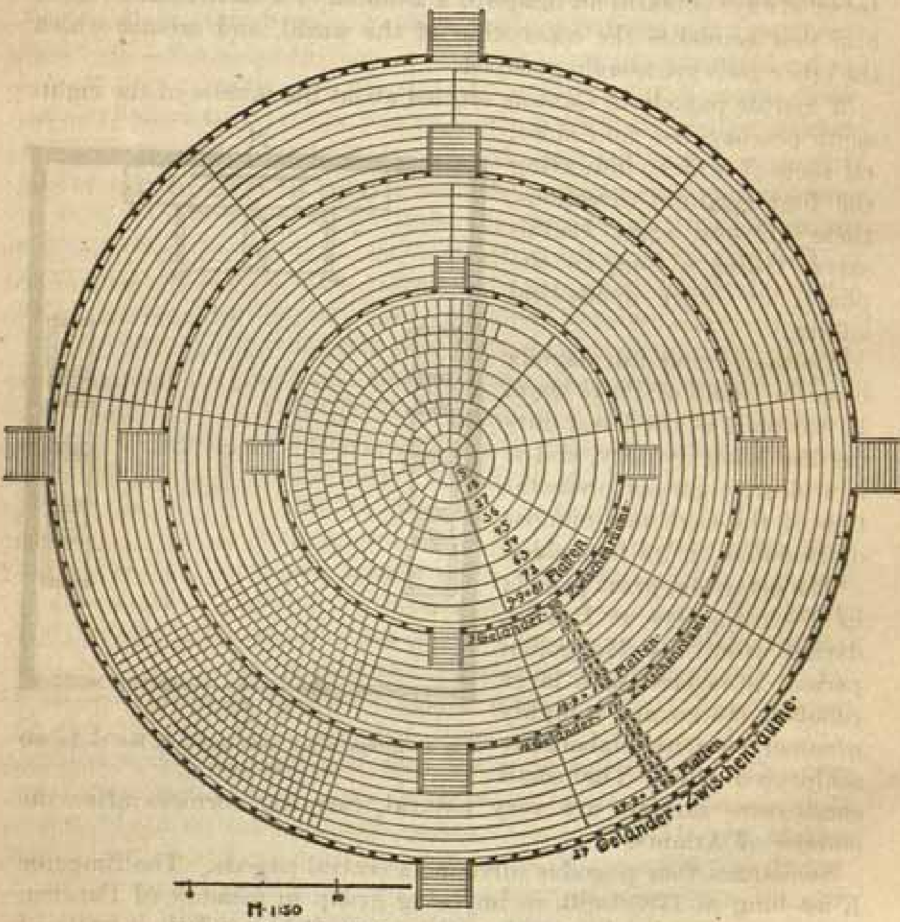


FIG. 5.—Temple of Heaven in Peking. Sacrificial altar.

that was planted by the late Empress-Dowager with her own hands. The buildings are in a dense grove of cypresses and pines, among which a species of pine, the *Pinus bungeana*, that has a snow-white bark. In the soft moonlight this grove is enchanting.

The ascent is by a wide staircase, the Buddhas greeting from above. Comfortable steps lead up into the interior of the buildings to the uppermost terrace on which the pagodas stand—one in the middle

and the others at the corners. The numbers 4, 8, and 16 are apparent. The four great Bodhisatvas sit on the sides of the central pagoda, while the $4 \times 4 = 16$ surfaces of the four side pagodas have the 16 disciples. In the course of time two were added in China, and they now have $2 \times 9 = 18$ disciples of Buddha—a number that has a more profound significance for the Chinese. Here and there they have erected temples for as many as 500 disciples or Lohan. The bronze umbrella that surmounts the central tower on the terrace is pierced to display the eight trigrams between clouds, finely alluding to the order higher up in the air. Two bottle-shaped pagodas also stand on the terrace; these have bottle-shaped bodies, representing the soap bubble, indicative of the frailty of life. But, as symbolical of eternal life, lovely Buddhas are throned in niches with lotus flowers; the overhanging soles of their feet rest in lotus sandals so as not to come in contact with the imperfect world.

The idea of sanctity in the interior of a pagoda has been, it is allowable to say, translated into practice, by placing the mummified gilded remains of a chief priest in the interior, as was done in the beautifully located city of Kiatingfu in Szech'uan.

The important temples are preferably threefold. They have three parallel axes, again expressing the trinity in architecture. The entrances to the Confucian temples and the temples in the sacred mountains (pl. 3) are threefold. The middle opening faces the *shên lu*, the pathway of the ghosts, that one dare not cross. A strip laid off in the pathway is inlaid with dragon plates, as a notice that only ghosts pass there. Even the Emperor must enter the Temple of Heaven by the eastern entrance when he goes to sacrifice to his ancestors and to Heaven. The middle is the incomprehensible, the holy (as it lies inclosed in the circle), the perfect, about which the two principles, male and female, contend. These conflicting forces of nature are embodied in the dragon, the national emblem of China. This is also conceived as double, male and female. In a celebrated ever-occurring representation two dragons are shown playing with a pearl. This motive is very cleverly executed on a bronze table of the Ming dynasty, in a temple on the summit of the sacred mountain Omeishan in Szech'uan. The dragons play with the pearl, the image of the highest purity and perfection. They play with it but never reach it.

The dragons are the embodiment of the male and female force. I wish to emphasize that this dualism has nothing to do with good and evil. It is the symbol of life, that the conflict of two principles does not permit perfect truth to be attained.

The combined beauty and artistic strength of this composition is repeated in a Confucian temple in Szech'uan. Two pairs of dragons are coiled upon the balustrade of the great bridge that crosses the

semicircular ritualistic pool; they look toward the center of the pathway of the ghosts in the main axis. This pathway is a silent, unspoken idea, related to some religions, in which the name of the highest Being dare not be mentioned. No steps lead up to the elevated hall, these are replaced with an inclined marble slab that is splendidly engraved with significant scenes (pl. 4, fig. 2).

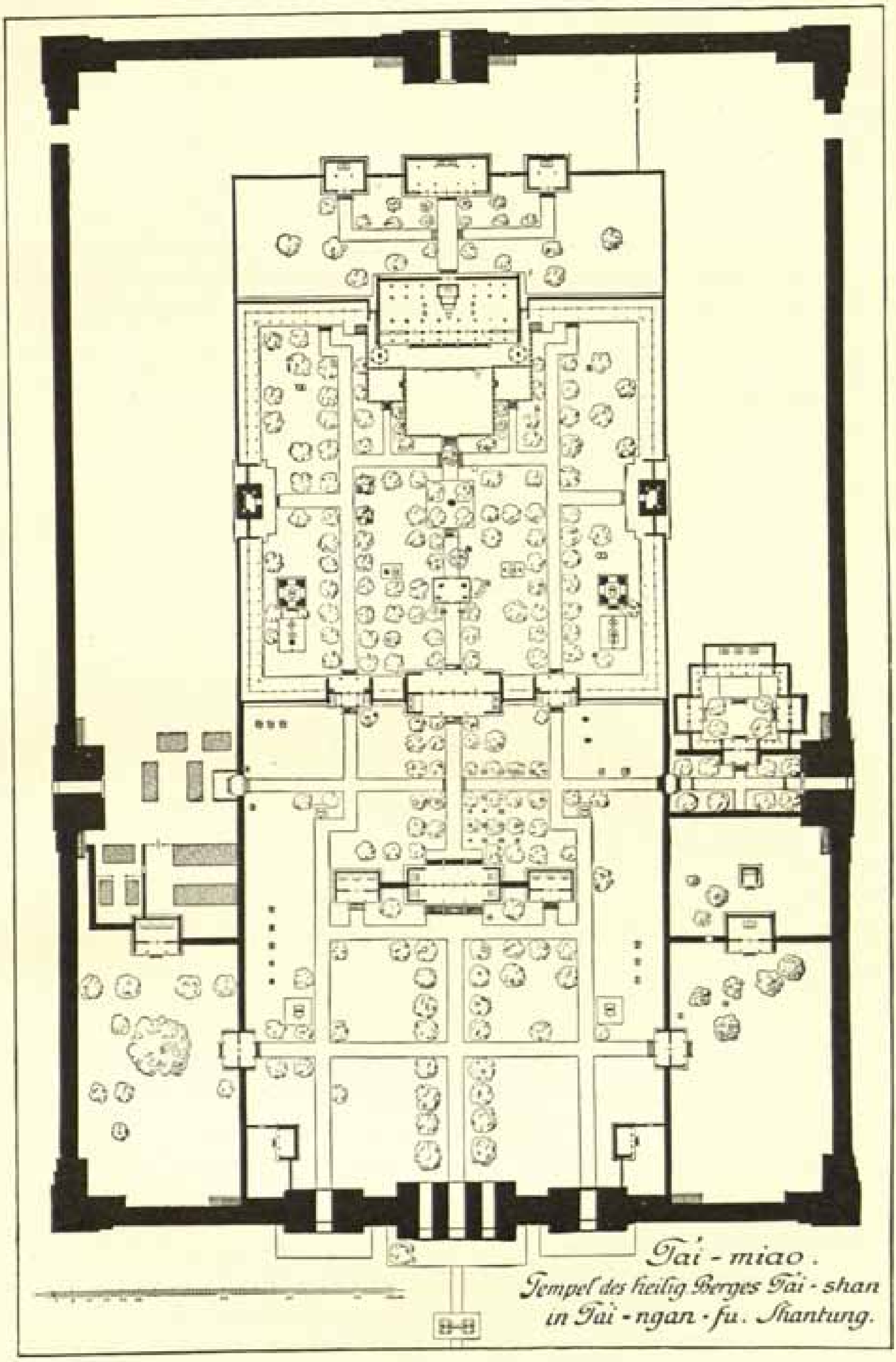
Lao-ye is known as the god of war by the Europeans, as he was a renowned general. But for the Chinese he is the god of excellent life conduct, of tried faith, and an ideal of these virtues. The two dragons are depicted as playing around this image of perfection, on the back wall of the altar in the home city of Lao-ye at Kai-chou in Shansi. It is a repetition of the expression of the struggle for highest perfection. This life-like statue of the hero from the golden period of China's knights, that of the three kingdoms, is specially honored. The image appears to be reading the Ch'un ch'iu, the fifth canonical book (pl. 4, fig. 1).

The dragon gate remains to be mentioned. This is the entrance to perfection. Whosoever crosses by the pathway of the ghosts—whosoever knows that the two principles of the gate are for the apprehension of the eternal—for this initiated one the door of wisdom is opened. It is said of a student who has passed his examinations that he has passed through the dragon gate. He has the pearl of perfection or is identified with it.

It is said "The fish rushes through the dragon gate." Formerly a stupid, ignorant, dumb fish, but after having passed through the dragon gate, he is changed into a dragon; that is, a being of intellect and power. That is done by the divine breath of the powerful dragon in the clouds in the air, which blows his animating breath through the dragon gate. In the swirl of waters between the cliffs and rocks, the carp swim around to partake of the enlightenment (pl. 5, fig. 2).

They are not content with two dragons, but multiply them as there are forces and phenomena. The most naturally increased number is 8, corresponding to the eight trigrams. Beneath a vaulted roof a dragon coils around each of the supporting columns, struggling toward the center from whose zenith the divine pearl of perfection is suspended.

The dragon always represents something thoroughly good, while the serpent something related to the demoniac, the incalculable, and in opposition, as if belonging to the devil Mephistopheles, but it is not in any respect wicked or evil of itself. It is combined with the conception of the dark kingdom of the nether world, as is conceived in the celebrated entrance Fêngtu, on the Yangtze in Szech'uan. This mountain has a mysterious opening near its summit, which is the entrance to the world below. It is covered with temples



GROUND PLAN OF T'AI-MIAO, THE TEMPLE AT THE FOOT OF THE SACRED MOUNTAIN, T'AI-SHAN, IN SHANTUNG.

LAO-YE, THE GOD OF EXCELLENT LIFE CONDUCT.

DRAGON BALUSTRADE IN CONFUCIAN TEMPLE AT WAN-HSIEN IN SZECH'UAN.

for all the different kinds of gods who have been in any manner associated with the other world. One of these temples enthrones the serpent king. Eight serpents coil around the columns before him, and one hangs down from the middle. This is in contrast with the eight blessed dragons with the pearl, as in the temple of Kuanyin, the goddess of mercy, on the sacred island, Pů-tǒ-shan, in the extreme east.

In this manner the embodiment of the numbers 3, 8, and 9 may be developed to ideally represent the infinity of phenomena. This idea is embodied by the impressive aureole of the Buddha with his thousand arms and hands in the temple of Great Lamentations at T'aiyüanfu, the capital of Shansi. Everything in our physical world as separated from the pure idea of the divine and from the true nature is imperfect, piecework, and fleeting. The Buddhist says that the best feature of matter is its transitoriness. All creatures may groan and bewail their existence and endeavor to become a Buddha from whom they came forth as the arms of the statue. This is the signification of the Buddha of Great Lamentations, of whom there are three gigantic images in the spacious halls of this temple.

The rhythm in the infinity of the world of phenomena is illustrated by the Buddha in the temple of the 500 Lohan in Suchon. He is here represented with four bodies growing out of the middle and having his thousand arms stretched out diagonally. These are the basic numbers 4 and 8 of the rhythmic world. They correspond to the four sacred Buddhist mountains, the four great Bodhisatvas and the swarm of gods throughout the world.

The old Chinese temples formed a quadrangle with corner turrets and four gates. The Buddhist thus conceives the spiritual world and represents it as Buddha's sacred castle.

Buddha's sacred castle is a representation of the conception of the world as a whole, like a city, as the Chinese think of their country with its five sacred mountains. The whole is inclosed in a quadrangle by a crenalated wall with the round sanctuary in the center. There is a gate on each side, four in all, and a tower on each corner. Four guardians, or disciples, stand on each side wall or sixteen in all (pl. 5, fig. 1).

The idea of having a stronghold of faith capable of military defense is actually carried out in Jehol in the Lama temple Potala, a copy of the castle of the late Dalailama in Lhassa. Massive walls surround the interior five structures, the approaches to which are terraced-like fortifications to secure the battlement and it is a symbol of challenge by the shield-bearer of religion.

The idea is developed on a grand scale in the plans of Peking and other large cities. The Emperor's throne is in the hall in the center of the palace of Peking. Numerous courts surround this palace, which all lie within the forbidden red city, this in turn is located

within the imperial city, and that within the Manchu city, all being arranged with accurate reference to the meridian line. Each of them has its gates and towers disposed exactly as those of the great temples.

The architecture of the gates and towers of such large cities as that at Hsinganfu, the ancient capital of the Empire (pl. 6, fig. 1), is naturally developed in accordance with their needs—with three towers in a flight, then the two lock chambers between, and the bastions of the city wall. But the idea is a practical expression of the accord with religion. These structures have their distinct forms of stability and architectural rhythmic tone as the Buddha's sacred castle.

The warlike corner towers of Peking are not only for military purposes, but have a religious signification and find their counterpart in the walled battlements of the temples in the sacred mountains.

Peking reflects the world. The four sides of the city contain the temples of heaven—agriculture, the sun, the moon, and the earth.

The Chinese regard the entire country as a rhythmic whole. The sacred mountains express this spiritual conception. There are five ancient Chinese sacred mountains, one each in the north, south, east, and west, and one in the center—again the number 5. Nature contributes more, as in the western mountain of Huashan in Shensi, which has five sharply outlined highest peaks that again illustrate the center and four cardinal directions. This is likewise the case at the Buddhist mountain Wut'aishan, whose five highest peaks present an image of the universe, which is also emphasized by its five sacred colors. Each of these old Chinese sacred mountains that rise up majestically from out of the midst of the plains has a large temple at its foot.

The extension of the axes of these temples leads directly across to the highest point of the sacred mountain. This is impressively seen from the Hua˜yin miao tower of the sacred temple of Huashan. The temples are built as fortified castles with crenalated walls, gates, and turrets inclosing the main sanctuary in its midst, with broad approaches through rectangular colonnades, and as a whole present a conception of the universe.

A brief description of the sacred mountains is of interest. That of T'aishan, in Shantung, is the most eastern, the most famous, and doubtless the most ancient of all. One goddess has gradually become the chief goddess of this mountain. She is the most popular among the people. She is supposed to make excursions over all the country, where she is worshiped, and as she travels about and returns she must be provided with travel palaces for rest, as for the Emperor. These are the small temples usually consisting of merely a prayer hall, which is often profusely decorated with handsome glazed ornaments and the most lively representations. In a central circle of a gable

of one of these small temples there is a representation of the pilgrims with pious zeal striving to make the weary journey to the summit, to reach the sanctuary of the goddess. The masses of pilgrims who to this day make these ascents bear out the realistic truth of this scene. Most pilgrims walk; the rich are carried in sedan chairs. A little below the summit of this mountain the southern gate of heaven is reached by means of steep steps known as heaven's ladder. The mountain has four such approaches in the four cardinal directions, and thereby reflects the totality of the sacred mountain with the world order. The bald rocky peak is 1,500 meters high and is covered with temples, ancient inscriptions, and religious curiosities. I passed a wretched October night, unprepared for inclement weather, in the highest temple, where broken windows on opposite sides permitted the cold storm to blow through uncomfortably.

The main hall of the temple of the southern sacred mountain Hêngshan, in Hunan, shows the elegant slender proportions of the Province of Hunan, where they always use their favorite long slender stone columns.

The serrated cylindrical mountain of western Huashan, in Shensi, is seen projecting from the mountain masses two days' journey distant. The ascent is really dangerous; nevertheless thousands of pilgrims annually ascend it. Iron chains are fastened to it to safeguard from falling from the precipice. I measured this precipice, which is 560 meters high in a vertical line. In June one finds a splendid forest and beautiful flowers in bloom at the summit, 2,000 meters high.

The flying clouds appear whitest at the highest peaks, and the Chinese associate them with their conception of the departed spirits. From these heights one looks down over the famous bend of the Huang or Yellow River, that appears quite as distinctly as that delineated on the map.

The four sacred Buddhist mountains were obviously regarded as sacred in ancient China already before the advent of Buddhism, and traces of the ancient sanctity are still seen on Wut'aishan and Omeishan. The Buddhists then drave the old Taoists away, as they are now doing gradually in the southern mountain Hêngshan. The four mountains are dedicated to the great Bodhisatvas of wisdom, efficiency, the goddess of mercy, and the god of the nether regions, that mercifully guides the soul. This sacred mountain is located in a geologically famous region near Nganking and is of volcanic origin.

The sacred Buddhist mountain Wut'aishan, in Shansi, is an exception to the other sacred mountains, inasmuch as the monastery buildings do not gradually extend up and connect with the summit to reach the holiest sanctuary, but, seventy in number, are distributed over the elevated plateau at a height of 1,800 meters, and surround

the imposing white pagoda, that is nearly 2,000 years old, as chickens around the hen. This is visited by Mongolian pilgrims in winter, when it is very cold. The mountain with its five symbolical peaks, here reaches to a height of over 3,000 meters (pl. 6, fig. 2).

The court of the largest temple affords a good point of view of the arrangement of the temples in this mountain. Its main hall is vaulted in its interior and shows traces of Indian influence on its façades. In the background similar buildings stand out with a number of pagodas and little temples of gilded bronze with splendid details of the Ming dynasty which holds such a prominent place from an artistic standpoint.

The temple on the Omeishan Mountain in Szech'uan is much more simple, the mountain being at an elevation of 3,300 meters. The buildings are made of boards with wooden posts and board roofs. These temples are arranged to accommodate large numbers of pilgrims. Some of them can quarter several thousand pilgrims at one time. The highest peak is crowned with a little house from which there is but a step to the sky.

A lifelike statue of a deceased high priest clothed in rich vestments sits in one of the temples in this neighborhood. Probably it was he who sang the praises of this most imposing sacred mountain.

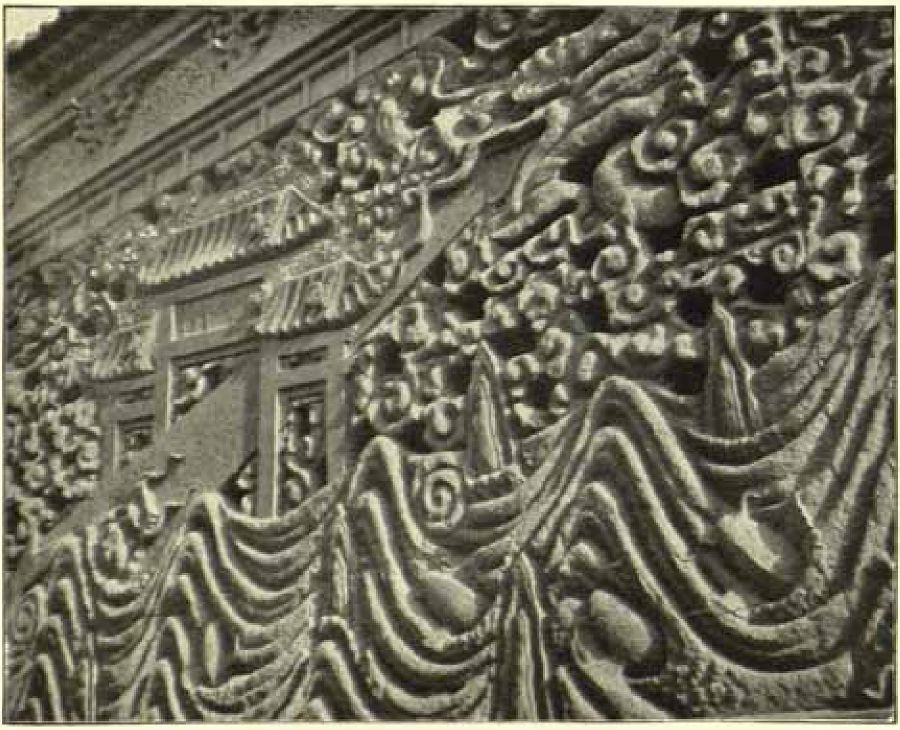
> Glory now spreads around Omeishan peak,
> Now by full autumnal moonlight I invite
> Holy spirits to drink and rhyme.
>
> With bamboo cane step by step I ascend the highest peak,
> What luck pure wind now waft through every space!
> Slowly burning incense I ascend to the holy halls in deep snow!

Pù-tò-shan in the Chusan Archipelago, east of Ningpo, is the sacred island of Kuanyin, the goddess of mercy, who in her propitious boat saves all people across the stormy sea of life to the banks of happiness. Her temple Fa-yü-szu, where "Buddha's law drops like rain," contains many precious relics. A handsome stone bridge forms the approach, behind which one sees the ascent to the highest summit. Here is an inscription: "Clouds hang over the cliffs where they are highest," and the thought that he who has acquired knowledge shall first share the grace of Buddha is expressed by the proverb: *Shan kao ji shêng* (the sun rises first on the mountain top).

This fine amalgamation of the reality in nature and the spiritual ideals is an important characteristic of Chinese poetry and art. Life is only a parable.

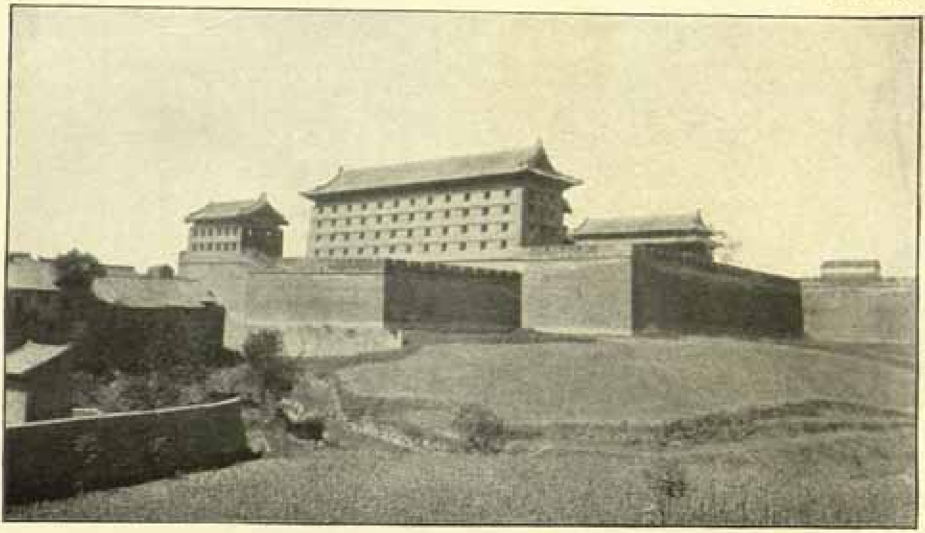
The railing of the bridge is covered with sculptures. Pleasing is the scene of two she goats fighting with a kid standing by, while a forest sprite on the branch of a tree comfortably observes the foolish struggle, indicated thereby as that of the world.

BUDDHA'S SACRED CASTLE.

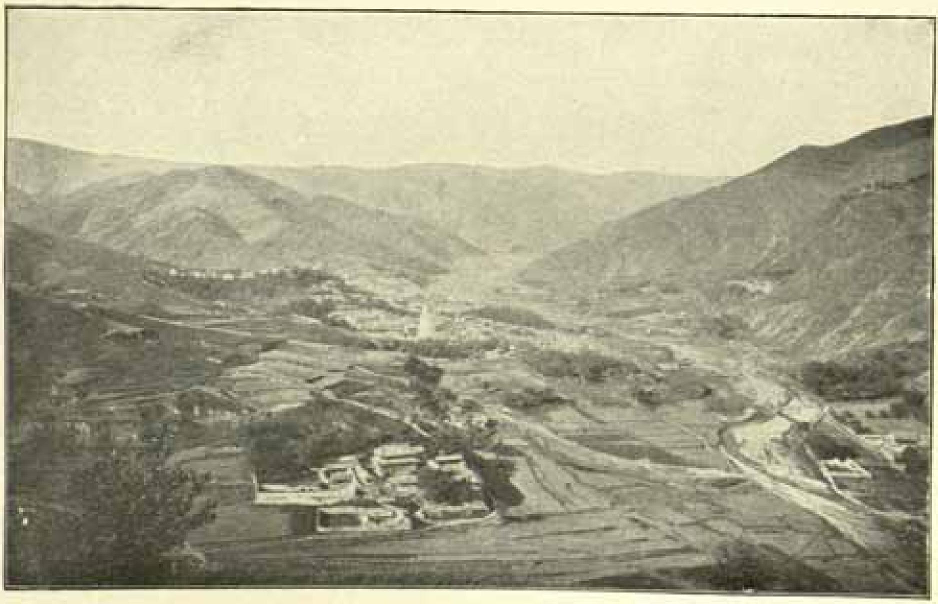


DRAGONS AND DRAGON GATE.

(Glazed terra cotta.)



THE TOWERS AT HSINGANFU.



WUT'AISHAN, THE SACRED BUDDHIST MOUNTAIN IN SHANSI.

An exceedingly lovely alabaster image of Kuanyin sits in a glass case in the hall of the temple. The lips, eyebrows, and eyes are modestly painted with pale red and gold, otherwise the countenance shines out clear and fine, while the figure is clothed with the richest brocaded vestments. Here is inscribed:

> The goddess hears the real tones of the heart and protects the supplicant in his affliction.

Another Kuanyin sits on an elegant altar. She is diminutive, but far famed on account of her costliness. A part of her face and breast as well as neck is formed by a large irregular real pearl that is about 10 centimeters in diameter; the rest of the face, hair, and drapery is of pure gold. The beauty of the altar is like that of an altar in the neighboring city of Ningpo. This is of wondeful composition, lavishly adorned with sculpture, painting, and gilding, and solemn in its effect.

This elegance is also found in the dwellings. There is a narrow street in Ningpo which contains exclusively modern wealthy business houses. Each house is like a good type for this class of buildings. The entire façade of the three stories is clearly composed. Here we notice the power of the Chinese line, which, however, is dissolved into endless details and carvings, due to their joy of living and the reality. It is the rhythm of the imposing ideal corresponding to the elaboration of the details, the harmony of the macrocosm and microcosm.

The tomb of the high priest is near the summit of the highest mountain on the island Pŭ-tŏ-shan, an auspicious location, with a beautiful outlook over the numerous islands of the Chusan Archipelago. Here the soul of the priest hovers invisibly intangible as a white cloud and hither he returned as to his home. The tomb is inscribed: "The White Cloud has returned." The Chinese have a special expression for the poetry of nothingness and the state of being entirely absorbed by Nature: *Kung hsiang* (empty thoughts). Another inscription on this tomb very beautifully expresses the charm of solitude:

> There is but one cloud on the mountain,
> High above the sea the moon keeps the third watch.

There are nine mountains in all, and the number satisfies the occult sense of the Chinese, who do not make any great distinction between the two classes of mountains, and speak of them as *wu yo sze ta ming shan* (the five sacred and four large famous mountains). They are the foci of religious thought and its manifestation. I saw but six, and sought to visit all, but my time would not permit. I must regret like the Chinese traveler:

> But yet I can not visit all the mountains,
> I must return to the mountain of my home.

A Chinese regards the mountains as the fathers of things. He is right even according to our conception. It is a self-evident fact that the plains originated from the mountains, that the ground upon which we work and live was formerly on them, and we thus derive our life and powers and soul therefrom. This fact is perhaps more a reality in China to-day than with us. The constant inundations of the plains, the country inclosed by the mountain ranges and in the numerous valleys, raises the level of the land annually. In Shantung and Honan, the Huang, the dreaded Yellow River, the constant sorrow of China, still lies higher than the broad expanse of the plains; and a catastrophe which will almost equal in damage that of 60 years ago may be predicted. The land is constantly in motion and demands unremitting labor on the part of the people. These geological facts and the constant changes have their effect upon the disposition of the entire people and make the stories of China's torpidity appear as fables.

Every Chinaman is conscious of the fact that the soil of the earth originally came from the mountains, to which he looks up with reverence. They were the first recipients of sacrifices. Buddhism personified the mysterious forces, and thousands of Buddhas are carved on the rocks. During the T'ang dynasty, 620 to 907, China was covered with such images. Countless Buddhas are carved on the most prominent cliffs that characterize the landscape, the course of a river, or a great highway. One of the finest examples of this kind is seen on the projecting cliffs on the Kia-ling River at Chao-hua in Szech'uan.

This idea is very dear to the Chinese, who regard the mountains as the source of life and that which animates the spiritual forces which fashion our life.

The import of these rock carvings is best recognized near the district town Kuang-yüan-hsien, in the northern part of Szech'uan along a river. A magnificent Buddha with his train and other representations of the gods of colossal dimensions, are carved on the cliffs on the opposite side of the river, alongside of which there is a temple. This image, as something divine and enternal, looks across the river upon the town that stands in his jurisdiction, and endows it with the sacred forces of the mountain (pl. 7, fig. 1).

A cave near Peking is covered with numerous small Buddhas—surrounding the dying Buddha. The caves are inhabited by spirits and saints. The Chinese written character for the word spirit is a combination of the characters for man and mountain. Chinese history is full of the sayings of famous men, sages, and priests:

> In life's evening when duty is performed
> He went to the mountains and became a spirit.

What profound sentiments, what poetry and emotion is found to prevail in the numerous temples of the mountains, that are em-

bedded in the midst of a wilderness of rocky cliffs with dense sacred groves, what precious hours are passed there far from the tumult of the world! as is inscribed in the words:

> The waters rush around,
> The mountains form a wreath,
> The holy here wish to while.
> The moon shines clear,
> The wind blows pure,
> The wise here meditate.

The priests, who see deeply into the soul of nature, have naturally selected not only the most beautiful sites for the temples but have furnished them internally in a manner that is only comparable with the European monasteries of the Middle Ages.

For several days I dwelt in the temple Miao-t'ai-sze, a most charming residence in the Tsin ling shan, the remarkable mountains of south Shensi, many days' journey remote from any great city (pl. 7, fig. 2). The guest house that was placed at my sole disposal is connected with a temple built in honor of Changliang, the great Chancellor of the first Emperor of the Han dynasty, 200 B. C. He is still remembered and to this day regarded as the protecting spirit of this region, where he was born and whither in his old age he returned. The place is surrounded by mountains that tower above the valley covered with forests inclosing a grove of bamboo, cypress, and pine, where one feels most impressively the charm of solitude. The poems inscribed in this temple should be read on the spot:

> The moon lightens the pure pines,
> Where the precious dragon floats and plays.
> The wind carries incense up the mountain,
> Where holy spirits joyfully return.

And further:

> Here vulgar noises are not heard.
> Here dwell a few days, and the place
> Becomes your sacred home.

Similar scenes abound over all China. Ancient temples with beautiful pagodas are found in the woods or amidst the mountains. The main halls of these temples contain images of Buddha's disciples that are artistic and lifelike.

Real rock temples play a large rôle in China because of the profound religious association with the mountains. Mienshan, an isolated massive limestone mountain, rises majestically from the rolling landscape and is torn and broken with many ravines and caves. It is south of T'aiyüanfu in Shansi and is thickly covered with trees. In it the largest temple consists of about 30 buildings, all under overhanging cliffs. The great cave resembles the Cave of the Winds at

Niagara Falls, and probably had a similar origin—from a waterfall. Pilgrims visit this place only once a year, but then in large numbers. The few priests generally live alone, shut in from the world, and thus become hermits. Many of them live in small huts or caves some distance from the monastery, as is still done to-day all over China (pl. 8, fig. 1).

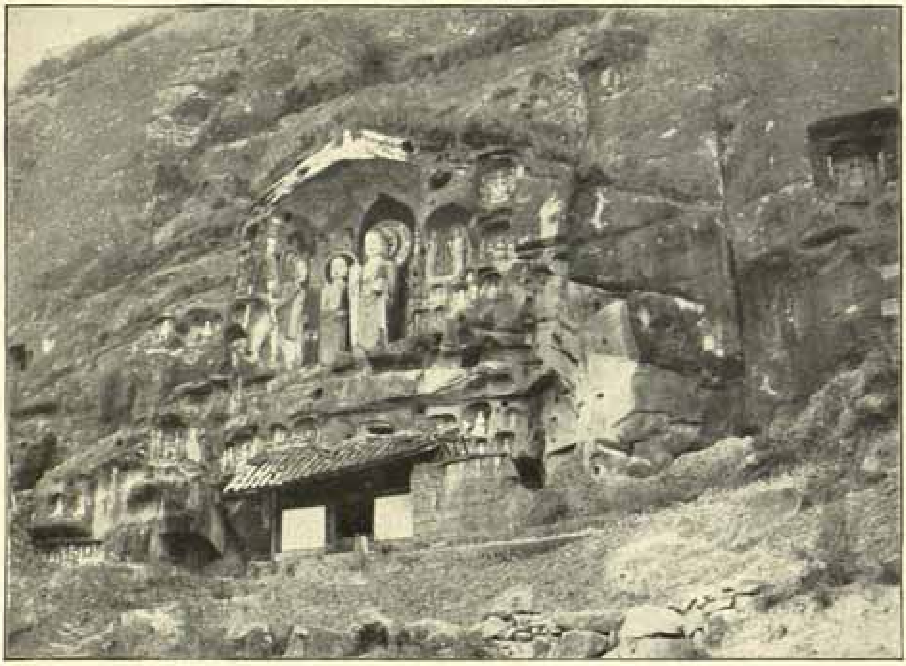
It therefore seemed natural that the eighteen disciples of Buddha, the Lohan, should be represented as a type of anchorets, in one of the temples at Omeishan. This is a celebrated type of these images modeled after those in a temple in Nanking. It occurs more frequestly in the marble pagoda of a temple on the West Lake of Hangchoufu, that fortunately escaped being destroyed in the Taiping rebellion. This has sixteen sides, agreeing with the original number of Buddha's disciples. It is vigorously decorated and tastefully composed; the images of the disciples are carved into the panels and conceived as anchorets.

