PROCEEDINGS

OF THE

American Philosophical Society

HELD AT PHILADELPHIA

FOR

PROMOTING USEFUL KNOWLEDGE

VOLUME LXV

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CONTENTS.

MINUTES OF THE MEETINGS

OF THE

AMERICAN PHILOSOPHICAL SOCIETY

DURING 1926.

Stated Meeting, January 8, 1926.

FRANCIS X. DERCUM, A.M., M.D., Ph.D., Vice-President, in the Chair.

The decease of the following member was announced:

Edward S. Morse, Sc.D., A.M., Ph.D., at Salem, Mass., December 20, 1925, æt. 87.

Professor William B. Scott read a paper on "The Isthmus of Panama as Controlling the Animal Life of North and South America," which was discussed by Messrs. Sydney G. Fisher and Hampton L. Carson, and illustrated by lantern slides.

Professor Scott also exhibited the brain cast of *Pithecanthropus*.

Dr. Horace C. Richards proposed the following amendment to the laws and also that the clause "and Library" should be omitted from Chapter VIII, Section 5:

CHAPTER IX.

Section 1. There shall be a Librarian to be appointed by the Council; he need not be a member of the Society.

2. He shall have under the direction of the Library Committee the custody and care of the books, manuscripts, maps, globes, charts, engravings, photographs and other printed or written matter belonging to the Society, which he shall dispose and arrange in such a manner as shall be judged most convenient. He shall keep a catalogue of them, as well as a record of the names of the donors.

3. He shall attend the Library daily, except Sundays and legal holidays, during such hours as the Society shall direct, except when allowed leave of absence by the presiding officer of the Society; and he shall lend out to any resident member, who is not indebted to the Society for fines or forfeitures, any books belonging to the Library, except such volumes as the Library Committee shall direct not to be lent.

4. He shall receive a salary to be fixed by the Council and be paid monthly.

5. He shall present annually, before the third Friday of January, to the Library Committee, a report on the condition and needs of the Library.

Dr. Richards proposed that the above amendment should be inserted in the Laws as Chapter IX, and that the succeeding chapters should be renumbered.

Special Meeting, January 20, 1926.

Francis X. Dercum, A.M., M.D., Ph.D., Vice-President, in the Chair.

Professor Monroe B. Snyder, Director Emeritus of the Philadelphia Observatory, read a paper on "Universal Atomic Volcanism and the Millikan Cosmic Rays," which was illustrated by lantern slides and discussed by Mr. Goodwin, Dr. Goodspeed, Dr. Dercum, Professor Snyder and a guest.

Stated Meeting, February 5, 1926.

Francis X. Dercum, A.M., M.D., Ph.D., Vice-President, in the Chair.

Dr. Richards, Chairman of the Library Committee, presented a list of the Frankliniana which William S. Mason, Esq., presented to the Society. A motion was made and unanimously carried that the Society's thanks and appreciation should be extended to Mr. Mason.

Hampton L. Carson, Esq., presented an address in Commemoration of Dr. I. Minis Hays.

Stated Meeting, March 5, 1926.

Francis X. Dercum, A.M., M.D., Ph.D., Vice-President, in the Chair.

The decease of the following member was announced:

Heike Kamerlingh Onnes, Ph.D., Sc.D., at Leiden, Holland, February 21, 1925, æt. 73.

Professor George H. Parker, Professor of Zoölogy and Director of the Zoölogical Laboratory, Harvard University, read a paper on

"The Life of the Nerve Cell" which was illustrated by lantern slides and discussed by Dr. Goodspeed and Dr. Dercum.

The Committee on Nomination of Officers made its report.

Stated General Meeting, April 22, 23, 24, 1926.

Charles D. Walcott, Sc.D., Ph.D., LL.D., President, in the Chair.

Opening Session, Thursday Afternoon, April 22d.

Francis X. Dercum, A.M., M.D., Ph.D., Vice-President, in the Chair.

The following papers were read:

"Self-sterility, Cross-fertility and Cross-sterility in Shepherd's Purse," by George H. Shull, B.S., Ph.D., Professor of Botany and Genetics, Princeton University, Herbert P. Riley, B.S., and Edmund Kiedrowski. Read by Mr. Kiedrowski.

"Beach Vegetation in the Philippines," by A. R. Kienholz, Ph.D., University of Illinois. (Introduced by Professor William Trelease.)

"Some Puzzling Pepper Leaves," by William Trelease, Sc.D., LL.D., Professor of Botany, University of Illinois.

"Research at the Boyce Thompson Institute," by John M. Coulter, A.M., Ph.D., Boyce Thompson Institute for Plant Research.

"Mutations in a Haploid (ln) Datura and Their Bearing on the Theory of Hybrid Origin of Mutants," by Albert F. Blakeslee, A.M., Ph.D., Assistant Director and Resident Investigator in Plant Genetics, Carnegie Station for Experimental Evolution, Cold Spring Harbor, L. I., N. Y. Discussed by Professor Shull.

"The Transmission of the 'Vegetative' Character in Sphærocarpos," by Charles E. Allen, B.S., Ph.D., Professor of Botany, University of Wisconsin.

"Permeability and Growth of Century-old Cells," by Daniel T.

MacDougal, Ph.D., LL.D., Director, Laboratory for Plant Physiology, Carnegie Institution of Washington. Discussed by Messrs. Donaldson, MacDougal, Dercum and Harshberger.

"An Accurate Identification of Wind-borne Pollens for Diagnostic Tests in Hay Fever," by George T. Moore, A.M., Ph.D., Director, Missouri Botanical Garden, St. Louis, Mo. Discussed by Messrs. Scott, Dercum, Allen and Moore.

"Actual Temperatures in the Tissues which Accompany Temperature Sensations," by Henry C. Bazett, F.R.C.S., M.D., A.M., Professor of Physiology, University of Pennsylvania. (Introduced by Dr. Alexander C. Abbott.)

"The Mechanism of Chemical Reactions," by Hugh S. Taylor, Ph.D., B.Sc., M.Sc., Sc.D., Assistant Professor of Physical Chemistry, Princeton University. (Introduced by Professor George A. Hulett.)

"The Metabolism of Uric Acid," by Withrow Morse, A.M., Ph.D., Professor of Physiological Chemistry and Toxicology, Jefferson Medical College. (Introduced by Dr. Francis X. Dercum.) Discussed by Dr. MacDougal.

"Mediterranean Garigue and Macchia," by John W. Harshberger, A.B., B.S., Ph.D., Professor of Botany, University of Pennsylvania.

"Corals vs. Nullipores," by William A. Setchell, A.M., Ph.D., Professor of Botany, University of California. Read by title.

"The History of *Œnothera biennis* Linnæus, *Œnothera grandiflora* and *Œnothera Lamarckiana* of de Vries in England," by Bradley Moore Davis, A.M., Ph.D., Professor of Botany, University of Michigan. Read by title.

Friday, April 23d.

Executive Session, 10 o'clock.

Charles D. Walcott, Sc.D., Ph.D., LL.D., President, in the Chair.

The President delivered his annual address.

The Finance Committee made its report.

Morning Session, 10:30 o'clock.

CHARLES D. WALCOTT, Sc.D., Ph.D., LL.D., President, in the Chair.

The following papers were read:

"Prerequisites of Mind," by Stewart Paton, M.A., M.D., Lecturer on Neurobiology, Princeton University.

"The Newer Knowledge of Physiological Action of Ultra-Violet Rays," by Alfred Hess, A.B., M.D., Clinical Professor of Pediatrics, University and Bellevue Hospital Medical College, New York. (Introduced by Dr. Henry H. Donaldson.) Discussed by Drs. Goodspeed and MacDougal.

"The Growth of Functional Neurones and Its Bearing upon the Development of Behavior," by George E. Coghill, A.B., M.S., Ph.D., Professor of Comparative Anatomy, The Wistar Institute. (Introduced by Dr. Clarence E. McClung.)

"The Present Status of Long-Range Weather Forecasting," by Robert DeC. Ward, A.M., Professor of Climatology, Harvard University.

"The Greenland Expedition of the University of Michigan," by William H. Hobbs, S.B., A.M., Ph.D., of Ann Arbor, Michigan.

"The Hittite Problem," by George A. Barton, A.M., Ph.D., D.D., LL.D.

"Christ's Entry into Jerusalem," by Paul Haupt, A.M., Ph.D., LL.D., Professor of Semitic Languages, Johns Hopkins University. Read by title.

"Culture Problems of Northeastern America and Their Bearing upon Asiatic and Eskimo Diffusion," by Frank G. Speck, A.B., A.M., Ph.D., Assistant Professor of Anthropology, University of Pennsylvania. (Introduced by Dr. Aleš Hrdlička.)

Afternoon Session, 2 o'clock.

HENRY NORRIS RUSSELL, A.M., Ph.D., in the Chair.

Dr. Albert F. Blakeslee and Dr. Joel Stebbins subscribed the Laws and were admitted into the Society.

The following papers were read:

"Discussion of the Kinetic Theory of Gravitation. III. Experimental Evidence Supporting Theory; Continual Generation of Heat in some Igneous Rocks. Its Relation to the Internal Heat of the Earth and Presumably of the Sun," by Charles F. Brush, Sc.D., Ph.D., LL.D., of Cleveland.

"What Are the Causes of the Earth's Magnetic Storms?" by Louis A. Bauer, C.E., M.S., M.A., Ph.D., Sc.D., Director, Department of Terrestrial Magnetism, Carnegie Institute of Washington.

"Some Results of the Eclipse of 1925, January 24," by Ernest W. Brown, M.A., Sc.D., Professor of Mathematics, Yale University. Discussed by Dr. Samuel A. Mitchell.

"The Flash Spectrum of the 1925 Eclipse," by Samuel A. Mitchell, M.A., Ph.D., LL.D., Professor of Astronomy and Director of the Leander McCormick Observatory, University of Virginia. Discussed by Dr. John A. Miller, Dr. Henry N. Russell, Dr. Ernest W. Brown and Dr. Louis A. Bauer.

"A Further Contribution to the Mode of Regulation of Urine Formation," by Alfred N. Richards, Ph.D., Professor of Pharmacology, University of Pennsylvania. (Introduced by Dr. Alexander C. Abbott.) Discussed by Dr. Donaldson.

"Germanium," by Louis M. Dennis, Ph.B., B.S., Sc.D., Professor of Inorganic Chemistry, Cornell University. (Introduced by Professor Edgar F. Smith.) Discussed by Dr. Henry N. Russell.

"Oxides of Germanium," by John H. Müller, A.M., Ph.D., Professor of Chemistry, University of Pennsylvania. (Introduced by Professor Edgar F. Smith.) Discussed by Dr. Henry N. Russell.

"Analytical Chemistry of Selenium and Tellurium," by Victor Lenher, Ph.D., Professor of Chemistry, University of Wisconsin. (Introduced by Professor Edgar F. Smith.) Read by title.

"Tungstates," by Edgar F. Smith, Ph.D., Chem.D., Sc.D., L.H.D., LL.D., Litt.D., M.D., Past Provost and Professor of Chemistry, University of Pennsylvania. Read by title.

"Equiangular Spiral Polygons as Presenting Themselves in Electrical Engineering," by Arthur E. Kennelly, A.M., Sc.D., Professor of Electrical Engineering, Harvard University.

"Universal Atomic Volcanism and the Ultimate Atom," by Monroe B. Snyder, M.A., Director Emeritus of the Philadelphia Observatory. Read by title.

On Friday evening, April 23d, Robert A. Millikan, A.B., Ph.D., Sc.D., LL.D., Director of the Norman Bridge Laboratory of Physics, California Institute of Technology, spoke on the "Last Fifteen Years of Physics."

Saturday, April 24th.

Executive Session, 9:30 o'clock.

Charles D. Walcott, Sc.D., Ph.D., LL.D., President, in the Chair.

Dr. Armin O. Leuschner and Dr. Frank Leverett, recently elected members, subscribed the Laws and were admitted into the Society.

The Society proceeded to an election. The Tellers subsequently reported that the following officers and members had been duly elected:

President.

Charles D. Walcott.

Vice-Presidents.

Henry F. Osborn,
William W. Campbell,
Francis X. Dercum.

Secretaries.

Arthur W. Goodspeed,
John A. Miller.

Curator.

William P. Wilson.

Treasurer.

Eli Kirk Price.

Councillors.

(To serve for 3 years.)

Herman V. Ames,
Whitman Cross,
Walton B. McDaniel,
Oswald Veblen.

Members.

Irving W. Bailey,
James M. Beck,
Gilbert Ames Bliss,
John Cadwalader, Jr.,
Roland Burrage Dixon,
William Charles Lawson Eglin,
William P. Gest,
Charles E. Hughes,
Charles Kenneth Leith,
Ralph Modjeski,
Oscar Riddle,
John M. Scott,
William F. G. Swann,
Henry Osborn Taylor,
Alfred North Whitehead.

The amendment to the Laws presented by Dr. Horace C. Richards at the Stated Meeting of January 8th, 1926, was approved by the Society.

Morning Session, 10 o'clock.

HENRY FAIRFIELD OSBORN, Sc.D., Ph.D., LL.D., Vice-President, in the Chair.

The following papers were read:

"The Pleistocene Glacial Stages: Were There More Than Four?" by Frank Leverett, B.Sc., Lecturer in Glacial Geology, University of Michigan.

"Geology of Southeastern Alaska," by A. F. Buddington, Ph.B., M.S., Ph.D., Assistant Professor of Geology, Princeton

University. (Introduced by Professor Charles H. Smyth, Jr.)

"The Present Condition of Knowledge on the Composition of Meteorites," by George P. Merrill, Ph.D., Sc.D., Head Curator, Department of Geology, U. S. National Museum.

"The Proposed Railroad Summer School of Geology of Princeton University," by R. M. Field, Assistant Professor of Geology, Princeton University. (Introduced by Professor William B. Scott.)

"The Structure of *Palæaspis*," by William L. Bryant, Director, Park Museum, Providence, R. I. (Introduced by Professor William B. Scott.)

"Progress in the Studies of Race and Race Mixtures, with Special Reference to the Work Carried on by Harvard University," by Ernest A. Hooton, B.A., M.A., Ph.D., B.Litt. (Introduced by Dr. Aleš Hrdlička.)

"The Peopling of Asia in the Light of New Evidence," by Aleš Hrdlička, M.D., Curator, Division of Physical Anthropology, U. S. National Museum.

"Sea-level Surfaces, and the Problem of Coastal Subsidence," by Douglas Johnson, Ph.D., Professor of Physiography, Columbia University.

Afternoon Session, 2 o'clock.

CHARLES D. WALCOTT, Sc.D., Ph.D., LL.D., President, in the Chair.

A portrait of William Berryman Scott, M.A., Ph.D., Sc.D., LL.D., President 1918–1925, by Robert Vonnoh, was presented, on behalf of the Society, by Henry Fairfield Osborn, Sc.D., Ph.D., LL.D., Vice-President.

The symposium followed, the subject being "Early American Civilizations and Their Relation to One Another."

Introduction by Aleš Hrdlička, M.D., Curator, Division of Physical Anthropology, U. S. National Museum.

The following papers were read:

"The Maya Civilization and Its Relation to the Surrounding

Cultures," by Alfred M. Tozzer, Ph.D., A.B., A.M., Professor of Anthropology, Harvard University.

"The Prehistoric Peruvians," by Charles W. Mead, Honorary Curator of Peruvian Archæology, American Museum of Natural History.

"The Cultures of Northwestern South America and Their Relations to Central America," by Marshall H. Saville, Professor of American Archæology, Columbia University.

"The Aztecs and Their Predecessors in the Valley of Mexico," by Zelia Nuttall, Honorary Professor of Archæology, National Museum, Mexico. Read by title.

"Samuel Pierpont Langley and Modern Aviation," by Charles D. Walcott, Secretary, Smithsonian Institution.

Stated Meeting, November 5, 1926.

FRANCIS X. DERCUM, A.M., M.D., Ph.D., Vice-President, in the Chair.

John M. Scott, Esq., newly elected member, subscribed the Laws and was admitted into the Society.

Acceptances of membership were received from Irving W. Bailey, James M. Beck, Gilbert Ames Bliss, John Cadwalader, Jr., Roland B. Dixon, William C. L. Eglin, William Gest, Charles E. Hughes, Charles K. Leith, Ralph Modjeski, Oscar Riddle, John M. Scott, William F. F. Swann, Henry O. Taylor and Alfred N. Whitehead.

The decease of the following members was announced:

William Hyde Appleton, A.M., Ph.D., LL.D., at Philadelphia, April 3, 1926, æt. 84.

John C. Smock, M.A., Ph.D., LL.D., at Hudson, New York, April 21, 1926, æt. 83.

Oscar Straus, A.M., LL.D., Litt.D., at New York, May 3, 1926, æt. 76.

Henry Skinner, M.D., Sc.D., at Narberth, Pa., May 30, 1926, æt. 65.

John Percival Postgate, Litt.D., at Cambridge, England, July 15, 1926, æt. 72.

Allen J. Smith, A.M., M.D., Sc.D., LL.D., at St. Davids, Pa., August 18, 1926, æt. 63.

Charles William Eliot, A.M., M.D., Ph.D., LL.D., at Northeast Harbor, Me., August 22, 1926, æt. 92.

William Romaine Newbold, A.B., Ph.D., LL.D., at Philadelphia, September 26, 1926, æt. 61.

Francis E. Nipher, B.S., A.M., LL.D., at St. Louis, October 6, 1926, æt. 78.

Emlen Hutchinson, A.B., at Bryn Mawr, Pa., October 24, 1926, æt. 83.

Professor John W. Harshberger, Professor of Botany, University of Pennsylvania, read a paper on "Alaska and Its Vegetation" which was illustrated by lantern slides and discussed by Professors Scott and Leverett.

After the reading of the paper informal communications were called for and Dr. Frank Leverett read a paper on "Some Remarkable Lobations of the Ice-border in Eastern Pennsylvania," which was discussed by Dr. Wilson, Dr. Harshberger and Professor Scott.

Stated Meeting of the Society, December 3, 1926.

Francis X. Dercum, A.M., M.D., Ph.D., Vice-President, in the Chair.

William P. Gest, Esq., Professor William C. L. Eglin and John Cadwalader, Jr., Esq., newly elected members, subscribed the Laws and were admitted into the Society.

The decease was announced of the following member:

James Furman Kemp, A.B., E.M., Sc.D., LL.D., at Great Neck, Long Island, November 17, 1926, æt. 67.

Professor J. Parsons Schaeffer, Professor of Anatomy, Jefferson Medical College, read, by invitation, a paper on "The Problem of an Individual Anatomy in Man," which was illustrated by lantern slides and discussed by Dr. McClung and Dr. Dercum.

OBITUARY NOTICES OF MEMBERS DECEASED.

ADDRESS BY HAMPTON L. CARSON IN COMMEMORATION OF I. MINIS HAYS.

Read before the American Philosophical Society, February 5, 1926.

Mr. President and Fellow Members of the American Philosophical Society:

The partiality of my colleagues has assigned to me the agreeable privilege of delivering an address commemorative of our late associate, I. MINIS HAYS.

The services rendered by Dr. Hays to this Society, through the many years of his active membership, were of such timely and continuous consequence that their substantial value and exact character cannot be placed in their proper perspective without attempting an outline sketch of the history of the Society itself, to serve as a suitable background.

It is generally known that the full title of the Society, as at present constituted, is that of THE AMERICAN PHILOSOPHICAL SOCIETY HELD AT PHILADELPHIA FOR PROMOTING USEFUL KNOWLEDGE. That is the title conferred by the Act of Incorporation enacted "by the Representatives of the freemen of the Commonwealth of Pennsylvania in General Assembly . . . Wednesday, the 15th of March, Anno Domini, 1780"—9 years before the organization of the Government of the United States under the Constitution as framed two years earlier by the Federal Convention.

Prior to the granting of this Charter of 1780, the same name had been used by an unincorporated body since the 2nd of January, 1769, at which time the first meeting under that title was held, and its first election of officers took place. This unincorporated body, under this title, was the result of the union of two prior societies existing as rivals side by side, zealously engaged in the same pursuits, and composed in about one-tenth of the same members. One had been known as "THE AMERICAN SOCIETY HELD AT PHILADELPHIA FOR PROMOTING AND PROPAGATING USEFUL KNOWLEDGE," and the other as "THE

AMERICAN PHILOSOPHICAL SOCIETY." The first and older body—originally called THE JUNTO,— had been sustained by the Popular Party led by Franklin, and the second by the Proprietary Party led by Deputy Governor James Hamilton. Good sense finally prevailed in sacrificing little jealousies and political dissensions to the honor of their country and the advantage of science by joining as a band of brothers for the advancement of knowledge. It is not difficult to ascertain that the influence and views of Franklin were predominant.

The existence of the second Society, like that of the first, was due to Franklin. In 1743, Franklin had issued a circular entitled "*A proposal for Promoting Useful Knowledge Among the British Plantations in America,*" and in that well-known paper he had urged "That one Society be formed of virtuosi, or ingenious men, residing in the several colonies, to be called the American Philosophical Society, who are to maintain a constant correspondence. That Philadelphia, being the city nearest the center of the continent colonies, communicating with all of them northward and southward by post, and with all the islands by sea, and having the advantage of a good growing library[1] be the center of the Society." The proposition was favorably received, and Franklin, when in New York in the spring of 1744, wrote to Cadwallader Colden, the Governor of that Province: "I can now acquaint you that the Society, as far as relates to Philadelphia, is actually formed, and has had several meetings to mutual satisfaction." Of this Society, Thomas Hopkinson was President, and Benjamin Franklin was Secretary, with Thomas Bond as Physician, John Bartram as Botanist, Thomas Godfrey as Mathematician, William Parsons as Geographer, and Dr. Phineas Bond as General Natural Philosopher among its members. This body was distinct from the original *Junto.*

Later, the friends of the Proprietary Party, which was the political foe of Franklin and his followers, dominated the younger association recruited largely from their own adherents. Governor John Penn became its Patron, and it enjoyed his special countenance and protection. They worked under the title THE AMERICAN

[1] The Philadelphia Library, founded by Franklin in 1731.

PHILOSOPHICAL SOCIETY, although the claim of Franklin to the authorship of this collocation of words is indisputably established by his Proposal of 1743.

In 1764, Franklin went abroad, but his party friends, stimulated by a letter written by him in 1765 to his friend, Hugh Roberts, urging that he would continue to meet the *Junto* because it was "one of the *oldest* Clubs, as it was one of the *best* in the King's dominions," revived or reorganized the *Junto*, and in December, 1766, extended its scope by admitting non-residents and changed its name to "THE AMERICAN SOCIETY HELD AT PHILADELPHIA FOR PROMOTING AND PROPAGATING USEFUL KNOWLEDGE." It elected Dr. Franklin—still absent abroad—as its President, and Charles Thomson as its Secretary.

For some years, the two societies continued to clash, but, after a year spent in the elaboration of details and the exercise of much diplomacy, terms were mutually agreed upon, resulting, in 1769, in the complete union of the two bodies under the present title, which is clearly a combination of the titles of both Societies.

The candidacy for the Presidency of the conjoined Society led to an active contest. The name of Dr. Franklin, who had been the President of *The American Society* since 1766, was pitted against that of Ex-Governor James Hamilton, who had been President of *The Philosophical Society* since 1763. In a poll of eighty-nine votes Franklin, although absent from the country and not returning until 1775, was elected and was annually reëlected until his death in 1790.

In 1840, Peter S. DuPonceau, then President of this Society, read, on June 26th, "An Historical Account of the Origin and Formation of the Society." With the fullest conviction of the soundness of his thesis he maintained that "the '*American Society*' was no other than the *Junto*," established by Franklin in *1727*. His argument occupied more than 50 pages. His views were keenly opposed. Joshua Francis Fisher, in a paper, read also on June 26, 1840, contested the identity of the original *Junto* with that of The American Society Held at Philadelphia for Promoting and Propagating Useful Knowledge.

The matter was thought of sufficient importance to justify the

immediate appointment of Dr. Franklin Bache, Judge John K. Kane, Professor A. D. Bache and Dr. Robley Dunglison as a special committee to study the evidence. After more than a year's investigation, a careful report of 45 pages was presented, in which the following conclusions were stated:

1. That the present Society was formed, on the 2nd of January, 1769, by the Union of the "American Philosophical Society" and "The American Society, held at Philadelphia for Promoting Useful Knowledge."
2. That the Philosophical Society was founded by Franklin on the 14th of May, 1743, (old style corresponding to 25th May new style), this being the date of the publication of his "Proposal for Promoting Useful Knowledge among the British Plantations in America."
3. That the American Society was begun under the name of the *Junto*, and bore this name from the year 1750, the earliest recorded date of its existence, until the 13th of December, 1766.
4. That the evidence before the Committee does not establish the identity of the *Junto* which was formed by Franklin in 1727, with that which afterwards became the American Society; though they appear to have been the same in many marked particulars.
5. That dating from the establishment of the elder parent Society, our centennial anniversary should be celebrated on the 14th (25th, new style) of May, 1843.
6. That Franklin, having established one of our parent Societies, and furnished, in his *Junto*, the model of the other, is justly entitled to be called our founder.

The Committee, however, admitted that chasms still remained in our early annals which required to be filled up, that doubts existed on some points, and discrepancies of opinion on others. Hence, they refrained from giving publicity to the Society's early history in its then imperfect state, and suggested a delay of action in the hope of obtaining more facts. It was: "Resolved that the papers of Mr. DuPonceau and Mr. Fisher, together with the supplementary contributions, be deposited in the Archives, as valuable contributions to the early history of the Society."

The papers and the evidence were deposited on the 15th of October, 1841, and were undisturbed for 67 years.

Acting on the recommendation of the Committee, that, dating from the establishment of the elder parent Society, "our centennial anniversary should be celebrated on the 14th (25th, new style) of May, 1843," [2] the Society, still under the Presidency of the venerable

[2] Conclusion No. 5, ut supra.

DuPonceau, met at noon, on the day designated, in the "saloon" of the Musical Fund Society, and celebrated with formal and interesting exercises "The Hundredth Anniversary of the Organization of the Association, under the name of the American Philosophical Society." After a brief opening address by President DuPonceau, Robert M. Patterson, M.D., one of the Vice-Presidents, delivered a discourse in which he touched the subject with delicacy but with clearness. It is quite evident that he regarded it as plausible that the Junto,—"a debating Society" as he described it, "not claiming to be a scientific body," was "one of the branches of which our present Society is composed, and it is at least the original after which that branch was modelled." He avoided a discussion of niceties, by planting himself upon the then undisputed ground that Franklin's *Proposal* of May 14–25, 1743, was "the true origin of The American Philosophical Society." [3]

Fifty years passed without renewed examination of the relations of the Society to the Junto. From May 22 to 26, 1893, the Society commemorated the Sesqui-Centennial Anniversary of its existence. President Fraley, then a nonagenarian and sightless, in an address, remarkable in its grasp upon the scientific progress of the age, without discussion or even a passing reference to the Junto, alluded to the origin of the Society as springing from Franklin's Proposal of 1743, and stated that in Franklin's view that "was a favorable time for bringing the scientific men of the country into unison and to establish a Society having for its model the Royal Society of London." [4]

No one, among the numerous speakers on that occasion, cast his eyes back upon the past or endeavored even by indirect suggestions to recall the Junto.

And so the years ran on, until in 1907, the Carnegie Foundation for the Advancement of Teaching reported a definition of a date of Founding. "*By Date of Founding,*" it declared, "is meant the year in which the institution was established out of which the present college or university has developed. Thus the year 1780 is the date

[3] *Proceedings of The American Philosophical Society,* Vol. III., V. P. Patterson's Discourse, 3–35.

[4] *Proceedings of The American Philosophical Society,* Vol. XXXII., May 1893, No. 143, p. 17.

of the foundation of an academy at Washington, Pennsylvania, from which Washington and Jefferson College grew." [5]

This definition stimulated inquiries among many institutions, arousing a general interest in what may be called corporate genealogical researches as to the ancestries of American institutions claiming to be venerable. The University of Pennsylvania, the Pennsylvania Hospital, the Philadelphia Library Company and this Society, in particular, became zealous in competitive efforts to establish an undoubted Franklin parentage.

On February 18, 1910, Charlemagne Tower, James T. Mitchell, Mayer Sulzberger, Samuel Dickson, Hampton L. Carson, E. P. Cheyney, Francis B. Gummere, W. W. Keen and I. Minis Hays were appointed as a Committee "to investigate and determine the date of the foundation of the Society." After four years of close research, rewarded by the discovery of new matter, consisting of long-forgotten letters, diaries, addresses, the Junto Minute Book, and a carefully compiled Chronological Statement covering the life of Franklin between 1727 and 1790, an elaborate report was presented and read before the Society by Mr. Tower, as Chairman, on May 1, 1914. There were, in point of fact, two reports—the report presented by Mr. Tower was also signed by Messrs. Sulzberger, Carson, Gummere, Dickson, Keen and Hays. These gentlemen discussed with particularity the old evidence examined by the Committee of 1840, as well as the newly discovered data, and reviewed the differences of opinion between Mr. DuPonceau and Mr. Fisher. The assumption of two distinct Juntos, on which rested the whole case of the older Committee, was held to be untenable, and the opinion was reported that *1727* was the date of the foundation of this Society. Professor Cheyney, in a separate report, while agreeing with the main conclusion that the origin of The American Philosophical Society should be carried back to the Junto founded by Franklin in 1727, was unable to agree with one section of the reasoning by which the result had been reached. He argued in favor of the two forms of Junto, and urged that while it might be fairly claimed that The Philosophical Society was derived from the ancient Junto, yet it was through a younger branch.

[5] Second Annual Report of President and Treasurer of Carnegie Foundation, 1907, p. 18.