The tombs, in view of the association with the sacred earth, are invariably located on the slopes of hills, where least liable to be destroyed by natural causes. This mode of building is suggestive of the idea that the dead have returned to the mountain from which all life emanates. In China the tombs have the finest architecture, occupy the most conspicuous sites, and are built with most extravagant art. The façade of a family tomb in western Szech'uan is an example of an effective artistic arrangement in imitation of wood architecture. Tombstones are placed in front of the façade, and in front of these they have the genii tables of eight stone seats to serve for the feast of the spirits on certain sacred days (pl. 8, fig. 2).

In this vicinity I discovered the remains of a tomb that was built in the period of the Han dynasty. Tombs of the Han dynasty were described by Chavannes and hitherto were not known outside of Shantung. The pillars of the tombs are similar, but the difference in art between Szech'uan and Shantung 2,000 years ago, was considerable. An earnest and severe art characterizes Shantung, while here the need for genre and life is revealed by the crouching figures in the corners and the lively relief designs between the consoles. The difference in the art in the different Provinces can here but briefly be alluded to in this one instance.

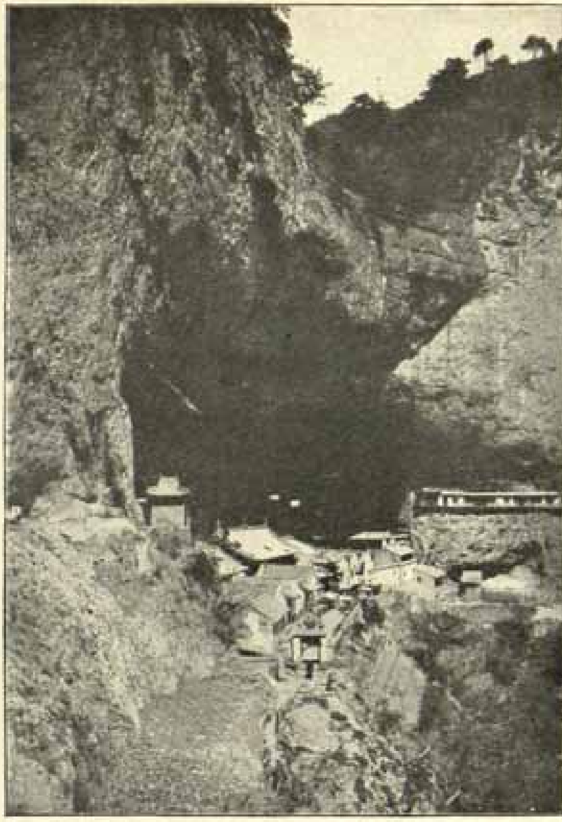
The much praised beauty of Szech'uan is revealed in many of the landscapes of burial grounds that are emphasized by arrangements of cypress, cane, and the terraced slopes forcibly accentuated by a single tree at the summit.

The Pailous, or honorary gateways, are memorials of the departed that are to be seen on all the highways in China, chiefly in Shantung and Szech'uan; in the latter they are generally built of red sand-



ROCK RELIEF AT KUANG-YÜAN-HSIEN IN SZECH'UAN.

COURT OF DWELLING IN THE TEMPLE MIAO-TAI-SZE IN SOUTH SHENSI.



TEMPLE IN THE CLIFFS OF THE MIEN-SHAN MOUNTAIN IN SHANSI.

FAÇADE OF A FAMILY TOMB AT YACHOUFU IN SZECH'UAN.

stone. The vigorously waved roofs and corners give outlines that are often capricious, but the harmony of the whole is maintained.

A quaint gateway in Wuch'aufu, near Canton, is built somewhat with Indian taste. Upon close examination the confused sculpture is solved and reveals elegant and finely wrought allusions to certain definite events.

In Szech'uan the idea of a gateway-arch is frequently employed in the development of façades for temples and dwellings. Everything is lavishly sculptured and painted. The edges of the pilasters are artistically composed of a mosaic of small blue and white pieces of porcelain, with brilliant festive effect.

In Szech'uan, more than the other Provinces, the natural beauty of the fields and highways is frequently enhanced by temples, bridges, and altars, which are affectionately remembered by Chinese in foreign countries. The Tú-ti altars appear everywhere, that is, the little roadside temples dedicated to the god of the place, who is identical with our genius loci. Grateful, pious people endow them by building stone flag masts surrounding the sanctuary and its single tree often in great numbers.

Large groups of sacred things are assembled at the most prominent places. At Tze-liu-tsing I found a Tú-ti altar in the street alongside of which there was a stone flag mast, a column surmounted by the head of Buddha somewhat back, then an altar for incense, and a large handsome altar for Kuanyin, the goddess of mercy, all of which constituted the sanctuary inclosed by clusters of bamboos which are named for her: "The Bamboo of the Goddess of Mercy." The Chinese thus put their soul into nature. One of the inscriptions reads:

> The lust of the world is vain forever,
> But if you place a Kuanyin image on your acre, that will endure.

The combined sentiment and grandeur with which they treat surfaces is exemplified by the imperial tombs of the present dynasty. The great temple tombs of the Emperors are located in a dense grove of pines 10 kilometers long and 8 kilometers wide, extending up along the massive cliffs of the mountain side. Gates alternate with bridges, avenues of stone animals with temple-kiosks; and the mortuary temple appears in front of the tumulus characterized by a structure several stories high. The entire arrangement is plain in the proportions, but is most nobly and solidly built.

This remembrance of the departed is obviously specially imposing in this case, but China is generally noted for the worship of the dead. The ordinary man honors his ancestors in his home and at their graves. The wealthy have special ancestral temples connected with their own dwellings, or on a selected place, the Tze-t'ang, that is often garnished with indescribable splendor.

The Ch'ên family, a young member of which is at this time a student in Berlin, has such an ancestral temple in the home at Canton. The temple consists of a series of courts and halls arranged on five parallel axes. The great guest room for family feasts is handsome and airy and most elaborately decorated. Each compartment contains the four tables and eight seats, repeating the well-known genii table arrangement of eight (pl. 9, fig. 1).

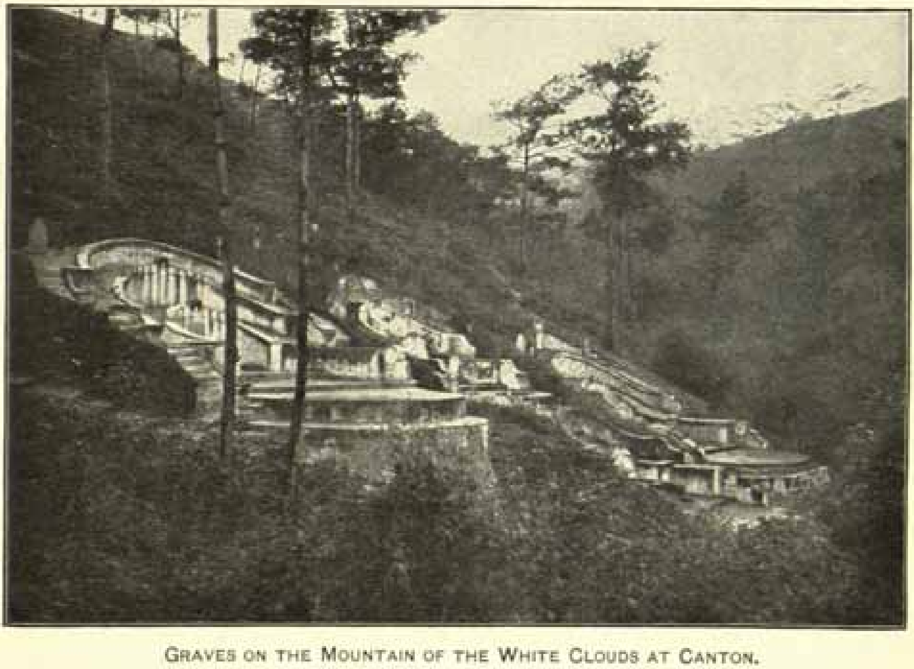
The ancestral hall proper has room for 4,000 small ancestral tablets on five most elaborately carved altars. In front of each of these five altars there are five blue ritual vases. Everything is built of the richest materials and significant also from an architectural point of view.

The mountains play an important part not only for the sites of temples, tombs, and ancestral temples but for the locations of the cities of the living. They prefer sites near a mountain, and when other advantageous conditions are available, such as the course of a river near the mountain, they consider the beauty of the location perfect. The Chinese designate this as Fêngshui, meaning that the city's relations to wind and water are perfect.

The large cities and almost all others are located in most clever concord with the natural conditions to combine most advantageously the industrial interests with the most beautiful environment possible. The manner in which the Chinese artistically build their structures to harmonize with the natural environment is astonishing. The Province of Szech'uan has the most beautifully located cities. Kiatingfu on the Min River, a branch of the Yangtze, is a conspicuous example. European gunboats steam by this city in the very heart of the Empire, among others the German gunboat *Vaterland* (pl. 10, fig. 1).

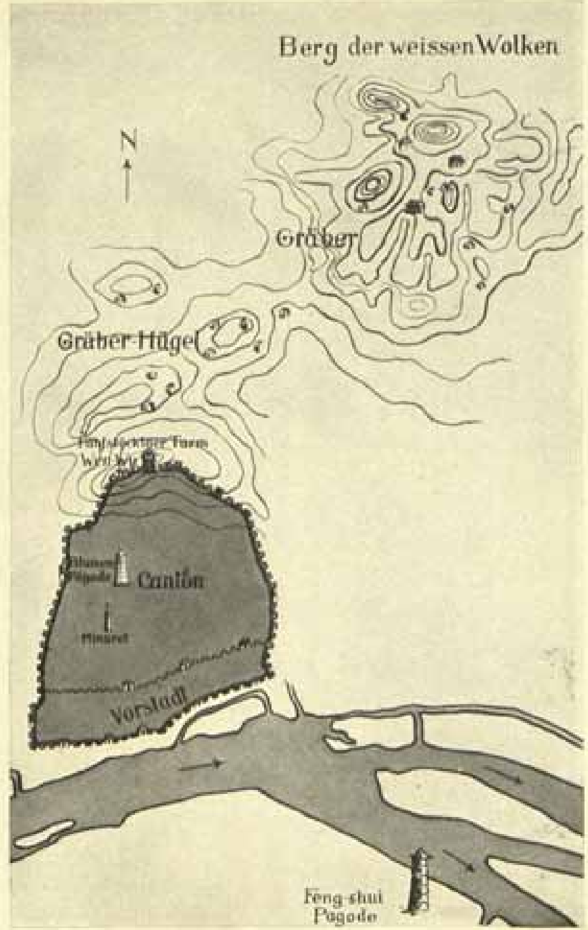
The river flows along the south and eastern sides, and the city spreads out from the corner northwestward where there is a mountain that is conceived to have been the progenitor of it, and from which it derives its forces and soul. With this conception the temple was built on its summit for the protecting god of the city. This temple has a pantheon arranged with a central compartment for the main god, Yü-huang, the Jewel Emperor, who is preferably conceived as the incorporation of the spirit of the mountain. He appears in three images, three manifestations, that are disposed one behind the other, so that the image most advanced in front appears to have a more human resemblance than the others that are more in the dim shadow of the altar in the rear. This is a most impressive representation of the triad. The great pantheon of the gods fills the other space within this temple. These gods are the embodiment of virtues and religious ideals that are specially revered in physical forms. The altars are placed in the axial lines. The two pillars on the sides

THE ANCESTRAL TEMPLE OF THE CH'ÊN FAMILY AT CANTON. THE RECEPTION HALL.



GRAVES ON THE MOUNTAIN OF THE WHITE CLOUDS AT CANTON.

PLAN OF THE CITY OF KIATINGFU.



PLAN OF THE CITY OF CANTON.

of the axis have lively modeled carved dragons coiled around them that reach out toward the main axis with the sanctuary in the center (fig. 6).

The river flows by steep cliffs opposite the southeast of the city, where it is surmounted by the pagoda of the city. It is a rule in China to have a tower in the southeast of the city, either on the city wall or without in its outskirts, for Kueihsing, the god of literature, who dwells in the sky in the constellation of the Great Bear. In Shansi these detached towers are to be seen near every town and village and have often a pleasing and a varied form. In Kiatingfu there are many other features that are supposed to guarantee sanctity

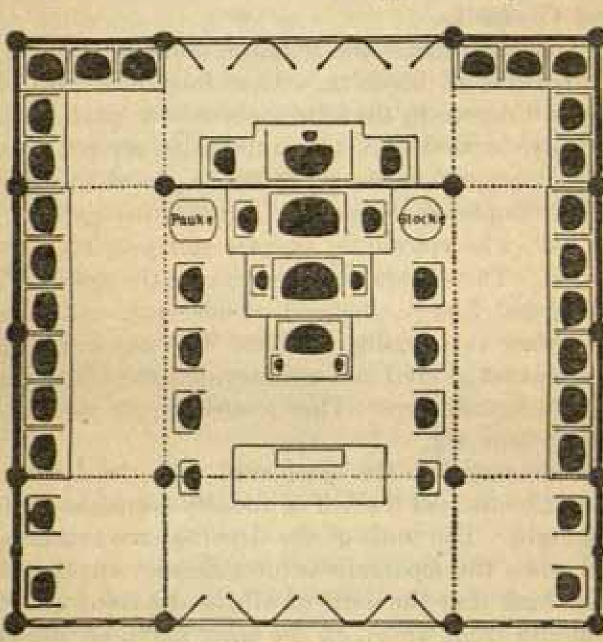


FIG. 6.—Ground plan of temple at Kiatingfu.

and peace to the city besides the pagoda. Among these there are a great many images of Buddhas carved on the cliffs opposite the city, one of these standing, is 6 meters high, another gigantic image sitting is 30 meters high. Besides hallowed caves, filled with gods, ancient temples, and great stones carved with the holy trigrams as previously described. The embalmed and gilded mummy of a high priest sits in one of the temples, and there are temples for the poet Su Tung-po and others. Sanctity is thus concentrated in what is conceived to be the proper place southeast of the city. From the opposite side the great temple of the "Ancient of the mountain" looks down, while another pagoda in the city holds the balance

(beetween the two pagodas of southeast and northwest). The beauty of this region may be imagined and is expressed by an inscription in the mountain temple: "How propitious is this site! Here one sees the river winding around, the broad plains stretching out to the southward, and to the westward the three highest peaks of Omeishan."

The reference to this patriarch of the mountain, and the triad of its highest peaks are reflected by the triad of the chief god in the temple.

This is, on the part of the Chinese, at the same time, a reminiscence of the Buddhistic trinity and the trinity of Chinese religion: Buddha, Laotze, and Confucius.

Similarly located cities are found elsewhere than in the most beautiful Province of Szech'an. This feature is also characteristically seen in Canton, in the extreme southern part of Kuangtung. This city is also located near a mountain, its revered ancestral progenitor, with a pagoda to the southeast to guard the spiritual city. A five-storied temple on the summit has the two gods sitting in the uppermost hall, who constantly oversee and promote the daily life of the Chinese. These gods are Wên-chang, the good of knowledge and learning, and Lao-ye, the god of efficiency and bravery. The Chinese designate this duality as Wên Wu, which Europeans have correctly translated as civil and military, but the Chinese give that a more profound signification. They guard the city and all prosperity depends upon their aid.

Canton is connected to the northward with the famous mountain of the White Clouds, and the hill of the city forms, as it were, a spur of this mountain. The souls of the departed are conceived as white clouds, and when the mountain is most densely enveloped in clouds the Chinese think that the souls of all the departed are congregated on the mountain from which, on the other hand, all life came. It is thus a conception of the circle of all existence.

This conception is given sublime expression by the disposition of the graves which beginning in the north of the city extend to the mountain of the White Clouds, where in many splendid temples countless gods are sitting, who in this life as well as in the future one are man's guides and ideals. This necropolis is even for China, which can be designated as one large cemetery, something immense. This covers an area 12 kilometers long and 7 kilometers wide, and it is literally filled with graves on the slopes of the valleys and to the summit of the mountain. Without any exaggeration there are many millions of graves in this cemetery. Some of the graves are very simple, others have grand tombs, and many of them are great artistic works.

This has an important bearing on the religious conception that death produces life. The mountain is called the White Cloud for the souls of the departed, thus emphasizing, "From life to death, out of death life." Higher up the mountain there are imposing grave inclosures amidst luxurious trees and plants. And when the Chinese look down and contemplate the busy city of millions in Canton they realize the vanity of this world and the preciousness of the rest that follows death. All is vanity in the physical world. He is at once a Chinese and a Buddhist. These ideas are further embodied in the image of Shou-hsing, the wise ancient hoary god who displays the symbol of the world, the sacred eight trigrams which explain the circle of existence as the meaning of life (pl. 9, fig. 2).

The Chinese thus feels himself to be closely connected with nature. He knows that he originated from it (nature) and shall return to it, and shall return to the earth, but then reappears in the persons of his children and grandchildren. He feels himself to be but a guest on earth, an insignificant part of the whole that he conceives as oneness. This is the purest partheism, and a wellspring for the outspoken social instinct of the race.

There is, however, an essential difference between the Chinese and the Hindu. The ideal of the Chinese is the greatness and wholeness of creation, and he embodies this thought in his art and religion. But as a practical man he realizes that as long as he is sojourning upon this earth he should arrange this life as comfortably as possible. Hence his sober, businesslike sense, his perseverance in work which should afford him the means for life and enjoyment. This harmonizing of high idealism with practical sense gives the Chinese people vitality and the right to have their ideas considered and esteemed as on an equality with our purely individualistic culture. And it may be due to the considerable admixture of individualism in the Chinese pantheism that the Chinese in his disposition is nearer to us than the racially more closely related, but dreamy and otherworldly Hindu.

We have observed how both the country and its history have equally demonstrated to the Chinese the grandeur of their conception of unity. His system of the universe is thus divided into the forces in the circle of the two principles, the male and female; in the eight trigrams symbolizing the development of the variety of the rhythmic and harmonic physical world. Finally, the unity of man and nature. It is not very different from our division of natural philosophy in physics, mechanical energy, multiplicity, and logic and biology. It is always apparently the same with mankind. But the peculiar conception and combination of these elements with its trend to pantheism gives Chinese culture a reality that is the best conceivable preparation for artistic accomplishment.

[illegible]

THE LOLOS OF KIENTCHANG, WESTERN CHINA.[1]

[With 4 plates.]

By Dr. A. F. Legendre.

There are a number of aboriginal peoples in the western part of China, in the Setchouen (Szech'uan) Alps, but the most interesting is the race known as the "Lolotte." Dwelling in a region perhaps the wildest on the earth, their physical and moral characteristics, their strange customs, and, above all, their superb courage in the face of that formidable foe, the "Son of Han," present a strong attraction to the European, opening up a wide field for observation.

I first became directly interested in the Lolos in the year 1904 in the vicinity of Fulin at the home of Father Martin, the missionary, who knows them best and who gave me most valuable information. But it was not until 1907 that I began to study them seriously in going directly to Kientchang, where I saw much of them in their villages, could study their daily life, their curious habits, and could note the horror of the bloody feuds between the rival clans and the warlike organization of the tribes.

In 1908 I visited many Lolo districts, and, profiting by the experience previously acquired, my observations on this occasion were much more accurate, and, being more extended, enabled me to verify my first impressions. In the villages, as a host, I gained the confidence of the families and could observe and interrogate them at my leisure. Finally, in January and February, 1909, I journeyed into the rougher and more turbulent region of Ta Leang Shan, where there were constant raids against the Chinese and bitter feuds between the clans. The journey was short but interesting in many respects.[2]

I shall briefly describe the physical character of the Lolo country. It occupies in the western part of the Province of Setchouen a vast region entirely mountainous. It is a chaos of high ridges and narrow valleys, with some lower ridges and plateaus cultivated to a certain extent with maize, buckwheat, and oats, but used chiefly as natural pastures. There are some large tracts where excellent grasses grow,

[1] Translated by permission from Revue de l'Ecole d'Anthropologie, Paris, 1910, vol. 20, pp. 185-205.
[2] See *La Geographie*, April, 1909.

capable of nourishing large herds of horses, mules, sheep, and goats. In the mountains there still exist some beautiful forests, where oaks, birches, and pines flourish, as well as the silver fir which covers the summits. Up to 11,500 feet altitude there is a marvelous undergrowth of slender bamboos and rhododendrons, where hide a great variety of animals—bears, wild boars, wild goats, antelopes, and deer.

These people are chiefly hunters and herders. They have learned agriculture from the Sifan and the Chinese, but spend no more time and effort at it than is actually necessary for subsistence. What they love most is constantly to roam in pursuit of wild animals.

This beautiful mountain region is favored with an exceptional climate. For a great part of the year, particularly in autumn and winter, the sky is of a rare purity and clearness. Summer is very hot and the thermometer is said to go as high as 40° C. (104° F.), both in the valleys and on the mountains up to a height of 5,600 feet, but the humidity is low. Winter, in the districts below 6,500 feet, is never severe, but, on the contrary, though at night the thermometer may fall below the freezing point, it will rise during the day to 15° or even 20° C. (59° or 68° F.) before sunset. In February I registered temperatures of 25° C. (77° F.) in the shade between noon and 2 p. m., but early in the morning it was less than −2° C. (28.4° F.). We may therefore class the climate as subject to extremes of temperature, but at the same time decidedly dry, even too dry in the valleys below 5,000 feet.

In his daily life the Lolo mountaineer leads a simple and frugal existence, content with his primitive shelter made of interlaced bamboo strips. The houses, made of rammed earth covered with fir planks, seen in certain districts, are copied from the Chinese style of construction, plainly deviating from the primitive huts.

The chief feature of the Lolo hut is the hearth, located in the center of the room, made of three triangular-shaped stones inclosing a hole from 10 to 12 inches in diameter and 4 inches deep. At the side, one often sees an elevation of three steps made of clay that look like shelves; but it is more than that. It is a sort of altar on which certain religious rites are performed, is the very sanctuary of the hearth, the sacred symbolic spot, after the fashion of the Greeks and Romans, the consecrated place in the poor man's house where generations of ancestors have found their moral and physical being strengthened.

Around this hearth the Lolo eats his buckwheat or oaten cakes, boiled maize, or else some stewed meat that he eats when half cooked. He also cooks the maize in cakes under the cinders. Oatmeal is his principal food, that which he takes with him by choice when he goes forth as a warrior or to engage in a feud. He fills a little bag of

goatskin with the meal, and when hungry he makes a ball of meal in the palm of his hand with water from a stream and eats it as it is.

The potato is well known to these primitive people and is quite largely cultivated by them. For his primitive menu the cook is not at all interested in what we term "condiments." The only seasoning he cares for is salt and he likes that chiefly as a delicacy. In the villages salt is eaten the same as sugar candy; pieces of it are passed from mouth to mouth and each one sucks it for a given time. Sugar is not at all disliked, but as the cane does not grow in the mountains the Lolo must get it by descending into the valleys at night and pillaging the Chinese fields. It is interesting to note in passing that the mountain herder disdains the milk of his cattle.

I return now to their dwellings.

To give a complete idea I can do no better than to describe the type of hut seen in the village of Bolo, near Yué Si. This hut is a wretched little affair, 13 to 16½ feet long, 8 to 10 feet wide, and about the same height. There is but one room, with a recess separated from the other portion by a half partition. This recess serves not only as an apartment for the household but also as a stable for the sheep when the tenant is too poor to build one outside the hut. There is really no furniture, neither table nor chair or other seat, much less a cupboard or closet. The inmates squat on the ground around the hearth, which serves as their dining table by day and a place for sleep at night. There is no sort of bed in any form. I stated that there was no trace of cupboard or closet in the huts, for what good would they be? These poor Lolos have no need of a wardrobe. They carry all their clothing on their backs, and wear it as long as they can, rarely having a complete change.

I saw no household utensils except the large Chinese scullion, like a spherical pot, and some wooden bowls, very curious and well turned. They had, however, some large, cylindrical bamboo baskets for storing grain, and sieves and winnowing baskets made of the same material. The hooks for hanging utensils or other objects are made of simple forked branches of trees. One other way of holding objects, such as baguettes or rods, consists of a double ring in the form of the figure 8, made of a rope of bindweed or young bamboo. These rods serve as rests for the large, flat baskets on which they dry the grain.

I have called the Lolo dwelling a hut and it is nothing more. Made of bamboo strips crossed and intertwined or cut into ropes and plaits, it offers but a meager shelter against the cold, wind, or rain, and the pine strips that form the roof are joined so poorly that the daylight shows through the wide cracks. The posts and joists are merely trunks or branches of trees, not squared or even stripped of

bark. The joists are not selected for fitting to the posts as supports, but are roughly held in place by the forked heads of the posts. You notice also that the rafters are not mortised but are merely crossed and fastened by bamboo binders. The tie-beams are fastened in the same way. The ridge, nothing more than the mere laying together of some narrow strips, is covered with a bamboo mat extending down about 18 inches on each side of the roof.

At Bolo I first observed how the Lolos weave their mantles and their leggings. I asked the chief's daughter, who had charge of this kind of work, to show me the implements for spinning and weaving. The spindle was a thin rod with a little disk in the center serving as a grasp for the fingers. One of the ends of the spindle was lengthened with iron to a point for attaching the mass of wool. The thread that was made was very coarse. The loom consists of three or four rods or stretchers for intercrossing the threads and a large wooden plate or blade for the underweaving. It was the primitive of primitives, without balancing apparatus, properly speaking, with neither "harness" nor "comb." The threads constituting the warp are brought together in a bundle at a stake driven in the ground.

I also saw them make a thread garment, in the meshes of which are worked fibers of the palm, *Trachycarpus excelsa*. This is the Lolo's mackintosh, the cape that he needs while guarding his sheep in rainy weather. The overlapping of the fibers is so effectively done that the surface offers no chance for water to settle in it, and heavy drops of rain run off without penetrating it at all. It is really a very original kind of waterproof.

PHYSICAL AND MORAL CHARACTERISTICS.

The Lolos are, as a whole, a vigorous and healthy race. Living as they do in the high mountains, where they are exposed to extremes of temperature, with mild days and icy nights, in miserable shelters, natural selection has played and still plays an important rôle in this group of humanity. The weak do not survive, they quickly disappear.

Giving to their fields only the minimum of time needful, and being occupied mostly with their cattle and in hunting for wild animals, the Lolos practically pass all their lives outdoors. They leave home in the morning to return only at nightfall. The steep slopes of the mountains and the abrupt sides of the plateaus cut into deep ravines make walking very difficult, so that this people have acquired an extreme suppleness of muscles, the agility of a deer. So also their favorite habit of the raid and the feud, the circuitous tramp required, keep the men in constant activity, developing a vigor and endurance rare in any other race, even the most warlike on the earth.

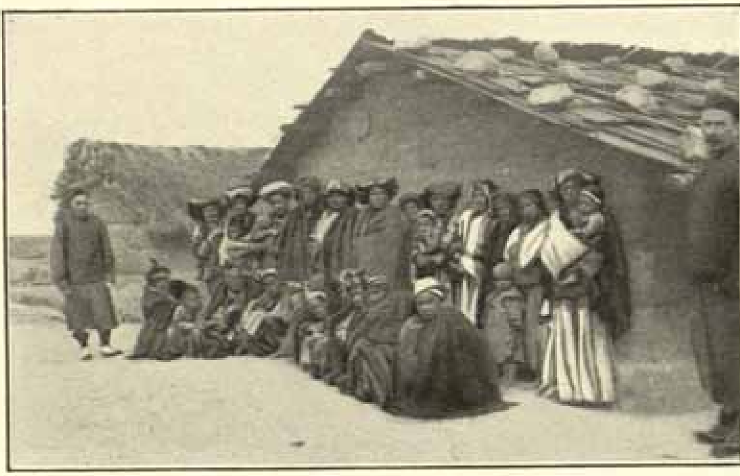


FIG. 1.—A LOLO CLAN. THE WOMEN WITH THEIR LARGE HEADDRESS. TYPE OF HOUSE. VALLEY OF NGAN NING.

FIG. 2.—LOLOS ON THE BORDERS OF MO LÉ GHIO.

FIG. 1.—GROUP OF LOLOTTES OF UPPER NGAN NING. TYPE OF HUT.

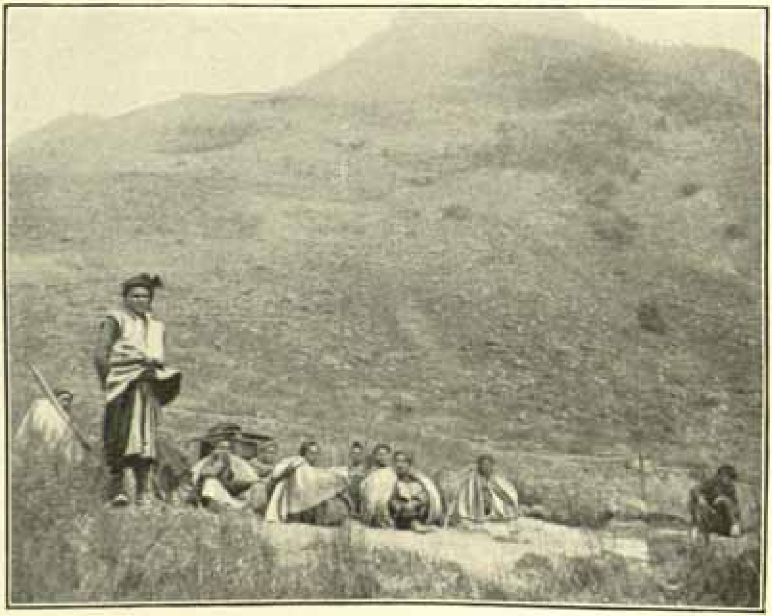


FIG. 2.—A HALF-BREED LOLO-CHINESE AT LEFT, STANDING.

The Lolo has the audacity of his vigorous physique, of his superb vitality. Always in motion, always on the alert, ready to meet any surprise, nothing troubles the mind of this fearless fighter. What he loves most of all is to attack the hated Chinese. It is a wild guerilla attack, brutal and frightful, which makes every door fly open, leaving the enemy at his mercy without the shadow of a defense.

In fights with men of his own race, warriors of his own stamp, he shows a prudence equal to his courage. He displays all the astuteness, all the strategy, of the red man, which he resembles in many respects. He habitually steals his silent march and falls at night with the suddenness of lightning on the hostile clan. It is in a feud above all that he thus fearlessly acquits himself. In these feuds of tribe against tribe they often settle quarrels in pitched battle by broad daylight at some place chosen in advance.

What the Lolo lacks in being a perfect warrior is not certain; it is not courage, nor ardor, for this race, says Father Martin, knows neither flight nor hiding before an enemy. This they do lack—perseverance, that will-power, that persistency of the white warrior, which leaves no respite to the enemy until he is overpowered.

The Lolo is the same in peace as in war; he ignores continuity, laying aside too readily the task he has begun. Like a child he is changeable, fluctuating, a vagrant morally as well as physically. For him life is a jest, hard sometimes, very often even bloody, but it is always a play; he has no other conception of his destiny. Generous, even wasteful, when he can be, careless to our mind, nothing seems to fix his thought beyond the present hour; nothing fixes it unless it is his ardent hatred toward the son of Han. His other enmities, personal or collective, although lively, even ferocious sometimes, as in a feud, do not have the same tenacity; for with the clans he makes truces, some agreements leading even to reconciliation. When fighting with the Chinese, however, there is no truce; this is a fight to the bitter end, a chronic raid; nothing can stop him.

The Lolo in this kind of attack always acts by surprise with such an astuteness and extreme swiftness that it is very difficult to ward off the first effects. The beginning of these dramas is a conflagration, a destructive fire lighted at all corners of the village at once by means of pine torches fixed at the end of the great Lolo lances 13 to 16 feet long. In a twinkling the miserable wooden and bamboo huts burst into flame; cattle, horses, and sheep gallop wildly about, precipitating disorder and greatly obstructing the defense. Animals and men, seeking to escape the fire, are driven back by the spears of the aggressors and forced into the center of the village. The fighters of the assailed clan may succeed by wild dashes in again meeting their ene-

mies in terrible hand-to-hand deadly encounter, when the cutlass replaces the useless lance.

Their bloody feuds too often form painful phases in the life of the Lolo. The clans, the tribes, often exhausted, lose the most valiant of their fighters in these frightful dramas, which at times lead to the extermination of an entire clan. I had with Father Guebriant a very vivid impression of a tribal feud and its atrocities. It was in February, 1907. Invited by a chief of a clan, we were directed toward Ya Long, near a hidden recess in the mountains at a height of 10,000 feet. Fortunately for us, a very rough halting place prevented our reaching the chief's village before nightfall. It was in this village, a mile and a quarter from us, that a frightful drama was enacted during the night. The village was completely reduced to ashes, and the wife of the chief of the clan, wounded by many lance cuts, escaped as by a miracle from the flames. His daughter, 16 years of age, was found dead, the body completely charred. Some slaves perished in the same manner, as also some domestic animals which could not be saved. This was the feud. You would be amazed with what fierceness they attack defenseless beings, for the law that rules the feud is the extermination of the enemy, even the women and the little ones. Not a bit of mercy. This is war more legitimate, if possible, than a fight against an invader. It is the war of the first ages of man, the fight to death, not for social domination, but for the safeguard, the preservation of the race.

Though the Lolo is terrible in his vengeances, he is altogether different in ordinary life. He is a valiant and loyal warrior who fights for the very pleasure of fighting, but always respects his wounded or captive enemy.

The Lolo owns some slaves, but he rarely treats them cruelly. On the contrary, he is kind to them, gives them fields to cultivate, is content with small rent, and finds wives and husbands for them in the tribe. He even gives them wide liberty on condition that they do not strive to abuse it.

He exhibits his unselfishness most of all in his treatment of the feeble, the disinherited ones of the tribe, women, children, and the aged, or those afflicted with contagious maladies, as lepers. All these beings are loved, succored, and never do they try to get rid of them. This warrior, so fierce in his vengeances, is full of compassion for these suffering ones, and he aids them to the limit of his resources.

He is likewise a man of good faith, who is anxious to keep his engagements. If he has given you his word, he holds to it to the end, even if some direct interest, some serious motives, should at any time arise to shatter his first resolution.

I have several times confided myself to the Lolos, placed myself in their hands, without having experienced the least deceit, the

least annoyance from it. They could with impunity have caused my disappearance with profit to themselves, but I am sure that not one of them ever thought of it; that their great desire was to make my journey through their districts the most agreeable possible for me. As the winter's cold is severe in the mountains, a rousing fire was carefully kept burning all night to protect me against the biting north wind. The poor people could not attain the result sought, so primitive is their cabin, so insufficient their shelter; but it was not their fault; they did all that was possible. Above all, the welcome was cordial and entirely unselfish.

ORGANIZATION OF THE FAMILY, THE CLAN, AND THE TRIBE.

The members of the Lolotte family are generally closely united. You find a true affection in the absolute equality of its parts. The wife is never such a slave as is nearly always the case among the Chinese; on the contrary, she is loved altogether as a woman and not at all as the perpetuator of the ancestral cult. Loved for herself, the true, intimate, and social companion of the husband, she always retains an individuality in the family, an acknowledged unity.

The daughter-in-law is always tolerated if not loved; is never ill-treated like the daughters of Han. Children in their turn are much petted and caressed; the girls receive the same care and affection as the boys, and are never considered to be inferior beings as they are in China.

Independence of the family.—From a social standpoint, the Lolotte family is well organized. It enjoys its own independence, forms a unit in the clan or the tribe, with no possibility of servitude or danger of absorption by the autocracy of a chief or a seignor. The husband is the unquestioned head of the family, the wife is a companion and a highly respected counselor. The boy belongs first of all to the father, and next to the chief of the tribe, but not until, under the law of the clan, as a sacred warrior, he attains to manhood at 18 years of age.

Education.—The child receives only a physical education, with no school or pedagogic instruction whatever, even for the son of a grand seignor. It is very seldom that even a nobleman (os noir) learns to read or write. They devote themselves to such exercises only in preparation for future sorcerer priests. The Lolo is in fact a very ignorant man who thinks only of running about the mountains with his pack of hounds and his herds or practicing his skill with the bow or the lance for his daring adventures.

The youth on the day when he becomes a sacred warrior is considered as of age. The young girl is free only at the date of her marriage, however late in life that may be. But she does not need

this legal consecration to enjoy the largest liberty. She comes and goes, visits her distant friends, is absent for long periods without anyone's concern. She has all the right and authority to take care of herself and this care is completely devolved on her.

Order of descent.—Among the Lolos as among most peoples, it is the male line of descent that ranks first. Inheritance is thus transmitted to the son or in case there is no offspring to the nearest relation in the male line, never to daughters or females, not even to the mother or the wife.

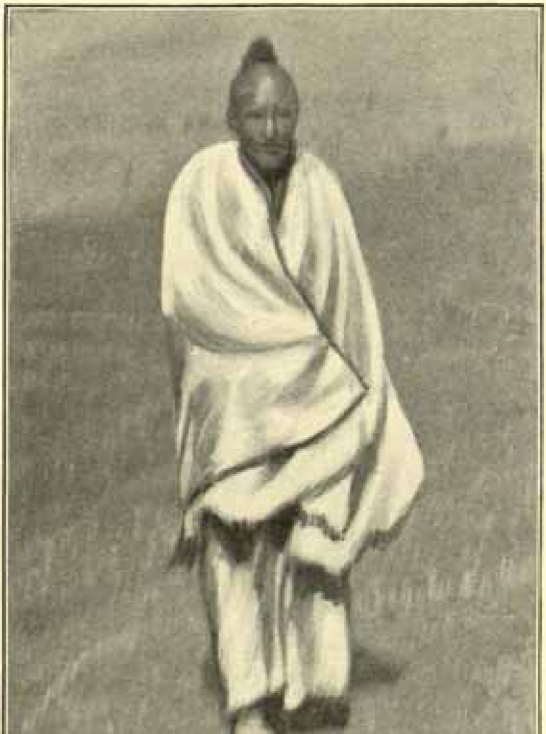
Marriage.—The Lolotte family is based on a formal union consecrated by the parents alone. There are certain traditions on the choice of a fiancé or fiancée which have nearly the force of law in all the tribes, one is that a young man should by preference seek his wife from his maternal grandmother's family, although the young girl can not make her choice in her own clan; the marriage is thus exogamous. The marriage consummated, the young wife returns to her family near her mother. So custom demands. She may remain there some days or weeks or months before returning to her husband's home. The wife is highly respected; if she is ill-treated she flees to her own home, and the husband is severely censured by all the clan, and if he pushes his companion to suicide he may pay for his brutality with his own life.

Social life—Feudal system.—The constitution which governs the clans much resembles the old feudal system of Europe. The tribe is ruled by a seignor, who has his vassals and serfs paying him rent and compulsory service. Each vassal is further required to furnish in time of war a certain number of armed men, the number being determined in advance.

It would seem as if this system would be burdensome to the majority of the people, but it is not at all so. The serfs enjoy a liberty that in the Middle Ages was never known by Europeans. Although they are really slaves, yet when once settled in a clan by marriage, their condition becomes difficult to distinguish from that of a serf properly speaking; they enjoy nearly the same independence. Feudal power is hereditary; election in any degree does not exist.

Castes.—Socially, the different members of a clan are divided into three classes or castes: (1) The Hé Y (Os noirs), which represents the aristocracy; (2) the Os blancs or middle class; (3) the slaves. The Os blanc remains such through centuries and the slave can never attain his freedom. As to the Hé Y, there is no social decadence possible for him, he can never fall into the middle class. It is proper to add that a marriage under any circumstances can effect no change in caste.

Justice and penalties.—There is no written criminal code no more than there is a civil one. It is tradition, custom, certain ancestral



TYPE OF LOLO OF THE LOW CLASS, SHOWING THE VAULTED SKULL, TENDING TOWARD A POINTED ARCH.

FIG. 1.—A LOLO OF THE HIGH CLASS AT LEFT.
A LOLO OF THE LOW CLASS AT RIGHT.

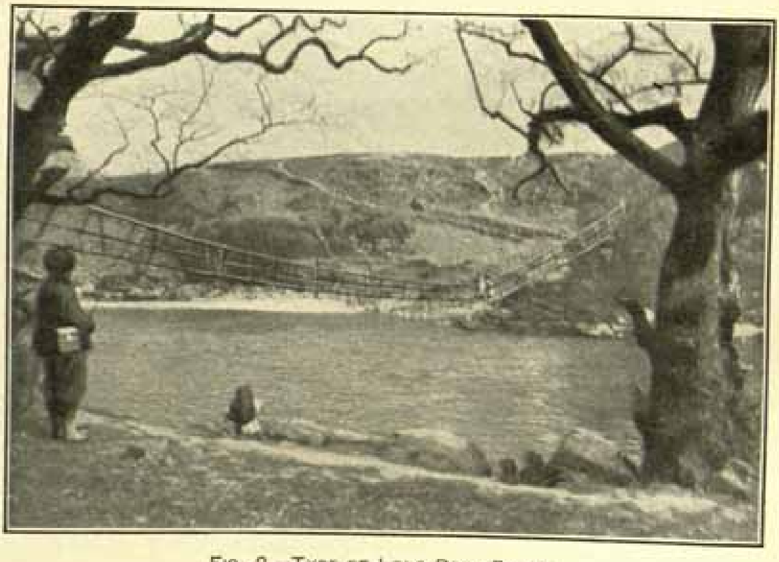


FIG. 2.—TYPE OF LOLO ROPE BRIDGE.

decisions, that hold the place and the authority of law. It is a primitive form of justice yet dignified and equitable. The ordinary theft as defined in Europe exists but little in the clans. If perchance a petty theft is committed, it is amicably arranged, but restitution is obligatory. If it is repeated and a serious falling out is caused between two or more families, the culprit is imprisoned by order of the seignor. If he will not mend his ways, but becomes a menace to the peace of the clan, he is drowned in a mountain torrent.

What the Lolo practices most of all is resenting by force of arms between tribes and clans that which a family or a group of such consider to be an injury, or they inflict on an adversary a damage equal to that received. This is not robbery. It is a legitimate ransom for a prior villainy. But the one who suffers most from this punishment by retaliation, constantly applied, is the Chinese. In pillaging at will with nameless impudence, the Lolo declares that he is regaining by his rightful usurpation his own valleys, his fertile fields, which the other gained by ruse. He scatters animals and men, desolates entire villages, ruins special districts—it becomes to him a sport, a pastime. There is no punishment for it. They rarely oppose the return of the pillagers, and there is little risk of being punished in their mountain homes.

Murder for robbery or personal vengeance is almost unknown. When a murder has been committed, the criminal is hung as soon as possible. If not he is buried alive in the forest, or, fastened to a tree in a solitary place, he dies from starvation or from the teeth of wild beasts. Some tribes inflict punishment by fire, each carrying his fire log to the place appointed for the execution.

If the murderer belongs to a different tribe, it means war at once and unrelenting. There is no isolated action by the family of the victim, but a getting together of all the clan—all the tribe, if necessary. The bloody feud is then at its height—vengeance for all.

Ownership of property.—A ruling principle in the property system is that the products of the soil belong to the one who cultivates the land and not to the chief of the clan, though some contracts are made for renting and farming with return in natural products.

The vast expanses, stretches of forest land, are by no means owned by the seignior, but they are the property of the clan as a community. The os noir or highest class has his own lands that he makes valuable through the aid of his serfs, and he has no right to increase them by monopolizing those of his neighbor's. He is also forbidden by the right of common custom from possessing himself of a heritage. The chief of a tribe has none of the prerogatives of a petty tyrant king. His rôle is chiefly that of a patriarch, limited to the guidance, the

counseling of an impetuous race, exceedingly jealous of their rights and of their liberty.

Civil liberty.—In this case, as in others, there is no written law; it is tradition which continues to have the force of law. In business transactions of all kinds there is no other guaranty than that of the pledged word of mouth. There is used, however, in the case of an employer, under certain circumstances, a stick cut with a series of notches and split through the notches from end to end like a tally stick. Each of the contracting parties takes one half of the stick; if a dispute arises, they place the two pieces together and the one disloyal is readily revealed.

RELIGIOUS IDEAS.

Religion.—The Lolo religion is based on a belief in spirits, beings immaterial, good and bad. He seldom thinks about the good spirits, even ignores them, but the evil spirits, on the contrary, to which misfortunes and maladies of all forms are attributed, become objects of solicitations, of formal supplications by the sorcerer priests; never by the interested party, for to be able to appease the evil spirits some sacrifices are very frequently offered, though there is no true cult, no real ritual. The prayer in the form known to us does not exist at all. The Lolo fully recognizes a sovereign God, omnipotent, Creator of all things, but he has not thought of building a temple to Him, nor of worshiping Him under any image whatever. For this God and the series of good and evil spirits there is only an official, the sorcerer of the tribe, whose rôle is limited to the practice of certain rites and the rendering of oracles. The sorcerer priest is also a healer, so they think, especially when the illness is considered as due to the entrance of an evil spirit which can be driven out only under the irresistible action of certain rites. In serious cases, when the adjurations have no effect, a sacrifice is made, by the burnt offering of a domestic animal, to the recalcitrant spirit—a cow, a goat, a lamb, or a fowl. The kind of animal to be offered is determined by an examination of the cracks made by fire in the shoulder blade of a goat or sheep.

If two fissures appear in the form of a cross, it is a good sign, the patient will be cured. If some fine cracks cut the arms of the cross, the result is doubtful, the spirit makes some restrictions, some further rites are required. It is then not a fowl that should be offered, but a cow. The sorcerer then repeats the process with lighted tinder. A new animal is sacrificed. The heart is offered to the sick one and must be eaten by him. The animal is not consumed on a brasier, as was done by the children of Israel, but it is eaten by the sick one's family, which offers to God only the blood of the victim.

In religious matters, the Lolo's mind presents two characteristics in strange opposition. There is not only a primitive belief in the

direct intervention of spirits as the agents of all their misfortunes, even of sickness, but, on the other hand, there is that skepticism of ancient civilizations which disdains to give alms to the deities by prayer or to erect temples or altars, or to prostrate or humiliate themselves; they despise fetiches and incense.

Every Lolo is possessed of a soul, a living and active though immaterial substance, impalpable, and invisible. At the death of the one which it animates, what becomes of this soul? If it has broken no sacred law, it remains in a condition of transitory rest, not really unhappy, but without joy, without positive happiness. It will expire, on the contrary, if it has done evil or violated the precepts of the traditional morals of its race. I must tell you that the Lolo shows but little respect for his deities; it is so little even in the case of the good ones, from whom he has nothing to fear, that he considers them as mere guardians of the body, protectors or aids of the lowest order.

Does he not say in the ritual chants preserved by the sorcerer priests: "May the good spirits go before you that the nail of your toe be not bruised! May the good spirits precede you, clearing obstacles, that the nail of your hand be not bruised!" Thus is chanted the celebration of marriage. They also add: "Protect by day, watch by night! May the good spirits hearken to you, that not one of your hairs may fall!"

ORIGIN OF THE LOLOS—TRADITIONS.

Father Martin gives the following versions on the origin of the first Lolo:

1. In very ancient times a man fell from the sky to the earth; he was naked. Then there fell another man and a woman and these two were married. The legend is silent as to what became of the first man. Then the the herb "jegu" grew, then ferns. Soon there were born a bear and an ape. Thus was made the human race, for the bear, man, and the monkey are of the same nature.

2. Man appeared on the earth, and there were born from him the bear and the monkey. The legend does not explain this reversed Darwinian theory.

3. First fell a white man, then a black man, then a red man; they had no clothes, but dressed themselves with leaves. These men remained a certain time, then disappeared. The sky then sent a couple that brought into the world two sons who, deprived of wives, could naturally not have posterity. Again the earth found itself without a single human representative. Then there came a new man, who also died without posterity. A woman then appeared, a sort of harpy, who remained childless. Finally there fell from the sky "Omou," who left 10 sons and daughters, and thus the entire earth was peopled.

Deluge.—"When man, increasing and multiplying, had invaded the entire world, then burst forth the deluge. On all sides the water gushed forth, from mountains, rivers, clouds, and fields. All mankind died except one brother and his sister of the ancient line of Omou. They cut down a tree (*Eloeococca vernicifera*), the sap of which is

very commonly used in China as varnish, somewhat resembling our fig tree, and built an ark in which they took refuge. Then the ark floated on the water over all the land. The waters having at last receded, the ark rested on Olou Mountain. The brother and sister having thus escaped the catastrophe that destroyed all other human beings, joined in marriage and bore numerous children. From the two older ones, the first were of the Sifan type (an aboriginal race of the Far West very near Tibet), the second the Lolo type, and the youngest the Chinese type. Fearing a new deluge they undertook to build a very high house. A Pou Ouosa (a deity) tried to dissuade them from this work, but they would not listen even to his threats. But when the workman on top of the structure said: 'Bring a beam,' and the one who was below sent up a stone, then, no longer understanding one another, they separated. The Sifan emigrated toward the north, the Lolo to the the east, and the Chinese to the south."

There is another version of the deluge. "Two brothers were tilling the ground. The god, A Pou Ouosa, said to them: 'Do not dig.' But they dug the more. A Pou Ouosa repeated: 'Do not dig, the end of the world is coming.' One believed the god, the other not at all. To the one who believed, A Pou Ouosa said: 'Make an ark of wood, you and your sister, and when the waters shall come you shall float within.' He said to the other: 'Build an ark of iron.' The deluge came; the brother and his sister who had taken refuge in the iron ark were drowned; the wooden ark floated and saved those who had believed in the word of God. The waters having lowered, the brother and his sister came out of the ark. The god, A Pou Ouosa, then said to them: 'There are no human beings on the earth, you must marry.' They hesitated, but such miraculous things were going on at that moment before their dazzled eyes that they yielded, understanding that it was the will of A Pou Ouosa. Their first offspring had flat feet; this was a bear. Then there was a second which bore some resemblance to a real man; this was a monkey. At last there came into the world a being that looked like a human being, and this one was really a man. Whence comes the tradition: 'The bear, the monkey, and man, all of the same nature.'"

Funeral rites.—In contrast with the Chinese, the Lolo of Kientchang has no cult for the dead, for ancestors. When a member of a clan has drawn his last breath, they carry him in a wooden box called the "mortuary box." They burn the body lying in the foetal position and all is ended. They do not even gather the ashes to take home. And in the future no kind of religious rite will be rendered to the shades of the deceased; he has absolutely disappeared from the clan.

In order to complete this review of the principal characteristics of the Lolo mountaineer, I shall here recall an interesting conversation

that I had with the chief of a large tribe in the valley of Ngan Ning, the seignior os noir, Vou Ka. I had won his confidence, which is the reason why on one fine day he confirmed or corrected a series of important statements that I had recorded during a preceding journey. These are only brief résumés but are very instructive.

Utensils.—It is said that there is one industry of the greatest necessity that is found among all races of men in every region on the face of the earth; that is pottery. The peoples of Africa and Oceanica, even in a savage state, fashion all sorts of earthenware receptacles from clay or sandy material. Among the Lolos, however, there is not a trace of native pottery. The bowls and teapots that are occasionally seen at the home of an os noir are of Chinese make, either purchased or presented. In the houses of Leang Shan or Mao Nieou Shan, you sometimes see a wooden bowl in the form of our soup tureen or fruit dish. It is generally well shaped and carefully turned, and I have recognized in this important detail the Chinese influence.

Money.—The Lolo, for commercial transactions, has no kind of native money. Though you may see some brass and silver coins, they are of Chinese origin. All he knows is to trade by direct exchange of merchandise, common barter.

Weights and measures.—There are no weights or measures among the Lolos. When he sells grain he gives you 1, 2, 10 loads, each representing the quantity that a man of ordinary strength can carry on the head, or, more rarely, in a basket. When he sells you any commodity he poises it in the hand or in both hands and tells you its value according to the weight estimated, which corresponds to no definite unit.

Professional trades.—There are but few trades. The only definite ones are weavers, carpenters, and blacksmiths. What particularly astonished me was that there are no tailors or dressmakers, properly speaking. Their clothing is made by the adults themselves. The servants may work for their mistress, the "ouatze" for the seignior, but there is no specializing of work in the ordinary meaning of the word.

Clothing.—Before the coming of the Chinese and their attempts at conquest, dating from the fourteenth century after Christ, before the Chinese had influenced the aboriginal customs and effected commercial exchanges, the Lolo dressed in the simplest, most primitive fashion. The women's skirt, the men's trousers, were merely a piece of very coarse woolen cloth, draped around the hips and reaching to the knees in numerous vertical folds. A cord held this cloth around the waist. The costume was completed by the mantle so characteristic of the Lolo people, the part of its dress that without alteration has come down to the present time. The mantle is also made of a large piece of coarse cloth. It is nearly square, and not

skillfully tailored, as in our country. It adapts itself to the shoulders, and is fitted to the neck by a cord passed through a fold in the upper border of the piece of goods. The mantle and the skirt comprise the entire costume.

The Chinese at one time offered for sale their cotton fabrics and recently those imported from Europe. The Lolos now purchase these, and even in the remote districts of Leang Shan nearly all the men wear cotton pantaloons and blouse, and the women wear a skirt and waist of like material. I have, however, in the mountains of Mao Nieou Shan seen some women slaves wearing coarse, gray or black, woolen petticoats, which are never white, though you frequently see white mantles. The petticoats are the natural color of the wool. I have not ascertained whether the Lolos know the art of dyeing fabrics, but at the present time, however it may have been heretofore, it is certain that for a long period the cotton fabrics spotted with bright colors (red, green, blue, and violet), which the women as well as the men have sought for the turban and their blouse, have been furnished by the Chinese. Once, says Vou Ka, the turban of the young man, as well as the hat of the young woman, or the bonnet of the young girl, were of wool. The fleece of his sheep furnished the Lolo with all his clothing, even his head covering.

The carpenter is the man who is but little employed, who works both with the hoe in the field and with the axe in the village. The squaring of timbers for structural work is so primitive, mortising so rarely done, the framing so rudimentary, by simply laying beams together to hold them in place, that it is useless to look for art from the Lolo carpenter.

As to what we term a cabinet maker, that profession is never found among those tribes, for the simple reason that the Lolo considers all furniture as useless.

The shoemaker would have little to do, for the Lolo either goes barefooted or wears straw sandals that nearly anyone can plait.

The blacksmith trade is the most important of all. Hoes are needed for the farmer, as well as a small plowshare, a very primitive kind of implement borrowed from the Chinese. And above all, the Lolo must have iron heads for lances and arrows, and ordinary blades for cutlasses, fine blades being purchased from the Tibetans.

The blacksmiths make nothing at all for structural work, not even hinges or handles for the doors; not a nail or a bolt—some strips of bamboo or bindweed answering for all these things. This is because the simple Lolo house is built as by a turn of the hand and can be completed in a day. This fact was proved by me several times, and I was not at all astonished in the case of the ordinary hut, the real home of the primitive mountaineer. Of course, more care is taken

in constructing the larger and more comfortable homes adapted from various Chinese types.

The mason and the locksmith, like the shoemaker, may be passed over without mention.

There are no merchants in the clans, properly speaking, nor shops. Each family supplies itself or receives from the seignior the material necessary for food and clothing. The real necessities of life are less complicated than one would imagine. The Chinese merchant never settles in the villages nor in the territory of a tribe, but sells his articles through a colporteur, traveling from group to group. He is very largely paid in cereals, wool, or animal hides.

After this review of the social and economic organization of the Lolos, various other subjects were discussed, and Vou Ka responded with no less clearness. I already knew much about these people, but it seemed very important to verify my first observations.

"Is it true that the Lolo does not wash himself; that he never disrobes to sleep?"—"He bathes in summer in the mountain streams, and washes his feet throughout the year at dawn of day, but has not felt the need of other washing. Our women, our housekeepers, with a strict sense of cleanliness, never knead corn or buckwheat flour without having carefully cleaned their hands and forearms in plenty of water. Otherwise they are not particular about washing; it is really useless. Our people are not accustomed to disrobe at night. He sleeps, as you have seen at Ta Cha Chou and at Y Lé, crouched before the fireplace wrapped in his mantle. We are always on the alert, always ready to face an approaching enemy or to rush to the call of the chief for an attack."

"Did you know of rice before the advent of the Chinese? Was it cultivated by any of the tribes?"—"That cereal was unknown to us. It was the Chinese who brought it to us and taught us how to cultivate it. It is, however, as you know, used only as a delicacy by such of our clans as possess rice fields."

"Is it true that you can prepare meat in such a way as to obtain a powder that will keep for a long time?"—"Our ancestors taught us to cut meat into thin strips and to dry them in the air or before a fire. When once hard and brittle, the strips are pounded in a mortar and reduced to fine particles. This meat powder will keep in good condition for two years when the desiccation has been thorough, but only one year or less under ordinary conditions. It is prepared for consumption by dissolving it in water."

"To make a fire did your ancestors have any method other than that now employed—that is, the flint? Have they any other processes of lighting than by chips or sticks of pine or fir?"—"No; they light the tinder, as you know, made from tops of the immortelle and other plants, by striking the flint with a piece of iron. Our ancestors never,

like the Chinese, used colza or other oil for illumination; we use that, and also pine cones held in the hand or fastened to something as you have seen."

I then called attention to the fact that coal, so abundant in these regions, is little used by the Lolos. In the clan of Vou Ka they have used it for only the past 40 years. In the different districts that I traversed, places far from the centers and inhabited by various tribes, I never saw them make anything but wood fires.

The chapter on religion is short, but Vou Ka declares that the tribes have no poussahs (grotesque religious images) such as the Chinese have. They never pray in his clan nor in others elsewhere. His god is his tuft of hair rolled up in his turban. This is his "corne." "Is the god represented by the tuft itself, or does he dwell there as an immaterial being?" I could not make my meaning clearer, yet Vou Ka appeared not to understand it; such fine distinctions were beyond his comprehension. When they make an offering, there is nothing religious or sacred about it; they drink some brandy mixed with blood, the blood of a dog that has been sacrificed.

Loutze Ming and others had given me some information upon the penalties or crime in the tribes or clans and I wished to hear them confirmed by Vou Ka. He explained them clearly, summing up as follows the common law—there is no written law:

> He who has killed should die. If there should be any attenuating circumstances they permit the criminal to execute himself either by water or by the rope, but if he hesitates they drown him at once in the mountain torrent or else hang him. There are no such horrible tortures as one finds among the Chinese.

Vou Ka confided to me that his people have none of the loose manners of the Chinese, and it is true. The Lolo has a very high idea of that sentiment which we call modesty.

This modesty is so real, so deeply rooted in the intelligence of these primitive people, that it is the depth of disgrace to a woman and to all her clan likewise if she should expose her naked body. I can cite a curious striking instance of this characteristic, really grand, all that a genuine sacrifice involves.

When two tribal enemies have long been in strife, so that frequent and deadly encounters cause desolation and ruin among families, with no hope of reconciliation, the wife of the chief of one of the tribes resolves to sacrifice her female modesty, in order to bring to an end the dreadful feud. Her decision made, she hastens by devious paths, on the day fixed for the encounter between the two bands of warriors, in order to reach the place before the fight begins.

Quickly, then, none daring to hold her back, she casts herself between the hostile ranks and in a becoming manner, in simple words, beseeches the fighters to put an end to a carnage which has lasted too long, which has threatened the annihilation of the brave and

strong of both tribes. "Do they still wish to yield to their hatred, to sacrifice themselves, forgetting that their wives, their children, and their white-haired aged ones will soon have no protectors?" If her prayer has no effect, as the warriors stand like statues, savagely keeping silent, she begs them for the last time to listen to her. But if the lances be not lowered, then heroically, with a bold gesture of sublime immodesty, she throws aside her clothes and stands entirely naked before the ranks of men. A clamor then breaks forth, vibrating through the depths of the ravines, mounting to the summits, a clamor of shame and of despair hurled forth by the warriors of both clans; this time the lances are lowered and the deadly feud is closed. By sacrificing her modesty the woman has triumphed; by this great sacrifice all their hatred is thus suddenly ended. There is shame for all these men for having provoked such an act by a respected wife of a chief, there is shame, but endured entirely by them! They tremble with horror for a long time, recalling it with anguish. Modesty! thou art not then merely a word in the land of the primitive Lolo!

I will give an amusing account of the ceremonial accompanying every Lolotte marriage; translated by Father Martin.

As soon as the fiancée arrives in the tribe of her adoption the marriage is celebrated with great pomp. If the family is well to do, the sorcerer is called with his book of traditional conjurations or adjurations and threats against evildoers. His rituals are said, a cup of "chao tsieou" in the hand which he pours out on the ground at the end or toward the four points of the compass; this is the ritual gesture. His principal rôle is to clear from the path of the young couple the evil genii, but he must also make some wishes for their happiness, for abundance of good things of this world, for posterity, and for long life. His cup of alcohol in hand, he cries:

A libation! A libation to the protecting spirits above, to the god Apou Ouosa, to the shades below, to the spirits of the mountains, to the spirits of the valleys, to the spirits of the East, to those of the West, to those of the North, to those of the South. A libation to you, spouse X! To you both, may the spirits on high give you full measure of happiness; likewise the spirits below! May the god Apou Ouosa load you with blessings! May he protect you by day, defend you during the night! May there come to you abundant posterity: some sons for the father, some daughters for the mother. May the sons live 99 years and the daughters 77, and may such posterity continue for 1,100 years! Protection by day, watchfulness by night! To you two, when you shall spend the day on the mountain and should the evil spirit come, may the evil one fly away! If the evil spirit comes, may it fly away! When the newly married husband shall enter or leave his house, if the evil one seeks to accompany him, may he be powerless, may he fly away! If it be that evil spirit X., may it fly away; if the evil spirit M., may it fly away; if the evil spirit N., may it fly away! If the newly married spouse goes into the village and the demon of the thickets should come toward her, may it fly away! If it be the chief of devils, may he flee! May the witches henceforth vanish! May evil omens cease! Away misfortune! Away sickness! You two married ones in your white old age, may you have youth with teeth complete! May

the guests come in crowds to the wedding! Enter it right, be at peace, return contented! In drinking at the siphon, do not drink to suffocation; in eating of the meat, do not choke yourself! Protection by day, watchfulness at night! May the good spirits listen to your prayers, that not a hair of your heads may fall!

POLITICAL ORGANIZATIONS OF THE LOLO COUNTRY.

I have said that the Lolos are divided into clans, into tribes, which not only lack a common bond, but are often in conflict, weakening and ruining themselves in bloody feuds. It is seldom that two or three tribes join against an enemy. When such an agreement is made it never lasts long, but is broken as soon as the expedition ends. The most powerful of the tribes, called Lo Hong, which can put in the field 10,000 fighters, some say 20,000, has never been able to assert its supremacy over the smallest tribes so as to make them submit to its law. Political isolation of the clans, favored, if not caused, by the nature of the soil and the wild character of the region, still predominates. It is kept this way by its pride, a peculiarity of the seigniors, and of the least little chief who can not conceive of an authority superior to his own. Scattered over a wide region, in small villages of 10 to 20 households, rarely more, connected by simple paths or trails often dangerous, the Lolos do not form a compact body of people that might be termed a nation. They are still in a stage of political evolution. No village, even that of the most powerful tribal chief, has yet been raised to the dignity of a city of the lowest class. An assemblage of a hundred families in a sort of small intrenched camp is altogether exceptional.

Origin of the Lolo.—How was it that Kientchang came to be the home of the Lolo; is it claimed that he was merely an immigrant in an ancient epoch? Why did he penetrate into this wild and inhospitable mountain pasture? Did he come to conquer it, driving back or uniting a more feeble race, or was he only a refugee in quest of a shelter, a human outcast driven aside by the flood of great invasions? Did he flee from the west or from the east, from Birmanie or some region of Szech'uan, or from a much greater distance? Some traditions place him as coming from Shensi, but it would be imprudent for any one to think of solving the problem at this time. It requires long and patient research on the conditions of this people's existence, its lack of culture rendering the study a very intricate one. It is likewise very difficult to determine its racial origin. The existing types present some variations, some ethnic order, that indicate a very varied ancestry. There is an undoubted mixture even in the noble caste, the Os noirs, among whom you would search in vain to make out one well-defined race.

THE PHYSIOLOGY OF SLEEP.[1]

By R. Legendre.

Sleep is one of the most necessary functions in our lives. It occupies a third of our existence. It is therefore not at all strange that it should be a subject of deep study and research by numerous investigators; in fact, poets, philosophers, psychologists, physicians, physiologists, and others contemplate the subject and examine it from their several points of view.

To poets, according to their feeling at the moment, sleep is in turn distasteful or pleasing. Wishing for action, they call it "brother of death," but more frequently, absorbed in reveries and dreams, they banish that thought, for sleep no more resembles death than does a smoothly flowing stream resemble the calm surface of a lake.

> Day is for evil doing, for weariness, and hate.

Night is the well-beloved, she who brings tranquillity, repose, and dreams; and the poets invoke her, begging her to stay.

> Oh, venerable night, from whose depths profound
> Through endless space peacefully flow
> Broad silvery streams from countless worlds,
> And into man pours calm divine.
>
> * * * * *
>
> All life is mute, for 'neath thy spreading wing
> It drinks of sleep at shade of eve,
> A milk deep and wondrous, that
> All lips imbibe in silence at thy dark breast.
>
> Sully Prudhomme.

Sleep seems even as a god who, with forehead crowned with poppies and wrapped in dreams, slumbers in the depths of an obscure grotto, isolated by the river of forgetfulness.

To philosophers, also, sleep is a subject of deep thought. It opens up, indeed, two great problems: First, one may ask what becomes of our consciousness during sleep, and the question is an important one when we agree with Descartes that thinking is proof of our existence. Should we believe that the mind acts continuously in our dreams?

[1] Lecture delivered May 7, 1911, at the National Museum of Natural History, Paris. Translated by permission from Revue Scientifique, Paris, forty-ninth year, June 17, 1911.

Or is our consciousness discontinued? If it be not continuous, how can we account for that deep feeling that we have of the unity and continuity of our personality?

Moreover, how do we distinguish the dream from the reality? Descartes says:

> How many times at night have I thought that I was in a certain room, that I was clothed, that I was near the fireplace, although I was undressed and in my bed! It is plain to me at this moment that it is not at all with sleepy eyes that I behold this paper; that this head that I nod is not at all drowsy; that it is with design and deliberate purpose that I extend this hand and feel of it. What happens to me in my sleep is not near so clear and distinct as this.

We certainly distinguish far more clearly the incidents of our daily life than those of our dreams. Yet, after all, who has not asked himself on waking up whether these thoughts were visions or the reality? And how can he be sure which is correct? This explains the perplexity of Pascal when he says:

> Who knows whether that other part of life when we think we are awake is but another kind of sleep, a trifle different from the first, to which we are aroused when we think we are asleep?

These two conceptions of a continuous personality and of the reality are subjects of psychological studies relative to sleep. Not only do psychologists observe these in respect to themselves but their variations in other persons. And they have demonstrated some curious phenomena. Though most men have a distinctive and strong personality, there are those in whom personality is disorganized, and some have come to have two absolutely independent personalities, as the hysterical individuals observed by MacNish, Azam, and others. Though the majority of men clearly distinguish the genuine from dreams, it is equally true that some can not make this distinction and take their dreams for realities and realities for dreams. Disorders of the personality and the perception of the reality are, however, pathological conditions and their study is altogether more within the domain of the physician than of the psychologist. The physician devotes himself to numerous problems pertaining to sleep. Aside from the hygiene of normal sleep which is within his jurisdiction, he must also consider its disturbances, such as hysteria and various conditions more or less comparable to sleep, as hypnotism, lethargy, anesthesia, coma, sleeping sickness, and the like.

Hysteria is an illness that most disturbs sleep. Besides the conditions of disorganization of the personality and the loss of perception of the reality of which I have spoken, hysteria presents other disorders, either provoked, as in hypnotism, or involuntary, as in lethargy. A discussion of these phenomena would be very interesting, but it would take too long a time.

Unconsciousness caused by chloroform, ether, and other anesthetics bears only a distant relation to natural sleep. It differs, among other things, in the impossibility of exciting an awakening. Coma differs still further, for it is very close to death; while sleeping sickness is comparable only in name, for it is caused by parasites and produces torpor only in its last stages. Laying aside all these questions, the exposition of which would require several lectures, I will talk to you of natural sleep alone, and of that only as a physiologist, for the physiologist also has his opinion to express upon the subject.

Generally the physiologist hardly speaks of sleep, and though it takes up the third of our lives, it is far from occupying a third part of physiological books. A page or a few lines is all we find about this subject even in the largest treatises. It is not only studies and definite theories concerning sleep that are lacking among physiologists, but precise observations are rare because they are difficult. How, in fact, can you experiment upon a being wrapped in slumber without waking him? How can you produce genuine sleep, which is really a voluntary act? How distinguish natural sleep from the state of torpor so often produced in experiments? Though all these questions are not answered, yet the subject seems to me to be of enough interest to warrant my showing you the actual conditions of this great problem. Let us first of all try to understand what that is which is called sleep, though it is much easier to tell what it is not than what it really is. It is certainly not like a narcotic state, nor hypnotism, nor the lethargy which I just mentioned. It is different from the changing rhythms of certain plants, as the truffle, the sensitive plant, and it differs also from the hibernating sleep of the snail, the marmot, and many other animals. But what is it exactly, and what do we know about it? There are definitions enough by psychologists as well as by physiologists, but none are satisfactory, and I believe it would be better to at once describe the mechanism of sleep rather than tediously to hunt for its precise formula.

Let us then examine a man asleep, a man in preference to an animal, for to external observations we can add a description of what we feel in ourselves. Contrary to what one would be inclined to believe, we do not go to sleep because we are fatigued, for great fatigue may indeed provoke insomnia, just as a long walk in the country will cause great exhaustion in a person who is not in training and often render difficult the customary slumber. We actually go to sleep either through habit or through a spirit of indifference to our surroundings. Through habit, we go to bed every evening and sleep all night. The sight of our bedroom, of our couch, the darkness, the silence, recall the habit, and incite us to slumber. But this is not merely a habit, for it varies with each individual. One who goes to bed regularly at 10 o'clock becomes sleepy each evening at that hour,

while another who has no fixed time for retiring does not feel the need of it at any special hour. Some, again, can not sleep in daylight, some heartily enjoy long morning naps, while others work by night and sleep through broad daylight. The best proof that a special time for sleep is merely a habit is that we can readily change the hours. If I wish I can pass this night without sleep, and likewise, if such be my desire, I can go to sleep as soon as this lecture is finished. An experiment may oblige us to pass one or even two nights without sleep, and without affecting the accuracy of our observations. A physician is awakened for an urgent operation; he performs it without a mistake. Who has not in mind the story of entombed miners looking for deliverance many days without ceasing? Not only can we sleep or stay awake at will, but we can regulate the duration of our slumber. Most persons sleep eight hours daily, but we can sleep longer if we make it a habit, and much less if we need to do so. Napoleon slept only three or four hours a day. What better example of habit is there than that of some children who can go to sleep only after the mother's good-night kiss, and that of persons who can sleep only in a certain position?

But our sleep is not always due to habit. The sight of others asleep near by, a monotonous or even a varied noise, have put us to sleep, without our thinking of it. So some persons fall asleep at their studies, at lectures, and even at the opera. The process of digestion and fatigue certainly favor sleepiness, but its true cause is indifference. To yawn, to doze, are signs of weariness. "They doze," says Bergson, "in the exact proportion to their lack of interest in their surroundings."

However, one must not believe that sleep is either merely a habit or an act of indifference alone for it is equivalent to a necessity, and we could not deprive ourselves of sleep without serious consequences. An animal deprived of sleep dies after a few days, much sooner than if it were deprived of food. We generally sleep longer and much sounder after prolonged wakefulness, when our attention has been most sustained. Sleep refreshes, it revives. If it is an instinct, a habit, it is an excellent one, and we would not know how to do without it.