These views were reconciled by a supplemental report signed by all nine members. Professor Cheyney attached his signature, and the name of Chief Justice Mitchell appeared for the first time as approving the report as recast. The findings of the entire Committee were stated as follows:

> The question whether Franklin was in a proper sense the founder of our Society is not in doubt. He founded The American Philosophical Society of 1743. He founded the Junto of 1727. The development of a junior Junto —if such a thing occurred—was unquestionably due to the impetus of the older Junto; and the change of the local Junto into a Society which included corresponding members from other colonies was a mere broadening of its purpose. In the sense of the ruling of the Carnegie Foundation it is clear that when Franklin founded his original Junto, he became the founder of the American Society. He is admitted by all to be the founder of the Philosophical Society. Our Society therefore owes its origin to him on both sides." [6]

It is not likely that a conclusion so deliberately reached will ever be disturbed. Apart from the patience and the time expended in research, the personnel of the Committee was unusual. The Chairman, an Ambassador of the United States to the Courts of Vienna, St. Petersburg and Berlin, was the biographer of Lafayette; the other members of the Committee included the Chief Justice of Pennsylvania and the President Judge of a Court of Common Pleas; two active trial advocates at the bar, one of them a former Attorney General of Pennsylvania; two eminent teachers of history, one of them a Professor in the University of Pennsylvania, the other a Professor in Bryn Mawr College; a world renowned surgeon, the President of the Society, and the indefatigable Secretary of the Society, whose exact knowledge of Franklin literature was unrivalled. All of them were men zealous in the pursuit of historical facts, skilled in analytical examination, experienced in the sifting and weighing of evidence, cautious in the formation of opinions and jealous in guard- the reputation of the Society against indiscreet publications. None

[6] An Historical Account of the Origin and Formation of The American Philosophical Society Held at Philadelphia For Promoting Useful Knowledge by Peter Stephen DuPonceau, President of the Society, with the Communication of J. Francis Fisher, Esq., and the Report of the Committee to which these Papers were Referred, Read October 15th, 1841. And the Report of The Committee on the Date of the Foundation of the Society, Accepted May 1, 1914. Philadelphia. The American Philosophical Society, 1914. Octavo—196 pages.

brought to the study of the problem preconceptions of the result, and none subscribed to the final report with mental reservations.

It had been demonstrated that the American Philosophical Society was the oldest learned Society in America, and one of the oldest in the world. In tracing its origin to Franklin's famous "Junto" it had vindicated the declaration of its ancient charter that its objects were "The prosecution and advancement of all useful branches of knowledge, for the benefit of their country and mankind."

To no member of the Committee, may I not say of the Society?, did the significance of this report appeal so strongly as to Dr. Hays. Familiar in an intensive sense with the career of Franklin, touching daily for years with his own fingers and reading with his own eyes the originals of the documents and letters of Franklin in the possession of the Society, the largest and most precious deposit of such material in existence, he had become thoroughly saturated with a knowledge of the man and of all the phases of his astonishing career. In the course of time he became a Franklin worshipper, and regarded the Society, actually as well as historically, as the embodiment of his scientific spirit. With no selfish desire to exploit himself, he laid aside all other occupations and devoted his time, his strength and his persistent energy to building up and fortifying the Society, as an active instrument in support of Franklin's far-reaching plans. One of our fellow-members, who knew him well, has expressed it in an epigram: "Dr. Hays' life was an ellipse with Benjamin Franklin and The American Philosophical Society in the 2 foci."[7] This is the key to Dr. Hays' work in our behalf, and it is eminently fitting that we should meet tonight to pay just tribute to his labors.

The paternal grandfather of Dr. Hays was Samuel Hays, a wealthy merchant, who, coming from New York, married in Philadelphia, in 1794, Richea Gratz, whose father and uncle, Michael and Bernard Gratz, were Signers of the celebrated Non-Importation Agreement of November 7, 1765. The sister of Mrs. Hays was Rebecca Gratz, the lifelong friend of Washington Irving, who furnished to Sir Walter Scott so captivating an account of her beauty and character that the great novelist made her the heroine of Ivanhoe.

Isaac Hays, born July 5, 1796, the son of Samuel and Richea

[7] Dr. W. W. Keen in a letter to the writer.

(Gratz) Hays, married, at the mature age of thirty-eight years in 1834, Sarah Minis of Savannah, Georgia, whose ancestors had come to America as personal friends of James Oglethorpe to help him found his colony, which was the last of the original Thirteen. The grandfather of Sarah Minis, Philip Minis, was the first white male child born in the colony of Georgia.[8]

Isaac Hays, the father of our late Associate, after having been classically educated in the school of Rev. Dr. Samuel B. Wylie, and the Department of Arts of the University of Pennsylvania, rose to distinction in the medical profession. His career, from 1820 to 1879, was marked by devotion to Natural Science, and to the highest interests of Medicine. He was the editor in 1828 of *Wilson's American Ornithology,* and was the correspondent of Prince Charles Lucien Bonaparte, himself one of the most eminent of ornithologists. Isaac Hays made his mark as a member of this Society as early as 1831, by reading a paper upon the *Mastodon Giganteus,* which was favorably commented upon by Dr. John C. Warren of Boston as late as 1852. In 1865, he became the President of the Academy of Natural Sciences, and was annually reëlected until advancing years persuaded him to retire. Quite early in his professional life he made a special study of the eye, and published several papers in the *Philadelphia Journal of the Medical and Physical Sciences,* which, as Professor Alfred Stillé has asserted, "laid the foundation of the high repute which Dr. Hays afterwards attained as an ophthalmic surgeon, and probably determined his selection as one of the first surgeons of *Wills Hospital* in 1834."[9] In fact, he invented one of the delicate instruments used in performing operations for cataract, which is still called "Hays' Knife." It was, however, as the Editor of *The American Journal of the Medical Sciences,* from 1827 to 1879, a period of almost fifty-three years, that he performed his most important services. He gave to that work "a cosmopolitan character which has constantly become more perfect, and which was never tarnished by

[8] These particulars were furnished by Mrs. Caspar Frederick Goodrich, the daughter of Dr. I. Minis Hays.

[9] Memoir of Isaac Hays, M.D., Read before the College of Physicians, February 4, 1880, by Alfred Stillé, M.D., LL.D. *Transactions,* 3d Series, Vol. V.

his negligence or indiscretion." [10] Dr. Billings, in his Centennial History of American Literature," described the *Journal* in these words:

> "The ninety-seven volumes of this Journal need no eulogy. They contain many original papers of the highest value; nearly all the real criticisms and reviews that we possess; and such carefully prepared summaries of the progress of medical science, and abstracts and notices of foreign works, that from this file alone, were all other productions of the press for the last fifty years destroyed, it would be possible to reproduce the great majority of the real contributions of the world to medical science during that period." [11]

In the work of this *Journal* Dr. Hays was aided by his son, Dr. I. Minis Hays for a period of ten years.

Having, by way of introduction, glanced at the main influences which shaped the character and animated the efforts of the late Secretary of this Society, we are now prepared to follow with understanding the particulars of his unobstrusive but most useful and fruitful life.

Isaac Minis Hays, or, as he was better known, I. Minis Hays, was born in the City of Philadelphia, July 26, 1847. Although he was five years older than the present speaker and therefore one of the bigger boys at school, I well remember him in the upper classes as a tall, thin, studious-looking lad at the Classical Institute of that very able but old-fashioned teacher, addicted to the use of the rod, the late Dr. John W. Faires, of fragrant memory. I do not remember him at College, as he had graduated from the Department of Arts of the University of Pennsylvania in 1866, but I recall him as a frequent visitor with his father to my father's house, and such was the intimacy between us that he never resented being called "Minis" by a younger boy. To the day of his death he was my close and confidential friend. We had many interests in common and throughout life, and although we had many differences of opinion, our mutual regard was unclouded.

He received his medical degree from the University of Pennsylvania in 1868, and that of A.M. in 1869. In the latter year he became assistant editor of *The American Journal of the Medical Sciences*, eventually succeeding his father to the editorship in 1879,

[10] Ibid., p. 16.

[11] As quoted by Dr. Stillé in his Address.

a position which he held until 1890. He also edited the *Medical News* from 1878 to 1889. His specialty was ophthalmology, and in this domain he wrote several articles. As early as 1873, he edited the American edition of *J. Soelberg Wells' Treatise on the Diseases of the Eye*.[12]

In 1876, during the time of the Centennial Celebration of our Independence, he was Secretary-General of the International Medical Congress which met in this city. He was active for many years as a member of the Association of American Physicians, and for twenty years was Chairman and member of the Library Committee of the College of Physicians of Philadelphia.

We are now to view him in a field of distinction which he made peculiarly his own. We find him gradually withdrawing from his medical environment and entering one which brought him into close contact with men of all callings and professions promoting improvements of a public nature which, in the noble language of the preamble to the charter of this Society, "are best carried on by Societies of liberal and ingenious men, uniting their labours, without regard to nation, sect or party, in one grand pursuit, alike interesting to all, whereby mutual prejudices are worn off, a humane and philosophical spirit is cherished, and youths are stimulated to a laudable diligence and emulation in the pursuit of wisdom."

The first twenty years of his life following the taking of his medical degree were but preparatory for the tasks he was then to assume, and his preliminary training, although highly specialized, was well adapted to nurture his later intellectual development. His long association with his father and his own responsibilities as an editor had brought him into familiar touch with all treatments, discoveries, instruments, operations, remedies and devices affecting the larger interests of medical science and surgery, closely allied with botany, chemistry, pharmacology and medical jurisprudence and toxicology. The learning of the medical world, overleaping national and local barriers, sought the pages of the *American Journal of the Medical Sciences* and earned either recognition or criticism. The broadening effect of such an experience was inescapable. So too, his training as a librarian disciplined him in the arrangement of

[12] *Amer. Journal Med. Sciences*, July, 1925, Sketch of Dr. Hays.

books, the classification of subjects, the collection of material, and the dissemination of knowledge. So too, he learned the importance of discussion, and the value to be derived from Congresses of experts, assembled to announce the results of special investigations or to debate and criticize prevalent theories and practices.

It was on February 19, 1886, at the age of thirty-nine years, that he became a member of this Society, under the Presidency of Frederick Fraley, and continued as such under the terms of Isaac J. Wistar, Edgar Fahs Smith, W. W. Keen and William B. Scott. His membership number was 2,071, the list being headed by Franklin in 1769. Since Franklin's day we have had to date 2,879 members. It was not long before his peculiar talents were perceived and availed of. On January 1, 1897, he became Secretary, retiring from the office of Senior Secretary May 1, 1922, a continuous incumbency of twenty-five years. During the year 1897, he served as Librarian *pro tem*, became Librarian on January 21, 1898, retiring May 1, 1922, but serving as Chairman of the Library Committee from that date until his death June 5, 1925.

His was not a disposition to sit in an easy chair in a sunny corner and browse upon the dusty volumes that chance threw in his way. He immediately set to work to discover what treasures we possessed, whether books, manuscripts, documents, pamphlets, letters, portraits, engravings or curios, illustrative of our history as a nation, a state or a city, or our development as a Society in enriching the literature of science in its broadest sense. He found an incongruous and ill-assorted mass, disorderly, inaccessible to students, unappreciated in its extent, variety and value, in danger of perishing from neglect and decay. With a passion for order, with a reverence for the past, with a high sense of duty to the present and to the future, and with a physical energy that knew not fatigue he addressed himself to the performance of a task that might well have discouraged a less ardent spirit. Year in and year out he toiled indefatigably, and the results have been not only gratifying but also surprising.

With a zeal as intense as that of a propagandist he felt that it was Franklin's Society, and that he was aiding in Franklin's work. It was a fine thing to be sustained by such an enthusiasm. He re-

vealed to us our treasures. Among these were the unrivalled deposit of what proved to be about eighty per cent. of all the known originals of Franklin documents; the Jefferson draft of the Declaration of Independence in his own handwriting, being the original autographic copy which Jefferson had sent to Richard Henry Lee of Virginia, interlined with amendments made by the Continental Congress; an original broadside of the Declaration, so scarce that no record can be found of its public sale; the original Charter of Privileges granted to the colonists by William Penn in 1701; Penn's Cash Book and many of his important papers, as well as some belonging to his Secretary, James Logan; a manuscript volume of the original or certified copies of the Laws of Pennsylvania prior to 1700—containing the only known copy of the earliest laws; the original manuscript minutes of the Provincial Council of Pennsylvania from 1693 to 1716; the original 18 note-books containing the field notes of Lewis and Clark's expedition for the exploration of the Northwest in 1804–06; a set of the Indian treaties of Pennsylvania; manuscripts relating to the Stamp Act and Non-Importation Agreement; books, broadsides, pamphlets and imprints relating to the entire Colonial and Revolutionary period; Priestley's manuscript of 1783, Zeisberger's manuscript on the language of Lenni Lenape or Delaware Indians, and the Minutes of this Society practically complete and continuous from the year 1750 to date, affording material for a history of science in America which cannot be found elsewhere.[13]

His feelings on unearthing all these must have been closely akin to those of Sir Flinders Petrie in far distant Egypt. It was elation and not vanity that gave to his smile a self-conscious look, and imparted to his stride, as he walked from his desk to our vaults to produce his exhibits, a pride that was more than personal.

He was not a collector nor an acquisitor. He was an investigator, a curator, an interpreter, and expositor in entire sympathy with the remark of Nigel, the Baron of the Exchequer of Henry II, who once exclaimed: "Know Sire! that buried learning, like buried treasure, yieldeth no profit." The objects that Dr. Hays brought to light and

[13] For an illustrated description of these and other articles see "A Plea for the American Philosophical Society and its Need of a New Building to be known as Franklin House," written by John Frederick Lewis, Esq.

caused to be known to the learned had long belonged to the Society. They had not been bought nor acquired at auction sales. They were the rich gifts of public-spirited, patriotic, and generous men and women who laid aside individual pride of possession for the public good in the days of Rittenhouse, Jefferson and DuPonceau. They had been lost sight of and forgotten. They needed recognition, identification, description, editing, classification, arrangement, protection, binding, indexing and cataloguing. All these things were done and well done, with intelligence and thoroughness.

So much for a general view. Let me now enter into some particulars gleaned from the Minutes, although it is impossible to do more within the compass of this address than to touch briefly the salient points. In this connection, I wish to acknowledge publicly my obligations to Mrs. Arthur MacNicholl, who, as Miss Kirkpatrick, was Dr. Hays' Secretary, to Miss L. E. Hanson, and to Mrs. Alexander R. Skinker, Assistant Secretary, for invaluable assistance in compiling this material.

His early acts were characteristic. While serving as Librarian *pro tem*, in 1897, he asked for and secured an appropriation for catalogues and a catalogue case, as well as for binding, and arranged exchanges of the Society's publications with those of other bodies for the benefit of the library. He suggested a memorial to Congress protesting against the proposed removal from the free list by the pending tariff bill of books, instruments, philosophical apparatus and works of art imported for incorporated libraries and other institutions of learning. He secured the appointment of a Committee to consider and report upon the advisability of the Society's publishing a Calendar of the Franklin Correspondence in its possession, and also to consider and report on the historic relation to the original document of the manuscript copy of the Declaration of Independence in Jefferson's handwriting in the possession of the Society. He called the attention of Dr. Stone, the Librarian of the Historical Society, to the manuscript volume of the Laws of the Province of Pennsylvania passed prior to November 1700, which in due course was brought to the notice of the State Commission engaged in publishing the text of the Statutes at Large. He secured also the appointment of a special committee to examine the historical manuscripts and early

American imprints in the Library of the Society and report as to what action it would be desirable to take to render them available for historical study.

The next year he became Librarian and so continued until May, 1922. During 1898, he presented the results of the examination of the historical documents and imprints and furnished a complete list of manuscripts. He secured a report from experts as to the proper measures to be taken to preserve the Jefferson Ms. of the Declaration of Independence, and verified the text by a comparison with the original Document in the Department of State in Washington. On April 1, 1898, he read "A Note on the History of the Jefferson Manuscript Draught of The Declaration of Independence," which was a masterpiece of historical descriptive analysis, deserving of the widest publicity as a means of correcting the errors indulged in by hasty writers, and even by eminent historians. Two weeks later, he read a paper entitled "A Journal kept During the siege of Fort William Henry, August 1757.[14] In December, he presented his first report as Librarian, which unfortunately remains unprinted, but which appears upon the Minutes, displaying how judiciously he reorganized the library and made it available for consultation. It illustrates his skill in bringing order out of chaos.