You know the signs that are forerunners of sleep. The first is a sensation of pricking or tingling of the eyes, which is explained to little children as the coming of the sandman. Then we begin to gape, the head grows heavy, the limbs weary, the eyes close, attention vanishes, the head bends, and we doze. For a time we still are conscious of the things about us, but presently the sense of smell and of touch are gone, the hearing weakens. With these last sensations are often mingled shapeless dreams, with little intensity, incoherent, then all ceases, our consciousness is gone, we sleep. Sleep varies in

duration; the newly born slumber 18 to 20 hours a day, adults about 8, and the aged only 5 or 6 hours. It varies also in intensity. Sometimes we can sleep "with clinched fists," and "a report of a cannon would not awaken us." At other times the least noise wakes us up. Then, certain noises disturb us more than others, and not always by their intensity; just as a sleeping mother is awakened by the slightest movement of her sick child and does not hear other sounds much louder in the street. The soldier in his tent is not awakened by the noise of his comrades returning late, but the sound of the bugle wakes him instantly. Clocks strike every hour of the night, but only the customary hour for rising awakens us. A passenger on a steamer sleeping amid the whirr of the propeller may be awakened by the cessation of the sound, so with the miller sleeping amid the clacking of the mill.

Sleep is not continuous from beginning to end. We have marked its intensity at different periods by observing the strength of irritation necessary to awake the sleeper and we have noted that it becomes deeper and deeper up to the second hour, then gradually diminishes in intensity until the awaking. Waking up, like going to sleep, is premeditated, spontaneous, or provoked. We awaken either because we have wished it, or have slept enough, or because of some exciting cause. Many persons can wake at any hour that they have previously fixed upon, and some never make a mistake of more than a quarter of an hour. In some cases the waking up may be due to habit. Sleep may cease the same hour each day because of a customary noise, as of the ringing of a bell or the passing of a vehicle, or at the dawn of day. A person may spontaneously end his sleep because he has slept enough, having passed the customary 8 hours in rest. But the best-known causes of waking are external or internal sensations. Hunger, thirst, cold, may awaken one. Disordered respiration or circulation, due to an uncomfortable position, produces wakefulness, often accompanied by nightmare. The emotion caused by certain dreams breaks our slumber. If I dream that I am going to be crushed or that I am drowning or falling, I wake in agony before the dream is ended. An unusual noise, a sudden gleam of light, likewise awakens, besides other sensations that I will presently mention.

In waking up we repass more or less rapidly through the same conditions as in going to sleep. Our consciousness gradually returns, our eyes open, and we remain an instant half awake, all ready to go to sleep again if the cause of the waking should cease; but if it continues, we take account of our condition, recover consciousness of our surroundings, recognize the time, the light, sounds, and, completely awake, with renewed knowledge of the real, we yield to our first judgment, recover our memory, and decide on our actions.

This observation that anyone can make leads us now to examine some of the definitions of normal sleep.

We may say with Barthez: "Sleep is a function of the vital principle alternating with being awake," or, better, a vital function alternating with being awake. With Sergueyeff, we recall that it is necessary and periodic; with Manacéine, that it is the period of repose of our consciousness; with Bergson, a reaction from indifference; with Claparède, that it is an instinct or a habit. All these definitions are exact and their resemblance characterizes the phenomena clearly enough. But if we would go further and know why we go to sleep, we must not only observe a man asleep, but more than that, we must analyze the action of various bodily functions during sleep.

Making experimental observations of sleep is peculiarly difficult. There is great risk of disturbance merely through one's presence, by noise, or on account of apprehension or irritation caused in the sleeper by the pressure of the instruments resting on him. Although there are difficulties almost impossible to overcome, yet physiologists have succeeded on several occasions in making important experiments upon sleeping men.

First of all, certain observations require no instruments, such as measuring the number of respirations or the beating of the heart. Then one can become accustomed to going to sleep while holding an instrument which will register various movements produced during sleep. Sometimes you come across cases where, as the result of a fall or from a surgical operation, there is an opening in the skull exposing the brain. By observing such cases we can actually see what happens to the hidden organs during sleep. All these methods of observing have resulted in establishing certain data that I will briefly review.

Digestion goes on effectively during sleep. The evening meal is digested during the night. The midday meal, especially when it is heavy, causes drowsiness in some persons. The proof that digestion is active in the night is the fact that waste is generally accumulated in the morning. Furthermore, in the case of persons who have died during the night the autopsy shows that digestion is further advanced the longer the period intervening between the last meal and death; from this fact the probable time of death has been indicated at coroner's inquests. The activity of the stomach indicates the cause of the anæmia of the brain which induces sleep. To the hygienist, digestion during sleep solves the problem of determining whether it is better to go to bed immediately after a repast or to wait several hours until digestion has commenced.

Excretory functions continue during sleep. It is a well-known fact that perspiration is then active and that the bladder is full in the morning. The heat of the bed may be a partial cause of perspira-

tion; still, the perspiration is then profuse, and Sanctorius states that one perspires as much during 7 hours of sleep as in 14 hours when awake. The kidneys are active at night and the urine in the morning is generally denser than in the daytime. According to M. Bouchard, who studied the effect of urinal poisons by injecting them into animals, those formed during sleep are convulsive and those formed when awake are narcotic. By their mixture much of the poisonous effect is lost.

Respiration is modified during sleep. It is easy to observe this in the case of those who snore, although the cause of snoring is little known. Generally the respiration is retarded during sleep, being deeper and more regular. In order to study this carefully, Mosso applied to his chest a pneumograph, which indicated the respiratory movements during sleep as well as when awake, and he established the fact that the inspirations are longer and the expirations shorter; the thoracic movements are greater than the abdominal ones; the rhythm is modified and from time to time the inspirations are replaced by distinct series, by pauses, or by more feeble respirations. Respiratory changes have been studied thoroughly by Pettenkofer and Voit, who used for that purpose a chamber of 12 cubic meters capacity made of sheet iron, in which a man could remain for several days, as the ventilation was regulated by two suction pumps. The atmosphere was analyzed as it came from the room and the amount of carbon dioxide eliminated was found to be less during sleep. St. Martin, who made his experiments on a turtledove, reached the same conclusion. This diminution of the amount of carbon dioxide exhaled may be due simply to cerebral repose in the absence of any muscular action, or to other causes. M. Raphaël Dubois has held the theory that the decreased exhalation of carbon dioxide is in proportion to an accumulation of the gas in the blood, which acts as an anesthetic up to a certain point, and then excites the centers of wakefulness. The body temperature generally decreases during sleep. Marie de Manacéine has observed that it falls as low as 36.45° C. during the summer and to 36.05° C. during winter, the lowest temperature occurring between midnight and 3 o'clock in the morning. The temperature of the brain also diminishes equally, according to observations by Mosso, which will have our attention presently.

The heart action is retarded during sleep. Former investigators discovered this by observing the pulse, and more recently this has been confirmed by definite experiments. Mosso, by the use of suitable instruments, was able to register the pulse in the forearm, the leg, and the brain. François Franck observed that the contractions become weaker and the interval between heart beat and pulse beat is greater than when awake; the arterial pressure diminishes,

to increase rapidly on awaking. Brush and Fayerweather observed a lowering of the pressure during the first five hours of sleep, followed by an increase up to the time of waking.

Externally you find at the approach of sleep, effects of a slackening of the circulation; sometimes the surface of the body becomes congested, indicating the need of a loosening of the clothing. Mosso, then François Franck, measured this expansion of the blood vessels near the surface, and Howell, then Lehmann, observed that it increases until the second hour of sleep, then diminishes until awaking. It has been possible to note the conditions of the circulation in the brain in subjects who have lost part of the skull, or on very young infants whose skull bones have not yet united. The first to make this observation was Blumenbach in 1795. He had occasion to examine a young man 18 years old, who before the age of 5 had fallen upon his forehead, sustaining a fracture of the skull, causing loss of part of the bone. When Blumenbach saw it the wound was healed, but one could feel an opening underneath; this was depressed during sleep, diminishing when awake, and replaced by a bump during a strain. Blumenbach concluded from this that there is less blood in the brain during sleep. Durham made these observations on some animals that were trepanned and chloroformed, and he noticed that the arteries as well as the veins were less swollen during sleep. Hammond confirmed these conclusions, and even before Durham, he had watched a man whose brain was laid bare by a railroad accident, and he saw the pressure of the brain diminish during sleep and rise up when the man awoke. He found the same condition in young infants. But the accuracy of these observations was doubted and was disputed by various writers, and it was only the registering experiments made by Mosso, François Franck, and Salathé that settled the question. Salathé held that the fontanels of young infants beat more strongly during sleep, indicating a diminution of pressure within the skull. François Franck, in the case of an invalid stricken with necrosis of the right parietal bone, observed the same movements of the brain and the same diminution of pressure. Mosso at last registered in several cases where the brain was accessible the movements which take place during sleep; the pulse, regular and uniform, was not so high as during wakefulness. Furthermore, Brodmann has added to these observations that the act of going to sleep is characterized by a sudden increase in the volume of the brain, and waking up by a diminution in its size.

These statements concerning anæmia of the brain and expansion of the blood vessels of the extremities during sleep has led certain writers to seek here an explanation for sleep. Five hundred years before Christ, Alcméon of Crotone said: "Sleep comes from a flowing back of the blood into the veins, and waking up is caused by its

retraction; if the blood retracts completely it means death." More recently many have likewise held that sleep is due to cerebral anæmia. It is true others have presented a contrary hypothesis, namely, that sleep is due to an influx of blood to the brain, while others still, discountenancing these contradictory statements or basing their opinions upon other experiments, have reached the conclusion, which seems to be the best, that neither sleep nor wakefulness depend upon cerebral circulation.

Sensibility is preserved during sleep, since we can then hear, feel, and smell. The working of the sense organs seems, however, to be modified. The eyes are generally shut tight; the tears less abundant, and by this diminution of lachrymal secretion is explained the pricking sensation which precedes the desire to sleep. Under the closed eyelids the eyes are directed upward and diverge, according to certain writers; and the pupils are contracted, being dilated again just at the moment of awaking. The sensitiveness of other sense organs is diminished, but it is hard to tell whether this reduction is due to the organs themselves or to the quieting of the nerve centers.

The muscles are generally relaxed. One may move very frequently while asleep, and we have read of persons sleeping on horseback or while walking, by which certain muscles are necessarily contracted. Galien, who heard such a statement made not long since, put no faith in it; but he was compelled to believe it when one night that he was obliged to walk constantly he fell asleep, and while going the distance of a furlong was distracted by a dream. The nerve centers also undergo modifications. The reflex movements dependent upon them increase a little before sleep, diminish, then disappear. So the subject who falls asleep and is tickled by merely touching the nose, hand, or foot responds less and less to these irritations and reacts only to those that are made more and more intense.

The cells of the nerve centers of animals killed while awake or asleep have likewise been examined to ascertain if the cells present any variations in appearance, and if the difference noted can be considered a histological cause of sleep. Stefanowska observed nothing in the case of sleeping mice, which was not astonishing, for in killing them they woke up. But others have believed they could discern something, and Mathias Duval has explained sleep as well as all other cerebral phenomena, by an ingenious hypothesis, which though without foundation has had the good fortune to rapidly become classic on account of its simplicity, and of which you have surely been informed. The nerve cells lengthen or contract and so permit or prevent communications between the centers; sleep would be simply due to their contraction.

Such are the physiological phenomena that have been observed when man is asleep. The simple observation of slumber has enabled

us to examine its definitions, and actual experiments permit a discussion of the theories which aim to explain it.

What causes sleep? Why do we sleep? An answer is difficult when we consider all the phenomena that we shall enumerate. If you aim to be precise there is great risk of being either inexact or incomplete, and on the other hand if you wish to make your statement general it will probably lack precision.

I hope that what I have pointed out may indicate the difficulties involved in an explanation of this phenomenon. To one who has observed and reflected but little, the explanation is very simple, for he easily imagines that such and such a cause induces sleep. But when the observations are accumulated, since their examination requires a careful study of all their phases, then the answer to the problem becomes difficult, and one is never certain of solving it, even after long research. It is in this spirit that I would like to have you listen to the conclusion of this lecture. The inconsistency existing between learned men sometimes brings a smile to the lips of those who do not understand all the difficulties of their work; but it is due only to their desire for the truth, to their thirst for progress, and I beg of you to consider the theories that I am about to propound to you with good will and sympathy.

Let us consider, then, the various explanations that have been given for sleep.

Some early writers thought that sleep depends on a flow of blood to the brain resulting from a recumbent position; but we have seen that the brain contains less blood during sleep, and we know besides that a person can lie down for a long time without sleeping. That theory, therefore, antedating the experiments, has no longer any interest other than one of curiosity. Repeated observations on the deplacement of the blood pressure from the brain to the extremities during sleep gave basis for the thought that sleep is due to cerebral anæmia. The diminution of the quantity of blood in the brain produces sleep by various mechanical actions. If, then, the brain fails to receive enough nourishment or if the waste be not quickly enough removed, the cerebral cells will cease to work either from anæmia or from intoxication. But other writers have criticised these hypotheses. Brodmann, as we have said, observed an increase of blood pressure at the moment of going to sleep and, still further, he could not establish the relation between the circulation in the brain and that of the extremities which forms the basis of these interpretations. Vulpian and Brown-Sequard have already stated that the experiments which produce either a great anæmia or a great rush of blood to the brain do not induce sleep. And Richet adds to the words of these critics that the variations of pressure due to waking up or to going to sleep are much less than those due to the position of the head, as shown by observations on pigeons.

Modifications of the blood and of the lymph have likewise been considered as causes of sleep. The blood, becoming more viscous and thicker, renders the working of the brain more difficult or dries up the nerve cells. Then, again, the lymph increases by drawing water from the cells. Devaux, who held this last hypothesis, justifies it by the observation that the eyelids and the skin of the face are swollen after a heavy and prolonged sleep. Unfortunately, experiment proves that there is no relation whatever between the need of sleep and the condition of the blood.

Besides these circulatory theories there are others which explain sleep by nerve-phenomena. Sleep might be due to an interruption of communication between the hemispheres of the brain and the rest of the nervous system. Or it could be caused by the interruption of the contact of the nerve cells, as we have already shown. Unfortunately, these theories lack experimental justification.

The idea of explaining sleep by inhibition, that is, by a function of arrest of the nerve centers, has mislead many physiologists. In its most complete form, as held by Forel and Oskar Vogt, this theory could be explained as follows: Sleep is an inhibition produced by a cerebral anæmia consecutive to the excitation of the vaso-motor centers by certain factors such as the sight of the bed, by the coming of night, etc., or by a feeling of heaviness in the brain.

Again, some writers have attributed sleep to the absence of external exciting causes, basing the theory on observations of invalids under the control of general anesthesia who go to sleep as soon as their eyes are closed and their ears stopped. Unfortunately, these patients are in such a nervous condition that their sleep is not normal. And although silence and perfect quiet favor sleep, yet we have already seen that one can sleep in broad daylight in spite of noise. Claparède has made a keen and striking criticism of these circulatory or nervous hypotheses. He says:

> We will confine our remarks to the following: First, the hypotheses mentioned are far from resting upon definite facts; many of them contradict one another; second, the supposed phenomena, were they real, might just as well be the results as the causes of sleep; and finally, the claim that these phenomena cause sleep, are the why and wherefore of its mechanism, remains problematical. Why that periodic anæmia or hyperæmia? Why that retraction of the nerve cells? Why that restraint, that unresponsiveness to external stimulation? The hypotheses presented only help to put off the solution of the problem.

There are also other theories concerning sleep which explain it from a chemical standpoint. According to these, we sleep because we are tired and because our nervous system is exhausted, in order to recuperate our energy. During sleep, our bodies are like "a clock that has stopped while the weights are raised again," or "like an engine when the fires are out and the firemen are renewing them," etc. These chemical theories contain a great deal of truth, and, with

good reason, they have been generally adopted. In reality, these theories are of two kinds. Just as the engine stops, either from lack of fuel or from an accumulation of ashes, so the organism may plunge into sleep either because the materials necessary for brain activity are exhausted, or because the waste material, generally toxic, is in too great a quantity.

Among the substances necessary to the working of the nerve centers there are two whose values are now well known, oxygen and chromatophile. The nerve centers in action consume considerable quantities of oxygen, and we may therefore suppose that sleep is due to a lack of sufficient oxygen in the brain, and that it collects in reserve a supply of gas necessary for the coming awakening. This is the theory held by Sommer and Pfluger, relying upon the researches on respiratory interchanges made by Pettenkoffer and Voit. The other substance necessary to the building up of the nerve cells, which accumulates during sleep, disappearing after prolonged activity, is that which Nissl discovered in nearly all the nerve cells and which is named chromatophile on account of its ability to give color easily. We might therefore explain sleep by the deterioration of chromatophile. That explanation was made by Daddi after having noted the disappearance of chromatophile during a case of prolonged insomnia.

But though the nerve centers contain substances indispensable to their working, they also produce during their activity certain waste substances, just as the stove ready to be lighted is full of fuel, then when it is lighted produces ashes that accumulate and diminish the draft. What is the "ashes" of the nervous system? It is a product of disassimilation well known for a long time; it is that which leaves the lungs when oxygen enters, the chemical carbon dioxide, commonly called carbonic-acid gas. M. Raphaël Dubois has considered it the cause of sleep. To tell the truth, he studied only the hibernal sleep of the marmot, and he concluded that a sleep through an entire winter is the same as daily sleep. We may ask whether this comparison is justifiable. Furthermore, according to M. Dubois, sleep is not a recuperation; we sleep because the carbon dioxide has accumulated in the blood, but, during sleep, the gas continues to accumulate until it is strong enough to excite the nerve centers to wake up.

Besides the carbon dioxide, there are other less-known wastes from nerve action. These wastes, which have been called "fatigue toxins" (which generate sleep) and which Molière would certainly have named "dormitive virtues," have also been considered as causes of sleep. Obersteiner thinks that these toxins consist principally of lactic acid; Preyer believes them easily oxidizable; Bing claims that they act chiefly in preventing oxidation; Errera and Bouchard believe them more or less analogous to the leucomaines; Lahuson thinks that they are autointoxicating narcotics. But these are merely hypotheses based on experiments as yet insufficient to prove their accuracy.

All these chemical theories of exhaustion or of intoxication are certainly more important than those we previously considered. They are in accord with the observation pure and simple that fatigue generally induces sleep and that sleep is a recuperator. They render intelligible the alternating between wakefulness and sleep. They are also the best-known theories and the ones generally adopted. Claparède, however, who has examined these theories, objects to them as insufficient, and argues against them as follows: First, there is no parallelism between exhaustion and sleep; one can sleep without being tired; great fatigue may disturb sleep. Second, according to the chemical theories, the alternation of waking and sleeping might assume a type of periodicity with short phases. Claparède says:

Here is an individual who goes to sleep at midnight; at 10 minutes before midnight he was—M. de la Palice can not dispute it—still wide awake. Why was he not asleep at 10 minutes before midnight? Our physiologists say it was because the toxic waste products had not then become sufficiently concentrated. But then why does not this same individual awaken at 10 minutes or quarter past midnight since, if sleep stops the accumulation of the toxic wastes without restricting their elimination, their relative proportion in the system would then return to what it was at 10 minutes before midnight; that is, to a proportion favorable to awaking.

Third, the toxic theory of sleep is antiphysiological, for it is singular that a process of intoxication severe enough to necessitate eight hours of sleep should be repeated daily without at last causing serious disorders. Finally, all the facts that have come under our observation in regard to sleep—voluntary or involuntary drowsiness, voluntary wakefulness, and the like—are not explainable by a chemical theory, no more than are other multiple forms of sleep, than the physiological phenomena that accompany it, nor the dreams. An observation of Vaschide and Vurpas on the Siamese twins shows well the weakness of the chemical theories of sleep; in fact, these twins, whose blood vessels communicate, often sleep or wake one after the other and one could sleep while the other suffered from insomnia.

In a general way, all physiological theories of sleep fail to successfully explain it, for none of them can take account of the psychological phenomena which accompany it. We have seen that a person sleeps or stays awake voluntarily or from habit, a condition that is not within the province of the physiologist either to study or to explain.

Claparède, who has so well observed the impossibility of a physiological solution, alone has sought to explain it by a theory both psychological and physiological, which he has called the "biological" theory of sleep. This biological theory is most interesting and ingenious. It merits a place by itself and will hold our attention for a time. According to Claparède, sleep is not merely a passive, negative condition, a cessation of the organic functions. On the contrary, it is itself a function, a positive activity, having its own biological

significance. One goes to sleep before the moment of complete exhaustion and in order to prevent it. Sleep is a function for the defense of the organism, and we have the desire to sleep before feeling an overpowering need of it, just as we are hungry and thirsty before there is an imperative necessity for eating and drinking, just as the swallow migrates before it is overcome by the cold, as a bird builds its nest before the time for laying its eggs. All these instinctive acts, all these instincts, begin before there is an absolute necessity. This conception of sleep as an active instinct preceding exhaustion changes the question entirely. Sleep is no longer a categorical positive necessity, but it becomes a very pliable, modifiable act. Like all instincts, it is regulated by the law of momentary interest. We sleep if our interest in slumber is the greatest at a given moment; but we could ward off sleep if some other instinct should predominate. This pliability of instinct enables us to understand the variations of sleep, the various causes of drowsiness and awaking. It enables us to understand dreams. The theory of Claparède has therefore a great advantage over all the others, since it alone can be applied to all the varied forms of sleep. Further, it does not exclude physiological theories, since it can accept them as stimuli of the sleep instinct. Inhibition, the fatigue-producing substances, the sensations of fatigue, and the like, become the causes of the interest that we take, at a given moment, in going to sleep.

But Claparède's theory reaches beyond the sphere of pure physiology into that of psychology. Nevertheless, it offers a new field of activity for the physiologist, who, relieved from the anxiety of searching for a complete explanation for sleep, need no longer be deterred by the inadequacy of his own theories, but may seek to complete and state precisely those parts of the biological theory of Claparède that pertains to his own peculiar sphere as a physiologist and are not yet solved. Sleep is an instinct of defense, but defense against what? This instinct is brought into play by various stimuli, but which of these are physiological? We shall not inquire further as to why we sleep, nor as to what it is that makes us sleep, but ask what does sleep protect against? What is it that gives us a desire to sleep?

My friend Piéron, lecturer at l'Ecole des Hautes-Études, has asked himself these questions, and has wished very much that I would help him to answer them. For six years we have been making numerous experiments to try to solve the problem, and it is the actual result of our researches that I would like to explain to you in concluding this lecture.

Sleep is an instinct that obeys a law of momentary interest, and there is very little hope of finding a physiological cause for its being brought into play. This explains why the physiological phenomena which accompany sleep are often not constant, why we can not

consider them as the causes of sleep, and, in fact, they appear very often to be the consequences rather than the causes.

But sleep is an instinct of defense, of protection. Against what does it protect? Will not the suppression of sleep, insomnia, show us the reason for that instinct, by exaggerating its causes; may we not the better see what belongs to the domain of physiology? We have been led to keep animals awake so as to study what happens to them under these conditions. The first difficulty was to prolong wakefulness with the least fatigue; in fact, the effects of fatigue might hide or disturb the very conditions that we may wish to study. Various experiments with severe and prolonged work, such as observations of deer driven at the course, have enabled us to distinguish the effects of fatigue from those of insomnia; and we have succeeded in preventing some dogs from sleeping while tiring them as little as possible.

Even under these conditions prolonged loss of sleep is always very serious, and after about 10 days the animals have generally reached the limit of resistance. During the entire period of this wakefulness the need of sleep becomes more and more imperative, and one can see among the seeming physiological factors of sleep those which tend to increase it and effect the need of sleep and those which do not disturb sleep and consequently can not be considered as its causes. The temperature of the body remains normal, the respiration undergoes no variation, and the amount of carbon dioxide in the blood does not increase, which enables us to exclude the theories of the impoverishment of the blood in oxygen and its enrichment in carbon dioxide as actual causes of sleep. Neither the blood nor the brain lose their portion of water, and this fact combats the theories that explain sleep by dehydration. Toward the tenth day the animal can no longer keep its eyes open; its paws are continually bending, it has lost all sensorial activity and only the strongest kind of stimulation will induce reaction. At this moment the brain shows cellular disturbance, localized exclusively in the frontal lobe, such as could not have been brought on by other means, and which, therefore, seem to be characteristic of insomnia. If such an animal is left to sleep at will, he plunges into a deep sleep from which he awakens completely refreshed, normal, and the alterations in the brain have then disappeared.

Prolonged wakefulness, therefore, is thus shown to bring on an imperative need of sleep and some cellular modifications in the frontal lobe of the brain. To what are these phenomena due? Is it to exhaustion or to intoxication? We are thus brought back to reexamine some of the chemical thoeries for which we sought to find an experimental basis.

If the need of sleep is due to an accumulation of toxic waste products in the organism, one ought to be able, by injecting these substances into a normal animal, to communicate the necessity for sleep. Our first experiments in that direction were unsuccessful. By injecting into a vein of a normal dog some blood or serum taken from a dog exhausted by loss of sleep, we had no very definite results, although in some cases we brought on some modifications of the cells of the frontal lobe, and by injecting these same substances directly into the brain we were no more successful. Could it, therefore, be concluded that wakefulness is not accompanied by the accumulation of toxic substances, and is caused only by the impoverishment of the nerve cells? This conclusion was possible, but it might equally be the case that the blood of the normal animal destroyed the substances injected in small doses, or that their quantity was too small. To remove this last doubt we made our injections by another method. There exists, in the interior and around the nerve centers, a liquid called the cerebro-spinal fluid, which completely envelops them. You can get this fluid either at the lower end of the spine, and is there reached by lumbar puncture, and in spinal anesthesia, or between the occipital bone and the first vertebra, at the level of the fourth ventricle of the brain, and it is there that we operated. To be sure, the operation is a delicate one, but it can be performed with a little practice. By observing certain necessary precautions, such as avoiding compression, one can without danger or trouble make injections at that level. The serum, or, better yet, the cerebro-spinal fluid, of an animal exhausted by loss of sleep, if injected under these conditions into a normal animal, produces in the latter in about half an hour an imperative need of sleep. The animal so injected is benumbed little by little, its eyelids blink, its limbs relax, its eyes close, it loses all attention, and it responds but feebly to strong stimulation. Its brain presents the characteristic lesions of insomnia. The injections, under the same conditions, of liquids from a normal animal have no effect at all. You, therefore, may conclude from these experiments that it is possible to transmit the absolute need of sleep from an exhausted animal to a normal one, and also that the liquids of exhausted animals have a property or contain a substance capable of producing sleep. If it is indeed a substance, do you ask me what it is? I can not yet tell you. It is that very research which is at the present moment occupying our attention.

This rapid review of the question of sleep will have shown you that it is a most complex problem. I would wish that it would likewise give you the impression that although physiology alone can not dream of solving the problem, it can at least offer a profitable contribution, and that its share, when it is contented with facts, is not less than the contributions of other sciences that are busy with the same problem.

PROFITABLE AND FRUITLESS LINES OF ENDEAVOR IN PUBLIC HEALTH WORK.[1]

By Edwin O. Jordan,

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It is in accord with the spirit of this congress to consider public health questions either from the point of view of things already accomplished by the application of the scientific method or from that of things to be done. I have chosen to speak especially of "the saving of waste and increase of efficiency" still to be expected when public health problems are approached in a scientific spirit.

It is well recognized to-day by many experts that while some of the ordinary activities of municipal health departments are of unquestionable value in conserving the health of a community, others are relatively ineffective or possibly worthless. One well-known writer[2] has thus expressed himself on this point:

> I boldly assert that if every case of communicable disease were promptly reported to the proper local board of health and as promptly placed under effective sanitary control and so kept until danger of infection had passed, all the other present-day activities of boards of health, whether local, State, or national, with the exception of those directed against certain causes of infant mortality and the possible further exception of some food and drug inspection, might be dropped with no appreciable effect upon the general health or mortality of any of our States or most of our cities.

In all fairness it must be admitted that a part of the energy of almost every municipal health department in this country is devoted to combating imaginary dangers or applied to tasks that have only a remote bearing on the public health.

This condition, as a rule, is not due to ignorance on the part of health officials, but to the pressure of public opinion. Such pressure is often exerted directly through legal ordinances passed by uninformed legislative bodies, but sometimes also through agitation by mistaken enthusiasts or through other channels of public opinion.

[1] Paper presented before the Congress of Technology, Boston, Apr. 10, 1911, to commemorate the fiftieth anniversary of the granting of the charter to the Massachusetts Institute of Technology. Printed in Science, June 2, 1911. Reprinted by permission.

[2] M. N. Baker, chairman committee on municipal health and sanitation, National Municipal League.

Back of the whole situation is the existence in the public mind of wrong or antiquated conceptions of disease and the causes of disease. It was unfortunate in many respects for the cause of public health that much of the popular interest in health matters was evoked before the germ theory of disease and its corollaries became fully developed. As the result of premature generalization the public has warmly espoused a number of wrong conceptions of disease and of ways of preventing disease. To be specific, two instances of this confusion are found in the demand for garbage disposal and plumbing inspection.

Sanitarians do not admit that even a grossly improper method of garbage disposal can have much to do with the spread of disease in a sewered city or that diphtheria or typhoid fever, or any other disease, is properly attributable to the entrance of sewer air into dwelling houses. So firmly embedded in public belief, however, is the connection of piles of decaying garbage with outbreaks of infectious disease and of defective plumbing with all sorts of maladies that to the average citizen garbage disposal and plumbing inspection bulk large as the chief if not the only activities of a municipal health department.

In the light of our present knowledge we may well ask what are the actual dangers to health from these two sources? It is now well known to bacteriologists that disease germs do not breed in garbage heaps, but that, on the contrary, if added from outside, they speedily die off. The offensive odors of decomposition may be unpleasant and undesirable; there is no evidence that they produce disease or dispose to disease. On the other hand, it may be argued that the existence of heaps of decomposing organic matter tends to maintain or create general habits of uncleanliness, which themselves are detrimental in a roundabout way to the health of a community. And again it is known that the house fly may breed in garbage piles, particularly if horse manure is present, and that under certain conditions this noxious insect may become the bearer of disease germs to food. But when the worst is said it must be admitted that the known danger to health from garbage piles and dumps is relatively insignificant compared with the danger from other well-known but less popularly feared sources. Disease does not originate in garbage piles, however offensive they may be. The house fly, however disgusting and annoying its habits, suffers from no disease transmissible to man, and does not convey disease unless it has access to material in which disease germs are present. The truth is that garbage disposal in large cities is more a matter of municipal housekeeping than of public health. Proper methods of garbage collection and destruction must be urged rather from economic and esthetic considerations than on hygienic grounds. There are of course certain features in the handling of refuse and waste that need hygienic control just as there are in street

cleaning, but the problem is essentially not one of public health. At present in some cities the department of health is burdened with the task of caring for the city waste, and its success or failure as a conservator of the public health is too often measured by the frequency with which coal ashes are scattered in alleys or the length of time that decaying vegetable matter remains in tin cans in hot weather. In some cases the larger part of the annual health department appropriation must be expended for garbage collection and disposal, leaving only a pitifully small residue for other needs. To mention a single instance, the collection and conservation of garbage and ashes cost the Minneapolis health department in 1909 about $57,000, leaving approximately $43,000 for all the other activities of a health department serving a city of over 300,000 inhabitants.

One thing should be clearly understood by municipal authorities and by the general public, that regular collection and cleanly handling of ashes and table scraps is not one of the surest and most profitable ways of protecting health and preventing disease. Efficient administration of this branch of public work should not be allowed to take the place of measures that directly affect the public health.[1]

Few dangers to health have loomed larger in the public eye than that from sewer gas. Elaborate and amazingly expensive systems of plumbing are required by law to be installed in every newly erected dwelling house in our large American cities. Plumbing inspection to-day occupies a large part of the working force of many municipal health departments. In Baltimore in 1908, to cite a single instance, this work was carried out by one inspector of plumbing, seven assistant inspectors of plumbing, and one drain inspector, at a total salary cost of $8,250, or about one-tenth of the total salary appropriation for all public-health work. And yet, if all the most recent and searching investigations, such as those of Winslow and others are to be believed, the actual peril to health involved in the entrance of small quantities of sewer air into houses is so small as to be practically negligible. It may be questioned whether plumbing inspection, as ordinarily conducted, can be shown to save a single life or prevent a single case of disease. There is certainly no reason to suppose that any infectious disease is due to germs carried in sewer air. It might reasonably be maintained that slightly leaky gas fixtures are a much more serious menace to the health of house dwellers than defective plumbing. At all events, our present knowledge affords small justification for the expenditure of public money to insure that the odor of peppermint does not enter our houses when oil of peppermint is designedly introduced into the house

[1] Anyone who fancies that to depreciate garbage disposal as a health measure is flogging a dead horse will be disabused of this impression if he has experience with the beginnings of a typhoid epidemic and learns how often public attention is diverted from significant issues like water supply, milk supply, and contact, by appeals to the prejudice against slovenly ways of handling harmless household refuse.

drains. It may be worth while for the housebuilder to satisfy himself of the character of the plumbing, as of the character of the mortar, but compulsory inspection by public officials is hardly warranted on the ground of a high degree of demonstrated danger to the public health. It is certain, too, that the enforced installation of immensely complicated and elaborate piping and trapping systems simply adds to the cost of building without any compensating hygienic advantages. The plumbing ordinances of our large cities often contain inconsistencies and contradictions, what is required in one city being sometimes forbidden in another. A revision and simplification of municipal plumbing regulations, a minimizing of official inspection, and especially an education of the public to the fact that diphtheria, typhoid fever, and scarlet fever have never been definitely traced to sewer air or bad plumbing are reform measures that might release a considerable sum of public money for use in really profitable lines of sanitary endeavor.

In the matter of heating and ventilation enormous sums have been spent and are being spent to renew the air in rooms and public assembly halls and to introduce pure air in what has been assumed to be necessary amounts. And yet if the work of Beu,[1] Heymann, Paul, Erclentz, Flügge,[2] Leonard Hill, and others means anything, it demonstrates that the whole effect from bad air and crowded rooms is due to heat and moisture and not to carbon dioxide or to any poisonous excretions in expired air. When all the effects of crowd poison upon a group of individuals in an experimentally sealed chamber can be eliminated by rapidly whirling electric fans, it is useless any longer to look upon carbon dioxide as a measure of danger. If we recoginze that all the discomfort from breathing air in a confined space is due to a disturbance of the thermal relations of the body, the problem of ventilation becomes very different from what has usually been supposed. In temperate climates, at all events, it ought to be much simpler to provide for proper heat regulation of the body than to warm a large volume of outside air and introduce it into a building continuously or at stated intervals. It may well be asked whether the elaborate legal regulations governing the supply of air and the cubic feet of bedroom space have a real basis in scientfic knowledge. If overheating, moisture content, and stagnation of the air are the chief things to be avoided, may this end not be reached more effectively and less expensively than by present methods?

One conspicuous function at present required of or voluntarily exercised by health departments is the practice of terminal disinfection after cases of infectious disease. This has come to play a large

[1] Zeitschr. Hyg., 1893, vol. 14, p. 64.

[2] Zeitschr. Hyg., 1905, vol. 49, p. 363.

part in municipal health activities and is responsible for an important share of the expense. In Boston, for example, in 1909 about one-tenth of the annual appropriation was expended for disinfection. One of the most experienced New England city health officers has recently seriously questioned the value of such an expenditure.[1] After a study of the ratios of recurrences in certain diseases he concludes that, "both theory and facts, so far as any data are available, indicate that terminal disinfection after diphtheria and scarlet fever is of no appreciable value." This view has met with strong support from the experience of a number of English health officials, even if it can not be regarded as conclusively proved. Every one now knows that the large sums of money spent in measures of disinfection directed against yellow fever gave little return in added safety. We can hardly take for granted that any process of combating disease is effectual simply because it is customary or traditional. It is evident that the whole question of disinfection needs to be studied afresh with a view to actual efficacy. It is not a subject for laboratory experimentation alone, but must be investigated as a problem of practical public-health administration.

Other instances of the application of energy and money to measures apparently of slight or doubtful value might be cited, but those already given are fairly typical. The question that should be asked in every case is not whether a particular measure is entirely devoid of value, but whether it is the most effective way of utilizing available resources. As matters now stand, there are a number of unquestionably valuable measures that can not be prosecuted with sufficient vigor because of the enforced diversion of funds into other and less-profitable channels.

Efficacious measures may sometimes be distinguished from the fruitless or relatively unprofitable by their direct and unmistakable outcome in the saving of life and the prevention of disease. A few illustrations may be noted.

The importance of control and supervision of the sources of public water supply has long been recognized, but the importance of controlling the quality of the public milk supply, although frequently urged by sanitarians, is not always appreciated. At the present time in the great majority of American cities it is safe to say that for every case of infectious disease due to drinking-water ten cases are caused by infected milk. It is difficult to secure adequate funds for the sanitary control of the milk supply. By sanitary control of milk is meant not the upholding of a rigorous standard of butter fat and total solids, but the maintenance of proper standards of cleanliness and health for dairy cows and especially the safeguarding the milk

[1] Chapin, Jour. Amer. Public Health Assoc., 1911, vol. 1, p. 32.

from infection during collection and transportation. Under some conditions the protection of the consumer against milk-borne infection may be best brought about by compulsory pasteurization of that portion of the milk supply which can not otherwise be raised to proper standard. Whatever method of control be adopted, it is certain that any genuine improvement in the character of a milk supply will be followed in the long run by a lessening in the amount of typhoid fever, diphtheria, scarlet fever, and to some extent tuberculosis. The early detection of a single case of typhoid fever or scarlet fever on a dairy farm may be the means not only of preventing an extensive epidemic, but of avoiding the formation of scores of new foci which can in turn serve to light up subsequent cases for many years. Proper pasteurization of milk has been followed in many cities, as in Glasgow, Liverpool, and London, by an immediate and material reduction in the amount of typhoid fever. In other words, the connection between an expenditure of public money and a direct return in prevention of disease can be more clearly demonstrated in the case of milk-supply control than in some other of the usual municipal health department activities.

The question whether the quality of a city milk supply can be more favorably influenced by inspection and supervision at the source, or by generally enforced and controlled pasteurization is one upon which there is still some difference of opinion among experts. There is little doubt, however, that simply as a matter of economy of administration much is to be said at present in favor of centralized pasteurization of a large portion of the supply. Viewed as a method for preventing a large number of cases of infectious disease at relatively small expenditure the pasteurization of milk certainly ranks high among effective health measures.

One of the important bacteriological advances of the last few years has been the discovery that a considerable number of healthy persons, convalescents, or others, harbor disease germs and that these persons are important agents in spreading disease. The detection and proper treatment of disease-germ carriers, particularly in the more serious diseases and before or in the early stages of an epidemic, is now recognized as an important although difficult task. The whole question of the control of germ carriers is one that needs more careful study with a view to determining the actual results of the methods adopted. From this point of view, inspection of school children, especially at the beginning of the school year, is probably to be classed as a highly profitable activity, although it is to be wished that fuller and better-studied statistics were available.

Inspection of school children is highly valuable, also, in detecting various common congenital or acquired defects. If the defects are remediable, their early discovery may avoid development into per-

manently crippling disorders. In other cases the application of simple corrective or palliative measures may greatly increase the industrial efficiency of the individual. If the defects are not remediable, their detection will at all events prevent the choice of unsuitable occupations, and will indicate desirable lines of education.

In rural communities, undoubtedly one of the simplest, as well as most important, health protective measures is the adoption, under compulsion if need be, of a safeguarded and standardized form of barrel privy.[1] A corollary hardly necessary to mention is the total abolition of the privy in all thickly settled towns. For lack of such regulations soil pollution occurs, the house fly finds an opportunity to transfer disease germs from excreta to food, and typhoid fever and hookworm disease become constant plagues over wide regions.

In the campaign against tuberculosis it is perhaps too early to evaluate the numerous methods that have been proposed for lessening or eradicating this disease, but it is already evident that some are more directly repaying than others in proportion to the effort involved. Among the methods for which public funds are legitimately available none is more promising than the provision of sanatoria for advanced cases of consumption. Newsholme and Koch have shown that the general diminution in the death rate from tuberculosis observed in most countries in recent years can be more reasonably attributed to the establishment of sanatoria than to any other factor, and that in addition to its humanitarian advantages, the segregation and proper control of the advanced and dangerously infective cases is one of the most useful methods that can be employed by the community to protect itself against the spread of tuberculous infection.

Another field in which practical workers are convinced that certain measures have direct efficacy in saving life is that of infant mortality. It has even been said that for the expenditure of a certain sum the saving of a life can be guaranteed. Certain it is that in few public health activities is the ratio between effort expended and results obtained so clearly seen. No one doubts to-day that prompt notification of births, education of the mother through any one of a number of agencies, and special provision for suitable feeding of infants during hot weather are factors that are bound to tell powerfully in the reduction of infant mortality. It may confidently be asserted that the degree of success achieved in this field will be limited only by the amount of endeavor the community is willing to put forth.

It is impossible at present to apply direct tests of efficiency to some measures that undoubtedly promote health. The influence of playgrounds, public baths, regulation of the hours of labor in extra-

[1] See Public Health Reports for 1910, published by the Public Health and Marine-Hospital Service, articles by Stiles and Gardner, and Lumsden, Roberts, and Stiles.

arduous industries and the like is real, if it can not be accurately determined or estimated. Certain activities of a health department may be worth continuing for their educational value, although their direct utility may be questioned. Many topics need investigation in order to discover their real bearing upon the public health. Among these are such matters as the effect of a smoky atmosphere, the alleged nervous strain due to city noise, and numerous important questions in the domain of food adulteration and contamination. Premature and drastic action by health authorities in matters concerning which there is profound disagreement among experts may cast discredit on other lines of activity in which there is and can be no difference of opinion.

For the present it seems worth while to emphasize more sharply than heretofore the distinction between public health measures of proved value and those that owe their existence to tradition or to misdirected and uninformed enthusiasm. Further study of the results obtained by certain of the usual and conventional health department activities is also much needed, and as a preliminary to such study the proper collection and handling of vital statistics is essential. It is poor management and unscientific procedure to continue to work blindly in matters pertaining to the public health, to employ measures of whose real efficiency we are ignorant, and even to refrain from collecting facts that might throw light upon their efficiency.

FACTORY SANITATION AND EFFICIENCY.[1]

By C.-E. A. Winslow.[2]

It may fairly be maintained that in most industries the largest element invested is what may be called life capital. For example, in the cotton industry in 1905 there was invested a capital of $613,-000,000, while the pay roll amounted to $96,000,000 a year. Capitalized at 5 per cent, this pay roll would correspond to an investment of $1,920,000,000 in the form of the hands and brains of the workers. The calculation is perhaps a fanciful one, but it illustrates the fundamental fact that the human element in industry is of large practical importance. Particularly in regions like New England, where there is no wealth of natural resources, prosperity depends on a skilled and intelligent operative class. Such a class Massachusetts has had in the past and the present interest in industrial education testifies to the conviction that the efficiency of the operative must be improved to the highest possible degree.

Once the operative is trained and at work it is generally assumed that the results obtained will depend only on his intrinsic qualities of intelligence and skill. The effect of the environment upon him is commonly ignored; but its practical importance is very great. In industries where it has been shown that the machine which makes a given fabric requires certain conditions of temperature and moisture for its successful operation these conditions are maintained with exemplary care. In every factory, however, there is another type of machine, the living machine, which is extraordinarily responsive to slight changes in the conditions which surround it. These conditions, in this relation, we habitually neglect.

I am not dealing now with the sociological and humanitarian aspects of the case. I am quite frankly and coldly, for the moment, treating the operative as a factor in production whose efficiency should be raised to the highest pitch, for his own sake, for that of his employer and for the welfare of the community at large.

The intimate relation between the conditions which surround the living machine and its efficiency is matter of common experience with

[1] Reprinted by permission from Technology and Efficiency. Proceedings of the Congress of Technology at Boston Apr. 10, 1911. pp. 442-448. Copyright 1911, by McGraw-Hill Book Co.

[2] Associate professor of biology, College of the City of New York, and curator of public health, American Museum of Natural History, New York City.

us all. Contrast your feelings and your effectiveness on a close, hot, muggy day in August and on a cool, brisk, bright October morning. Many a factory operative is kept at the August level by an August atmosphere all through the winter months. He works listlessly, he half accomplishes his task, he breaks and wastes the property and the material entrusted to his care. If he works by the day the loss to the employer is direct; if he works by the piece the burden of interest on extra machinery has just as truly to be borne. At the close of the day the operative passes from an overcrowded, overheated workroom into the chill night air. His vitality lowered by the atmosphere in which he has lived, he falls a pray to minor illness, cold and grip, and the disturbing effect of absences is added to inefficiency. Back of it all lurks tuberculosis, the great social and industrial disease which lays its heavy death tax upon the whole community after the industry has borne its more direct penalty of subnormal vitality and actual illness.

The remedy for all this is not simply ventilation in the ordinary sense in which we have come to understand the term. Mr. R. W. Gilbert, of the Massachusetts Institute of Technology, begins a suggestive paper on "The economics of factory ventilation," in the Engineering Magazine for December last, as follows:

> Webster's definition of the word ventilation is "to air" or "to replace foul air by fresh." In actual practice, however, ventilation should mean more than this. It should mean the conditioning of the air of any inclosed space to the best requirements of the occupants of that space.

Conditioning of the air so that the human machine may work under the most favorable conditions—this is one of the chief elements of industrial efficiency, as it is of individual health and happiness.

The chief factors in air conditioning for the living machine, the factors which in most cases far outweigh all others put together, are the temperature and humidity of the air. In many a plant after spending money for an elaborate system of ventilation, the air has been kept too hot or too dry or too moist, and the effect on comfort and efficiency has been worse than nil. It is a curious instance of the way in which we neglect the obvious practical things and attend to remote and theoretical ones, that for years more attention has been bestowed on the testing of air for carbon dioxide, which was supposed to indicate some mysterious danger, than on the actual concrete effect of overheating. Yet heat, and particularly heat combined with excessive humidity, is the one condition in air that has been proved beyond a doubt to be universally a cause of discomfort, inefficiency, and disease. Flügge and his pupils in Germany and Haldane in England [1] have shown that when the temperature rises to 80° with moderate humidity or much above 70° with high humidity, depres-

[1] The literature on this subject is well summarized with references to original sources by T. R. Crowder in "A study of the ventilation of sleeping cars," Archives of Internal Medicine, vol. 7, p. 85.

sion, headache, dizziness, and the other symptoms associated with badly ventilated rooms begin to manifest themselves. At 78° with saturated air Haldane found that the temperature of the body itself began to rise. The wonderful heat-regulating mechanism which enables us to adjust ourselves to our environment had broken down and an actual state of fever had set in. Overheating and excess of moisture is the very worst condition existing in the atmosphere and the very commonest.

The importance of the chemical impurities in the air has dwindled rapidly with the investigations of recent years. The common index of vitiation, due either to human beings or to lighting and heating appliances, is carbon dioxide; but carbon dioxide in itself has no harmful effects in tenfold the concentration it ever reaches in ordinary factory air. Nor is there any reduction of oxygen which has any physiological significance. In the Black Hole of Calcutta and below the battened-down hatches of the ship *Londonderry* there was actual suffocation due to oxygen starvation, but this can never occur under normal conditions of habitation. It was long believed that the carbon dioxide was an index of some subtle and mysterious "crowd poison" or "morbific matter." All attempts to prove the existence of such poisons have incontinently failed. There are very perceptible odors in an ill-ventilated room, due to decomposing organic matter on the bodies, in the mouths, and on the clothes of the occupants. These odors may exert an unfavorable psychical effect upon the sensitively organized, but as a rule they are not noticed by those in the room, but only by those who enter it from a fresher atmosphere. Careful laboratory experiments have quite failed to demonstrate any unfavorable effects from rebreathed air if the surrounding temperature is kept at a proper level. In exhaustive experiments by Benedict and Milner (Bulletin 136, Office of Experiment Stations, U. S. Department of Agriculture), 17 different subjects were kept for periods varying from 2 hours to 13 days in a small chamber with a capacity of 189 cubic feet in which the air was changed only slowly while the temperature was kept down from outside. The amount of carbon dioxide was usually over 35 parts (or eight to nine times the normal), and during the day when the subject was active it was over 100 parts, and at one time it reached 240 parts. Yet there was no perceptible injurious effect.

The main point in air conditioning is, then, the maintenance of a low temperature and of a humidity not too excessive. For maximum efficiency the temperature should never pass 70° F., and the humidity should not be above 70 per cent of saturation. At the same time a too low humidity should also be avoided. We have little exact information upon this point, but it is a matter of common knowledge with many persons that very dry air, especially at 70° or over, is excessively stimulating and produces nervousness and discomfort. It would

probably be desirable to keep the relative humidity between 60° and 70°.

Another point which may be emphasized in the light of current opinion is the importance of "perflation," or the flushing out of a room at intervals, with vigorous drafts of fresh cool air. Where there are no air currents the hot, moist, vitiated air from the body clings round us like an "aerial blanket," as Prof. Sedgwick calls it, and each of us is surrounded by a zone of concentrated discomfort. The delightful sensation of walking or riding against a wind is perhaps largely due to the dispersion of this foul envelope, and it is important that a fresh blast of air should sometimes blow over the body in order to produce a similar effect. The same process will scatter the odors which have been noted as unpleasant and to some persons potentially injurious. The principal value of the carbon-dioxide test to-day lies in the fact that under ordinary conditions high carbon dioxide indicates that there are no air currents changing the atmosphere about the bodies of the occupants.

There is one other problem of atmospheric pollution to which special reference should be made. The presence of noxious fumes, and still more the presence of fine inorganic or organic dust, in the air constitutes a grave menace to health in many processes and is an important contributory cause of tuberculosis. The normal body has its "fighting edge" and can protect itself against the tubercle bacillus if given a fair chance; but the lung tissue, which is lacerated by sharp particles of granite or steel quickly succumbs to the bacterial invader. In dusty trades, like stone cutting and cutlery working and emery grinding, 75 per cent of all deaths among the operatives are often due to tuberculosis, against 25 per cent for the normal adult population. This may be fairly interpreted as meaning that the actual death rate from tuberculosis in these trades is from two to four times as high as in a corresponding average population. In other words, three or four or five out of a thousand of these workers are sacrificed every year to the conditions under which they labor. The elimination of the dust by special hoods and fans is imperative in such industries and must be supplemented in extreme cases by the compulsory use of respirators.

It is extraordinary how little is known to-day of the actual conditions of factory air, either by manufacturers or by sanitarians. So far as I am aware the New York department of labor is the only State department dealing with factory inspection which collects and publishes exact data in regard to the quality of the atmosphere in the workshops. If the conditions indicated in these reports by Dr. C. T. Graham Rogers are typical, and there is no reason to doubt that they are, for the smaller industries at least, there is urgent need for betterment. The table below shows that of 215 workrooms inspected 156, or 73 per cent, had a temperature of over 72° and 63,

or 29 per cent, exceeded 79°. Relative humidity exceeded 70 per cent in 39, or 18 per cent of the workrooms. In tabulating these analyses I have excluded all cases where the outdoor temperature was over 70°.

Temperature and humidity in New York factories.

[Reports of the Commissioner of Labor for 1908, 1909, and 1910.]

Industry.	Number of workrooms with temperature.			Number with relative humidity over 70 per cent.
	72° or less.	73° to 79°.	80° or over.	
Printing shops	2	25	29	3
Clothing shops	9	23	7	6
Bakeries	1	20	15	7
Pearl button factories	33	9	0	14
Cigarmaking shops	8	4	5	7
Laundries	0	7	7	1
Miscellaneous	6	5	0	1
Total	59	93	63	39

In the report on the sanitary condition of factories and workshops, made by the Massachusetts State Board of Health in 1907, is the following comment upon the boot and shoe industry:

In the majority of factories visited the ventilation was found to be poor, and in many of them distinctly bad. Of the rooms not especially dusty, 102 were badly ventilated and 26 were overcrowded. In the rooms in which large amounts of dusts are evolved, the number of machines with means for efficient or fairly efficient removal of dust was found to be 1,630; the number either inefficiently equipped or devoid of equipment was 2,769.

Of 84 of the many dusty rooms reported, 40 were also overcrowded, 35 were dark, 21 were overheated, and 18 were overcrowded, dark, and overheated. In more than one-third of the factories visited, the conditions of water-closets were not commendable; most of them were dark and dirty to very dirty.

There is plenty of evidence, though of a scattered and ill-digested sort, that the elimination of such conditions as these brings a direct return in increased efficiency of production. The classic case of the United States Pension Bureau is always quoted in this connection. The removal of the offices of the department from scattered and poorly ventilated buildings to new and well-ventilated quarters reduced the number of days of absence due to illness from 18,736, in the neighborhood of which figure it had been for several successive years, to 10,114.

In an investigation of my own of conditions in the operating room of the New England Telephone & Telegraph Co., at Cambridge, Mass., I found that before the installation of a ventilating system, 4.9 per cent of the force (50 to 60 girls) were absent during the winter months of 1906 and 4.5 per cent in 1907. The ventilating duct which was put in was a simple one and cost only $75 to install,

but in the winter of 1908 following its introduction the absences were cut down to 1.9 per cent of the force employed, without any other change in conditions or personnel so far as I was able to discover.

The vice president of the Manhattan Trust Co. of New York states that by proper ventilation he has so increased the efficiency of his clerical force that he has been able to reduce the number of employees 4 per cent.

In the printing establishment of Mr. C. J. O'Brien, in New York, a ventilating system was installed because of the insistence of the State department of labor that the law be complied with, the order having been resisted for two years. After the system had been in use a year, the proprietor stated that had he known in advance of the results to be obtained no order would have been necessary to have brought about the installation. Whereas formerly the men had left work on busy days in an exhausted condition and sickness was common, now the men left work on all days in an entirely different condition, and sickness had been very much reduced. The errors of typesetting and time required for making corrections were greatly reduced.

It is much to be desired that this problem should be studied by careful quantitative methods as a definite factor in the profit and loss account. The National Electric Lamp Association is approaching the question of sanitary conditions in this manner, comparing in detail the temperature and humidity of its workrooms with the hours of work, the pay and the efficiency of its employees. Only by such systematic study can it be determined how much factory sanitation is really worth in any given case. The evidence is already strong enough, however, to warrant some investigation. In cases where preliminary study shows its value, why should not the sanitary inspection of a factory be made a part of its routine operation just as supervision of its mechanical features is a part of its organization to-day? It is not solely or chiefly the problems of ventilation as ordinarily understood that should be studied; and it must be remembered that there is never anything magical in a "ventilating system." "Systems" are as dangerous in sanitation as quackery in medicine. The problem must be approached from a broad biological viewpoint, and should include all the conditions which make for lowered vitality. Temperature and humidity come first and foremost and dust and fumes must be guarded against in certain processes. The cleanliness of the factory, the purity of drinking water, the quality of lighting, the sanitary provisions, and a dozen other points will suggest themselves to the skilled investigator when on the ground. He may find in many of these directions economic methods by which efficiency can be promoted.

The consulting factory sanitarian will be a new factor in industry, but the progress of industrial economy and of sanitary science unite in pointing to the need for such an expert.

THE PHYSIOLOGICAL INFLUENCE OF OZONE.[1]

By Leonard Hill, F.R.S., and Martin Flack.

(From the laboratory of the London Hospital Medical College.)

Ozone has been extolled as the active health-giving agent in mountain and sea air, its virtues have been vaunted as a therapeutic agent, until these have, by mere reiteration, become part and parcel of common belief; and yet exact physiological evidence in favor of its good effects has been hitherto almost entirely wanting. Ozone has been found occasionally in traces in the atmosphere, it has been proved to have active oxidizing properties, and on these facts the superstructure of its therapy has been reared.

Popular attention has been fixed on the mysterious and the unknown, and has neglected the prepotent power of cold wind and sunlight to influence the nervous health and metabolism of man. The only thoroughly well-ascertained knowledge concerning the physiological effect of ozone so far attained is that it causes irritation and œdema of the lungs, and death if inhaled in relatively strong concentration for any time, e. g., 0.05 per cent, death in two hours (Schwarzenbach); 1 per cent in one hour (Barlow).

A. Loewy and N. Zuntz [2] write that "the physiological foundations of an ozone-therapy can scarcely be discussed, so little is the extent of our exact knowledge on this subject." The old idea that ozone passing into the blood acts as an oxidizing agent there, thus destroying organized and unorganized poisons, was exploded by Pflüger [3] who pointed out that ozone is immediately destroyed on contact with blood; even if it were not, there is no reason why it should oxidize toxins rather than normal constituents of the blood.

C. Binz [4] observed that "animals submitted to ozone became quiet and appeared to sleep." W. Sigmund [5] also noted this effect in white mice, gold fish, and insects. He considered that ozone is not a very dangerous substance, for even small animals could bear for a time a relatively large amount without serious effect; warm-blooded animals were the more sensitive.

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[1] Reprinted by permission from the Proceedings of the Royal Society, London, B. vol. 84, 1911, pp. 404–415. Received by the Society July 6; read Dec. 7, 1911.

[2] Handbuch der Sauerstofftherapie, Michaelis, Berlin, 1906, p. 61

[3] Pflüger's Archiv, vol. 10, p. 251.

[4] Berl. Klin. Wochensch., 1882, Nos. 1, 2, 43.

[5] Cent. f. Bakter. (ii), 1905, vol. 14, p. 635.

Filipow[1] found weak concentrations had no effect on men or animals, while a higher concentration of ozone caused irritation of the respiratory tract.

Schultz[2] confirmed this irritative effect, and found long-continued breathing of ozone caused pathological changes, particularly in the lungs, which were the cause of death. Schultz considered that the ozone passed into the blood and injured the lung secondarily. Bohr and Maar[3] overthrew this supposition by the ingenious experiment they devised of making one lung breathe ozonized air and the other normal air. They found this lung remained normal while the ozonized lung became œdematous.

Using a concentration of ozone which produced no visible change in the pulmonary structure, these observers found that it caused a diminished uptake of oxygen; the other lung compensated for the deficiency by an increased uptake. This occurred in both cold-blooded (tortoise) and warm-blooded animals. In the former the initial effect of ozone was occasionally a slightly increased oxygen uptake. If the inhalation of ozone were continuous the increased uptake by the lung ventilated with normal air finally fell away and became deficient; this occurred sooner in the mammal than in the tortoise.

The CO_2 output was also diminished, but not so markedly as the oxygen uptake, thus the respiratory quotients often rose over 1. The effect of ozone on the respiratory exchange came on gradually, and with weak concentrations often reached its height after the cessation of the ozone inhalation—there was, in fact, an after-effect which took some little time to pass off. The effect was not modified by a preliminary division of the vagi and pulmonary sympathetic nerves.

The blood of the ozonized animal had no toxic effect when transfused into another. Bohr concluded that the effect was primarily on the lungs, and as the oxygen uptake was affected more than the CO_2 output, he claimed that his results supported his view that the pulmonary epithelium by its secretory activity controlled the passage of the respiratory gases. Butte and Peyron[4] likewise record that ozone when inhaled diminishes the metabolism.

One of the obstacles in the way of investigation has been the difficulty of obtaining pure ozone free from oxides of nitrogen, and another has been the want of an accurate method of estimating the concentration of ozone. There has been devised lately an ingenious apparatus for producing ozone, which eliminates the production of the oxides of nitrogen, and allows the ready use of ozone for bleaching, sterilizing water or ventilating purposes. The ozone is generated by

[1] Arch. f. d. Ges. Physiol., vol. 34, p. 335.
[2] Arch. f. exper. Path., 1882, vol. 29, p. 364.
[3] Skand. Arch. f. Physiol., 1904, vol. 16, p. 41.
[4] Comp. Rend. Soc. Biol., vol. 46; Progrès Médical, 1894, No. 30, p. 61.

the electrical discharge of high-potential currents across sheets of fine gauze set parallel and insulated from each other. The gauze net insures the equality of the discharge over the whole surface, and prevents that excessive high-tension discharge at certain rough points, which occurring in the older form of instruments fitted with smooth metal plates, causes the production of oxides of nitrogen from the burning of atmospheric nitrogen.[1] Our object therefore has been to determine the effects of undoubtedly pure ozone, especially in concentrations far less than those used by previous observers.

Method of estimation of concentration of ozone.—The air containing ozone is sucked by an aspirator or filter pump through a 1 per cent solution of potassium iodide, acidified with a small quantity of 10 per cent sulphuric acid contained in a Drechsel wash bottle. It is essential that contact with rubber be avoided. After 10 liters of air have been passed through the wash bottle, the acidified KI is removed and freshly prepared pure starch emulsion added. A blue color indicates the presence of ozone. The amount is estimated by titration with sodium hyposulphite solution until this blue color is discharged. The hyposulphite solution is prepared by dissolving 22.2 grams in in 1 liter of distilled water, so that 1 c. c. of the solution is equivalent to 100 parts per million of ozone in the air collected as a 10-liter sample. For small quantities of ozone the solution may be diluted 10 or 100 times, giving 1 c. c. of the solution, equal, respectively, to ten parts and one part per million of ozone in the air collected.

Lethal dose of ozone.—To determine this the animals were placed in a large air-tight chamber. The ozonized air was then driven through by means of a gas engine driving an air pump, and the concentration of ozone determined in the issuing air. The animals could be observed through the glass windows of the chamber, which could also, if necessary, be lighted by electric light. Our experiments show that animals may die after being submitted to 15 to 20 parts per million for two hours. We do not doubt that a lower concentration would have a fatal effect if breathed for a much longer period.

The cause of death is acute inflammation of the respiratory tract. The lungs become intensely congested and œdematous. Microscopically the pulmonary alveoli appear full of an inflammatory exudation. Many of the alveoli are full of blood, for so intense is the irritant effect that hemorrhages take place. There are no other signs of the effect of ozone in the body. On inhaling ozonized air ourselves and expiring through the iodine test solution we find no evidence of ozone in the exhaled air. It is all taken up by the wet mucous surface of the respiratory tract and exerts its effect there.

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[1] Mr. Edward L. Joseph, the inventor of the "Ozonair" apparatus, was good enough to give us the use of a complete installation and place his information at our disposal.

TABLE I.—*Lethal dose.*

[January to March, 1910.]

Animals.	Parts of ozone per million.	Duration of exposure.		Result.
		H.	*m.*	
2 rats	15	2½	0	Died following night, lung showing pneumonia.
Do	2	3¾	0	No ill effects.
Do	3-5	3¾	0	Do.
2 rats, 1 cat	7½	3¾	0	Rats quiet, fur standing up; recovered. Cat killed next day; signs of lung irritation.
1 dog, 3 rats	10-20	2	0	Disordered breathing of all animals; all recovered.
2 goats	9½	3½	0	Jerky breathing; soon recovered.
Do	7	3½	0	Dyspnoeic; 1 had snuffles; soon recovered.
1 dog, 2 rats	11½	2¾	0	Dog's breath disordered; developed cough and bad breathing 1 hour after; all eventually recovered.
2 goats	9½	3	5	Depressed; breathing disordered; moist sounds; recovered.
2 rats	10	4	0	Fur ruffled; recovered.
1 rat	11	2	0	No permanent ill effects.
1 mouse	20	2	0	Died; pneumonic signs found post mortem.
Do	40	1	0	Very disordered breathing; eventually recovered.

On breathing two to three parts per million, we ourselves find it irritating to the respiratory tract, with a tendency to produce, in this concentration, headache and oppression. The irritation set up by ozone, together with its strong characteristic smell, affords ample warning, and would prevent anyone exposing himself unintentionally to a dangerous concentration. The irritation set up would naturally make anyone remove himself from the influence of the ozone before any serious damage to the lungs had been set up. As far as we can see, then, no serious risk can arise from the use of ozone generators so long as the generators are not placed in a confined space from which escape is impossible.

It is only possible to estimate concentrations of much less than one part of ozone per million parts of air by passing very large quantities of the ozonized air through the acidified potassium iodide solution. We find concentrations of far less than one in a million parts can be both smelled and tasted; the physiological test for ozone therefore is extraordinarily delicate. If ozone is used in a ventilating system, we think it should be in such concentration as is scarcely perceptible to a keen sense of smell.

Ozone has most potent action as a deodorizer. We tested this by filling our experimental chamber with the smoke of shag tobacco, ammonium sulphide, or carbon bisulphide vapor. At other times we placed in the chamber stinking meat, or human feces. After putting in action the two small ozonizers, placed in the roof of the chamber, for two minutes, we were not able to detect the odors of

these substances. The smell of the ozone masked all other smells. The masking of these smells gives no proof of the destruction of the evil-smelling emanations, for Zwaardemaker has shown that two smells can neutralize each other—e. g., ammonia introduced up one nostril and acetic acid up the other.

Erlandsen and L. Schwarz[1] concluded, from a series of careful observations on the effect of ozone on ammonia and hydrogen sulphide, trimethylamine, butyric, and valerianic acids, indol and skatol, that the smells are only masked and not destroyed by the presence of ozone. The odoriferous substance and ozone were introduced into the chamber together. After a period the ozone disappeared from the chamber, and the smell was found to have returned. The smell of tobacco, in particular, was masked and not destroyed.

From a hygienic standpoint the ozone may be useful as a deodorizer, since, from the point of view of its effect on the nervous system, it does not matter whether the evil smell is masked or destroyed. The question is, which is preferable, the evil smell or the smell of ozone. Certain smells are objectionable, and become more so if persistent and uniform. In cold-meat or dry-goods stores, tube railways, etc., ozone may have its use as a deodorizer and freshener of the atmosphere, relieving the stale and tedious quality of the air.

In a room fitted with a gas radiator (without flue) we have found, by a series of daily observations, that ozone relieves the disagreeable quality of the air. It seems to give a certain tang to the air, and, by stimulating nerve endings in the respiratory tract, relieves the monotony of overwarm and close air. We were informed by an engineer employed in a large public office that he added Sanitas to the water used for spraying and cooling the air which was pumped into the building on a Plenum system. In the late afternoon the clerks often telephoned down to him and asked for "more Sanitas"—anything to change the monotony of air always warmed to 65° F.

Under the conditions of natural life we are "blown upon by every wind, and wet with every shower." The cutaneous sense organs are submitted to ceaseless flux of physical and chemical conditions, more or less blood and tissue lymph, higher or lower temperature, etc. The heating and ventilating engineer has aimed at giving us in our buildings a uniform summer temperature, unchanged by wind or calm, warm sunshine, or cold shadow of the clouds. In the House of Commons the air is drawn in from over the Thames, cooled and wetted by a water spray, and carried in at the rate of 40,000 to 50,000 feet a minute—a fine bracing current. Before it reaches the House it is warmed by passing over steam radiators, mixed, and passed in a uniform draftless stream at 63° F., through the gauze-covered floor

[1] Zeit. f. Hygiene u. Infections-Krankheiten, 1910, vol. 67, p. 391.

of the House. When the division bell rings, the current is switched from the House on to the division lobbies. Hour after hour the same uniformity is maintained, which leads the open-air man to complain that it is too hot, and the old East Indian to revile the cold. The fault lies in the uniformity. When the House is cleared for division, it should be swept, in our opinion, with a current of cool air straight from the water sprays.

In such conditions of uniformity an ozonizer, just as a cigarette, may relieve the tedium of the nervous system. Ozonized air may help under the depressing conditions which obtain in many shops and factories by varying the stimulation of the nervous system.

It has been claimed that traces of ozone in the atmosphere, by its oxidizing properties, destroy dust, bacteria, noxious gases, and render the air pure. There is no doubt that ozone in the presence of water and in strong concentration is a powerful oxidizing agent. It is actually used for the sterilization of the water supply of certain towns. The ozonized air is thoroughly mixed with the water and brought into intimate contact with the bacteria. On dry bacteria concentrated ozone has no action (Ohlmüller[1]). In weak concentrations, such as can be inhaled safely, we found ozone had no sterilizing effect when bubbled through moist cultures of *Bacillus coli communis*. The ozone only acts on the surface, and in weak concentrations can not be expected to pass through relatively thick layers of wet material.

Erlandsen and Schwarz rightly point out that there is no justification for the assertion made by Lübbert that "organic dust, ill-smelling particles, and agents of infection can not exist in the presence of ozone, and that a demonstrable excess of ozone indicates absolute purity of the air."

Owing to its powerful bactericidal action when passed through water in high concentrations, it might be thought that inhalation of ozone would be of value in the treatment of infections of the respiratory tract, and such inhalations have been used, e. g., for pulmonary tuberculosis.

Against the use of all such bactericidal agents in the treatment of pulmonary disease is the fact that the bacilli are growing in the substance of the wet tissues, and therefore to kill the bacilli a concentration must be used which would also kill the tissues.

One of the most potent methods of treatment is to draw blood in increased volume to the infected part, by fomentations, blisters, etc., the blood itself having bactericidal and immunizing properties. We suggest that inhalation of weak concentrations of ozone, by mildly irritating the respiratory tract, may bring more blood to the part and thus have the curative effect of a fomentation or blister.

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[1] Arbeiten a. d. Kais. Gesundheitsamte, vol. 8, p. 229.

Fat has a power of absorbing ozone until it smells strongly of ozone, and it retains the ozone for a long time. Mr. F. Kidd kindly tried for us the application of ozonized lard or vaseline to foul chronic ulcers of the leg, but found that while hot fomentations were efficacious in cleaning up and rendering sweet control cases of ulcer, the ozonized ointment had little effect.

For the investigation of the respiratory metabolism we used the Haldane-Pembrey gravimetric method. Mice or small rats were placed in a beaker fitted with a thermometer and the beaker placed in a Hearson air bath to keep the external temperature constant. In a first series of experiments the ozone was generated by a specially made small ozonizer, and led partly through the animal chamber and partly through a collecting wash bottle, in order that its concentration might be determined.

The water vapor given off by the animal varied so much with the passing of urine and feces, and possibly with the animal putting up its fur, as it does when depressed by the ozone, that we can lay no weight on the calculation of oxygen intake. The weakness of the gravimetric method lies in the fact that the oxygen is calculated from the difference between loss of body weight and output of water and CO_2, and not directly measured.

We shall confine our considerations in these experiments to the loss of body weight, and the CO_2 output. Table II shows the loss of weight sustained by the animal, the amounts of H_2O and CO_2 given off before, during, and after ozone. It is seen that there is a marked depression during and after the administration of ozone. The table gives a random selection made from 25 similar experiments.

The figures for the loss of weight represent the loss of weight of the animals weighed in the respiration chamber. Evaporation of urine and feces when passed contribute to this loss. As the loss of body weight is also influenced by the passing and evaporation of the urine and water from the feces, the CO_2 output results are the more trustworthy.

As the concentration of ozone given by the small generator seemed to be too high, we obtained the ozone in the following experiments by generating it in a room, the ozonizer being placed at distances varying from 100 to 350 cm. from the inlet of the ventilation current which was drawn through the animal chamber. Table III gives the loss of weight and amount of CO_2 given off in milligrammes in the last eight experiments made under these conditions, the reading for the oxygen as before being variable. In all, 16 similar experiments were made on small rats.

TABLE II.