In 1899, he secured the more frequent publication of the *Proceedings* of the Society, which furnished a more prompt and attractive medium to authors than had theretofore prevailed. In 1900, he read a paper entitled "A Contribution to the Bibliography of the Declaration of Independence." This, too, is of permanent value, and should be consulted by cautious students. At the same time he aided in the formulation of rules to regulate the manner of noticing the deaths of members.

We now approach his *magnum opus*. Such had been his diligence that towards the close of the year 1900, he was able to report that "the arrangement of the loose Franklin papers has been completed. Two folio volumes have been bound, which makes in all 17 volumes bound and added to our Franklin collection. Work has been begun in repairing and mounting the 59 volumes of Franklin papers

[14] Both of the above papers by Dr. Hays are printed in the *Proceedings of the American Philosophical Society,* July, 1898, Vol. XXXVII, No. 157.

which are deteriorating in their present condition. This important work is being done in such a way that it is believed that it will last as long as it is possible to preserve Mss."

In the following six years he superintended the mounting of all our Franklin documents in 137 volumes, strongly bound in red turkey Morocco, constituting about 80 per cent. of all known originals. The Letters *to* Franklin occupy volumes 1 to 87; the Letters *by* Franklin occupy volumes 87 to 137. All are bound up in large folio size. Besides these there are 8 volumes of Letters to and from William Temple Franklin.

All these were utilized by Professor Albert H. Smyth in writing his Life of Franklin, and in editing his authoritative edition of Franklin *Writings* in ten volumes, octavo. In his Preface, Professor Smyth asserts:

> "The American Philosophical Society is the depository of the most valuable portion of Franklin's Manuscripts. It is an immense collection. The stoutest heart might well be appalled by the volume and range of these 13,000 documents, comprising a correspondence carried on in nine languages with all the world, and dealing with every theory of philosophy and every scheme of politics familiar and unfamiliar in the eighteenth century. I am deeply indebted to the custodians of the public collections of Franklin's papers. Chief of all stands Dr. I. Minis Hays, the Librarian of the American Philosophical Society, from whom came the first suggestion of this undertaking, and who has never failed to further its progress by encouragement and fruitful suggestion. It is due to his pride in the Philosophical Society's possession of the Franklin papers and to his urgent enthusiasm and unsleeping care, they have been admirably classified and calendared and made easily available to scholars."

In 1904, Dr. Hays published "The Chronology of Benjamin Franklin," and a second edition appeared in 1913. A competent judge has pronounced this work to be "the best epitome" of Franklin's career that he has ever seen, and added "Our knowledge of Franklin as a personality owes much to the historical researches of Dr. Hays." In 1908, there appeared in five noble volumes the "Calendar of the Papers of Benjamin Franklin in the Library of the American Philosophical Society," as arranged by Dr. Hays. The magnitude of these tasks and the perfection of their execution can be appreciated only by those who take the pains of personal examination.

In April 1903, Dr. Hays, who always planned in advance with a

sufficiently ample margin of time to assure success, called the attention of the General Annual Meeting to the approaching 200th anniversary of the birth of Franklin, which would occur in January, 1906, and moved that proper steps be taken to commemorate the occasion in a befitting manner. A committee of twenty-six members, including many distinguished names, was appointed. An admirable programme was arranged, the celebration lasting three days, in which the University of Pennsylvania, the Franklin Institute, the Pennsylvania Hospital, the Philadelphia Library, the Academy of Natural Sciences, and learned bodies throughout the world participated by representation. President Eliot of Harvard, the Honorable Joseph H. Choate, Dr. Horace Howard Furness, Hon. Elihu Root, and other well-known speakers delivered notable addresses. The memorial volume appeared in 1906, and preserves in dignified form the utterances of Franklin eulogists.

Dr. Furness discoursed on "Franklin as a Citizen and a Philanthropist";

President Eliot on "Franklin as a Printer and Philosopher";

Mr. Choate on "Franklin as a Statesman and Diplomatist";

Mr. Carson on "Franklin and His Relations to the University of Pennsylvania";

Professor Nichols on "Franklin's Researches in Electricity";

Professor Rutherford on "Modern Theories of Electricity and their Relation to the Franklinian Theory."

Andrew Carnegie, Lord Rector of St. Andrews, presented an Address, which was followed by Addresses from Sister Societies and Institutions of Learning, both at home and abroad.

Mr. Root, as Secretary of State, presented to France the gold medal authorized by Congress, which was received by the French Ambassador to the United State, Mons. J. J. Jusserand.

Such was the general interest in the Franklin Bi-Centennial that the Legislature of Pennsylvania appropriated $25,000 to the American Philosophical Society for the purpose of defraying expenses, and Congress directed the striking of a gold memorial medal. France erected a bronze statue of Franklin in Paris in the Rue Franklin, and the banker John H. Harjes forwarded to Dr. Hays two cases

containing replicas of the bronze plaques inserted in the pedestal of the statue.

So energetic a part had Dr. Hays taken in promoting the success of these various exercises that a resolution of thanks by the Society was adopted by a standing vote on April 20, 1906, and a loving cup and scroll were presented to him by his friends at a luncheon given in his honor at the University Club. The gift was a complete surprise, but it gave pleasure to the recipient to show it in after years to his intimates as one of his most valued possessions.

While the Minutes of this Society reveal that it was on the initiative of Dr. Hays that the many steps were taken to preserve the relics and works of Franklin and to do honor to his memory, yet he did not obtrude himself upon the public notice. He was well aware that his gifts were those of an organizer and not those of the platform; his associates, and they were numerous and able, well knew that his was the driving force that kept the machinery in motion. The future students of the Franklin period, if they delve to sufficient depth, will acknowledge their indebtedness to his patient and thorough labors for exact knowledge of details which were unknown to or escaped the attention of Parton, Bigelow and other popular biographers of Franklin.

So completely possessed did Dr. Hays become of a Franklin adoration that he conceived the idea of the erection of a permanent memorial to be known as *Franklin House,* to be the home of this Society, in which there should be a room devoted to the public display of the relics possessed by it of its illustrious founder. To this end Mr. John Frederick Lewis prepared and had printed a handsomely illustrated "Plea for the American Philosophical Society and its Need of a New Building to be known as Franklin House." Successive efforts were made to induce the Legislature, under several Governors, to appropriate a sum sufficient for the purpose. In 1908, the Senate of Pennsylvania unanimously passed a bill appropriating $350,000, but it failed to be reported back to the House for action before the adjournment of the session. Subsequent efforts, although strongly and eloquently urged before Legislative committees, failed of adoption.

In 1911, January 6th, Dr. Hays moved that a Committee of five

members, with the President and Treasurer *ex officio*, be appointed "to consider and report upon a site for a New Hall of the Society." Strong opposition was encountered from those reluctant to leave the ancient hall with its precious associations. The debates were frequent and animated, but finally the view prevailed that to stay in the present inadequate and dangerous quarters, too small to house our library, too combustible to be safe, too much of a menace to Independence Hall, too incapable of enlargement, too fatal to the hopes of growth, was to stifle the soul of Franklin's projects, and to abandon all reasonable expectations of continued usefulness. An advantageous contract was made under Mayor Reyburn's administration with the City of Philadelphia for the exchange of our present building for a splendid site on the Parkway at Sixteenth and Race Streets. The arrangements have been nearly perfected, and the dream of Dr. Hays of a *Franklin House* is shortly to be realized. The conservatism of Dr. Hays, at times irritatingly stubborn, yielded in this particular with wise alacrity to a statesmanlike vision of the future, demanding "ample room and verge enough" to carry on the Proposal of Franklin for Promoting Useful Knowledge. Sites must sometimes be abandoned and old buildings razed, save only the hallowed shrines of American Freedom, if "liberal and ingenious men" are to stimulate youth "to a laudable diligence and emulation in the pursuit of wisdom."

In close relationship to the labors which have been reviewed, aptly qualified by his previous experience as an editor of the writings of medical specialists, Dr. Hays edited with scrupulous care all the volumes of *Proceedings* from 1898 to 1922 in 24 volumes, octavo, and *Transactions* of the Society from the year 1898 to 1924, inclusive in 3 volumes, large quarto. These publications embrace within that period 27 volumes of an average content of 500 pages each. 13,500 pages, and constitute the articulate organs of expression of the aggregate thought of the Society in reaching the scientific minds of the civilized world. They fully sustain the reputation of the Society as a learned body, taking rank with the foremost of those most distinguished as active disseminators of knowledge, whether at home or abroad. So varied, minute, and extensive are they in character, that no history of this Society can be prepared, in fact no history of

American scientific thought would be complete, without a careful analysis of their contents. It cannot be pretended, nor even intimated that Dr. Hays' knowledge, great though it was, compassed this "infinite variety," but the superintendance of the publication of the papers to the satisfaction of each contributor, accompanied, as many papers were, by diagrams, drawings, maps, statistical tables, and illustrations, required patience, tact, diligence and care, not only in an extensive correspondence, but also in the reading and correction of proofs and in practical knowledge of typography. Of this indispensable art Dr. Hays was a consummate master, and generously assisted those uninstructed in such details. The Letter-books of the Secretary and Librarian for this period, 1898 to 1922, run into thousands of pages, contained in 96 books of an average of 500 letters each, 48,000 in all, and by their dates indicate how promptly maintained was the correspondence of the Society.

The most signal service rendered by Dr. Hays in keeping the Society abreast of the times and conspicuous in the eyes of the learned, was the institution of the *Annual General Meeting.* The Minutes, under date of May 7th, 1901, disclose as follows:

Dr. Hays moved the following preambles and resolutions;

WHEREAS the American Philosophical Society is and always has been a Society of national scope, whose place of meeting was originally fixed at Philadelphia for reasons of convenience now less potent than formerly, and

WHEREAS the growth and wide extent of our country and the multiplication of local societies tend to keep from our regular meetings those members who do not reside within a short distance of Philadelphia, and

WHEREAS it is desirable that measures be taken to bring the distant members into more active participation in the work of the Society, therefore be it

Resolved, that a committee of five be appointed by the President to consider the advisability, and if deemed advisable, to arrange for a General Meeting at a time most convenient to all the members.

That this meeting shall cover one or more days as may be considered advisable, and it is hoped that the high scientific character and broad interest of the papers to be presented shall ensure the fair attendance of a good proportion of distant members.—Adopted.

1912, November 1. Dr. Hays offered the following:

Resolved that until otherwise ordered the President be authorized and directed to appoint annually a Committee of five members together with the Secretaries, with power to add to their number, to arrange for a General Meeting to be held in each year in the latter half of the week in which the third Tuesday in April falls.—Adopted.

The date thus fixed was so arranged as to fit in felicitously with the annual meeting of the National Academy of Sciences, meeting in Washington, appropriating to ourselves the latter part of the week, to be followed the next week by the Academy. Thus we secured an attendance from all parts of the United States, and sometimes of visitors from abroad. The significance of this General Meeting is best described in the words of President Scott, upon the retirement of Dr. Hays from the Secretariat:

"It is difficult to understand what the Society can do without Dr. Hays for he has been its mainspring and driving force for years past. The Society was in a moribund, or at least comatose, condition when he began his work; and Dr. Leidy about that time described it to me as an example of 'how a Society that pretended to demand some measure of distinction from those whom it elected to membership, was doomed to sterility and inactivity by that very fact.' Now this has all been changed, and the Annual General Meeting of this Society which was inaugurated on Dr. Hays' suggestion is universally regarded as of great importance. The late Professor Pickering, when a Vice-President of this Society, once remarked from this Chair that this annual meeting had become, in his opinion, the most important and most interesting scientific event of the year. All this we owe to Dr. Hays, and it is fitting that the Society should recognize his valuable services."

Sometimes, the General Meeting was associated with an anniversary of world wide recognition. Thus, in April (22, 23, 24) 1909, a part of the meeting was reserved for a celebration of the Centennial of the birth of Charles Robert Darwin, a member of this Society, and the semi-centennial of the promulgation of his theory of the "Origin of Species." At the same time the greetings of the Society were extended by cable to Sir George Dalton Harker and Dr. Alfred Russell Wallace, the friends and collaborators of Darwin, then still alive, and both of them members of this Society.

Sometimes the regular monthly meetings were marked by special programmes. Thus, Nansen was received, and delivered an address to a crowded hall. I can recall the sturdy features of the Norseman with shaggy head and beard and modestly undecorated bosom in contrast with Admiral Melville, who fairly blazed with ribbons and medals and buttons. Beside them, sat Wayne MacVeagh, with a scarlet necktie, and Samuel Dickson and George F. Edmunds, with white hair and flowing white beards, whose dignity of mien suggested

what the Gauls must have felt when first they saw the Roman Senate upon the invasion of the Imperial City. So too, I recall the notable meeting called to listen to a paper by John Bassett Moore, upon the meaning and scope of the phrase *Contraband of War,* followed by a discussion by Judge George Gray and Frederick R. Coudert, the first, the most renowned of American authorities in International Law, and the remaining two most competent to follow. So too, I recall an enlivening evening devoted to a discussion of *Water,* participated in by physicians, surgeons, alienists, and even members of the Bar, from which the uninstructed laymen learned that 90 per cent. of the human brain consisted of water, and that too in pre-Volstead days.

Some of the minor activities of Dr. Hays were as follows: As Librarian he discovered some duplicates of books, pamphlets, imperfect imprints, or unavailable copies of manuscripts, and these with the approval of the Library Committee he sold, the proceeds establishing the funds known as the Benjamin Franklin Fund, the Thomas Jefferson Library Fund, the Joseph Parker Norris Fund and the Robert Proud Library Fund. I have been informed that but for the vigilance of Dr. Hays these funds would have never been established.

In attendance upon the meetings of the many Committees of which he was a member, Dr. Hays was punctuality itself, and it is remarkable to note that in the many years he was Secretary, there were less than half a dozen meetings of the Socity at which he was not present.

In December, 1913, Dr. Hays called attention to the error in assigning the marble bust by Houdon, possessed by the Society, to Lavoisier instead of Condorcet.

I now exhibit a beautiful specimen of Dr. Hays' skill in diplomatic correspondence. Upon the accession of Woodrow Wilson to the Presidency of the United States, Dr. Hays moved the presentation of the following address which was adopted:

To His Excellency
Woodrow Wilson
President of the United States.

Sir:

The American Philosophical Society extends its cordial congratulations to you as one of its fellow members upon your accession to the Presidency of the

United States. You carry into public life the ideals of the scholar and you will show in the New World, as has been proved so often in the Old, that philosophical training, in the best and broadest sense of the term, is a help to the practical statesman. Your studies in history and political science will illuminate your task of giving to the Nation a wise and strong government.

It was Montesquieu, the good genius of the makers of our national Constitution, who said that for a safe voyage of the Ship of State, the spirit of the Laws should serve as compass, and history should be the chart. This Society confidently believes that you have at your command this compass and this chart; that with your firm hand at the helm the Ship of State will safely ride the seas; and that, like those of your distinguished predecessors in the Presidency, who were its members, you will help to make the future history of the Nation worthy of its past.

Seven times since the founding of the Republic the American Philosophical Society has had cause for congratulation in the selection of one of its members as President of the United States. Washington, Adams, Jefferson, Madison, the second Adams, Buchanan and Grant were honored names upon its roll before the popular vote inscribed them in the list of American Presidents. To you, the eighth in turn of its members to enter upon this high office, this Society extends warmest greeting.

Given under the seal and in the name of the American Philosophical Society held at Philadelphia for Promoting Useful Knowledge, this seventh day of March, 1913.

WILLIAM W. KEEN,
President.

(SEAL)
Attest:
I. MINIS HAYS,
Secretary.