Animal.		Air.	Air.	Air.	Ozone.	After first.	After second.	After third.	After fourth.	Remarks.
Mouse....	Time, in minutes	15	15	15	105	15	15	15	15	Ozone 1½ parts per million. Breathing noticeably disordered.
	Loss of weight...	115	121	125	185	55	35	47	46	
	H_2O given off...	125	130	121	....	64	45	50	55	
	CO_2 given off....	87	90	85	....	50	33	30	53	
Do.....	Time, in minutes	20	20	....	120	20	20	20	20	Ozone 6 parts per million. Breathing markedly disordered.
	Loss of weight...	385	258	....	409	98	93	83	71	
	H_2O given off...	151	222	....	....	225	133	94	88	
	CO_2 given off....	101	86	....	....	30	21.5	22	24	
Do.....	Time, in minutes	20	20	20	90	20	20	....	....	Ozone 1½ parts per million.
	Loss of weight...	210	270	210	198	34	150	....	....	
	H_2O given off...	140	260	200	....	76	180	....	....	
	CO_2 given off....	121	146	146	....	30	50	....	....	
Do.....	Time, in minutes	75	....	....	75	75	....	....	....	Ozone less than 1 part per million. 2 inches from ozonizer.
	Loss of weight...	415	....	....	335	104	....	....	....	
	H_2O given off...	303	....	....	344	180	....	....	....	
	CO_2 given off....	163	....	....	80	97	....	....	....	
Do.....	Time, in minutes	60	....	....	60	60	60	60	....	Ozone well less than 1 part per million. 1 foot from ozonizer.
	Loss of weight...	380	....	....	515	325	325	380	....	
	H_2O given off...	425	....	....	525	337	335	393	....	
	CO_2 given off....	207	....	....	64	150	112	208	....	
Do.....	Time, in minutes	75	....	....	75	75	60	....	....	Ozone well less than 1 part per million. 100 cm. from ozonizer.
	Loss of weight...	405	....	....	250	185	236	....	....	
	H_2O given off...	320	....	....	233	189	135	....	....	
	CO_2 given off....	164	....	....	123	144	115	....	....	

In all these experiments the animals were given a preliminary half-hour or so on air, in which to settle down and adjust themselves to their new surroundings. Judging by the CO_2 given off in some cases, the ozone appears to have perhaps a transitory stimulating effect, followed by a corresponding depressant effect; in others there is but little evidence of any action of the ozone at all at concentrations such as these. The ozone itself was always in concentrations far less than one part per million, and varied from day to day according to the atmospheric conditions prevailing. We should state that several of our figures obtained during and after ozone show a R.Q. above 1, confirming the observations of Bohr as to the diminished uptake of oxygen.

Turning to the investigation of the respiratory metabolism of man under the influence of ozone, we selected the method devised recently by Dr. Gordon Douglas,[1] of Oxford, owing to its simplicity and efficiency.

[1] C. G. Douglas, Journ. Physiol., 1911, vol. 42; Proceedings, p. xvii.

TABLE III.

Rat.		Air, ½ hour.	Air, ½ hour.	Air, ½ hour.	Ozone, ½ hour.	First (after ½ hour).	Second (after ½ hour).	Third (after ½ hour).	Fourth (after ½ hour).
A....	Loss of weight........	102	103	....	90	88	74	....	....
	CO_2 given off........	132	135	....	73	132	129	....	....
B....	Loss of weight........	119	130	....	70	88	144	200	....
	CO_2 given off........	104	120	....	130	127	156	108	....
A....	Loss of weight........	113	122	....	63	57	65	75	....
	CO_2 given off........	91	94	....	86	83	100	99	....
C....	Loss of weight........	168	155	....	190	235	191	122	145
	CO_2 given off........	173	158	....	199	187	182	140	155
D....	Loss of weight........	107	104	103	136	80	97	128	95
	CO_2 given off........	142	130	129	155	127	130	132	128
E....	Loss of weight........	225	230	215	145	185	123	202	....
	CO_2 given off........	132	135	114	91	97	77	101	....
F....	Loss of weight........	145	270	225	235	215	235	165	....
	CO_2 given off........	163	177	162	165	145	137	102	....
G....	Loss of weight........	115	195	197	148	177	143	109	[1] 149 255
	CO_2 given off........	153	188	200	163	205	173	175	[1] 110 138

[1] Here the upper number represents the result of a further ½ hour of ozone, and the lower numbers that of the succeeding ½ hour in air.

The subject was provided with a mouthpiece, fitted with inspiratory and expiratory valves. (We used the excellent mica valves made by Messrs. Siebe, Gorman & Co., and used in their mine rescue apparatus.) While inspiring atmospheric air, the subject expired into a large canvas-rubber bag of suitable construction, and previously emptied of air. After a period of 10 minutes a fresh bag was substituted, and the volume of expired air in the first bag was measured by pressing the contents of the bag through the meter, and a sample of the expired air was collected and analyzed. Successive samples were thus taken, some when the air was ozonized and some when it was not. The composition of the atmospheric air being known, the requisite data were calculated from the measurements of the meter and the analysis of the samples, all results being reduced to 0° C. and 760 mm.

In all we have made 19 experiments, and append the details of the last 7. In the preliminary trials of the method we found considerable variations in the metabolism in successive periods of time. These were due to want of complete rest on the part of the subject. (See Table IV.)

Our last series of experiments were carried out with the subject recumbent on a couch and prepared for the test by a preliminary period of rest. Even then, the opening and shutting of the windows

(to vary the condition of ozonization of the air) must have somewhat influenced our results by altering the cooling effect of the air on the body. These tests were carried out in warm summer weather, and in the final experiment the windows were kept shut all the time and the room ventilated by opening the doors leading into other and larger laboratories. In this experiment we obtained results which we regard as the most conclusive of all.

The metabolism varies with the degree of complete rest of the subject. If he moves slightly more or less—e. g., in reading, talking—this will affect the result, and thus we can not expect figures more concordant than those we have obtained. Looking at the figures in columns 4 and 6, we can not find any conclusive evidence that ozone altered the respiratory metabolism. Note particularly the final experiment (No. 7), in which the windows were shut and the conditions even all through.

The ozone was given in a concentration that made the air smell quite strongly, and in some cases it was pushed even to an unpleasant degree. Taking these figures together with those obtained on mice, we must conclude that we have failed to obtain certain evidence that inhalation of ozone in weak concentration stimulates the respiratory metabolism, i. e., the output of CO_2 and use of O_2. On the other hand, our experiments conclusively show that any considerable concentration of ozone depresses the respiratory metabolism.

We think that the beneficial results obtained by the use of pure ozone in ventilation must be reached by the effect of ozone on the nervous system—by its stimulating the mucous membrane, neutralizing smells, and relieving the depressing uniformity of close air. Our experiments show that no harm results to man from breathing air ozonized till the air smells quite strongly of ozone, for periods of half to one hour.

Perhaps the most interesting observation made in the research is this: When the respiratory tract is irritated by ozone the animal becomes motionless, sits hunched up with its fur erect, thus showing the signs of depression. The ozone lessens the respiratory exchange, reduces it even to one-seventh, at a time when the lung shows no changes visible to the naked eye; the animal adjusts its behavior to this condition, and keeps very still and quiet. Its body temperature at the same time falls. The damage to the lung can not be serious, since this depressant effect is quite evanescent.

TABLE IV.

1. Subject breathing for 10 minutes.	2. Amount inspired, in liters.	3. Amount of CO_2 in sample.	4. Amount of CO_2 expired per minute.	5. Oxygen in sample.	6. Corrected amount of oxygen taken in per minute.	Remarks.
L. W.:						
Air	87.4	4.21	367	16.26	420.4	Nearly asleep. No effort with tube. Window open.
Ozone	95.3	4.31	413	16.09	475.5	Reading. Effort of putting on tube. Window shut.
Air	99.3	4.18	409	16.39	463.6	Reading. Effort of putting on tube. Window open.
L. H.:						
Air	107.9	4.21	453	16.63	466.2	Windows open.
Do	100.3	3.93	393	16.83	419.2	Do.
Ozone	111.6	3.89	431	16.4	515.9	Windows shut.
Do	96.9	3.90	387	16.87	399.2	Do.
Air	131.5	3.96	517	17.07	501	Window open. Bothered by valves.
L. H.:						
Air	107.8	4.05	437.6	16.85	441	Windows open.
Do	100.7	4.00	403	16.75	425.8	Do.
Ozone	86.02	4.05	348	16.39	402.5	Windows shut.
S. E.:						
Air	66.43	4.25	282.4	16.195	323.6	Reading. Windows open.
Do	58.45	3.85	226.7	16.83	241.9	Do.
Ozone	58.51	4.34	254.3	16.104	291.1	Reading. Windows shut.
Do	66.95	3.53	236.3	17.49	229.1	Do.
M. F.:						
Air	83.56	4.15	346.7	16.5	375.2	Reading. Windows open.
Do	93.37	3.65	340.8	16.93	382.8	Troubled with mouthpiece slightly. R. Q. 89.
Ozone	76.95	3.91	300.9	16.36	365.6	Reading. Window shut. R.Q. 82.
Do	97.81	3.48	340.3	18.0	274.8	Reading. Troubled with mouthpiece slightly. R. Q. 1.25.
Air	70.13	3.99	279.9	16.73	298.8	Window open. R. Q. 93.
A. W.:						
Air	68.6	4.19	287.4	17.03	261.3	Windows open.
Do	74.8	3.48	260.3	17.438	262.3	Do.
Ozone	92.4	3.80	351.2	17.20	341.9	Windows shut.
Do	73.7	3.94	290.4	16.43	341.3	Do.
Do	67.5	3.80	256.5	16.57	304.5	Do.
Air	60.0	4.15	249.0	16.32	285.0	Windows open.
Do	45.5	3.91	177.5	18.11	114.9	Do.
A. W.:						
Air	65.9	4.25	280.07	16.15	325	Windows shut all the time.
Do	50.2	5.08	265.01	16.19	233.4	Do.
Ozone	63.2	4.44	280.60	15.01	327.3	Do.
Do	56.3	4.236	238.48	15.91	293.9	Do.
Do	65.9	4.31	284.02	16.05	331.5	Do.
Air	63.7	4.31	274.55	16.01	323.6	Do.
Do	61.8	4.50	278.10	15.93	318.3	Do.

In pneumonia we see the same thing; the patient is forced by the feeling of illness to keep quiet in bed. How this adjustment is brought about is a subject for further research. It will be of especial interest to see the effect of ozone on the oxygen partial pressure of the blood. We would draw attention to the fact that high pressures of oxygen produce inflammation of the lung (Lorrain Smith, L. Hill, and J. J. R. Macleod) similar to that produced by ozone. It is this resemblance which in part led us to make this research.

CONCLUSIONS.

(1) Ozone is a powerful deodorizer. It masks rather than destroys smells. Its practical value in relieving the nervous system from the depressant influence of an unpleasant odor is none the less for this.

(2) A concentration as little as 1 per million is irritating to the respiratory tract. Exposure for two hours to a concentration of 15 to 20 per million is not without risk to life. The irritative effect and the discomfort produced thereby—cough, headache—give ample warning, and there is no risk from inhaling ozone so long as an outlet for the instinctive escape from its influence is open. It is necessary that systems of ventilation in which ozone is used should be dealt with by those experienced in the matter, so that concentrations may be supplied which will not irritate the respiratory tract.

(3) The respiratory metabolism is reduced by ozone, in concentrations even less than 1 part per million. There is no conclusive evidence of a preliminary stimulation of metabolism preceding the fall.

(4) The beneficial effect of ozone obtained by the ozone ventilating systems is to be explained by its effect on the nervous system. By exciting the olfactory nerves and those of the respiratory tract and skin, it may relieve the monotony of close air, the smell of tube railways, in cold meat stores, hide stores, and other trades.

(5) There is no harm in breathing weak concentrations of ozone, such as can be scarcely sensed by a keen sense of smell.

(6) Ozone in somewhat higher concentrations (1 per million) may have some value as a therapeutic agent if inhaled for brief periods; by irritating the respiratory tract it may act as a blister or fomentation and bring more blood and tissue lymph to the part. The blood and tissue lymph contain the immunizing and curative properties. It seems to us a simple and convenient way of applying a "blister" to the respiratory tract.

This research has been carried out with the aid of a grant from the London Hospital research fund.

[*Note added November 21, 1911.*—We have found that exposure for 10 minutes to 2 parts in 10 millions of ozone may lower the rectal temperature of rats as much as 3°, while control rats maintained their normal temperature of 38.5° C.]

TRAVELING AT HIGH SPEEDS ON THE SURFACE OF THE EARTH AND ABOVE IT.[1]

By Prof. H. S. Hele-Shaw, LL. D., F. R. S., M. Inst. C. E., M. R. I.

The Spirit of the time shall teach me speed.—*King John.*

There are few things so important to man from a material point of view as the power of locomotion; seeing, therefore, that in this respect he is far less well endowed by nature than many, if not most, living creatures, it is no wonder that he has striven from the earliest times to overcome his inferiority by means of mechanical devices. The marvelous results of these unceasing attempts which to-day we enjoy, or, as some people would prefer to say, "take advantage of," are accepted by most of us as a mere matter of course, and we are further apt to assume that the progress which has been so marked during the last century, and particularly in recent years, will continue indefinitely. Now, quite apart from mere locomotion, the question of speed is one of great scientific interest, and, more than this, it is the real test of the power of locomotion. This is not a mere accident, but has its root in something far deeper. The desire for speed is a quality inherent in man, and is doubtless a primordial instinct, the reason for which we see in all other animals, being derived from prehistoric ages. Speed was from the first a necessity of life to enable the weak to escape from the strong and to enable the strong to prey upon the weak, and men depended, just as much as the animals did, for their very existence on fleetness and speed of motion.

From what few and somewhat uncertain records we have of the achievements of man in running in the ancient sports, it does not seem there is very much difference between his powers then and in modern times. As to modern times, we find that for the short distance of 100 yards, and for the longer distance of a mile, the records of 25 years ago still stand, notwithstanding the strenuous efforts made to improve upon them on many scores of occasions each subsequent year. Thus we have for the former the record of E. Donovan in 1886, 21.3 miles an hour, and in the same year the record of W. G. George for the mile, 14.2 miles an hour, which have never been beaten; while for one distance, that of 200 yards, the record of

[1] Lecture before the Royal Institution of Great Britain, Friday, Mar. 31, 1911. Reprinted by permission, with author's additions, from separate of Proceedings of Royal Institution.

Seward in 1847, or 64 years ago, still stands. In fact, a study of all the records of 25 distances shows that several of them remain unbroken after comparatively long periods, viz, from a quarter to half a century.

Thus, so far as his own unaided powers of locomotion are concerned, man may be considered, for all practical purposes, to have reached long ago the limit of speed possibility. From earliest times, however, he has brought the muscular effort of other animals into his service, and has devoted his intellect toward improving their speed for his own uses. You will see graphically recorded in figure 1 the speeds of all the Derby winners from the year 1856—i. e., for more than half a century. The average speed, which may be taken as somewhere above 30 miles an hour, has doubtless slightly increased,

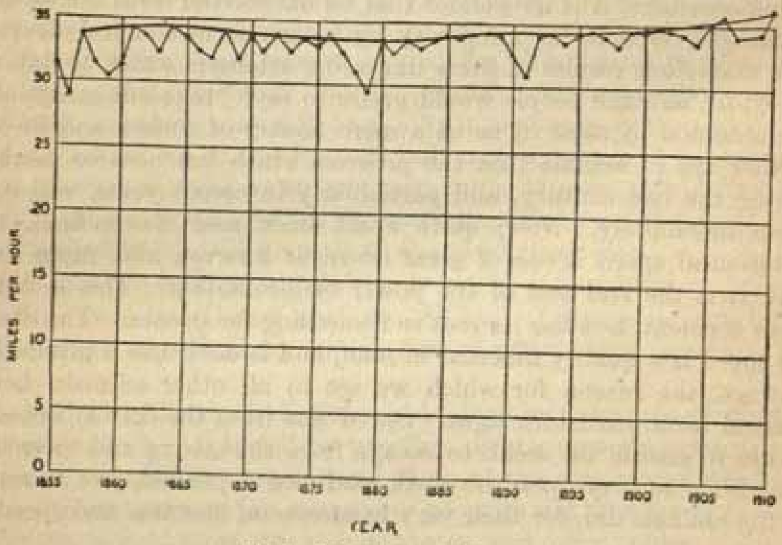


FIG. 1.—Derby winners for 55 years.

but it will be seen from the dotted line which has been drawn at the top of the maximum speeds what comparatively little increase has been obtained for an expenditure of the many millions represented directly and indirectly in the training and breeding of these horses, and it may be reasonably assumed that here again the limit has been reached for the fleetest animal, by the aid of which man can increase his speed of locomotion by using muscular power other than his own.

What, then, are the physical reasons for this limitation? It is not due to the chief cause, which we shall see later puts a practical limit to very high speeds in mechanical locomotion, namely, the resistance of the atmosphere. Neither is it due to the effective work done in movement, since with a body moving along a level plain—i. e., at a constant distance from the earth's center—this effective work is

nil. To understand the matter we must study the nature of animal locomotion. The surface of the earth is rough, sliding along it being obviously out of the question; nature has made provision for animal movement as follows: One part of the body first rests on the ground, another part supported by this is advanced, being raised clear of the ground, to rest in turn upon the ground and serve in turn as a support, so that the part behind may be raised and advanced to a fresh position. In man and other animals the feet form the points of support for this process; but the same method of locomotion is employed by creatures without feet, which have to crawl or glide, such as snakes or worms.

This process, whether with animals or reptiles, as you will see, involves in the raising of the body an expenditure of work which is not recovered, and further an expenditure of work in stopping and starting some portion of the body in its movements. My assistant now walks in front of the blackboard holding a piece of chalk level with his head, and you will see the rising and falling motion. I have prepared a wooden model to represent the action of his legs, and you will see that these legs, being equal to his in length, produce almost exactly the same curve underneath, so that you have a complete explanation of this movement, viz, the rotation of the hip about the ankle as a pivot. There is a third case of loss, namely, the energy involved in swinging the legs. About 30 years ago the distinguished French professor, Marey, actually investigated the loss involved from each of these three causes, and I have on the wall a diagram in which you will see all three given graphically. The number of steps per minute, you will notice, increases until a pace is reached when it becomes painful to walk faster, and you will also notice from the diagram that at about 90 steps per minute the gait changes to a run—that is to say, a springing action takes place, the hind foot leaving the ground before the front is put down upon it.

I have another diagram showing how the length of stride at first increases with the pace, and afterwards begins to fall off before the walking breaks into a run. The reason why a man or an animal changes his pace at this point is obvious, and it is because a faster speed is possible with a less effort. As the speed of running is increased the total effort becomes greater, but the three elements shown on the diagram are differently divided; the rise and fall element is less, but the work done in swinging the legs is more, while the chief element, in the muscular effort expended, is the loss of energy involved in stopping and starting as each spring reaches a maximum. Time does not permit me to pursue this interesting subject further except to point out that exactly similar causes operate in the natural locomotion of other animals which move on legs.

We therefore now know that the limit of speed is controlled by two factors:

(1) Physical endurance, owing to the expenditure of work occurring at an increasing rate as the speed is increased.

(2) The physical impossibility of giving a reciprocating movement to the legs quicker than a certain limited period of time.

I have prepared a chart (fig. 2) which shows the maximum recorded velocities of man's progression in walking and running. The speeds are set up as vertical ordinates, and the abscissæ represent the distances over which the respective speeds were maintained. It will be

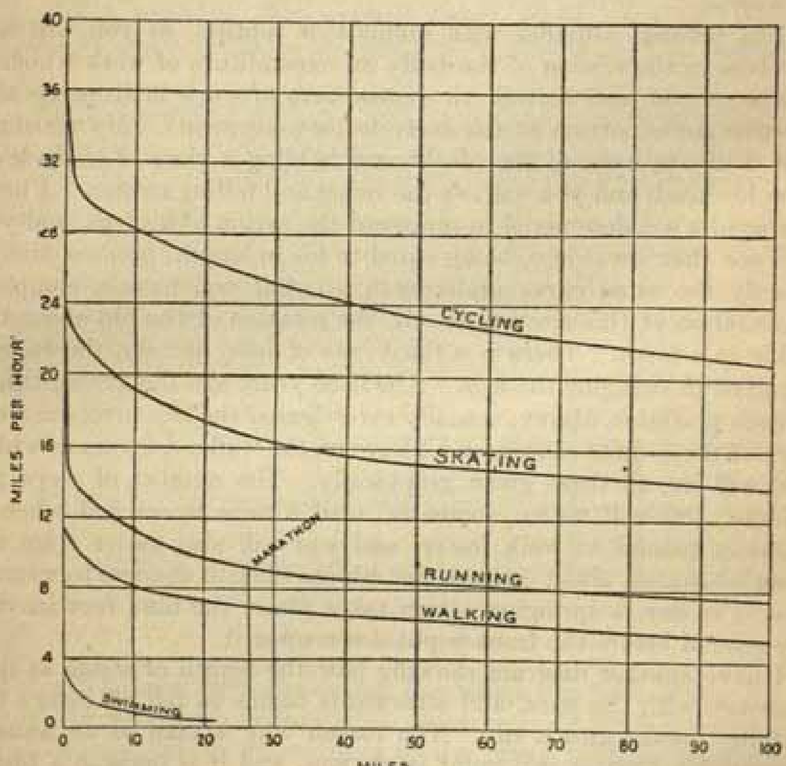


FIG. 2.—Speed records for human muscular effort.

seen that the maximum speed of walking is about 9 miles an hour for a short distance, but when the long distance of 100 miles is covered, the quickest rate recorded falls to 5½ miles an hour. For running, the quickest speed which I have mentioned, viz, 21⅓ miles an hour for 100 yards, falls to 7½ miles an hour as the average speed for a distance of 100 miles.

We do not know the speed of the original historical run from Marathon to Athens, but we do know that Dorando ran the modern Marathon from Windsor Castle to the stadium at Shepherd's Bush, a distance of

26 miles 385 yards in (to be exact) 2 hours 55 minutes 18⅗ seconds, or at the rate of 9 miles per hour, which, you see, fits very well on our curve.

We may notice in passing that in walking fast and starting to run the arms swing in time with the opposite leg, as in the modern picture on the diagram exhibited. In the picture, however, copied on the same diagram from an ancient Greek vase, although the attitude of the legs is the same, it might appear at first sight as if the arms were swinging in the contrary way. As a matter of fact, a closer examination shows that in all the figures on the vase the arms are in the same position, although the legs are in different phases. This seems to indicate that the arms of a Greek runner were held in a fixed position, as shown, and from the position of the hands, with the evident intention of cutting the wind. If this is true, it indicates that even then it was clearly recognized that if there was any effect of the wind it was just as important behind as in front, a matter I shall have to allude to hereafter.

What man can do by his muscular effort in the water is shown by the small curve in the corner. The greatest distance shown (fig. 2) is about 21 miles by Capt. Webb at about 1 mile per hour, although for a short distance it will be seen that a man can swim at about 4 miles per hour. I do not put in flying, because man has not yet flown by his own muscular effort, and flying men to-day are using engines of from 20 to 100 horsepower, i. e., from 200 to 1,000 man power. Gliding per se is no more than falling through the air (more or less) gradually, as in a parachute.

Before proceeding to see what man has done to increase his powers of purely muscular locomotion by means of mechanical devices we will study the details of locomotion in the other animals. We are able to do this by the method of Mr. Muybridge, since developed in the invention of the cinematograph, and which was explained by Mr. Muybridge for the first time in this country about 30 years ago in a lecture in this hall.

Take first the galloping horse. The lantern diagram shows clearly the various phases in the action of a horse, and shows how the animal is not only able to attain its high speed by its length of stride, but by doing what man can not do to the same extent—drawing up its body and in springing forward, using alternately its fore and hind feet, so as to get a stride which no two-footed creature could attain on the level ground. I may point out that the kangaroo, though using only two legs, makes effective use of its tail in the spring. The horse springs clear of the ground off its forefeet, only you will notice that it uses both its fore and hind legs as the spokes of a wheel on which it rolls when walking (exactly as man does), though it rolls and swings alternately in galloping. The same kind of diagram could be con-

structed for the effort exerted at different speeds by the horse, as has been produced by Marey for the man, only the distribution of energy would probably be very different.

Turning next to other animals, it is interesting to observe that a greyhound gets its high speed in proportion to its size owing to the great flexibility of its long body, which enables it to draw its hind legs forward each time for the next bound, and also bound forward both from its fore and hind legs. The other animals in galloping have each the same general kind of movement, although the deer, curiously enough, only bounds from its hind legs, and differs in this respect from the horse; and also it will be noticed the want of flexibility in the body of an animal may be one of the causes of its relatively slow speed. But whether it be man, horse, dog, or any other animal, the same characteristic is found, namely, that locomotion, apart from the bounding action, takes place by a sort of rolling action on the ground. The idea which had persisted since the delineation of horses in Assyrian and Egyptian pictures, that both the fore or both the hind legs are put on the ground simultaneously, is thus exploded. As Mr. Muybridge truly said:

> When, during a gallop, the fore and hind legs are severally and consecutively thrust forward and backward to their fullest extent, their comparative inaction may create in the mind of the careless observer an impression of indistinct outlines; these successive appearances were probably combined by the earliest sculptors and painters, and with grotesque exaggeration adopted as the solitary position to illustrate great speed.

As a matter of fact, each leg in turn, as it rests on the ground, stops for a moment just as much as in the forward position above mentioned, and if you watch a dog galloping you can see quite clearly the rolling stroke action I have mentioned.

With the above facts in mind, we can understand exactly the limitations to animal locomotion. In the words of Mr. Muybridge:

> When the body of an animal is being carried forward with uniform motion, the limbs in their relation to it have alternately a progressive and a retrogressive action, their various portions accelerating in comparative speed and repose as they extend downward to the feet, which are subjected to successive changes from a condition of absolute rest to a varying increased velocity in comparison with that of the body.

Hence, all animal locomotion absolutely lacks that continuity of movement, the production of which we shall see is the distinguishing feature and the direct cause of the high speeds attained in mechanical locomotion.

The exchange of the intermittent movement of nature for one having the desired continuity of movement has been effected by means of what is possibly the greatest and yet the simplest of all human inventions, namely, the wheel. The wheel was made and used probably thousands of years before man learned to replace muscular effort

by that of steam and the other forces of nature, the origin of the wheel being absolutely lost in antiquity.

From the models which I now show will be noticed the way in which the wheel acts and how it overcomes the defect of animal locomotion, giving a rotary and continuous movement instead of a reciprocating and variable one. At one and the same time the wheel, therefore, does away with the three causes of loss shown in the diagram as occurring with animal locomotion. The mere use of the wheel has enabled man himself, by his own muscular effort, enormously to increase his individual power of locomotion. The top curve on figure 2 shows, in comparison with the other curves of walking and running, his unpaced records on a bicycle, in using which it will be realized that all three causes of loss which occur in running and walking are obviated. You will notice a similar difference in speed as the distance varies to that which is made evident in the curves for walking and running. For the distance of 100 miles the average speed is thus only 21 miles an hour, while that for a one-fourth mile is more than 35 miles an hour. In view of the results shown by the curve, it is not surprising that the bicycle has entered largely into the conditions of modern life. I am not able to give you any exact figures of the quantity of bicycles turned out each year in this country, but I can tell you that in the post office alone there are now 12,000 bicycles employed, and their number is always on the increase; the distance covered on them by men and boys in the year is more than 120,000,000 miles.

I have not dealt with paced bicycle records, as such are not the result of muscular effort, but of being pushed along by the current of wind which follows up the pacing machine, such as occurs when a man on a "push" bicycle is paced by a motor vehicle. In a record first set up in America for 60 miles an hour on a bicycle, a man was paced by a locomotive engine, running at 60 miles an hour along a special track; the rider was nearly killed when he tried to drop behind, owing to the whirlwind which was being dragged along by the engine; ultimately his life was saved by his being lifted bodily off his bicycle onto the locomotive. There is no record as to what became of the bicycle.

Curiously enough, records for ice skating and roller skating are almost the same, and far below that on the bicycle, which I think proves distinctly that the reciprocating movement of the limbs limits man's powers, whether he is sliding on the ice or using wheels as with roller skates. This is so, notwithstanding that he carries along with him when on a bicycle the extra weight of the bicycle, but the reciprocating movement of his legs is so slow, owing to the gearing up of the driving wheel, as to give him the material advantage shown by the respective curves. Further, in skating, there is no doubt that

the movement of his limbs entails a certain amount of rising and falling, as well as reciprocating motion and consequent loss which occurs in running.

Now, in theory, the wheel is perfect, and in the case of a perfectly hard, circular wheel, rolling on a perfectly hard track, there should be no resistance. This you can well imagine from the lantern model which I now show in operation. In this there is no appreciable resistance, but it is just in this direction that the wheel has defects unknown to nature's methods, since men and animals move upon the ankle joint in a quite superior way to the rolling of an ordinary wheel. In passing I may remark that the more man improves the roads, and the higher his standard of locomotion becomes, the more will he feel the need of a mechanical walking machine (it will be a walking machine, though possibly moving at 20 miles per hour) to progress over parts of the earth where roads do not exist, or are still in an evil condition. The better his mechanical appliances for producing such a walking machine, the sooner will this come about, as this is really a vital factor in the solution of the problem. No wheel, however, is quite hard and round, and no road is quite hard and smooth, and there is always an arc of contact, more or less appreciable, which causes a loss, since rubbing takes place instead of true rolling, as shown in the next lantern slide. The next lantern working model I show illustrates the other effect, in which the wheel meets obstacles and is deflected by them from its course, giving exactly the same kind of loss which I showed you takes place with a man in walking, and which is made apparent by making the car write its own record on a piece of smoked glass, exactly as my assistant wrote his record of rise and fall on the blackboard.

Thus there are two ways in which the wheel can be improved:

(1) By perfecting the wheel and hardening the track—and that is the secret of the development of the railway system.

(2) By causing the obstacle to be absorbed in the tire of the wheel—that is the real secret of the success of the pneumatic tire.

The working model now on the screen illustrates the latter point, and shows at once how the three causes of resistance to animal locomotion are overcome.

To-day we can replace the muscular energy of man by almost unlimited mechanical power, and figure 3 is a comparative speed chart, which I have prepared and which indicates the enormous advance in the speed record which has been made over the best unaided muscular efforts of any animal. It is curious to see that the highest speed ever attained on a railway is closely approached by that obtained with motor vehicles. The records for the latter are as follows:

The Darracq car of 200 horsepower has done 122¼ miles an hour for 2 miles. A Fiat car, driven by Nazarro at Brooklands, 126 miles

an hour. A Stanley steam car, 127 miles an hour, and a Benz car has done 127½ miles an hour.

The maximum recorded speeds of a railway were on the experimental line of Messrs. Siemens, on the Berlin-Zossen High Speed Railway, where a speed of rather more than 130 miles an hour was attained. The electric current employed was 10,000 volts, 400 horsepower motors being used. On the Marienfel-Zossen experimental line, the speed attained with 250 horsepower was apparently rather

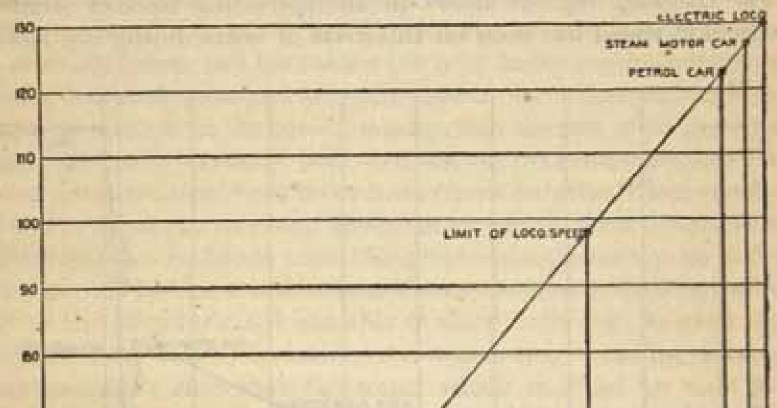


FIG. 3.—Graphical table of maximum speeds.

less, though in that locomotive four motors were employed, the current being, as in the other case, 10,000 volts. The lantern diagrams are a picture of the vehicles actually employed, and of the track on which the experiments were made. As a set-off against the sober engineering pictures, I show a picture taken from an American motor journal, illustrating a motor vehicle and locomotive at top speed, the former passing on a level crossing in front of the latter.

The foregoing are the record speeds so far obtained of mechanical locomotion, and it will be interesting to see what are the record speeds attained in the other elements. Until the other day, as Mr. Parsons told us in his lecture, the speed on water which has never been exceeded was that of the ill-fated turbine boats, *Viper* and *Cobra*, of about 43 miles an hour. The ship which at present holds the record for speed is the torpedo destroyer *Tartar*, built by Messrs. John Thornycroft; this, under Admiralty tests, giving a speed of 41 miles an hour.

The diagram (fig. 4) shows in an interesting manner what the progress in speed has been for this class of boats during the last few

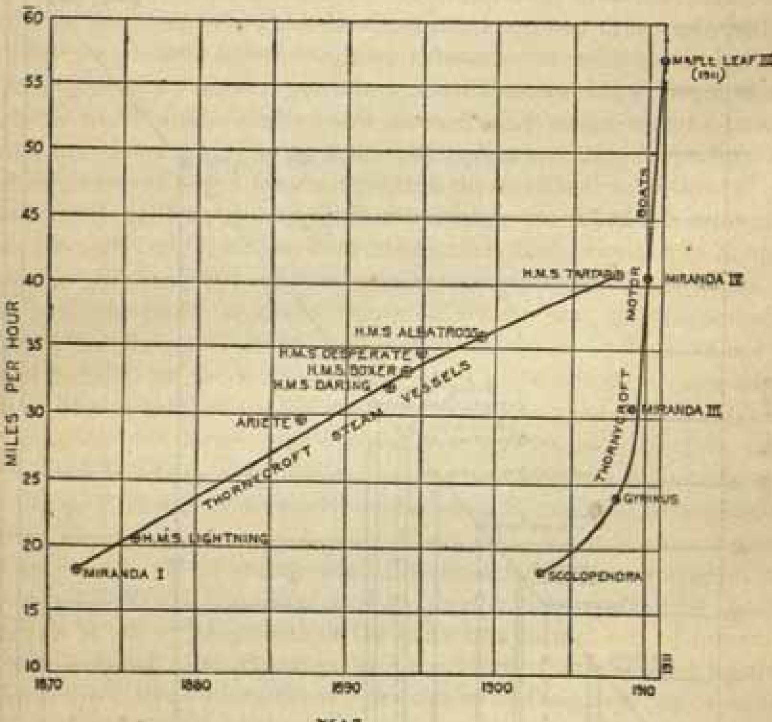


Fig. 4.—Speed records for Thornycroft warships and motor boats.

years, and may be taken as typical, and about which curves Sir John Thornycroft writes as follows:

> I do not think the curve would be materially altered if vessels of other builders were brought in, although there would naturally be more points on it.

I am able, however, to give you the results to-night of something which has altogether put in the shade even the speeds of the two first-mentioned boats. This has been attained by a boat which, though corresponding in some respects with previous hydroplane boats, has been designed by Sir John Thornycroft to possess a certain amount

of seaworthiness. The rate of progress in the increasing speeds in this class of boat is shown on a separate curve (fig. 4), from which you will see that the celebrated *Miranda* held as a hydroplane the record with the *Tartar* for speed, the *Ursula* also holding the record of about the same speed as a motor boat. Only a few days ago, however, the new boat *Maple Leaf III* has attained the extraordinary speed of nearly 50 knots; that is to say, a speed approaching 60 miles an hour, using 600 horsepower to effect this speed. To use a vulgar expression, this certainly smashes all previous records for speed. I do not pretend to give exact figures in this case, because such have not been officially taken, but the statement is probably on the low side as the boat has not been yet properly tuned up. You will see one remarkable thing from the curve, namely, that the rate of progress has been so rapid in this class of boat, and the curve rises so steeply, that in about three months' time there is due from Sir John Thornycroft a boat which will travel at about 100 miles an hour. I am afraid, however, it would not be fair to press this graphical argument quite so far.

Through the kindness of Sir John Thornycroft and Mr. Edgar, the owner of the *Maple Leaf*, I am able to show both the *Miranda* and the *Maple Leaf III*. The latter, you will see, is traveling at such an extraordinary rate that the water which is lifted up does not fall to the surface again until the boat itself has traveled several lengths away. You may be interested to see a model of this last boat, which has been kindly prepared for me to show to-night, as well as the *Tartar* and *Miranda*. You will notice the form of the *Maple Leaf III* is that of a steeped hydroplane, which in a modified form was first suggested by Mr. Ramus many years ago; it is the secret of placing the weight, and also the development of light engines giving large horsepower, which has enabled the dream of Mr. Ramus to be fulfilled.