This letter, handsomely engrossed, was presented, pursuant to special appointment at the White House, to President Wilson by a special committee, consisting of Dr. Keen, as President of The American Philosophical Society, I. Minis Hays, as Secretary, and Dr. David Jayne Hill, Honorable Elihu Root, Dr. Charles D. Walcott, and Dr. Otto H. Tittman, as members of the Society.

To this letter the President of the United States replied:

March 19, 1913.

THE WHITE HOUSE,
WASHINGTON.

My dear Doctor Keen:

May I not express to you, and through you to the members of the American Philosophical Society, my deep and sincere appreciation of the cordial message

brought me from the Society by you and your associates this afternoon? Nothing has gratified me more. I do not know of any association whose confidence I would rather enjoy. It has been a matter of peculiar pride to me to be associated with the American Philosophical Society, and that that distinguished body should feel honored by my elevation to the Presidency is a source of genuine satisfaction to me. I can only say in reply to their gracious address that I shall hope and strive at all times to deserve their respect and confidence.

Cordially and sincerely yours,

WOODROW WILSON.

DR. WILLIAM W. KEEN,
Philadelphia, Pa.

Dr. Hays was quick in extending sympathy and assistance to sister societies in distress. When the earthquake of 1906 wrought such havoc on the Pacific coast, he offered at the General Meeting the following resolution:

That the Society has heard with profound grief of the appalling disaster that has befallen San Francisco and its neighboring towns, and desires to express its deep sympathy for their citizens and particularly for its sister Society, the California Academy of Sciences, and as a slight evidence of its sympathy the Secretaries be instructed to send to the California Academy of Sciences a complete set of its "Transactions" and "Proceedings" as far as the same may be available, as soon as the California Academy of Sciences is prepared to reform the library.

In 1917, when the Wistar Association, better known as The Wistar Party, celebrated the Centennial anniversary of its organization, Dr. Hays read a paper entitled "Caspar Wistar as a Citizen and Philosopher." It was remembered that he was at that time the Dean of the Association and that he had entered upon the twenty-first year of his Secretaryship of this Society. Thereupon, a portrait in oil of Dr. Hays was presented by the Association to this Society, and it now hangs upon our middle wall in fit companionship with those of our zealous officers who have passed from life.

The last paper written by Dr. Hays was read by him at the General Meeting in April, 1924, "On the Authorship of the Anonymous Pamphlet published in London in 1760, entitled 'The Interest of Great Britain considered with regard to her Colonies and the Acquisition of Canada and Guadaloupe'." He proved incontestably from a comparison of documents, from singularities of expression,

from similarities of arguments appearing at different times, and from a knowledge of handwriting that Franklin was the author. Thus he ended as he had begun by a votive offering to his idol.

Let us now turn to Dr. Hays' personal characteristics.

He was by temperament strongly conservative; by some he was regarded as ultra-conservative. He was fond of ancient things and of ancient ways. He was devoted to a ritual. With an intimate knowledge of the history and traditions of the Society, and deeply imbued with a reverence for its Founder he loved to maintain the formalities and procedure suitable to the dignity of an old-fashioned body. With him the admission of a new member was often of more consequence than to the member himself. He never failed to place before the Chair a copy of the By-laws opened to page 17, and to point quietly to By-law 14, which read as follows:

> The admission of a member into the Society shall be in manner and form following, he having first made the payment required by the laws. Immediately before the reading of the Minutes he shall subscribe the laws in the Roll-book and be introduced to the President, who, taking him by the hand, shall say: *By the authority and in the name of The American Philosophical Society held at Philadelphia for Promoting Useful Knowledge, I do admit you a member thereof.*

As he had control of the Minute Book, he could readily exact strict compliance with the rule.

Whenever a vote was to be taken by ballot, he always orally summoned to the box, in due order, by the proper official designation, the President, the Vice-President, the Secretaries, the Treasurer, the Councillors, and then the members. He knew by heart the 18 Rules prescribing the Order of Business, and never did he allow them to be overlooked by an inexperienced Chairman. The business was never allowed to be hurried, nor the order inadvertently reversed without a whispered correction of the Chair.

So highly did he regard the distinctive honor of membership, that one of the earliest reforms which he induced the Council and afterwards the Society to accept, against much opposition, was the restriction to fifteen in the number of resident members to be elected each year, the selection to be made by the Council from a long list of nominees presented in strict accordance with the rules as to quali-

fications. This restriction, however well it has worked in sustaining the value of our blue ribbon, together with the rise of other Societies and the formation of other foci of scientific activity both in Philadelphia and elsewhere, has cramped our attendance, especially at monthly meetings, within narrow bounds. It may be difficult to maintain so severely restricted a membership when in our new Hall, especially if we should receive considerable pecuniary assistance from alien sources. As our population of eligibles increases, as the discussion of problems dealing with the mystery of the universe and of man's existence becomes enlarged, and our membership includes men prominent in medicine, law, literature, art, industry and worldly affairs as well as in science in all its aspects and subdivisions, it will be impossible not to advance in accordance with the broad lines of Franklin's sympathies with human affairs.

Dr. Hays had comparatively little to do with the selection of the persons who addressed the monthly meetings, who for years have been selected by a committee, nor did he select those who read papers at the Annual Meeting, that task being entrusted to a very large committee being divided into sub-committees on each subject, each subcommittee being held to the responsibility of seeing that each department of science or scholarship which it represented should be duly and adequately represented on the programme, but "he was always fertile in suggestions in the meetings of the General Committee, especially as to the topics for the annual Symposium which would be most likely to appeal to the lay public." [15]

In preparing this address, I have freely used material supplied to me by his colleagues, for which I cheerfully make acknowledgment. Let me give you a composite result. One of my correspondents writes:

When Dr. Hays became one of the Secretaries of the American Philosophical Society, he found that body in almost a moribund condition, or at all events in a condition of coma. I very well remember that Dr. Leidy used to use the contrast between the Academy of Natural Sciences and the Philosophical Society, the former an active and vigorous institution, the latter merely a blue ribbon, as an argument against requiring any distinction in the membership. Dr. Hays' whole heart was bound up in the Society; and its welfare and reputation were, I think, the principal objects for which he lived;

[15] Information furnished to the writer by President W. B. Scott.

and the resuscitation of the Society, and its advance to its present high place in the esteem of the scientific public, are almost entirely due to Dr. Hays. Of course, many people helped him in this work; but he was the inspirer of all his assistants, and the plans which have worked out so successfully have, in almost all instances, originated with him.[16]

Another one writes:

Dr. Hays' life was an Ellipse with Benjamin Franklin and the American Philosophical Society in the 2 foci. . . . He knew the A. P. S. *au fond* better than any of the rest of us I am sure. . . . There perished with him, I fear, many data as to the early history of the A. P. S.[17]

Another one writes:

I am not able to give you any data *in re* Dr. Hays' method of procedure in arranging for the spring meetings of the American Philosophical Society. I do know that he was the active spirit and that he called in to his aid the members of the Council of the Society.[18]

Another one writes:

Dr. Hays' position in the American Philosophical Society was somewhat unique. His devotion to the Society was close and personal. . . . I need hardly add that the success of the meetings, both monthly and annual, are due largely to his untiring efforts and to the interest which he succeeded in arousing among the members. It is no exaggeration to say that for more than a quarter of a century, he was the active driving force of the Society. He more than any one else was instrumental in transforming a scientific body which had lapsed into a condition of almost complete "innocuous desuetude" into a living, active organism and one which reassumed its importance among the scientific bodies of the world. . . . For many years he was at the Society daily for hours at a time. The correspondence and other matters pertaining to the Society received his close personal care and attention; indeed, the Society engrossed in large measure his life.[19]

Another one writes:

Dr. Hays was completely wrapped up in the welfare of the Philosophical Society for many years. He took hold of it when it was at a very low ebb in its activities and brought it up to an institution useful in its work and respected in its character by people of learning. He seemed to be the right man in the right place, and in all his life's work I do not think he accomplished results comparable with the effective work he did as Secretary of the Philosophical Society. Doctor Hays had a peculiarly subtle imagination and was

[16] President W. B. Scott.
[17] President W. W. Keen.
[18] President Edgar Fahs Smith.
[19] Vice President F. X. Dercum.

very diplomatic in his methods. He had his own firm convictions regarding the welfare of the Philosophical Society, but he never tried to force them on a committee or other governing body when he realized that the sentiment of the majority was not with him. He accomplished his work by compromise rather than by forcing his wishes on unwilling bodies. It was by this means that he was able to do so much constructive work for the Society.[20]

Another one writes:

I am really not familiar with his correspondence on the arrangements for papers to be delivered before the Annual Meeting, except that I know he was most careful in trying to distribute the subjects so that the field of science might be covered as fully as possible. He always carefully investigated the standing of non-members suggested for papers, and edited with great care various confidential publications issued by the Society. In all cases of difference of opinion in the Council he seemed to be able to carry his point against all opposition. As a matter of fact, his opinion generally proved to be the right and proper one for the good of the Society, and his tenacity was justified.[21]

Another one writes:

While Dr. Hays lived he had no other duties of importance except to look after the interests of the Philosophical Society, both as to its library, its programs, its celebrations and the like. In his capacity as Senior Secretary he combined all these duties and his secretarial associates usually fell in line with his initial proceedings with little question as to their propriety. . . . His knowledge of the Society and its work in all detail made it rather impertinent for any of us to question his views as to fact, and most of us had too little experience to have very positive views as to policy.[22]

The man thus depicted was unquestionably a man of much force. Occasionally, it is true, he was regarded as arbitrary. When differing with him, as at times I did, I never found him disagreeably so. He was tenacious of his views and resolute in their expression, but his invariable courtesy and affability softened asperities. In general conversation he was charming; in special talks his speech was full of instruction. For a man who had travelled but little, if at all in the real sense, his knowledge of the world and of men was surprisingly large. Books, maps, biographies, reviews, original docu-

[20] R. A. F. Penrose, Jr., President of The Academy of Natural Sciences.

[21] Dr. W. P. Wilson, Curator of The American Philosophical Society, Director of the Commercial Museum.

[22] Professor Arthur W. Goodspeed, Senior Secretary, American Philosophical Society.

ments, and standard encyclopedias furnished ample material. His mind was a capacious store house, well stocked and well arranged. His memory was both retentive and reproductive. His talents were not forensic, and he rarely participated in debates upon the floor. Whatever he had to say, however, was clearly and concisely expressed, and his use of words was exact, and without hesitation.

His administrative rôle was that of a perpetual Secretary or Cabinet officer. Possessed of ample private means, and well disciplined by prior long experiences which singularly equipped him for his task; with a definite end in view and sustained by high ideals, he was able, as few others would have been, to devote his entire attention and strength to the business of the Society, making it the sole object of his charge.

In all useful and influential Associations, whether national or local, the linch-pin of organizations is the Secretary. Presidents may come or go; their terms may be long or short, their policies may vary, encouraging stagnation or threatening stability; directors or councillors may be attentive or negligent, but an efficient Secretary, devoting himself exclusively to his task, and wisely retained from year to year, is indispensable to success. His knowledge of details and their ramifications, his familiarity with traditions and customs, his grasp upon prior administrative life; his daily attendance, his absorption in his work, his singleness of aim, his tenacity of purpose, his ardor of interest, his pride in performance, all these contribute to his usefulness and cannot fail to strengthen his hands. If his merits be great, and his ambitions unselfish, he cannot fail to become in the course of time the strong arm of an institution on which others lean.

Such a Secretary was Doctor Hays.

At the meeting of April 22, 1922, Dr. Hays declined reëlection as Secretary. For twenty-five years his name had appeared upon the ballot and the members had learned to associate it with the annually recurring election as a matter of course. President Scott, from the Chair, declared:

The members of the Society will have noted with feelings akin to dismay that for the first time in many years the name of Dr. I. Minis Hays is absent from the list of Secretaries, Dr. Hays having retired in spite of many urgent requests that he should continue in office.

President Scott then used the words which I have already quoted in relation to the establishment of the annual meeting. At the close of his remarks, Secretary Goodspeed then presented the following Resolutions, which were unanimously adopted:

WHEREAS we have known for some time of the intended retirement at this time of our senior Secretary and Librarian, Dr. I. Minis Hays, and

WHEREAS we are all deeply impressed with the inestimable value of his long and faithful service to our honorable Society, we, the members, hereby wish to record our deep appreciation of all Dr. Hays has done to forward the interests of this Society, and our sincere regret that he is to be no longer with us in his former official capacity, together with our earnest desire that he may yet for many years remain our willing adviser in the conduct of the affairs of the Society.

A final proof of his loyalty must be mentioned. His last will and testament, subject to the estates of his children, and their issue if any, bequeathed his considerable residuary estate to this Society, containing elaborate provisions as to the establishment of a New Hall.

From this general review of the career of Doctor Hays, the reason is now apparent why he could not be induced to write a history of the Society. His was not a nature to delight in narrative, and then boastfully exclaim *Quorum pars magna fui.*

From our comprehensive glance at the history of the Society, its ancient and illustrious origin, its elevation of purpose, its isolation of position, it occurs to us that in the world of thought it resembles an Alpine lake, broad, clear, deep, with unruffled and reflecting surface, amid lofty peaks, close to the stars.

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THE PRESENT STATUS OF LONG-RANGE WEATHER FORECASTING.

By Professor Robert DeC. Ward,
Harvard University.

(Written for the April meeting, 1926, of the American Philosophical Society.)

In view of the present widespread interest, popular as well as scientific, in long-range weather forecasting, it may be useful to review briefly some of the outstanding facts in this matter as they now appear. The purpose of this paper is rather to take an account of stock than to offer any new and original contribution to the discussion. Some general conclusions reached by the writer are, however, included. There are times when, with important developments apparently close at hand, it is well to know just where we now stand.

Man's natural craving for advance knowledge of coming weather extends thousands of years back of any attempts at scientific weather forecasting. Realizing that he has not the necessary foresight himself, he has imagined animals to be endowed with some peculiar sense which enables them to know, weeks or months ahead, what the weather will be. Thus a large group of animal weather proverbs has come into existence. Millions of people believe that the thickness of fur on a muskrat, or the number of nuts stored by a squirrel, or a supposedly early migration of certain birds, indicates a severe winter. Yet it is certain that animals have no such foresight. Their

habits, the thickness of their fur, and other characteristics depend upon their health, the food supply, and many other conditions which have preceded, and not upon any instinct which enables them to sense the character of a season in advance.

Another aspect of supposedly long-range forecasting is seen in certain almanacs which are popularly thought to give reasonably reliable indications of the weather a year in advance. Such almanacs, however, merely contain statements of the average weather conditions of each month. If, for example, the words "Severe cold, snow, and high winds" appear opposite a week or ten days of January in an almanac, the statement is sure to be true for certain sections of the country. A random assignment of a "severe storm" to some particular day in winter will often "hit." To those who do not consider the matter, this looks like a clever long-range forecast. By remembering only the occasional "hits" and disregarding the "misses," as most people naturally do, such almanac statements appear to be correct most of the time. But they are in no sense forecasts. Nor are they usually correct. Any one reasonably familiar with the average weather of his locality can make up such an almanac years in advance. Not long ago a widely known American "weather prophet" died. It is reported that when his health was failing a certain patent-medicine company, which had in the past used his prophecies for advertising purposes, offered him a considerable sum of money if he would make forecasts fifty years in advance!

Then, again, there are persons who, using certain scientific facts as a basis but drawing unwarranted or at least unsafe conclusions from them, make seasonal weather predictions several months ahead. These "forecasts" are expressed in very general terms, as that "the winter will be long and severe," or "the summer will be abnormally cold." Over an extended area, like that of the United States, for example, the winter is sure to be long and severe somewhere, and it is equally sure not to have those characteristics everywhere. Such a "forecast" is practically sure to be verified in some localities. Even where and when it happens to "hit," it is too vague and general to be of real value. Furthermore, these forecasts are so broadly generalized, and cover such large areas, that no rigid and adequate verification is possible. The author of the predictions makes his own

verifications in his own way—obviously a very unsafe proceeding. His self-determined percentages of verification are not likely to run too low.

Occasionally, for a limited and variable period, very general forecasts based on sequences in the character of the seasons may be possible. Thus there may be a series of several successive winters slightly warmer than normal, or a series of summers somewhat wetter than normal. Yet just when a definite sequence seems to have started, the chain is somehow likely to break; the sequence ends; forecasts based upon it go into the discard. In time, with further study, something more definite may develop along this line. Thus far, however, the general results have been negative. There is a popular impression that a very cold winter is likely to be followed by an unusually hot summer, or a warm winter by a cool summer. The conclusions of meteorologists are contrary to the popular belief. It seems that, on the whole, a season well above normal in temperature is somewhat more likely to be followed closely by a season or seasons warmer, not colder, than normal. In Berlin, Hellmann found that a very cold winter usually follows a very cool summer, and a moderately mild winter follows a moderately warm summer. The probability of a definite sequence in such cases is, however, too small to be of any practical value in forecasting.

It seems to be the general consensus of the most expert meteorological judgment at present that there is not, as yet, sufficient unimpeachable evidence to justify a belief in *permanent* "changes" of climate, over large areas, within historic times. That there are certain fluctuations in the values of the climatic elements is, however, a well-established fact. Not only do individual years differ in their temperature, rainfall, etc., but there are also variations extending over a decade or so, and even over many decades, or centuries.

In the temperate zones "abnormal" weather is normal. Months, and seasons, are quite commonly warmer or colder, wetter or drier, than the normal or average. When these abnormalities or departures are slight, they attract no attention. On the other hand, the excess or deficiency of temperature, or of rain or snow, may be so considerable as to be distinctly noticeable, even without instrumental record. Thus, the winter of 1920–21 was one of rather persistent

and unusual mildness east of the Rocky Mountains. The higher temperatures were the equivalent of travel over considerable distances southward. On the other hand, 1919–20 was a colder winter than usual. Occasional extreme cases of such abnormalities are remembered for years, and become part of our weather history. Thus the summer of 1816 brought late snows, and frost occurred in every summer month over much of New England. The year 1816 became known as "eighteen hundred and froze-to-death," and "the year without a summer." A prediction that the year 1926 will be "summerless," and that crops will fail in many places, has recently been given wide publicity. There is no sound and safe basis for any such general forecast, so long in advance. The coming summer may be abnormally cool. It may be abnormally warm. Over an extended area, such as the United States for example, any summer is more likely than not to be "abnormally" cool in some sections, but is also likely to be "abnormally" warm in others. That is the natural way with our seasons. Whatever happens in the way of next summer's weather will be the complex resultant of many variables, whose final product no man can at present foresee.

A longer period of weather fluctuation than that from year to year appears to be associated with the sunspot cycles. Numerous studies have been and are being made along this line. Some of them extend back into the seventeenth century. Evidence of sunspot periods in temperature, in rainfall, and in the frequency of tropical cyclones, has been discovered by different investigators. There is already a very considerable literature on this subject. The results of these studies, it may probably be safely said, have not come up to expectations. In some cases the relation to sunspot periodicity seems to be open to debate. In other cases, the results are more or less contradictory. At any rate, it is not yet clear that the variations in the weather elements in the sunspot period are sufficiently marked, uniform or persistent, over large areas, to make practical application of the periodicity possible in regular weather forecasting.

A longer period than that of the sunspot cycle, and one which is generally recognized as having been clearly established, is known as the Brückner 35-year cycle, after Professor Eduard Brückner who first discovered it. In a cycle whose average length is about 35

years, but which may vary between 20 and 50 years, there comes a series of years that is somewhat cooler and more rainy, and a series of years that is somewhat warmer and drier, than "normal." These fluctuations have been shown by Brückner to bear close relations to crop yield and prices, to movements of population, and to economic conditions in general.

Variations covering still longer periods have been discussed by numerous other authorities. Thus C. F. Marvin, the Chief of the Weather Bureau, as a result of a study of New England rainfalls over a period of nearly 200 years, concludes that while there is no evidence of any permanent change in climate, more or less definite periods of from 50 to 100 years or more seem to occur from time to time during which "the climatic conditions of a more or less limited region suffer a material change in the value of the running average of conditions."[1]

Further, Mr. H. H. Clayton has recently announced that he finds a general underlying upward trend in the temperature of the northern United States and Canada, "like a slowly rising tide," while the trend in the southern United States is downward. The contrast between the weather of the north and south, according to Clayton, seems to be diminishing; the climate as a whole to be ameliorating. These results are based on temperature records extending back, in a few cases, to the closing years of the eighteenth century.

These few examples of fluctuations, or of periodicities, in the weather elements are selected more or less at random. The list is very far from complete. Enough has been said, however, to indicate the very great interest and importance of this whole subject of such variations in the weather elements in their relation to the general question of long-range forecasting. At present, and until such periodicities or variations are more fully understood, long-range fore-

[1] Charles F. Marvin, "Concerning Normals, Secular Trends, and Climatic Changes," *Monthly Weather Review*, Vol. 51, 1923, pp. 383–390. The method used and the results obtained by Marvin have been criticized by McAdie, who believes "that neither seasonal droughts nor seasonal floods can be studied if mean annual rainfalls are used as criteria," and that "these trends can not be used to advantage" (Alexander McAdie: "Wet and Dry Seasons," *Annals Astron. Obsy. Harv. Coll.*, Vol. 86, Part 4, 1924, pp. 227–232).

casts sufficiently definite and reliable to be of practical value cannot be based upon them.

During one week last autumn there came to the writer's desk three letters. One was from a lumber dealer; another, from a manufacturer of overshoes; the third, from the owner of a woolen mill. Each letter contained the same question: "Will the coming winter be mild or severe?" Would logging operations be difficult and expensive? Would there be unusually large sales of rubbers and of arctics? Would people buy heavy woolen clothing? If the question could have been definitely and positively answered, these three correspondents would doubtless have profited very handsomely thereby. Indeed, it is impossible to overestimate the money value that definite and detailed long-range weather forecasts would have for all classes of people, in all sorts of occupations. At a conference on oceanography and marine meteorology held at the Scripps Institution of Oceanography on November 6 and 7, 1925, four speakers emphasized the benefits to be expected from long-range forecasts of seasonal rainfall in Southern California. One speaker represented an electric light and power company; another was an irrigation engineer; the third was a forest supervisor, and the fourth was a farm adviser.

In spite of this great popular demand, everywhere, for forecasts covering a considerable period in advance, it is significant that the government weather services of the world, with a few exceptions, issue their regular detailed forecasts for only a day or so in advance. Occasionally it is possible to extend the forecast, in more general terms, to as much as three or four days ahead. Once a week the United States Weather Bureau issues a statement for a week in advance. This is not a forecast. It is called the "weather outlook," and is based on the general distribution of pressure, especially over the Pacific Ocean and the northwest, and upon the general movements of areas of high and low pressure. One such "outlook" recently given to the press for the North and Middle Atlantic States read as follows: "Period of snows over North and rains and snows over South portion about middle of week; temperatures near or below normal." The difference between the specific daily forecast and such a broad generalized statement is easily recognized. The British Meteorological Office also issues similar general forecasts for a week

in advance. Further, in India, the Weather Service issues a seasonal forecast, but the conditions there are peculiar; the forecast is very general, and it concerns the general character of the monsoon rainfall only. The forecasts of the Argentine Meteorological Office, covering several days in advance, will be referred to later.

Why do not months, seasons, years, decades, even centuries, "run true"? The answer is difficult because weather controls are many and complex. Our day-to-day weather is essentially controlled by passing conditions of lower and higher pressure. These, in their turn, determine the course of the winds and regulate temperatures and rain or snowfall. A slight change in the usual paths followed by these pressure conditions may decidedly alter the character of the season's, or the year's, weather. These paths are largely dependent upon the location and intensity of certain very much larger, more or less permanent areas of low and high pressure, located over the continents and oceans. These so-called "centers of action" vary seasonally and in longer periods, exerting marked influences, through the winds which circulate around them, and through the storm paths which they control, upon the weather and climate of nearby and even of distant lands. Within the last decade or so some remarkable correlations have been shown to exist between the great so-called "centers of action" of the atmosphere and the seasonal weather in adjacent, or even in fairly remote regions. The general character of the winter in western Canada and the northwestern United States seems to depend largely upon the varying characteristics of the low-pressure center of action over the northern part of the North Pacific Ocean, while the character of the winter and of the summer in the eastern United States is to a considerable extent controlled by a varying but essentially permanent bank of high pressure over the North Atlantic Ocean, in Latitudes 30°–35°.

What causes the variations in these "centers of action"? The temperatures of the ocean surface water have something to do with their character, location and extent, but the observational data in this matter are scarce, except over limited areas, and proofs so far submitted are not wholly convincing. The temperatures over the continents are directly concerned in determining the seasonal pressure conditions over the lands. Water is very conservative as regards its

temperature. It parts with its heat or cold reluctantly. The warmth or the chill of distant ocean waters can therefore be transported over great distances in the slow-moving ocean currents, and then, months later, be carried onto far-away lands by winds. In this way seasons warmer or colder and also wetter or drier than normal may result. In Europe, several years ago, Meinardus, Petterson, and others called attention to the close relation existing between the temperatures, pressures, and winds over the North Atlantic Ocean and the weather of western Europe some months later. In the United States Dr. G. F. McEwen, of the Scripps Institution, La Jolla, California, on the basis of ocean surface temperatures, acting through pressures and pressure gradients upon the winds, has recently been forecasting an excess or a deficiency of the winter rains of southern California.

Back of all such seasonal, and longer, variations in temperature, pressure, winds and weather there must obviously be some ultimate cause. Attention is naturally directed to the sun. The sun is now known to be a variable star. Its heat-output is not constant. There are long-period variations, as in the sunspot cycle, and doubtless also in longer cycles. There are also shorter, irregular periods of the order of weeks or days. These variations all seem to be relatively very slight when the sun's radiation as a whole is considered, although in the region where the variation is most marked, *i.e.*, in the blue end of the spectrum, the percentage of change is considerable. Moreover the effects are, generally speaking, the opposite of what would naturally be expected. Instead of being higher at times of greater solar activity, temperatures over many parts of the world are then slightly lower. The sequence of cause and effect is thus highly complex. Temperature is by no means the only element. Evaporation, cloudiness, rainfall, storminess, winds, are all involved. Yet there are many distinctly hopeful signs of progress. More heat from the sun should promote evaporation, and thus tend to increase cloudiness and rainfall. Further, more cloud would cut off sunshine and in that way lower temperatures. Because of the complexity of the weather it is impossible to reach definite and generally acceptable conclusions as to the detailed effects of variations in solar radiation on climates as a whole. Moreover, the effects, whatever they are,

would naturally differ in different localities, with varying land and water, topographic, and other controls.

Competent investigators are patiently trying to discover the laws that govern our complex atmospheric conditions in the endeavor to hasten the day when definite long-range forecasting, on a thoroughly scientific basis, may be realized. Among these investigations the work on the variations in the intensity of the sun's heat carried on during the past two decades by Dr. C. G. Abbot and his associates of the Astrophysical Observatory of the Smithsonian Institution has attracted much attention. These observations were begun at Mt. Wilson, California, in 1905, in Chile in 1918, and in Arizona in 1920. Recently the National Geographic Society has provided funds for the installation and support of a third station, to be located at a favorable place in the Eastern Hemisphere, and to coöperate with the stations already in operation in Chile and in Arizona. As stated in the last Report of the Astrophysical Observatory of the Smithsonian Institution (for the year ending June 30, 1925), "the chief object of the work at present is to secure the most exact measurements of the variation of the sun in order to provide proper data for studying the influence of the solar changes on weather conditions of the United States and the whole world."

The connection of Mr. H. H. Clayton with this work began about ten years ago, when he was Chief Forecaster of the Argentine Meteorological Office in Buenos Aires. His studies had satisfied him that there was a relation between the variations in solar radiation as reported by the Smithsonian Institution and weather changes. An arrangement was made with the Smithsonian Institution for sending daily telegraphic despatches from the Chilean station to Buenos Aires, and the data thus obtained were used by Clayton in preparing official forecasts issued by the Argentine Meteorological Office. These forecasts were begun in December, 1918, and have been continued ever since. Once a week an official bulletin is issued by the Argentine service which gives a forecast of the temperatures to be expected every morning and evening for a week in advance. In addition, the dates and the intensities of expected rainfalls are also given. Since Clayton's retirement from active service, in 1922, these forecasts have been continued by Hoxmark. While it seems to be agreed

that the Argentine weekly forecasts are far from perfect, they appear to have received widespread public approval.

After his return to the United States, in 1922, Mr. Clayton continued his researches, and in 1923 published a volume, entitled "World Weather," which embodied the results of his investigations extending over some thirty years. The results of his work have led him to the conclusion that certain recognizable changes in pressure, temperature and rainfall depend upon variations in the intensity of solar radiation, and that not only longer oscillations in climatic conditions but also day-to-day weather respond to the sun's activities. It is on the basis of these conclusions that he believes it possible to forecast weather days, weeks and even months in advance. There are, however, weighty opinions on the other side. For example Sir Gilbert Walker, for many years Director General of the Indian Observatories, has expressed the view that, for explaining the weather abnormalities of the seasons, the variations of solar radiation are inadequate, and that we must seek the reasons in the previous distribution of seasonal features over the earth. World-wide reactions of the weather are evidently closely connected with the slowly-moving ocean currents in which solar variations or wind-made temperature abnormalities persist for months. The fact that seasonal weather abnormalities in different parts of the world show stronger relations among themselves than with solar changes must not relegate to a minor position the study of solar variations in connection with terrestrial weather changes. The solar changes may from time to time strengthen and thereby maintain reactions between terrestrial centers which might otherwise become weaker. (*Indian Meteorological Memoirs*, Vol. 24, 1923, Part 4.)

During the past two years, aided by a grant from Mr. John A. Roebling, Mr. Clayton has been studying the weather of North America in relation to apparent variations in solar radiation, and in order further to test his work has made experimental temperature forecasts for New York City. Daily telegraphic despatches were sent him giving the solar values as observed at the Smithsonian field stations in Chile and in California on the day preceding. Using these data, together with visual observations of the sun's disc, he then made his forecasts of the expected daily maximum temperatures at

New York for three, four and five days in advance. The average weekly and average monthly temperature departures were also forecasted two days before the beginning of each week or month. All these forecasts were at once sent to the Smithsonian Institution, where they were compared with the actual conditions by mathematical methods "which eliminated personal bias." In regard to the results, it is stated in the last Annual Report of the Smithsonian Institution (1925) that "a moderate degree of fore-knowledge is certainly in-indicated, both for the specific forecasts of three, four, and five days in advance, and for the more general average forecasts of weeks or months." The Report adds further, "Our entire purpose in the matter is, and has always been, to make such experiments as might indicate what value, if any, would attach to the introduction of a new variable, namely, the variation of the sun, in weather forecasting. Our forecasts are made privately and only as tests of the experimental conclusions." Because of the lack of further financial support these experimental forecasts stopped at the end of 1925.