Turning to the last of the three elements, namely, air, it was my intention to have dealt with it at greater length than I now find it is possible to do, but, thanks to the daily press and illustrated journals, this subject is as fresh in the minds of everybody as it is familiar. It is not necessary in this room to remark that the wild talk of almost incredible speeds has very little foundation. Bodies move quickly enough in the air, and very often far too quickly, but what is generally overlooked is that the difficulty of the problem lies in the matter of supporting the body in the air rather than moving through it, a problem which is very much simpler for land and water. The human body itself, while of about equal specific gravity with water, is about 800 times as heavy as air, and probably, taken in conjunction with the motor and aeroplane, the weight which has to be supported is several thousand times as heavy relatively to the air which it displaces. Inasmuch as the support of the air necessitates the use of an

inclined plane and a corresponding expenditure of energy, the speeds made horizontally and independently of the wind have, at the present time, barely exceeded half the record speeds made on wheel vehicles. As a matter of fact, only the other day the record for passenger flight was broken by M. Nieuport at Mourmelon, when he flew with two passengers for 1h. 4m. 58⅗s., and covered 68.35 miles at an average speed of 63 miles per hour. It is difficult to say exactly what the true speed at present is round a course, but we may safely take it as probably under 70 miles an hour, the record being, so far as I have been able to ascertain, by M. Nieuport on March 9 this year at Chalons—68 miles 168 yards in the hour.

We now see the relative position of the record speeds in the three elements on our speed chart (fig. 3), and it is obvious that while on land the speed has been far exceeded of the fastest animal, on water it has probably only recently surpassed that speed, while in the air, in all probability, it is still considerably below it. We must not, however, from this argue that flying speeds will for safe flying machines rise so far beyond that of birds as land locomotion has risen above the speed of animals, for it looks as if the speed records on land would be at least equal for some time, if not greater, than that possible with safety in the air. At the same time there is no doubt that speed is the one great factor of safety in flying, and aerial speed records are sure to go on rising year by year, but time does not permit me to pursue this subject further to-night.

Instead of vague surmises as to what may be done in the future, let us spend a few minutes looking into the question of these limits. The two chief things on which the limit of speed in locomotion will depend are:

(1) The motive power available.

(2) The resistance, and the manner in which those resistances operate.

But inasmuch as we are not merely considering the human body as a projectile, we do not take into account such speeds as have been attained by man in such ways as, for instance, in a high dive, say, of nearly 100 miles an hour, or even the thrilling descents such as are made in a bobsleigh. We must really consider speeds which can be made with safety; and there are two further questions which arise:

(1) Knowledge as to possible obstacles, coupled with a power of safely stopping within the distance to which our knowledge extends, i. e. signaling and brakes.

(2) Vibration.

These two latter really limit conditions of high speed for practical traveling.

In daily life the limiting conditions of speed in traveling depend largely on the distance in which we can safely come to rest. As

the population increases and there is less room for everybody, the question of brakepower becomes more and more important, and with it, of course, the power of starting from rest quickly, or, to put it in scientific words, the power of rapidly effecting both positive and negative acceleration. We are very differently constructed from the particles of air in which we live, and do not yet travel as fast, but fortunately, as yet, we are not quite so crowded, since, according to Lord Kelvin, they move about amongst each other at the ordinary atmospheric temperature and pressure at an average speed of 1,800 miles an hour, and they can not avoid fewer than 5,000 million collisions in every second. As you see in the streets, and as I shall show you with regard to suburban traffic, high speed is becoming more and more a question of starting and stopping rapidly. I remember in the early days of cycle racing, in order to lighten the machine, the racing men had no brake, until they found what is now well recognized—that the speed at which you can travel depends upon the safe distance in which you can stop. I can illustrate this by dropping an egg from the dome of this building, which I can do without causing it any injury, even when it is traveling at 30 miles an hour, if I have proper means for bringing it to rest. I also drop a wineglass from the same height and bring it to rest quite safely.

Owing largely to the perfection of the continuous brake, the speed records obtained on several railways are from 96 to 98 miles an hour, which I have put down on the diagram, and it is possible that 100 miles an hour has been reached, and even exceeded; but this is a very different matter from the highest express running which is found really practicable. You will see on the speed chart (fig. 3) a line indicating the average railway speeds of the fastest running (without stopping) for the 15 principal railways of the country. The average distance of the quick runs is 51.7 miles, and the average fastest running is 56.2 miles per hour. On either side of this line are the two fastest speeds namely, 61½ miles per hour for 44¼ miles on the North-eastern Railway from Darlington to York, and the lowest of these is 51 miles an hour, over the 51 miles from Victoria to Brighton on the London, Brighton & South Coast Railway. This shows how little the high speeds of all the railways of this country differ from one another, and indicates, at any rate for the present conditions, the highest speeds of traveling found suitable to our wants.

I will take as another illustration of actual traveling the case of suburban traffic; and we have only time for one example, namely, the traffic from the Mansion House to Ealing on the Metropolitan & District Railway, the details of which have been kindly provided. by Mr. Blake, the superintendent of the line. Figure 5 shows in

graphical form the quickening in speed from the opening of the line in 1880 to the present time. You will notice that this increase of speed has been followed by remarkable results; the first immediate result is the possibility of a greater number of trains, and the curve of the rise in the number of trains is shown on the diagram; but the really significant feature is the rise in the number of passengers carried, 35,000,000–72,000,000, which is the direct result of the increased facility in traveling. Now, it is in such a case that the importance of the signaling and braking come to be almost preeminent, quite apart from the mere mechanical problem.

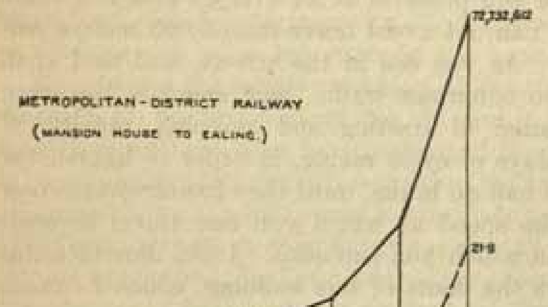


FIG. 5.

I may point out that the District Railway, in common with most other electric railways of this country, has what is known as a "track system of signaling," which apart from the fact that the driver holds what is known as "the dead man's handle," which upon being released causes the train to stop, the train independently stops itself upon coming to a portion of the line not cleared by the previous train.

I have given you some examples that this country is not so far behind as we are so often told; and we have another in the fact that the District Railway has created a most beautiful system, by which the signalman is now absolutely independent of fog or darkness; he can see every train, or rather its picture, as it moves along the track in an illuminated diagram in front of him. No one could watch, as I have had the privilege of doing, the operation of this system in a signal box without feeling certain that it must become universal in a very short time. You may like to see an actual panel from a signal box and a view of what the interior is like with the signalman operating, instead of cumbrous levers, only a few small handles.

With regard to the question of vibration and oscillation, these are gradually being diminished as machinery is perfected, and you will see from the model illustration that they are important and may become very serious. They have, for instance, given Mr. Brennan much trouble in perfecting his wonderful monorail, with which we shall yet perhaps see every record broken; and you will remember Mr. Parsons's statement in this hall a week or two ago that an ounce out of balance on the Laval turbine represents an actual pull at the axle of no less than a ton.

There are many other features which I have not time to enter into. There is one, however, which I will briefly touch upon, as it is the secret of our safe railway traveling. I will illustrate the matter by an experiment in which a pair of wheels connected by an axle keyed firmly to both are made to run along a pair of rails. You will notice that the wheels are "coned" instead of having cylindrical rims, and it is easy to see that any movement sidewise is at once corrected automatically, and within certain limits no rim at all is required for the flanges in order to keep the wheels upon the rails. The same model illustrates the important property of "super-elevation" applied to the outer rail of a curve. You will see, with proper super-elevation, the wheels run safely around this sharp curve even at a high speed. Time does not permit me to enter at any length on the question of development of power or the nature of resistance to motion. I will content myself with saying that with regard to the former we have already seen that the power of flight has been made possible by the invention of the small high-power internal-combustion engine, and it is to the same invention that the marvelous speeds obtained with small boats is due. We can scarcely realize what will be the result when the internal-combustion engine has been developed further for the purpose of locomotion. Our prospects of a further great advance in speed record breaking appears to lie in this direction, and we already hear of a new car of 250 horsepower with which a speed of 140 miles per hour is confidently expected.

On water, as on land, our actual speed of traveling falls far below maximum speed records, and we do not commercially travel at much more than half the possible speed, as you see from figure 3, where the speed of the *Mauretania* is shown graphically. Figure 6 is a chart of the progress of Atlantic shipping, taking the Cunard Line as an example, and these curves indicate that the rate of increase of horsepower and tonnage is rising far faster than the rate of speed and indicates how relatively highly the rate of power has increased for the gain of speed.

We have now passed briefly in review the nature of the problems which confront us in our continuous efforts to increase the safe and practical speeds of mechanical locomotion. We see that at the root

of it all lies the question of artificial power and the harnessing in compact and convenient form the stored-up sources of energy in nature in order to overcome the opposing resistance, and we can realize that, although we have obviously reached the limits of animal locomotion, we are far from having reached any limitation in regard to the speed of self-propelled machines. We see that in all three forms of locomotion—earth, air, and water—the advance has been far more rapid during the last few years than ever before, and we can realize that there is yet a considerable margin by which speed of traveling could be increased as the demand for it is made; and nothing is more certain than that the demand will be made.

I began my lecture by pointing out why speed was instinctively taken as a test and a measure of locomotion from the earliest times.

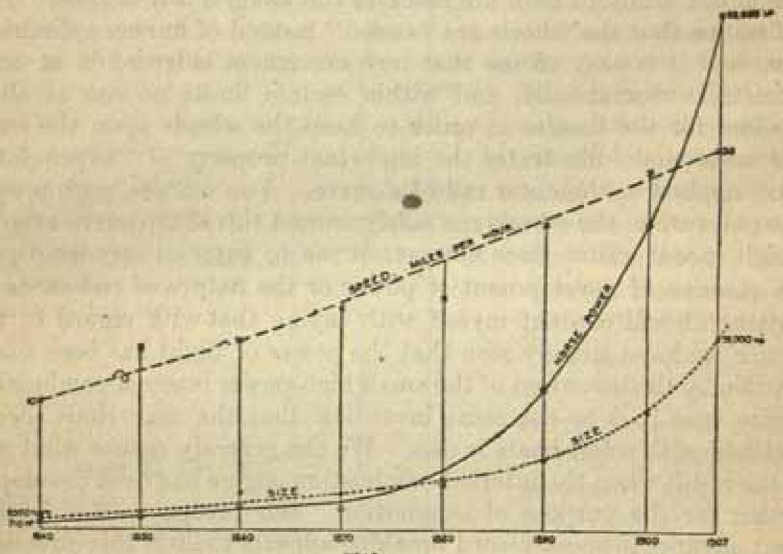


FIG. 6.—Progress in Atlantic steamers (Cunard).

Shakespeare makes one of his characters say, "The spirit of the time shall teach me speed," but he might have said this of any period equally with that of King John, though never more so than of to-day, for the changes in the requirements of civilization have only altered in detail, and speed is of as much importance as ever in the struggle of life. The probably unconscious recognition of this fact has always led question of speed to be raised as prime factors in proposals for new modes of locomotion, and it is interesting to look back only a comparatively few years to see, in raising these views, this was always the case, but how little any ideas of future possibilities were realized. When George Stephenson, backed up by a few courageous and enterprising men, was fighting the battle of the railway and in

particular trying to secure the passing of the bill for improved communication between Liverpool and Manchester, the question of speed was the most important one raised. The opposing counsel, Mr. Harrison, spoke as follows:

> When we set out with the original prospectus, we were to gallop, I know not at what rate; I believe it was at the rate of 12 miles an hour. My learned friend, Mr. Adam, contemplated—possibly alluding to Ireland—that some of the Irish members would arrive in the wagons to a division. My learned friend says that they would go at the rate of 12 miles an hour with the aid of the devil in the form of a locomotive, sitting, as postilion on the fore horse, and an honorable member sitting behind him to stir up the fire, and keep it at full speed. But the speed at which these locomotive engines are to go has slackened: Mr. Adams does not go faster now than 5 miles an hour. The learned sergeant (Spankie) says he should like to have 7, but he would be content to go 6. I will show he can not go 6; and probably, for any practical purposes, I may be able to show that I can keep up with him by the canal. * * * Locomotive engines are liable to be operated upon by the weather. The wind will affect them; and any gale of wind which would affect the traffic on the Mersey would render it impossible to set off a locomotive engine either by poking the fire or keeping up the pressure of steam till the boiler was ready to burst.

The committee, after hearing the arguments of Mr. Harrison, threw out the bill for the Liverpool & Manchester Railway by a majority of 19 to 13. In order to realize that the above ideas were general, the following may be quoted from the great journal of the day, The Quarterly:

> What can be more palpably absurd and ridiculous than the prospect held out of locomotives traveling twice as fast as stage coaches? * * * We trust that Parliament will, in all railways it may sanction, limit the speed to 8 or 9 miles an hour, which we entirely agree with Mr. Sylvester is as great as can be ventured on with safety.

Even in more recent times we see the struggle for the road locomotion question turned on one of speed, and the supporters of the new departure were unable to make any headway for many years, partly because the speed limit was put at between 3 and 4 miles an hour—that is, the limit of a walking man. A few years ago the speed of 12 miles an hour, which, after a great struggle, was obtained, gave place to 20 miles an hour. You can see from the diagrams which Mr. Legros gave in a recent paper before the Institution of Mechanical Engineers, and which have been brought up to date, how the speedier self-propelled vehicle is leading to the disappearance of the horse—at any rate in London—and the difficulty which most people seem to feel is not how to get above the speed limit, but how to keep within it, and the papers show, by a daily crop of sad examples, how only too painfully easy it is not to do so.

Nothing points more clearly to what I have indicated as the basis of our instinctive desire for speed, than the fact that our measure of speed is entirely relative. Thus 60 miles an hour would be a slow speed for a motor car on a racing track, as seen by the speeds of the motor races at Brooklands last Saturday (March 25), but this speed,

which would be even quite good along the open road to Brighton, would be considered decidedly on the high side for motoring along the Strand. Our ideas of what is slow and what is fast are largely derived from habit, and particularly from surrounding conditions and from our mode of estimation. For instance, we have been carried in this hall during the last hour with the surface of the earth round its axis a distance of about 600 miles. This speed would require a line on our speed chart about as high as the dome of the hall to represent it graphically. But if we judge the speed from observing the apparent rate of motion of the moon and stars overhead, we could never realize this. Far less could we realize by the change in the seasons the speed at which we are traveling with the earth round the sun, accomplishing a distance, as we do, of 540 million miles in 365 days, which represents roughly, a distance of 60,000 miles per hour. We have thus traveled together, since we came into this hall, a speed of 60,000 miles. The line required on our chart for this speed would be about as high as St. Paul's Cathedral. But these speeds fall far short of those of certain heavenly bodies with which we are familiar, such as the meteors, some of which are traveling at 160,000 miles an hour, and the recent comet, which probably exceeded this speed one part of its journey round the sun; whereas the fastest speed which man has, up to the present, been able to produce, even in a projectile, amounts to between 2,000 and 3,000 miles an hour (the Krupp 10.7 centimeter having a velocity of 3,291 meters per second, and a 6-inch Vickers, 3,190 meters per second). The highest projectile speeds we have attained are thus only about one-tenth of the speed at which Jules Verne fired M. Barbicane and his friends off, in order to overcome the earth's gravity and reach the moon, since the speed he required was 12,000 yards per second, or 24,000 miles per hour. Such an idea we are quite justified in thinking absurd, but we might have been justified in thinking many of the things absurd which Jules Verne wrote about, only 40 years ago, and which have since come to pass. Take Round the World in Eighty Days. In that case it cost Phineas Fogg £19,000 to take himself and his servant round the world in 80 days. A telephone inquiry of Messrs. Cook an hour or two ago elicited the fact that anyone present can start to-morrow morning and go round the world, with a servant, in less than half the above time, and for less than one-fiftieth of the above sum.

Thus though, impelled by instinct, man will ever continue to strive to increase his speeds of traveling, and with the refinement of machinery and invention doubtless succeed in doing so, it may be safely said that, notwithstanding the still increasing upward angle on some of the speed lines of the charts I have shown to-night, this rate of increase will before long begin to take place at a continually diminishing rate. Such feats as the journey from Paris to London within the

hour may be regarded as quite a feasible engineering proposition in the future, though possibly a tube will be used for the purpose, without the employment of wheels, and with a modification of the pneumatic system of that great genius Brunel. We should, however, in doing this journey, be only traveling at half the rate we are actually moving at this spot around the earth's axis, while to do it at the rate we are traveling round the sun we should only occupy a quarter of a minute. This latter speed, apart from the fact that it is getting very near the point at which meteors fuse with the friction of the earth's atmosphere, seems to be quite outside the limit of the possibilities of artificial locomotion by man, but how far we shall go toward it, who can tell?

Note.—Since delivering the above lecture, M. André Jager Schmidt, of the Excelsior, has made a tour round the world in 39 days 19 hours 43 minutes 37 seconds. The cost of doing this was £242 8s. The actual cost of the railway ticket round the world being £115, the rest being extra payment to insure expedition.

Further note, February 14, 1912.—Since the foregoing lecture I showed that the curves of fatigue for metals coincided in a remarkable way with the curves of fatigue for muscular effort given in fig. 2. The following statement of my remarks on this subject appears in the Proceedings of the Institution of Mechanical Engineers for 1912:

Dr. H. S. Hele-Shaw (member of council) said he was responsible for the curves which appeared on the diagram exhibited [fig. 7], "Endurance of Metals," and there seemed to be a great deal of curiosity amongst the members as to what cycling, running, and skating had to do with the subject of the paper. A short time ago he gave a Friday evening lecture at the Royal Institution on Traveling at High Speeds, and he then gave, he believed for the first time, the plotted records for muscular fatigue. The records, as would be seen, consisted of plotted curves for the highest speeds, that is, the greatest efforts, and the distances over which it was possible to maintain those speeds, which speeds were represented by the vertical lines in the diagram. He thought every engineer would at once understand without further explanation what the curves showed. For instance, taking the running curves, it would be noticed that it was possible for a man to run 100 yards at the rate of about 21 miles an hour; but if he ran for 100 miles he could only run at the rate of 7¾ miles an hour. The same principle applied to all the other records. He did not wish to enlarge upon the details of the particular curves, but his assistant, Mr. T. E. Beacham, B. Sc., who drew them up, pointed out to him the remarkable similarity of the curves obtained by the authors for the fatigue of metals, and his own curves for muscular fatigue . One of the author's curves was taken at random, and the scale altered, and it would be seen that it was exactly the same kind of curve as those on the muscular fatigue diagram. The curve selected happened to be figure 31 [fig. 7], which dealt with specimen No. 29, and that was plotted in the dotted line shown in the diagram. Now the question arose, Was there any reason for the similarity between the curve for muscular fatigue, and the curve for metal fatigue? It would be noticed, in the first place, that the results from the muscular tests corresponded to the breakdown in the metal tests. The curves for muscular endurance were the final result of many thousands of efforts to achieve the greatest possible effect for a given speed and a given distance, and when the man

had achieved that object he had broken down, at any rate, temporarily. It was well known that in a 100-yards race the man who made the greatest effort, and put the greatest possible endurance into that effort, was practically absolutely exhausted, and this corresponded to the yielding of the metal specimen when it gave way. It was the same with the man who ran 100 miles, but he could only maintain a less speed for that distance; the same result was obtained with the breaking down of the metal under less stress when the reversal of stress was further prolonged, and there was every reason for both kinds of curves being logarithmic in form as they were. Thus, muscular fatigue corresponded in a certain way to the endurance tests of metals.

It was only quite recently that physiologists had understood the reason of the limits of muscular endurance, which limit was reached because of the formation of the toxins

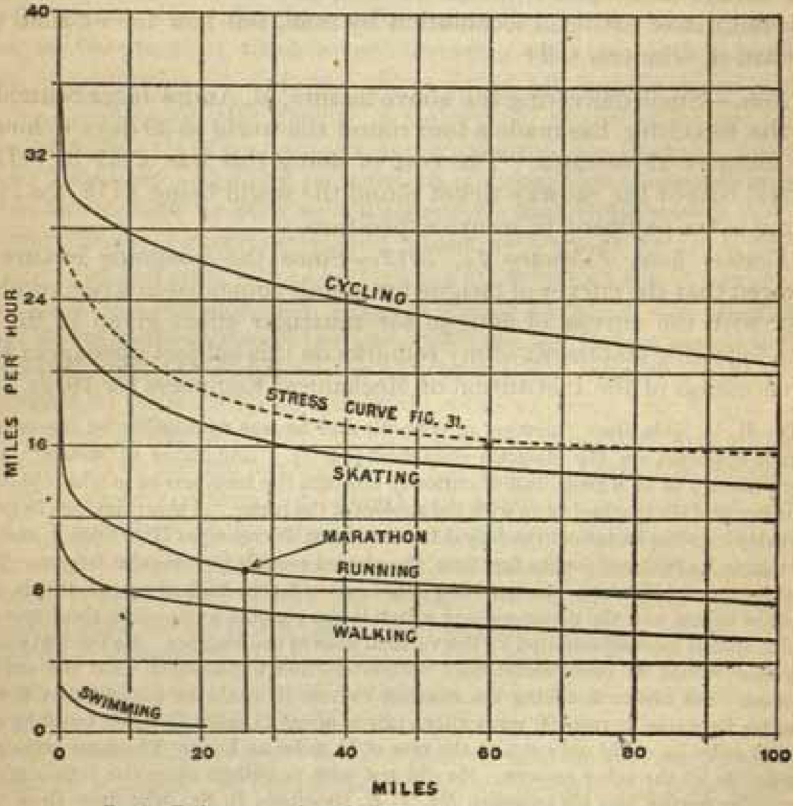
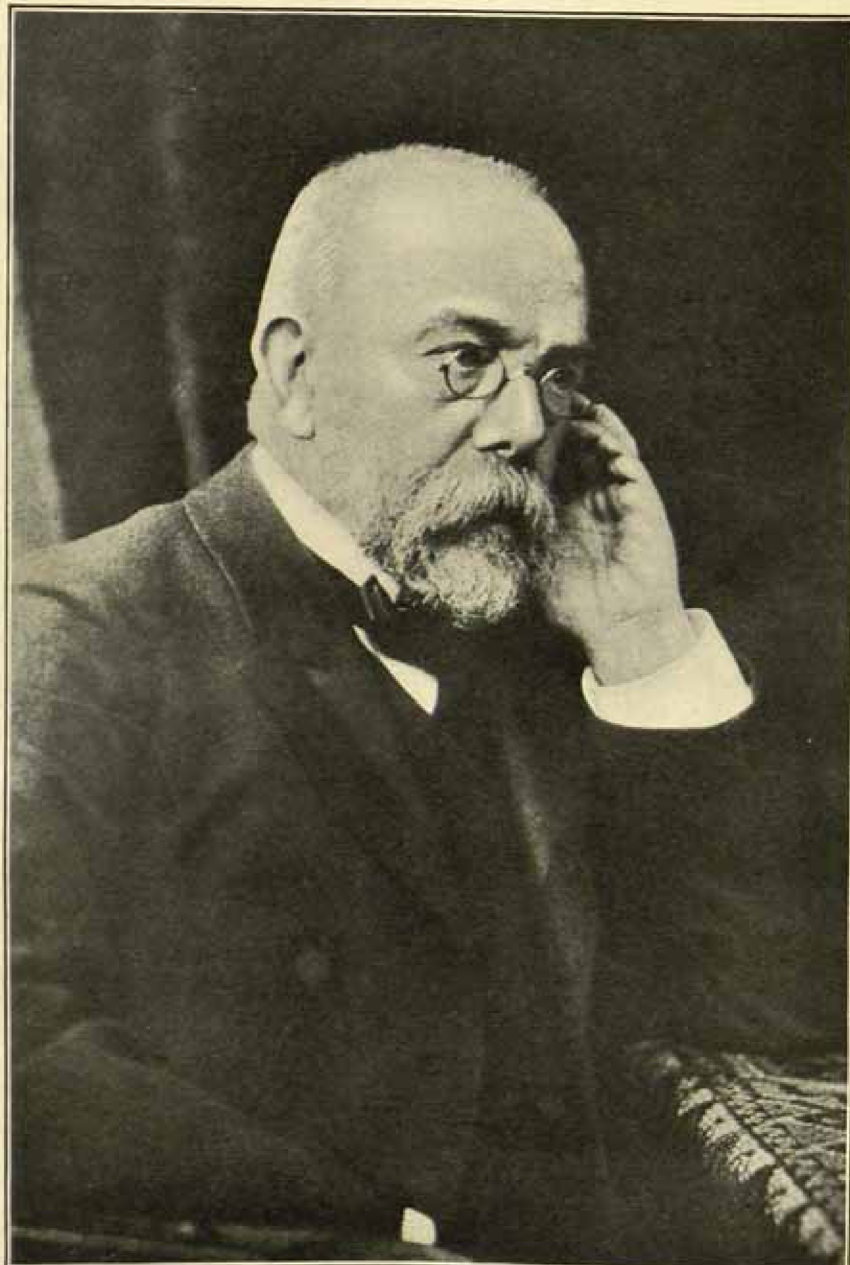


FIG. 7.—Fatigue curve of metals, compared with muscular fatigue, fig. 2.

in the muscles, and which toxins must be dissipated and the muscle renewed. Thus, if a man made a certain effort, he could not renew the toxins sufficiently quickly to keep that effort going beyond a certain distance. In the case of metals was there anything similar comparable with that? In that connection he approached a subject that had already been alluded to by previous speakers, though not in such a way as to account for the results he had referred to. Scientists at the present time, did, however, know the reason, and had discovered an explanation of the extraordinarily puzzling phenomenon of fatigue of metals as well as of muscular fatigue. He had before him a proof copy of the most valuable and interesting lectures[1] that Dr. Rosenhain delivered

[1] Proceedings 1911, pt. 2, p. 241.

before the Institution, and he asked the members to read the explanation, given in the clearest possible language, as to why a specimen which was subjected to repeated reversal of stress must, according to the teaching of microphotography, inevitably fail at a lower stress than under the ordinary test. A certain number of crystals always occupied an unfavorable position, and they yielded at a certain stress before the other particles yielded. If they were allowed to remain in that new position they might possibly fix themselves there, but if the stress was reversed the movement found these particles in a weakened state; and if it was again reversed they again gave way, and thus threw a greater stress on the surrounding particles, and at last caused fissures to form and a fracture to take place. This was the ultimate cause of the apparent crystallization of a fractured specimen. Engineers used to be taught, only a little while ago, that a metal crystallized after a certain time when it was subjected to alternating stresses. A direct contradiction of that teaching was contained in Dr. Rosenhain's lectures. As a matter of fact it was not a crystallization. The crystals were there before, and they were there afterwards. The facets which had a crystallized appearance were facets of fracture which were gradually produced by the alternation of stresses, and thereby the breaking down of the specimen was obtained He thought the members would agree with him that one thing was very apparent from the paper and the discussion, namely, the limited extent of our knowledge of the subject. After listening to the remarks of the authors and of the gentlemen who had taken part in the discussion, the members must feel they had a great way yet to go before the real nature of the many phenomena of the resistance of metals was understood. He trusted that more experiments would be carried out, with the object of teaching the members to realize what was actually going on in the materials they had to use, and at the same time he desired to thank the authors for their extremely valuable experimental work, which was of a character to aid the building up of a sound theory of the subject.



ROBERT KOCH, 1843-1910.

ROBERT KOCH, 1843–1910.[1]

[With 1 plate.]

By C. J. M.

Prof. Koch was one of the great discoverers of medicine. His researches have exercised a profound influence not only upon the development of medical science, but also upon the welfare of mankind.

Born in 1843 at Klausthal, and educated at the Gymnasium, he studied medicine in Göttingen from 1862 to 1866. After a short period as assistant at the hospital in Hamburg, he commenced practice in Langenhagen, Hanover. In 1867 he removed to Rackwitz, in Posen, where, in addition to carrying on a country practice, he found time to study for and to take a degree in physical science. In 1872 he became district surgeon in Wollstein. It was while at Wollstein that Koch's attention was first seriously turned to the interpretation of infectious diseases. The study of the work of Pasteur and his pupils on fermentation and putrefaction, and of Lister on the antiseptic treatment of wounds, led him to the conclusion that the etiology of infection was not to be found in miasmata from the soil, as commonly entertained at this time, but much more probably, in the entrance into the tissues of microbes, and their multiplication therein.

At the time Koch commenced to investigate infectious diseases, bacteriology had become differentiated as a department of scientific inquiry, but the methods proper to the new science were not developed and, although a number of cardinal facts had been brought to light, knowledge on the subject was chaotic, and advance temporarily checked. Diseases of man and animals presented unlimited problems, but the means to attack them were lacking. The means which led to the next important advances were supplied by Robert Koch, who possessed that rare combination of intellectual qualities which enabled him, not only to see what was the next question to

[1] Reprinted by permission from Proceedings of the Royal Society, London, Series B, vol. 83, No. B 567 May 31, 1911, pp. xviii–xxiv.

ask of nature in order to advance one step further, but also to devise experimental methods which insured an answer to this question. In this last faculty Koch was preeminent, and the methods of this youngest of the sciences are to a large extent the methods of Robert Koch.

Two of his earliest papers—that on the etiology of anthrax, founded on the life history of *Bacillus anthracis* published in 1876, and that on experiments on the etiology of wound infections, published in 1878, written when district surgeon at Wollstein—have become classics. This work was carried out in addition to the duties of a practitioner of medicine, and without the assistance of any laboratory equipment beyond a good microscope. Pollender and Davaine had seen the anthrax bacillus 20 years earlier in the blood of infected animals, and in 1863 the latter had shown that the blood containing the bacilli was capable of infecting animals, if inoculated into them. That these bacilli were in reality the cause of the disease was, however, controverted. Koch reasoned that as the disease remained attached to certain pastures, if the anthrax bacilli were the living virus, they ought to grow outside the body as well as inside. He succeeded in cultivating many successive generations of them in broth, and also watched their growth upon a hot stage. He discovered that they formed spores when grown outside the body or when blood containing them was allowed to dry; determined the greatly increased resistance of the spores to physical and chemical agents; and showed that as long, and only as long, as the broth or dried material contained bacilli or spores capable of propagating themselves, these remained infective for animals.

The importance of the anthrax work can hardly be overestimated. It afforded for the first time convincing proof of the causal relation of a particular bacillus to a particular disease. Owing to the unmistakable character of the bacillus, and its presence in large numbers in the blood of infected animals, its study could be profitably undertaken with the means available.

Koch was unremitting in his efforts to improve his microscopical technique, and in the same year published a paper on the investigation, preservation, and photographing of bacteria, in which an account of the preparation and staining of dry films is given. The method described is very much that still in daily use. The paper is accompanied by photomicrographs of bacteria, the excellence of which is rarely equaled at the present day. Koch pointed out that he had persevered in this work because he was obsessed with the idea that the hitherto conflicting results of investigations on the causation of infective diseases had their foundation in the incompleteness of the methods used.

Koch's interest in traumatic infectious diseases seems to have been stimulated by the disasters due to these causes among the wounded in the Franco-Prussian War. The results of Lister's antiseptic methods had demonstrated that means directed against the infection of wounds with microbes obviated these diseases. Micrococci and bacteria had frequently been found in pus, diphtheritic ulceration, in the tissues at the edge of advancing erysipelas, and in pyæmic deposits. Microorganisms had also been discovered in the blood of relapsing fever and puerperal fever. Further, Coze and Feltz and Davaine had inoculated rabbits with the blood of patients dead of puerperal fever, and had succeeded in carrying on the infection through successive generations of these animals. Nevertheless, the evidence that a particular organism was the cause of a particualr disease was far from conclusive. Many observers concluded that bacteria were universally present in the normal body. Others failed to find any organisms in obviously septic conditions. There was no practicable means of separating one coccus from another coccus, and bacteria of identical appearance were found to be associated with a variety of diseases. The parasitic nature of traumatic diseases was probable, but unproven.

Koch began his work on traumatic infective diseases with the conviction that the most fruitful line of investigation would be a comparative one, namely, to induce septic infections in animals and see whether they would "breed true" upon successive reinoculations, controlling the experimental observations by careful microscopic examination throughout. He used for the purpose of infecting his animals putrid serum or bouillon. This, he found, contained a large variety of organisms of different sizes and shapes, which he was unable to separate from one another. He hoped that, implanted into the body of an animal, a selection might occur, and only those pathogenic for the particular species survive. His anticipations were justified, and the injection of small quantities of such materials was followed, in a number of instances, by the development of a fatal illness with the presence in the blood of one only of the many forms present in the original material. He was able to carry on the disease from one animal to another, always with the same symptoms and the presence of the same organism. Moreover, if the same material containing a variety of organisms were injected into animals of different species, one microbe flourished in the one species and another in the second, showing that a particular microbe could establish itself in one animal and not in a neighboring species.

The animal body is, as Koch said, an excellent apparatus for pure cultivation, and he succeeded to some extent in doing what had been the stumbling block to all progress, namely, to isolate one organism from another.

The publication of these three papers raised the hitherto obscure physician of Wollstein to the first rank of scientific investigators, but they were merely the beginning of his scientific career. Their importance and the genius of their author was recognized by Struck, the enlightened director of the German health office, who invited Koch to accept a position in that department. The chemical and hygiene laboratories attached to the department had been extensively equipped, but bacteriology was naturally unprovided for. A room was, however, found for him, and in these humble surroundings he settled down to pursue his inquiries. He was soon joined by Loeffler and Gaffky, who became his first assistants. The three worked together enthusiastically in the one room, fitting up the laboratory, inventing apparatus, and improving methods. The great problem confronting them was to find a practicable means of obtaining a pure culture outside the body. Koch accomplished this by the simple expedient of adding gelatin to the nutrient medium. The gelatin-containing medium was inoculated whilst warm with a minute amount of the material, poured in a thin layer upon a plate and allowed to set. In this way bacterial colonies originating from individual microbes were obtained. Portions from the colonies were subsequently sown into separate tubes of broth or other fluid suitable for their growth. The discovery of this technique made advance possible.

Another line of investigation undertaken at this time, on account of its importance in the technique of bacteriology, was concerned with disinfection and sterilization. The experiments of Koch and his pupils, made upon pure cultures of pathogenic bacteria, is the foundation upon which all later work on this subject has been built. It also led to the substitution of the more convenient steam sterilization for dry heat.

One can not emphasize too strongly to what a large extent Koch provided the tools of inquiry at each stage in the development of bacteriology, but he did not rest there. From 1880 onward followed a period of extraordinary activity. In a dozen years the etiological factor of 11 important human diseases—tubercle, cholera, typhoid, diphtheria, erysipelas, tetanus, glanders, pneumonia, epidemic meningitis, influenza, and plague, as well as numerous animal diseases—was discovered by Koch and his pupils.

After the completion of his work on anthrax Koch's individual efforts were directed more particularly to the discovery of the infective agent in tuberculosis, whilst diphtheria and typhoid were being investigated by his assistants, Loeffler and Gaffky. The work of Klencke and Villemin and the further experiments of Cohnheim and Salomonsen, had established that the disease tuberculosis was due to an infective agent which was capable of propagating itself in the animal

body. Miliary tubercles were examined microscopically for some signs of a microbe, but for long without success. At last, by a modification in the method of staining, a fine bacillus was discovered, and its presence in the majority of preparations established. Efforts to grow the organism in pure culture at first failed, but subsequently, by infinite patience, he succeeded in growing it upon coagulated serum. Once isolated and grown upon a succession of media, the establishment of the bacillus as the etiological factor presented no difficulty, and at the Physiological Society in Berlin on March 24, 1882, Koch presented the proof that he had discovered the cause of one of the most widespread and dreaded of human diseases.

From the discovery of the cause of a disease, its prevention or cure does not necessarily follow, but in the campaign against an enemy it is of first importance to be acquainted with his nature and peculiarities. Koch interested himself, at once, in studying the life history and methods of warfare of the tubercle bacillus. These studies were, however, interrupted. Cholera was in Egypt and threatened Europe, and the German Government organized a commission, with Koch as leader, to proceed to Egypt to study the disease, and draw up recommendations for dealing with it, should it reach Germany. Shortly after reaching Egypt the outbreak there ceased. In the meantime, however, Koch had obtained important information leading him to suspect a particular comma-shaped bacillus as the specific cause of the disease. The material for the furtherance of his inquiry having failed in Egypt, Koch proceeded to India, where cholera is endemic, and completed his investigations. He satisfied himself that the comma bacillus was the constant companion of the cholera disease, that its abundance was commensurate with the severity of the attack, and that it penetrated beneath the epithelium in the affected part. He never succeeded in obtaining it from the healthy or diseased intestine, other than in the case of cholera. It was comparatively easy to obtain it in pure culture, and its characteristics were studied, but the completion of the evidence to convict this organism was lacking, as a true cholera process can not be artificially produced in any of the laboratory animals. Incidentally, whilst in Egypt, he discovered amœbæ in dysentery, and the bacillus responsible for the widespread ophthalmia in that country.

As previously mentioned, at the time Koch was ordered to Egypt to investigate cholera he was engaged in the attempt to discover some means to modify the infection by the tubercle bacillus in the animal body. Proceeding on the assumption that the tubercle bacillus exercises its pathogenic effects by means of a chemical poison, Koch investigated the action of the dead bacilli and their products upon normal animals, and also the effect of a previous injection with dead bacilli upon a subsequent inoculation of living ones. This

led to the important observation that in animals previously treated with dead bacilli the later inoculation of living organisms occasioned an energetic local reaction, leading in some cases to their destruction.

From his experiments he was led to the conclusion that, not only could a guinea pig be immunized against tubercle by repeated injections of the products of tubercle bacillus, but that the same tissue reaction could be stimulated, and the disease brought to a standstill by this means. Later (1890) he published his well-known results upon tuberculin, by means of which tuberculosis could be not only diagnosed, but in the early stages might, he hoped, be cured. The possible remedy was enthusiastically welcomed by the whole world. Medical men thronged to Berlin from all parts to see the results of its application. The treatment was applied to all sorts of cases in what we now know were colossal doses. The results were disappointing, and in many cases disastrous. The premature publication of his results with tuberculin was a misfortune, and the failure of the treatment obscured for the time-being the great value of Koch's work, and even exposed him to opprobrium. Koch had, however, made a great discovery, but underestimated the potency of the agent he had brought to light. Tuberculin is an invaluable diagnostic for early tuberculosis in man and animals, and is universally employed. Since 1890 it has been consistently employed by a number of physicians all over the world for the treatment of tubercle with what appear to be beneficial results, and of recent years its employment has again been resuscitated by Wright. It is now administered in much smaller doses, and with careful observance of the effect of each injection.

During the next eight years, 1891–1899, Koch was occupied with investigations into a large number of diseases of men and animals. The list includes leprosy, rinderpest, plague, surra, Texas fever, and malaria. These investigations necessitated his spending much of his time abroad. It would be difficult to judge just how much of the knowledge gained upon these diseases to attribute to Koch, as he was accompanied by one or more distinguished workers, as in the case of the German plague commission which visited India. It is very clear, however, from the published reports and papers, that the insight and experience with which he directed the inquiries materially enhanced our knowledge of the causation and means of spread of these diseases.

Koch's work upon malaria needs special mention. Whilst in tropical countries, his attention was naturally drawn to this disease. Laveran's discovery of the malarial parasite had been made, but the mechanism of the spread of the disease was unknown. Manson's discovery that filaria was inoculated by the mosquito, Theobald Smith's proof that Texas fever was transmitted by ticks, and Bruce's demonstration that the tsetse-fly disease was due to a protozoan parasite, and merely conveyed by the fly, suggested to Koch, as to others,

that malaria might be transmitted by a biting insect. He was, indeed, engaged upon experiments with mosquitoes, and had nearly satisfied himself that malaria was thus transmitted, when Ross published his results. Koch was, however, largely instrumental in showing that the three types of malaria were associated with three distinct parasites, and that none of these were infective for the lower animals, a result of great importance, from the point of view of malaria prophylaxis. He also cleared up the difficulty as to the reservoir of the disease in a population the adults of which could not be found to harbor the parasite by showing that the young children, even to the extent of 90 to 100 per cent, were infected.

In 1901 Koch reported to the British Congress on Tuberculosis the results of experiments which he had carried on during the preceding two tears in conjunction with Schutz upon the pathogenicity of the human tubercle bacillus for domestic animals. Briefly stated, Koch's main conclusion from their experiments was that human tuberculosis differs from bovine and can not be transmitted to cattle. The far more important question: "Is man susceptible to bovine tuberculosis?" was then considered. No direct experimental proof of this converse proposition is possible, but from the fact that men—and particularly children—consume large quantities of bovine tubercle bacilli in milk, and yet tuberculosis of the intestine is rare, Koch concluded that man is little if at all susceptible to the bovine variety of the bacillus. He pointed out that the question whether man is susceptible to bovine tuberculosis at all was not decided, but expressed the belief that infection of human beings is of so rare occurrence that it is not necessary to take any measures against it. It was the last conclusion that caused so much consternation, as most countries were embarked in considerable expenditure with a view to minimizing the chances of infection by milk and meat. Koch may have been unwise in stating his views, but he did so with the conviction that bovine tubercle is not an important source of infection, and with the earnest desire that we should not squander our energies in subordinate directions, but should concentrate them in efforts to diminish man-to-man infection through the respiratory tract.

The importance attached to a considered opinion of so distinguished an authority led to the appointment of numerous commissions of inquiry in Europe and America. Of these the work of the English Royal Commission has been the most extensive. These investigations have shown that the sharp distinction between the two varieties though usually manifest, is not so absolute as Koch supposed, and that bacilli of the bovine type are not so uncommonly found in human infections as he was led to believe. The frank expression of opinion by Koch on this subject has been the stimulus for an enormous

amount of valuable work in connection with tuberculosis throughout the civilized world, but the relative importance of infection from one another through sputum and from bovines through dairy produce is still an open question, and will not be settled for many years to come.

Before closing this sketch of his life work, it remains to add a few words upon Koch as a teacher. In 1885 he removed from the health department and became a professor in the faculty of medicine and director of the new hygiene institute, attached to the University of Berlin. Here, with the help of his assistants, numbers of those who later became leading bacteriologists in all countries were trained in his methods and endowed with some portion of his enthusiasm and earnestness. The admiration with which he was regarded by his pupils, and the absolute faith which he inspired, amounted in many cases to actual worship, and afford further evidence of the essential greatness of the man.

Amongst the numerous honors conferred upon him by scientific and academic bodies throughout the civilized world was the foreign membership of the Royal Society, to which he was elected in 1897.

There have no doubt been many discoverers as great as Koch, but it must be seldom that one has been so individually associated with the development of a science. Bacteriology has to so great an extent grown up around Koch that the title "Father of Bacteriology" has been conferred upon him by his admiring compatriots.

SIR JOSEPH DALTON HOOKER, 1817-1911.

SIR JOSEPH DALTON HOOKER, O. M., G. C. S. I., F. R. S., 1817–1911.[1]

[With 1 plate.]

By Lieut. Col. D. Prain, C. M. G., F. R. S.,
Director of the Royal Botanic Gardens, Kew.

The most distinguished son of a very distinguished father, Joseph Dalton Hooker, was born at Halesworth, in Suffolk, on June 30, 1817. Early in 1820 his father was appointed by the Crown to fill the chair of botany in the University of Glasgow, a post which he held until, in 1841, he became director of the Royal Gardens at Kew. As a consequence Hooker was educated in Glasgow, passing through the high school to the universiy, from which he obtained the degree of M. D. in 1839. Devoted as a lad to the reading of works of travel, we learn from Hooker himself that he was especially impressed by Turner's description of the Himalayan Peak of Chumlari, and by the account of the Antarctic island of Kerguelen contained in Cook's voyages. An opportunity of investigating the latter came to him very early in his career. When he completed his medical studies, Hooker entered the Royal Navy as an assistant surgeon, and was gazetted to the *Erebus*, then about to start, along with the *Terror*, on the famous Antarctic expedition led by the eminent navigator Sir James Clark Ross. Throughout this expedition the young assistant surgeon held the post of botanist, and during its three years' cruise in the southern seas he was able to visit New Zealand, Australia, Tasmania, Kerguelen, Tierra del Fuego, and the Falkland Islands, amassing large collections and acquiring a vast amount of botanical information.

Shortly after the close of this expedition, Hooker, in 1843, became assistant to Graham, then professor of botany in the University of Edinburgh, and in 1845, when Graham was succeeded by the elder Balfour, Hooker was appointed botanist to the geological survey of Great Britain. Much of his time during this period was devoted to the preparation for publication of the results obtained during the course of his Antarctic voyages. But in 1847 this work was temporarily suspended, and his appointment on the geological survey was

[1] Reprinted by permission from Nature, London, Dec. 21, 1911, No. 2199.

relinquished, in order that Hooker might add, by further travel, to his first-hand knowledge of the vegetation of sub-Antarctic and temperate regions, a corresponding acquaintance with the botany of tropical countries. The region selected was northeastern India, then a practically unexplored tract. The undertaking, originally designed as a private enterprise, through a series of happy accidents received official recognition, and the expenses involved were to a partial extent met from public funds. Hooker left England in November, 1847, reaching India in January, 1848. After some three months spent in the Gangetic Plain and Behar, during which he ascended the sacred hill of Parasnath, Hooker made his way to the Himalayas, reaching Darjeeling in Sikkim in the middle of April. The next two years were devoted to the botanical exploration and topographical survey of the Himalayan State of Sikkim and of a number of the passes which lead from that country into Tibet; if he did not actually reach he at least had opportunities of seeing the noble peak of Chumlari, which had helped to fire his youthful ambition to become a great traveler. Toward the close of the year 1848 Hooker had an opportunity, which has come to no one since, of crossing the western frontier of Sikkim and exploring a portion of eastern Nepal. During the greater part of the time spent in the eastern Himalayas, Hooker traveled and surveyed alone, but in October, 1849, he was joined by Dr. Campbell, the superintendent of Darjeeling, who had obtained official authority to visit Sikkim. Shortly after Campbell joined him, the Sikkim authorities seized the opportunity thus offered to imprison and maltreat Campbell, at the same time confining Hooker, whom, however, they refrained from injuring. The captives were released toward the end of December, 1849, and the next three months were spent by Hooker in arranging at Darjeeling his vast collections.

Early in 1847 Dr. Thomas Thomson, of the Indian medical service, son of a colleague of the elder Hooker in the University of Glasgow, and an old classmate and intimate friend of his own, had been deputed by Lord Hardinge to visit and report upon certain portions of the western Himalaya and Tibet. This mission completed, Thomson made his way to Darjeeling in order to join Hooker, and the year 1850 was devoted by the two friends to the botanical investigation of eastern Bengal, Chittagong, Silhet and the Khasia Hills.

On his return to England in 1851 Hooker resumed the task of publishing his Antarctic results, and began, in conjunction with Thomson, to elaborate those of the Indian journeys. The collaboration of the two friends in the preparation of a "Flora Indica," the first and only volume of which appeared in 1855, ceased when Thomson returned to India, and the appointment of Hooker in that year to the post of assistant director at Kew under his father brought with it duties more than adequate to occupy the time and attention of an

ordinary official. The performance of these duties, however, did not impede his Antarctic studies, and in 1860, which saw the completion of the great work on the botany of the Antarctic voyage, Hooker was able to add still further to his extensive knowledge of topographical botany. In the autumn of that year he was asked by Capt. Washington, hydrographer of the Royal Navy, to take part in a scientific visit to Syria and Palestine. In the course of this journey he ascended Lebanon and investigated the history, position, and age of the cedar grove which has made that mountain a household word, but of which until then nothing was accurately known.

On the death of the venerable Sir William Jackson Hooker in 1865, Hooker was appointed director of the Royal Gardens, Kew, in succession to his father. This position he held during the next 20 years. The engrossing work and added responsibilities of this period did not, however, prevent Hooker from taking his full share of those public duties which naturally fall to the lot of men of his eminence. He presided over the thirty-eighth meeting of the British Association held at Norwich in 1868, and over the department of zoology and botany in the biological section at the meeting held at Belfast in 1874. In 1873 he undertook the arduous duties of president of the Royal Society, and occupied the presidential chair for the next five years. Nor did these duties entirely debar him from further botanical travel. In 1871 he undertook, in company with the late Mr. Ball and Mr. G. Maw, a botanical expedition to Morocco and the Atlas Range; in 1877, in company with his intimate friend, Dr. Asa Gray, and with Dr. Hayden, of the United States Survey, he took part in an important botanical journey to Colorado, Wyoming, Utah, the Rocky Mountains, the Sierra Nevada, and California.

From the time of his retirement in 1885, Hooker's life was spent at The Camp, near Sunningdale, where he had built for himself a home, the grounds of which, furnished with all the advantages that knowledge and taste can provide, contain one of the most interesting collections of plant forms in this country. Here he devoted himself with the energy and enthusiasm of one commencing his career to the completion of tasks already in hand and to the initiation of new ones. His critical acumen, which remained unaffected by advancing age, and his physical vigor, which became seriously impaired only a few weeks before his death, enabled him, in the freedom from administrative duties which retirement had brought, to accomplish work which as regards its amount must be considered the ample harvest of a lifetime, and as regards its quality, and no higher tribute could well be bestowed, fully sustained the reputation of his earlier publications.

The work which Hooker accomplished can be but briefly outlined here. Space forbids a complete enumeration of his many contributions to natural knowledge; all that can be done is to endeavor to

indicate the various lines of his intellectual activity, and to note how these were affected by the leading events in his personal history. While still an undergraduate, Hooker had been at work in his father's herbarium in Glasgow. The earliest of his results appear in a paper on Indian mosses, written in collaboration with the late Prof. Harvey, which was published in 1840, shortly after he had joined the expedition under Ross. Work connected with cryptogamic plants was one of his strongest early inclinations, for some of the most important of his papers, prepared during the years 1844 to 1847, when he had returned from the Antarctic, deal with the hepatics, lichens, mosses, and algæ of the southern circumpolar regions. But a predilection for work on fossil botany manifested itself almost as early in his career; another early paper, written and published in 1842, while still botanist on the *Erebus*, deals with an examination of a Tasmanian fossil wood. As his general work on the Antarctic material he had accumulated made progress, we find, however, that his cryptogamic work came to be done more and more in collaboration with workers who had made some particular lower group their special province. The botanical results of the Antarctic voyage occupy six quarto volumes subdivided into three sections: (1) The Flora Antarctica, completed in 1847, before he left for India; (2) the Flora Novæ Zelandiæ, issued in 1853, after his return from the East; and (3) the Flora Tasmaniæ, published in 1860, after he had become assistant director at Kew.

But the preparation of the first section of the Antarctic work did not impede his activities while connected with the geological survey between 1845 and 1847. Before undertaking the duties of the post he had already given attention to problems connected with fossil botany; while attached to the survey he prepared during 1846–47 several important papers on the subject, the most notable of these being a discussion of the vegetation of the Carboniferous period as compared with that of the present day, which was printed in 1848. But his interest in the subject did not end with the severance of his connection with the geological department; two interesting papers on fossil botany from his pen were published in 1855. After his appointment as assistant director, however, he made no further formal contribution to knowledge in this particular field. His Antarctic work and his duties in connection with the geological survey did not, however, suffice to occupy all his time prior to his departure for India. He drew up an Enumeration of the Plants of the Galapagos Archipelago, issued in 1847, and collaborated with the late Mr. Bentham in preparing the Flora Nigritiana, incorporated by Sir W. J. Hooker in the Niger Flora, published in 1849.

Some of the results of Hooker's Indian observations, notably those relating to his journeys in the Indian plains, were published by the

Asiatic Society of Bengal in 1848. But if on his return to England in 1851 he reverted with energy to the elaboration of his Antarctic results, the Indian material was not neglected. He began, in collaboration with Thomson, that Flora Indica, the issue of which in 1855 has already been alluded to. In connection with this work two sumptuous illustrated folios were issued; the first, on The Rhododendrons of the Sikkim-Himalaya, was edited from Hooker's notes, sketches, and material, by his father, between 1849 and 1851; the second, Illustrations of Himalayan Plants, chiefly made for an Indian friend, Mr. Cathcart, in the Darjeeling neighborhood, was edited, with descriptions by Hooker himself, in 1855.

This was, however, by no means all that he was able to accomplish. In addition to the families formally described in the solitary volume of their Flora Indica, Hooker and Thomson discussed in the Linnean Society's Journal various problems of interest relating to individual Indian plants, and issued a series of papers, Præcursores ad Floram Indicam, dealing more completely with a number of important natural families. Finally, Hooker's Himalayan Journals, one of the most fascinating books of travel in our language, in which his Indian journeys are dealt with generally, was issued in two octavo volumes in 1854. Probably no botanical field work has proved more fertile in interest or provided material of greater value in the discussion of biological and phytogeographical problems than that done by Hooker. Yet great as were his botanical results and pardonable as it is in the bontanical worker to look upon these as Hooker's highest achievement, it is doubtful whether the topographical results were not of even greater moment. These results, reduced by Hooker himself, with the assistance, as he tells us, of various Anglo-Indian friends who came under the magic spell of his personality, were arranged at Darjeeling during the early months of 1851. They formed the basis of a map, published by the Indian trigonometrical survey, with the aid of which, such is its accuracy and its detail, the operations of various campaigns and political missions have been carried to a successful issue.

The 10 years during which Hooker was assistant director at Kew were marked by extraordinary activity. The time that could be spared from executive duties was far from being entirely absorbed in Antarctic and Indian work. In 1862, and again in 1864, he dealt with important collections of plants from Fernando Po and the Cameroons in papers valuable in themselves and in the evidence they afford that his interest in the flora of the Dark Continent, first evinced in 1847, had never abated. This interest showed itself once more in a paper of 1875, which may be mentioned out of sequence, on the subalpine vegetation of Kilimanjaro. In this case, however, the interest was associated with another which had guided much of his

Antarctic study and had manifested itself in 1856 and in 1861 in dealing with the Arctic plants collected during the Franklin searches and the McClintock expedition. The problems involved were dealt with in a comprehensive fashion in 1861 in Hooker's classic, Outlines of the Distribution of Arctic Plants. A group of kindred problems had presented themselves to Hooker when engaged in the study of the vegetation of the more o. tlying Antarctic and sub-Antarctic islands, and subsequently when dealing with the plants of Galapagos. To this period, therefore, we may most properly ascribe the formation of the views enunciated in a notable discourse on Insular Floras, delivered at the meeting of the British Association at Norwich in 1866. Yet another allied group of problems called for consideration in connection with his Antarctic, Indian, and African studies; his conclusions with regard to these are stated in his Introductory Essay to the Flora of Tasmania, published in 1860; the opinions there expressed on the origination and distribution of species suffice to explain the action which Hooker took when, in conjunction with Lyell, he had induced Darwin, in 1858, to publish a preliminary sketch of his famous hypothesis.

To the same period of his activities belongs the share taken by Hooker between 1858 and 1864 in the preparation of Thwaites's enumeration of the plants of Ceylon. To this period we owe, moreover, the codification of the results given in the second portion of the Antarctic flora in the form of a Handbook of the New Zealand Flora, contributed to the series of Colonial floras published under Government authority. The work was issued in part in 1863; the concluding portion was published in 1867, shortly after the period had come to an end. But to this period we owe, in addition, various important special studies on the structure and affinities of Balanophoreæ, published in 1856; on the origin and development of the pitchers of Nepenthes, in 1859; and on Welwitschia, in 1863. The most obvious result of Hooker's visit to Syria in 1860 is a paper on the cedars of Lebanon, Taurus, Algeria, and India, published in 1862. In this article a subject of great interest and considerable difficulty is handled with masterly skill. But the journey bore further fruit in the form of a singularly pleasing sketch of the botany of Syria and Palestine, contributed in 1863 to Smith's Bible Dictionary. Extensive and important as these various contributions to botanical knowledge are, they do not include all that Hooker accomplished while assistant director; the most onerous and important undertaking initiated during this period has still to be mentioned. In renewed collaboration with Mr. Bentham was commenced one of the oustanding botanical monuments of the nineteenth century, in the form of a great Genera Plantarum; of the three volumes which this work includes, the first was completed in 1865.

Hooker's succession in that year to the directorship of Kew brought with it all the responsibilities connected with the administration of that national institution. These, however, did not prevent him from continuing to take his share in the preparation of the Genera Plantarum, the second volume of which was completed in 1876, the third and concluding one in 1883. The directorship, however, brought with it the duties of continuing the Botanical Magazine and the Icones Plantarum, edited by his predecessor. These duties Hooker continued to fulfill even after his retirement in 1885; in the case of the Icones until 1889, in that of the Magazine until 1902, and with the collaboration of Mr. W. B. Hemsley for two years longer, his connection with this historic serial ending in 1904, with the completion of the one hundred and thirtieth volume. The death of his father imposed on Hooker yet another filial duty of the most arduous character, that of replacing in 1870, by his own Student's Flora, the British Flora of his predecessor. In 1873 he annotated and rearranged the natural families of plants in an English version of the Traité général of Le Maout and Decaisne, and in 1876 he wrote for the series of science primers that on Botany.

The results of Hooker's journeys in North Africa in 1871 are given in A Journal of a Tour in Marocco and the Great Atlas, written in collaboration with Ball and published in 1873; those of his visit to North America in 1877 were summarized by himself in Nature, vol. 16, p. 539.

Of the addresses and discourses delivered by Hooker during this period, that on Insular Floras of 1866 has already been alluded to. That delivered from the president's chair to the British Association in 1868, with its whole-hearted advocacy of an acceptance of the hypothesis of Mr. Darwin as the surest means of promoting natural knowledge, was perhaps more important in its effect on scientific thought generally. His British Association sectional address of 1874, on The Carnivorous Habits of Plants, was an illuminating review of those problems to which his own observations and researches on Nepenthes in 1859 had directed attention.

It has recently been remarked that "so broad-based were the foundations of Kew as laid by Sir William Hooker that they have been but little extended by his followers. Their work has been to build a noble superstructure. Viewed in detail, Kew is hardly anywhere the same as it was in 1865. But the framework is very much the same." These remarks are so just that no useful purpose could be served by any attempt to enumerate here the various manifestations of Hooker's activity as an administrator, or to detail the alterations and additions which marked his directorship. That activity, as was said by Prof. Asa Gray in the article on Hooker in our Scientific Worthies series (Nature, vol. 16, p. 538), was exercised "in such

wise as to win, along with national applause, the gratitude of the scientific world." Nor is more than a passing allusion due to a bitter controversy in 1872, Hooker's unsought share in which the world of science made its own. Those whose curiosity extends to the unedifying may find the details in a parliamentary paper; it is sufficient to remark that in the following session the Royal Society chose Hooker to preside over their councils.

We have yet to allude to what was the heaviest and the most prolonged task of Hooker's life, the publication of the Flora of British India. During his collaboration with Thomson, prior to 1855, in the elaboration of the results of their Indian journeys, the two friends had been able to render available for scientific study the botanical treasures preserved in the East India House. The heavy but essential task of distributing these involved as a corollary the preparation and issue of a catalogue of the specimens dealt with. This catalogue Hooker was able to publish in 1865. A similar necessity subsequently arose in connection with the Peninsular Indian herbarium brought together by the late Dr. Wight. This subsidiary distribution was completed and the requisite ancillary catalogue was prepared by 1870. The task of preparing for British India a flora on the lines of those written at Kew on behalf of the various colonies could at last be undertaken. This task was at once begun; the opening part of the initial volume appeared in 1872, and the volume was completed in 1875. It was followed by the second volume, finished in 1879, by the third, finished in 1882, and by the fourth, the concluding part of which was issued, just as Hooker retired, in 1885.

Nearly half of the gigantic task had still to be accomplished, so that in Hooker's case retirement, if it brought relief from administrative cares, did not bring leisure. The heavy labor was faced without flinching; the progress of the work remained unchecked. The fifth volume, containing four parts, was completed in 1890; the sixth, also a volume of four parts, in 1894; the seventh and concluding volume appeared in 1897.

In the meantime, however, Hooker undertook a new and onerous task. Shortly before his death the late Mr. Darwin informed Hooker of his intention to devote a considerable sum to be expended in providing some work of utility to biological science, and to arrange that its completion be assured should this not be accomplished during his lifetime. The difficulties which he had experienced in his own studies led Darwin to suggest that this work might take the form of an index to the names, authorities, and countries of all flowering plants. At Darwin's request, the direction and supervision of the work was undertaken by Hooker; the actual preparation was entrusted to Mr. B. D. Jackson. The result is the Index Kewensis, of which the publication alone occupied the period from 1892 to 1895. During the

period devoted to its preparation and publication the work received the unremitting care and attention of its director and its compiler. Other works, however valuable they may be, admit, as a rule, of some relative estimate. To the Index Kewensis no such mode of judgment is applicable; it is simply invaluable, and stands a lasting monument to the wisdom and generosity of Darwin, the piety and sagacity of Hooker, the care and fidelity of Jackson. While this Index was in progress, Hooker arranged for publication in 1895 a century of drawings of orchids, for which he provided descriptions, from among the manuscript figures placed at his disposal by the Calcutta herbarium in connection with his own work on the Flora of British India. Scarcely had the responsibility attaching to the preparation of the Index been laid aside ere Hooker undertook, as an act of justice to the memory of a distinguished predecessor, to edit the Journal of the Right Hon. Sir Joseph Banks, during Captain Cook's first voyage, 1768–71; this work was published in 1896.

The time-consuming and exacting labor which the preparation of the Indian flora entailed had barely ended when the chivalrous generosity of Hooker was once more invoked. The late Dr. Trimen had undertaken the preparation of a Handbook of the Flora of Ceylon. Three volumes of this work were issued between 1893 and 1895. While it was in progress Trimen was mortally stricken; the third volume was issued with the hand of death upon the author. When Trimen died the Government of Ceylon sought Hooker's aid. With indomitable courage the veteran of over 80 undertook the heavy task of completing the work of another author who had fallen a victim in the prime of life, under restrictions as to scope and style which, whether they met with his approval or not, were at any rate different from those hitherto observed by himself. Perhaps no more touching token of regard than this was ever paid to the memory of a friend. The fourth volume of the Ceylon flora, to some extent edited from material left by Trimen, appeared in 1898; the fifth and concluding volume, which it fell to Hooker to prepare himself, was issued in 1900. Still, as he himself once expressed it, "dragging the lengthening chain" of the Botanical Magazine, Hooker devoted the next two years of his own life to writing that of his father, which appeared in the Annals of Botany in December, 1902. Coincident with the appearance of this tribute of filial piety came the arrangement which relieved him of some of the pressure which the editing of the Magazine entailed, but not the anticipated freedom. At the request of the Government of India, Hooker undertook to prepare for the Imperial Gazetteer a sketch of the vegetation of the Indian Empire. This task, one of the most difficult, when regard is had to the limitation of space almost necessarily imposed, that could well be undertaken, was successfully accomplished and has resulted in an essay

comparable with that on the botany of Syria and Palestine, written 30 years earlier.

The active intellect which had for five and sixty years taken a fierce delight in laborious days, and had throughout found a task to be more congenial in proportion to its difficulty, was not likely to seek satisfaction in an unbroken round of quiet breathing. If new worlds need not be sought for conquest, at least some unregulated province might be reduced to order. Among the families of Indian plants dealt with by Hooker and Thomson in their Præcursores, one of the most fascinating, whether for the variety of its forms or the intricacy of their relationships, had been the Balsamineæ. Since 1859, when their paper appeared, a host of new Indian and Chinese forms had been reported; the characters met with in some of these appeared to invalidate earlier conclusions. To the study of this interesting group Hooker devoted his attention from 1904 onward, evolving order out of an apparent chaos, and in the course of his studies placed those in charge of most of the important herbaria in Europe under a deep obligation by supplying them with a uniform nomenclature for their specimens. On this work, which, so far at least as the Asiatic forms are concerned, had been practically completed, Hooker was engaged almost to the last.

Shortly summarized, and omitting here any reference to excursions into the domain of economic, morphological, and physiological botany, or to systematic studies of material from countries in which he did not himself travel, we find evidence of the existence of several definite lines of active interest, athwart which fell the shadow of various outstanding events in Hooker's career. The record indicates that Hooker's strongest and earliest predilections were perhaps toward the study of cryptogamic plants and work on fossil botany. The first predilection reached its culmination in 1844, when he returned from the circumpolar expedition on which he had started in 1839. The pressure exercised by problems, to the elucidation of which the evidence of flowering plants with their more special organization and more restricted distribution is of greater value, gradually led to the abandonment of this field of study, which was not reentered after he left for India in 1847. The predilection for work on fossil botany naturally reached its culmination while Hooker was attached to the geological survey. Its influence, though not entirely inhibited, was less active after Hooker's return from the East, and this field of study was abandoned when he became assistant director of Kew in 1855.

The predilection for the study of those problems that relate to the origination and distribution of species, to which his experience as a field naturalist on circumpolar islands and among the peaks and valleys of the Himalayas had given so great an impetus, reached its culmination while he was assistant director at Kew, and is manifested

most strongly in the classical essays which date from 1860 to 1866. Without attempting to estimate the interaction effects of the work of Darwin on that of Hooker and vice versa, we may here direct attention to the fact of their existence. Nor could it be otherwise; the two men studied and wrote, on terms of intimate and affectionate friendship, in an atmosphere surcharged with great and pregnant thought.

With Hooker's succession to the directorship of Kew in 1865, the Antarctic work had practically ended, for the concluding moiety of the New Zealand handbook appeared in 1867. He was now able to do for India what he had already done for Tasmania and New Zealand, and if, when he retired in 1885, only half of his Indian systematic work had been accomplished, there was no break in its continuity. If we except his masterly sketch of the vegetation of India, prepared after the Indian Flora had been completed, we are without a record of his conclusions from Indian botanical evidence, comparable with the brilliant generalizations based on his study of the Arctic, Antarctic, and insular floras of the globe. This may be a cause for regret; it can be no cause for surprise. Not only is the Indian field the wider of the two; Hooker completed the essential preliminary spadework in the other during the 16 years between 1844 and 1860, whereas the corresponding Indian toil exacted over 40 years of labor between 1854 and 1897. When the Indian preliminary work was done, it only served to prove that the relationships of the Indian, Malayan, and Chinese floras are so intimate as to demand their conjoint consideration.

The completion of the Indian Flora in 1897, rather than the demission of the directorship at Kew, marks the close of a period in Hooker's work. The next epoch, a comparatively brief one, was devoted to the performance of acts of piety to the memory and regard for the wishes of predecessors or of contemporaries whom he had outlived. These tasks ended, the evening of his life was devoted by Hooker to work which in many respects was, even for one so wide in his range and so varied in his interests, a new departure. His great Antarctic Flora, his still greater Indian one, are splendid examples of broad canvases upon which in bold and striking lines the hand of a master has depicted the salient and essential features of a highly diversified landscape, and no one has ever portrayed with a surer touch. In the work to which Hooker devoted the closing years of his life, he has treated a single natural family as a precious gem, upon which, with a hand as sure as the one that has given us the ample atmosphere of his great pictures, he has engraved an exquisite intaglio.

To offer here an estimate of the quality of Hooker's work would surely be out of place. That task has already been performed in the pages of Nature by one who was in the strictest sense Hooker's

contemporary, and who, if he had not the advantage of such perspective as time affords, at least had all the benefit of distance in space to aid his judgment. It is sufficient here to say that the estimate made in 1877 has been fully sustained by all that has happened since; it is, moreover, interesting to reflect that the hope then so fondly expressed that Hooker, already in his sixtieth year, might still be only in mid-career has been fulfilled almost to a day. If it be urged that in one respect the judgment of 1877 is at a disadvantage as being from the pen of one who, like Darwin, was bound to Hooker by the ties of almost lifelong affection, then we can only say that no one now alive who has enjoyed the privilege of Hooker's acquaintance may venture to judge his work, because to know Hooker was to love him. The breadth of his interests, the depth of his knowledge, and the wisdom of his counsel combined to inspire reverence and regard. But above all these qualities, and beyond the singular charm of his manner, shone the unstudied and unstinted kindness which compelled affection.

A member of the Linnean Society since 1842, Hooker was a member of the council during 24 years, and for 15 of these was one of its vice presidents. He was also a member of the Geological Society, which he joined in 1846. He was elected a fellow of the Royal Society in 1847, and served on the council during 17 years, for 6 of these as a vice president and for 5 as president. A correspondent of the Institute and a member of the Academies of Berlin, Bologna, Boston, Brussels, Copenhagen, Florence, Göttingen, Munich, Rome, St. Petersburg, Stockholm, and Vienna, he enjoyed, in addition, the freedom of practically every society or corporation devoted to the promotion of natural or technical knowledge within and beyond the British Empire. Not a few of these bodies have bestowed on Hooker still further distinctions. On the recommendation of the Royal Society he received a Royal medal in 1854; by the same society he was awarded the Copley medal, its highest honor, in 1887, and the Darwin medal in 1892. From the Society of Arts he received their Albert medal in 1883; from the Geographical Society their Founder's medal in 1884; from the Linnean Society their Linnean medal in 1888, a medal struck to celebrate his own eightieth birthday in 1897, and one of the medals struck in 1908 to commemorate the fiftieth anniversary of the publication of the joint communication of Darwin and Wallace on natural selection, in the original presentation of which to the society he had played so important a part. The Manchester Philosophical Society awarded him a medal in 1898, and in 1907 he received, in circumstances of singular dignity, from the Swedish Academy, what he himself has characterized as the crowning honor of his long life—the solitary medal, struck especially for the occasion,

to commemorate the two-hundredth anniversary of the birth of the great Linnæus.

Among his academic distinctions were the honorary degree of D. C. L., conferred upon him by the University of Oxford, and that of LL. D. from the Universities of Cambridge, Edinburgh, Dublin, and his own alma mater, Glasgow.

His foreign distinctions have included membership of the Royal Swedish Order of the Polar Star and the Royal Prussian Order "Pour le Mérite." By his own Government he was made a C. B. in 1869, the year following his presidentship of the British Association; he was made a K. C. S. I. in 1877, toward the close of his presidentship of the Royal Society. He was in 1897 promoted to the grade of G. C. S. I., when, in his eightieth year, the Flora of British India was completed; and in 1907, on his ninetieth birthday, he received the Order of Merit.

Hale and robust in his venerable old age, the veteran Hooker not only attended the Darwin-Wallace celebration organized by the Linnean Society in 1908, addressing the delegates and fellows present in a speech which recounted the part played by himself half a century earlier; he also attended the celebration at Cambridge in 1909 which commemorated the centenary of the birth of his friend Darwin. At work until within a few weeks of his death, and keenly interested in current topics to the last, Hooker passed peacefully away in his sleep, at his residence, The Camp, near Sunningdale, at midnight on Sunday, December 10. As was befitting, an invitation was offered to receive his remains in Westminster Abbey. Hooker had, however, expressed his wish that they should rest in the tomb in which his illustrious father's body was laid. This wish was fulfilled, and on Friday, December 15, he was buried in the family grave in the old churchyard of Kew. The cortege followed the coffin to the church, as was meet, from the house so long occupied by, and so full of memories connected with, his father and himself. At Kew, where so much of what he accomplished was done, he sleeps with his people, and Kew with its old churchyard is now more sacred even than it was to botanical pilgrims.

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