Certain general impressions regarding this whole subject may be stated in conclusion as the opinions of a professionally interested outsider who has endeavored to remain absolutely unprejudiced and impartial. (1) There can be no possible question regarding the very great importance to man of reliable long-range weather forecasts. These have far more than a passing "popular" interest. They would be of the highest value in industry, in transportation, in health, and in numberless other lines of human activity or safety. It is perfectly clear that what man most wants is a specific, definite, detailed forecast. He would like to know, not merely the average or the highest and lowest temperatures, or the probable rainfall, important as these are, but also the type of weather as a whole which will accompany these conditions. It is, for example, not quite enough to know, in advance, the maximum or the minimum temperatures. A more vital question is how long such temperatures will last; whether they will be accompanied by wind; whether the sun will shine or not. Similarly, an excess or deficiency of rainfall may be indicated for a certain week. This is highly valuable information, but still more useful would be a foreknowledge of the character and of the duration of the rain or snow. Will it come in one storm, or

in more than one? Will it rain or snow continuously, for hours or days, or will the precipitation be intermittent? Such detailed forecasts are obviously not yet possible, but they are the kind that the public wants, and will, sometime in the future, probably be able to secure.

(2) The question that has risen regarding the reliability of the Smithsonian observations need not here be entered into. It was inevitable that scientific men in search of the truth should ask how much of the slight variability from day to day is the result of actual variations of the solar constant, and how much may be due to instrumental errors, to errors in the methods of reduction and correction, and to changes in the transparency of the earth's atmosphere. Searching analysis; more observations, of ever-increasing accuracy and refinement; honest, fair and good-tempered discussion—these will in time settle all such questions. Science has nothing to lose, and everything to gain, by honest and intelligent criticism, if carried out with the single purpose of seeking the truth. An interested and unprejudiced non-scientific outsider might perhaps be disposed to wonder whether, if the available results as to the apparent variability of solar radiation can be used in practical long-range forecasting, it makes any difference to the average person whether these data represent real facts as to solar variability, or are affected by atmospheric conditions, by instrumental errors, or by the personal equation.

(3) Regarding the value of the forecasts made several days in advance by the Argentine Meteorological Office a sufficient answer is to be found in the fact that these forecasts have been published for seven years, and that they seem to have met with general popular approval and support.

(4) Regarding Mr. Clayton's recent long-range temperature forecasts for New York City there is no available detailed information. These forecasts have been purely experimental, and were not published. It is, therefore, impossible to form any definite opinion in regard to them, how specific and detailed they were; how practically useful they would be from an economic standpoint; how they were verified. All that is known concerning them is that "a moderate degree of fore-knowledge is certainly indicated."

(5) There is no immediate likelihood that the official weather services of the world will use observations of solar radiation for extending the regular periods now covered by their forecasts. Such observations are not yet generally available.[2] Furthermore, meteorologists as a body are not ready to make use of them. A British view of this matter, as recently given by the editor of *The Meteorological Magazine* (Vol. 60, Nov., 1925, p. 239), is that "a relation of some sort (between variations of the solar constant and the weather) almost certainly exists and will be discovered by future research, but it will probably be long before this new method will be able to add anything to the high technique of daily forecasting by synoptic charts."

If *definite* and *detailed* effects upon the weather resulting from given fluctuations of the solar constant could be known in advance, and if any *actual* variations of solar radiation could also be known in advance, then it seems reasonable to think that definite forecasts, *of real economic value*, extending over considerable periods of time, would be possible. But it is to be observed that there are two very important "ifs" in this problem.

(6) Another line of attack on the problem of long-range forecasts is being carried on by a group of meteorologists who are studying the disturbances or variations that occur in the general circulation of the earth's atmosphere without any necessary reference to extra-terrestrial controls. This great circulation long ago reached something appoaching equilibrium, but its pressures, winds, temperatures, clouds and rainfall are subject to fluctuations and irregularities, seasonal, annual, and over longer periods. In other words, the atmospheric machine does not always "run true." If the variations from a "normal" condition could be foreseen, and the many complex interrelations and effects of these variations were known, then long-range forecasts along these lines would be possible. Here again, however, there is a vast amount of hard scientific spade-work to be done before the relations involved in this problem are understood.

[2] The regular observations of the solar constant of radiation made by the Smithsonian Institution at the Montezuma (Chile) station have, however, recently been made available for any responsible persons or institutions, and these values are now printed on the daily weather map published by the United States Weather Bureau in Washington.

The results thus far reached are still, as a whole, by no means as satisfactory as could be desired, and are not yet generally applicable to definite seasonal forecasts. There is, however, promise for the future.

Harvard University,
March 27, 1926.

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FURTHER STUDIES ON THE PREPARATION OF METALLIC GERMANIUM AND THE VOLATILITY OF THE METAL IN HYDROGEN AND IN VACUO.

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(Contributed from the John Harrison Laboratory of Chemistry of the University of Pennsylvania.)

Shortly after the discovery of germanium, Winkler stated that the dioxide of this element was reduced by hydrogen at a red heat but expressed the belief that reduction to metal was incomplete.[1] At a comparatively recent date Müller attempted to use the ratio of the dioxide to metal so prepared, in a redetermination of the atomic weight of germanium. It was stated at that time that the reduction to metal in hydrogen failed to give satisfactory results—first because the protracted heating in hydrogen was attended by small but distinctly measurable loss of the metal in the hydrogen stream which loss was thought at the time to be due to the formation of hydride. The complete quantitative results were not published because a totally different method was employed in making a redetermination of the atomic weight in question. Secondly it was observed that traces of chlorine were difficult to remove from germanic oxide prepared by hydrolysis of the tetrachloride and also that the oxide made by oxidation of the sulphide contained sulphur which was likewise difficult to eliminate. It should be noted however, that these impurities, present only in traces, would have had very little if any influence upon the preparation of a very pure metal by subsequent reduction of this metal in hydrogen though their presence would make it inadvisable to weigh the oxide for atomic weight determination.[2]

[1] *Journ. prakt. Chem.*, 34, 202 (1886).
[2] *Journ. Amer. Chem. Soc.*, 43, 5, 1087 (1921).

Later Dennis and his co-workers found that the reduction of small amounts of germanic oxide (of the magnitude of 0.35 g.) was complete in about two hours when heated in hydrogen at 500° to 540° C. and that no germanium or any compound of the element volatilized under these circumstances.[3]

In the same communication it was shown that metallic germanium which was free from oxide does not lose weight when heated in hydrogen to a temperature not exceeding 800° C., but that volatilization of metal does take place when hydrogen is passed over the molten metal.

The following investigation concerns a further study of the volatility of germanium.

Apparatus and Material.

The germanium dioxide was obtained originally from germaniferous zinc oxide procured through the courtesy of the New Jersey Company. The methods used for the preparation of the pure oxide need not be considereded in detail but it may be stated that the following operations were mainly depended upon for the elimination of the impurities present in the crude oxide: Repeated distillation of the tetrachloride in a current of chlorine[4] and repeated recrystallization of potassium fluogermanate for the removal of the last traces of arsenic.[5] The fluogermanate was then converted to the tetrachloride followed by the redistillation of the latter which was then hydrolyzed to oxide. The crusts of oxide which separated upon hydrolysis of the chloride were filtered out and the acid filtrate and washings discarded. The only impurity left in the oxide at this stage in the purification was a small amount of chlorine which could not be removed by simply washing with a limited amount of water. It was found possible to remove this by protracted ignition of the finely divided product in superheated steam which was carried out in silica apparatus. The waste steam was condensed and the resulting water tested for chlorine in the usual way until negative tests were obtained both in the water and the ignited oxide. The oxide was finally

[3] *Journ. Amer. Chem. Soc.*, 45, 9, 20933 (1923).
[4] *Journ. Amer. Chem. Soc.*, 43, 2131 (1921).
[5] *Journ. Amer. Chem. Soc.*, 43, 2549 (1921); 43, 1085 (1921).

ignited in air at 900°–950° C. to effect complete dehydration and preserved in silica vessels for use.

Hydrogen.—The hydrogen was prepared electrolytically using a 15 per cent. sodium hydroxide solution and nickel electrodes. In the whole of the washing and drying system connections were of fused glass followed by accurately ground joints in the silica apparatus containing boats or weighing tubes. The hydrogen was washed and dried in a train containing the following materials in the order given, —saturated silver sulphate solution, alkaline permanganate, solid caustic soda, concentrated sulphuric acid, heated palladium asbestos, soda lime, concentrated sulphuric acid, Askarite, and finally phosphorus pentoxide.

For the reduction of the oxide the apparatus used was entirely of silica and all heating effected by an electric resistance furnace. To minimize errors due to sudden temperature changes the furnace was covered with a thick layer of insulating material, using a tight fitting silica furnace core into which the clear quartz tube and contained bottling tube tightly fitted. The samples of oxide were placed in silica bottling apparatus similar to the type used by Richards in several of his atomic weight determinations and hence could not have been contaminated from the outside.

Temperatures were measured by a platinum rhodium thermo couple the junction of which was placed immediately beside the weighing tube containing the oxide or metal. The instrument was calibrated just before use and during a number of experiments was checked by the use of pure silver, the melting point of which is fortunately close to the observed melting point of metallic germanium. The error in temperature readings could not have been greater that ± 5° C.

The hydrogen issuing from the end of the silica tube was conducted through a trap containing saturated silver sulphate solution during the process of reducing the oxide to metal and while heating the latter in the same gas and at the anterior end of the quartz tube a " T " tube was inserted to allow the atmosphere of hydrogen to be replaced by dry air.

The balance was a Troemner No. 10, Sensibility 1/50 mg.

Weights gold plated with platinum fractions, calibrated by Richard's substitution method.

Reduction of Germanium Dioxide in Hydrogen.

The samples of oxide were contained in a silica weighing tube with accurately ground stoppers at both ends, the quantity introduced being roughly determined by a preliminary weighing before transferring to the weighing tube. The stoppered tube was then introduced into the silica bottling apparatus before described and the stoppers removed. A slow current of dry air, washed free from dust, carbon dioxide and other impurities, was then passed through the system and the temperature raised to 900°–950° C. Heating under these conditions was continued until the residual oxide had come to constant weight, (± 0.00002 g.). Pure dry hydrogen was then allowed to pass over the weighed dioxide (1.69443 g.) to expel the air from the system and the temperature slowly raised to 500° C. At this point the surface of the oxide became gray and when the temperature became 600° C. the material in the weighing tube had become much darker. As the reduction slowly proceeded at this temperature a small dark deposit appeared in the upper or cooler part of the weighing tube but no trace of such sublimate was observable toward the end of the weighing tube nor in the silica tube surrounding. The heating in hydrogen at 600° to 625° C. was continued for thirty-two hours, after which no further loss in weight occurred. The temperature was then raised in steps as indicated in the table below. It appears that each additional heating period was attended by a slight loss in weight. The loss in weight was small but measurable as shown in the table and at no time in the total number of hours could a constant weight be obtained. The experiment was not discontinued until the weight of the residual metal was less than that required for the amount of oxide used, calculating on the assumption that the atomic weight of germanium is 72.5. It should be noted that the oxide used was very finely divided (by hydrolysis of the tetrachloride), and that the metal so produced therefore presented to the hydrogen a surface many times greater than that obtainable by pulverizing a button of the metal. The constricted ends of the weighing

tube with their narrow opening and carefully regulated, slowly entering hydogen stream could not have permitted mechanical loss.

Toward the end of the experiment a small mirror was found in the cold part of the silica tube beyound the furnace core. This was dissolved in a little freshly distilled ammonium hydroxide containing a few drops of pure hydrogen peroxide. Both of these reagents were carefully tested and showed no weighable residue upon evaporation. From the ammoniacal peroxide solution by evaporation and ignition a residue of 0.00026 g. of germanium dioxide was recovered. The mirror was of silvery lustre by reflected light and red by transmitted light and differed strikingly in appearance from germanous oxide which can of course be obtained as a sublimate upon heating the partially reduced oxide rapidly in a hydrogen stream. Films of germanous oxide purposely prepared for comparison with the metallic deposit were also made and later described.

The waste hydrogen as before mentioned was washed through a trap containing silver sulphate solution. The contents of the trap upon subsequent analysis was found to contain 0.00017 g. of germanium calculated as metal.

TABLE I.

Weight of germanium dioxide taken 1.69443
Weight of metal present if Ge = 72.5 .... 1.17572

Hours Heating in Hydrogen.	Temperature, C°.	Weight of Contents of Weighing Tube.
8	595	1.23219
6	595	1.17636
4.5	595	1.17628
7	595	1.17619
6.5	595	1.17618
6	783	1.17602
7.5	783	1.17601
7	843	1.17564
4	843	1.17561
7	868	1.17544
6.5	868	1.17534
11	868	1.17529
6	890	1.17511
6.5	890	1.17505

From the results shown in the above table, it seems reasonable to believe that metallic germanium, in a fine state of division, constantly

loses weight when heated in hydrogen at temperatures considerable below its melting point. The loss in weight is admittedly small and might easily escape notice unless the periods of heating were extended over four or five hours. In the first five heating periods in which the temperature never passed the 600° mark, the residue in the weighing tube most likely still contained a little oxygen as the calculated amount of metal was not obtained in thirty-two hours at this temperature. It seems probable that complete reduction of the oxide at temperatures lower than 600° C. is difficult, if at all possible.

Hydrogen Contained in Germanium Melted and Cooled in an Atmosphere of that Gas.

1.7085 g. of germanium dioxide were reduced in hydrogen, continuing the heating in that gas at 650° to 700° C. until the weight of the residual metal was slightly less than that calculated from the above quantity of oxide. The metal was then heated to 1000° C. in the same gas for several hours. The molten globule was allowed to slowly cool in hydrogen and the metal so obtained was preserved in a weighing bottle in a desiccator for twenty days. The globule was then placed in a silica tube from which the air was exhausted by a Toepler pump. The metal was then slowly heated and all gas evolved was pumped off and collected in a eudiometer over mercury. A small amount of gas was first observed at 690° C. and a larger amount was collected at the melting point of the metal. The gas collected was mixed with oxygen and sparked at reduced pressure. The presence of hydrogen was evidenced by the slight explosion of the mixed gases and the amount calculated by diminution in volume. From the results obtained it was found that 1 gram of the metal melted and cooled in hydrogen contained 0.186 c.c. hydrogen under normal conditions of temperature and pressure.

In this experiment and in a number of qualitative experiments with the metal prepared in the same way, metallic mirrors were found in the cooler portion of the quartz tube which projected from the furnace. Slight volatilization of the metal and consequent mirror formation began in each case at temperatures between 750° and 800° C. in vacuo while heavy shining mirrors were much more rapidly formed as the metal neared the melting point.

Melting Point of Germanium in Hydrogen and in Vacuo.

In the foregoing experiments it was observed that metallic germanium did not appear to have the same melting point in an atmosphere of hydrogen as in vacuo and therefore these melting points were investigated more carefully. The metal which had been prepared by reduction in hydrogen as shown in Table I. was melted in hydrogen and while in a molten condition in a silica tube was allowed to cool very slowly in that gas at ordinary pressure. One half of this metal was set aside as metal number 1. The other half was placed in a silica tube and the latter then exhausted by means of a Toepler pump. The metal was then melted and all gas evolved was immediately pumped off. After cooling in vacuo this was set aside as metal number 2.

The globule of metal number 1 was broken into a number of angular fragments which were placed in a silica tube which was filled with hydrogen at atmospheric pressure. Metal number 2, similarly broken, was put into silica tube of the same size and sealed off in vacuo. The pieces of metal were kept in one end of the tube in each case so that small pieces of it could be tapped down into the heated portion of the container when needed. In this way a number of experiments could be made without reopening either tube. The ends of the silica tubes containing the pieces of metal to be melted and a thermo couple junction, protected by a silica tube of the same thickness of wall, were fastened together with platinum wire and inserted into the resistance furnace. The temperature was slowly raised to the melting point and the moment at which the sharp edged pieces of metal began to flow was observed through a small mica window in the wall of the furnace and at the same instant the temperature reading was taken by a second operator. The metal in an atmosphere of hydrogen began to flow into globular form at 959° C., while that sealed off in vacuo melted at 975° C. As the temperature of the furnace was rising quite slowly throughout the experiment a considerable time interval existed between the melting of the first and second sample; hence the difference in the two melting points could not have been due to accidental variation in radiation from the separate containers. The above experiment was repeated

several times, but no measurable differences in the above recorded melting points could be detected. As a check, small pieces of very pure metallic silver were placed in a silica tube alongside of the tubes containing the samples of germanium and the whole experiment repeated. The germanium in hydrogen again melted at 959° C., the silver then melted at 961° C. (the true melting point of that metal) while the sample of germanium in vacuo did not melt until the temperature rose to 975° C.

Melting Point of Germanium in Carbon Dioxide.

Some of the metal which had been used in the above experiment was placed in a graphite crucible and was covered with a layer of sugar charcoal and then melted for one hour at 1000°–1050° C. The surface of the globule was cleaned by scraping and broken as before into sharp-edged fragments. These were placed in a silica tube which was evacuated and filled with dry carbon dioxide and the tube sealed off. The particles of metal melted at 958° C. In this experiment a small amount of oxide was produced as was evidenced by a slight film of grayish deposit which collected on the wall of the silica container. The melting point was slightly lower than that recorded for the metal in hydrogen, but as the limit of error in temperature reading was greater than the noted difference in melting points it could not be concluded that a true difference between these two melting points existed. The formation of oxide leads one to suspect, however, that the melting point was still further lowered.

Formation of Metallic Mirrors by Heating the Metal in Vacuo.

In all of the experiments with metallic germanium detailed in this paper mirrors of the metal were obtained by volatilization of more or less of the metal and which were similar in appearance to those obtained by Müller and Smith through the decomposition of the hydride.[6] In order to determine whether the formation of such mirrors was due to simple volatilization of the metal at elevated temperature or the presence of hydrogen, the following experiments were made.

[6] *Journ. Amer. Chem. Soc.*, 44, 1909 (1922).

A portion of germanium dioxide was mixed with four times its weight of sugar carbon and placed in a narrow bore silica tube closed at one end. A plug of sugar carbon was inserted to well cover the mixture. The air in the tube was then thoroughly exhausted. The tube was connected with the air pump and the mixture slowly heated to reaction temperature and finally to 1000° C. The gas evolved was pumped off continually and the residue cooled in vacuo. The small globules of metals were removed and separated from the excess of carbon and were put back in the original tube which had been thoroughly cleaned. The tube was then evacuated by the Toepler pump and sealed off in vacuo. The tube was placed in the resistance furnace and the temperature of the metal raised to 760° C. At this temperature a distinct mirror of shining metal formed just beyond the heated portion of the tube in the furnace. Five successive mirrors were formed by progressively pulling the heated tube short distances out of the furnace core. The mirrors formed during thirty minutes heating were dissolved by ammoniacal peroxide and the dioxide so produced was determined quantitatively. The unvolatilized metal was also determined by oxidizing with fuming nitric acid and ignition to oxide. 0.00653 g. of metal had been deposited as mirror and 0.00914 g. of metal had remained in the heated end of the tube.

It is of interest to note that the metal is volatile in vacuo at 760° C. and that the rate of volatilization at this temperature was about 2.5 mg. per hour.

A quantity of metallic germanium was prepared by the reduction of the oxide in hydrogen and the metal then treated in the same manner as that recommended by Dennis, Tressler and Hance,[7] repeatedly refusing the metal under a flux of carefully purified sodium chloride. The button of metal so prepared was boiled with water, all visible traces of the flux removed and was then kept in a molten state in hydrogen for several hours and cooled in the same gas. The ingot of metal so obtained was broken in half and the two pieces treated as follows: One portion was re-fused in hydrogen and while molten the tube was evacuated, after cooling in high vacuo the silica tube container was sealed off. The other portion of metal was placed

[7] *Journ. Amer. Chem. Soc.*, 45, 9 (1923).

in a similar tube which was filled with hydrogen at normal pressure. The two tubes each containing about 0.35 g. of metal, were then heated in the resistance furnace, side by side, to a temperature of 800° C. Successive metallic mirrors were formed in each of these tubes and were deposited in the cooler part of the tubes just beyond the furnace wall. As would be expected the evacuated tube gave a mirror more rapidly but volatilization of metal was plainly shown in both cases.

It was realized that protracted heating and reheating of germanium in hydrogen above the melting point for the purpose of removing the last trace of oxygen would require an indefinitely long time if the quantity of metal were large and it should be noted that a quantity of the metal as small as 0.1 g. would require a very long period of heating, even at the melting point for complete volatilization. For this reason it seemed advisable to work with still smaller amounts of metal so that all of a given sample might be shown to be capable of sublimation and thus remove any doubt arising from the assumption that the previously prepared metal contained traces of the lower oxide which might have been mistaken for volatilizing metal. Accordingly, silica tubes were prepared containing shining opaque mirrors of metal by heating a mixture of hydrogen and germanium hydride (or hydrides). The hydride-hydrogen mixture was prepared in the following manner: Hydrogen was evolved from an aluminium-potassium hydroxide generator and the entire apparatus used was swept out with this gas. Potassium fluo-germanate (solution in air-free water) was then allowed to flow into the generator. The evolved gas mixture was stored over water from which the air had been expelled by boiling under reduced pressure. The water in the gasometer was protected from air contact by alkaline pyrogallol traps. Hydrogen was run through the silica deposition tubes and the hydride hydrogen mixture then admitted. At the point heated by a Meeker burner heavy metallic mirrors were deposited in the silica tubes. Some of these tubes were sealed off in vacuo and others sealed while filled with hydrogen and all were subjected to the heat treatment previously described. In every case it was found that these mirrors could be completely volatilized from one end of the tube to the other at 800° C. and by reversing the position of these tubes in the

furnace the operation could be repeated as often as desired. No trace of nonvolatile residue was visible in any experiment.

From the above results it seems evident that metallic germanium is slowly but completely volatile at temperatures considerably below its melting point, and that such volatility cannot be due to an impurity in the shape of unreduced lower oxide, though the latter is distinctly volatile and likely to be present in the metal as ordinarily prepared.

Germanous Oxide.

In the earlier work of Winkler[8] it was observed that germanous oxide could be prepared by heating mixtures of the metal and the dioxide. Later, Biltz[9] states that germanium dioxide appears not to be reduced by germanium under these conditions, but seems to serve only as an absorbent for air because of its spongy nature, by virtue of which the germanium powders oxidation is promoted. Dennis,[10] heated a mixture of the metal and oxide in nitrogen and found that some germanous oxide was produced.

Some pure germanium prepared as described earlier in this paper and which had been reduced at temperatures below the melting point of the metal was intimately mixed in an agate mortar with the equivalent quantity of the pure, equally finely divided dioxide. The mixture containing 0.34156 g. of germanium and 0.49226 g. of the dioxide was spread over the bottom of a silica boat which was then placed in a silica tube. The container was then evacuated as far as possible with a Toepler pump and sealed off. The mixture was slowly heated in resistance furnace. Vigorous action began at about 800° C. with formation of a dense black sublimate directly above the boat. After half an hour the apparatus was allowed to cool and the boat removed and weighed. The loss in weight was 0.22528 g. which was about twenty-seven per cent. of the original mixture. Reheating of the unvolatilized material in the boat resulted in the formation of very little more of the lower oxide and after long heating the residue seemed to be simply unchanged dioxide.

[8] *Journ. Prakt. Chem.*, 143 (34), 210 (1886).
[9] *Zeitschr. Anorg. Chem.*, 72, 317 (1911).
[10] *Journ. Amer. Chem. Soc.*, 45, 9, 2041 (1923).

The black sublimate was digested with 1-1 hydrochloric acid in absence of air in which it slowly dissolved. One portion of the solution gave the yellow hydrated monoxide when treated with an excess of ammonium hydroxide and the other portion after nearly neutralizing gave the expected orange germanous sulphide with hydrogen sulphide.

The above experiment gave deposits of the monoxide which were compared with the metallic mirrors previously described. The monoxide is very dark and while of metallic luster does not resemble the metallic films obtained from the hydride or by volatilizing the metal.

Metallographic Examination of Germanium Prepared by Different Methods.

As a possible means of comparing the relative degrees of purity of metallic germanium prepared by various methods, samples of metal were submitted to Mr. A. K. Graham whose coöperation permitted the preparation of the metallographic data presented in this section.

Great care was taken in preparing the samples of metal for microscopic study. After placing the samples on a flat glass plate inside a half-inch length of three-eighth-inch copper tube and filling with sealing wax, they were taken down on files and graded emery and hubert papers in paraffin oil by hand. The oil was necessary to prevent the particles of emery from becoming embedded and at the same time allowed polishing without undue flowing or heating. Final polishing was carried out on wet wheels in the usual manner.

Two etching reagents were found satisfactory. Ammonium hydroxide-hydrogen peroxide mixture attacked the surface of the metal very slowly but uniformly, leaving the impurities for the most part unattacked and in relief. Silver nitrate also revealed impurities in some of the samples and was superior in its ability to show up the grain boundaries, twinning, etc., particularly in the case of the purer metal.

Metallic germanium prepared by the method described by Dennis [11] was first examined. This metal showed large grain structure, see

[11] *Journ. Amer. Chem. Soc.*, 45, 20037 (1923).

Figs. 1 and 2. The grain boundaries however contained impurities and a number of blow holes were visible. Segregated areas of this impurity at higher magnification are shown in Figs. 3 and 4. The

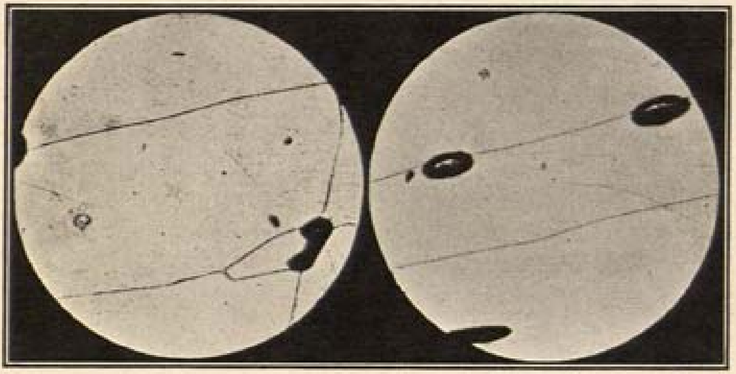

FIG. 1. 50 ×. H_2O_2. Showing large structure.
FIG. 2. 50 ×. H_2O_2. Impurity in boundaries and blowholes.

material was not readily attacked by the ammonia hydrogen peroxide mixture and appeared to have a light pinkish tint. The piece of

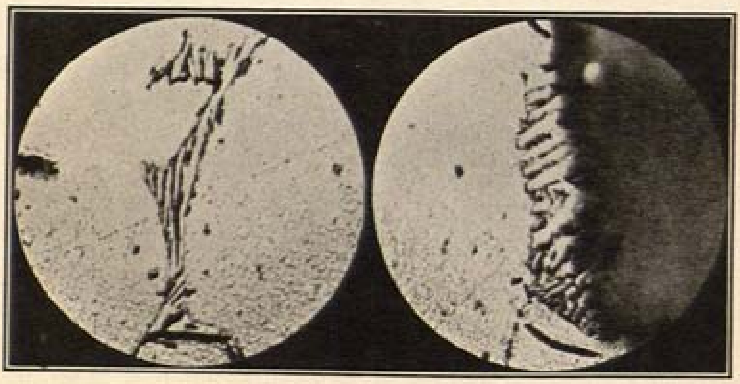

FIG. 3. 350 ×. H_2O_2. Impurity within grain boundaries.
FIG. 4. 350 ×. H_2O_2. Impurity lining blowhole.

metal was removed from the tube and wax setting without in any way injuring the polished surface and was heated in a stream of hydrogen for thirty minutes at 800° C. and was cooled in the same

gas. Reëxamination under the microscope showed that enclosed material in the grain boundaries was either partly volatile or decidedly attacked by hydrogen at this temperature as its polished surface had

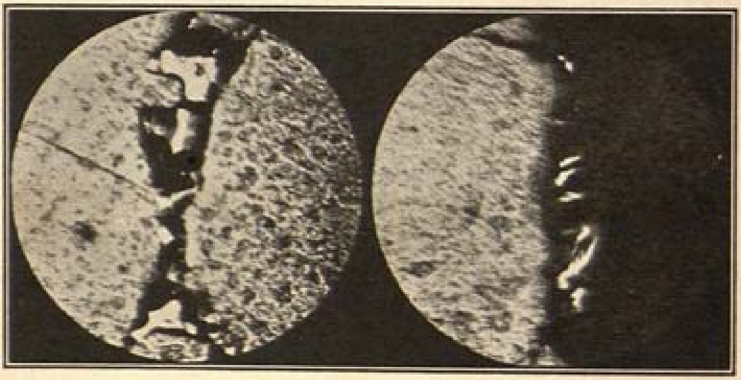

FIG. 5. 350 ×. H_2O_2. FIG. 6. 350 ×. H_2O_2.
Same as 3 and 4 after treatment in hydrogen at 800° C.

nearly disappeared. Figs. 5 and 6, which correspond to 3 and 4 respectively, show the result of this treatment.

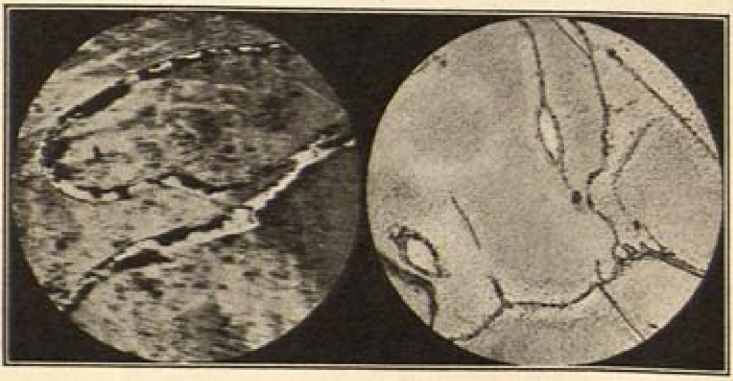

FIG. 7. 220 ×. H_2O_2. FIG. 8. 50 ×. $AgNO_3$.
After treatment in hydrogen at 1070° C. for four hours.

It was thought that if this material were readily attacked by hydrogen that further subjection of the metal to the action of this gas would result in the production of still purer metal, especially if

the temperature were raised considerably above the melting point and the liquid metal were agitated to bring the enclosed material to the surface. Accordingly the metal was replaced in the hydrogen stream at 1070° C. and kept so for four hours. The hydrogen was pumped out while the metal was slowly cooled and the metal was reground and polished as before. The metal was now nearly free from blow holes but the amount of impurity in the grain boundaries instead of becoming smaller appeared to have increased.

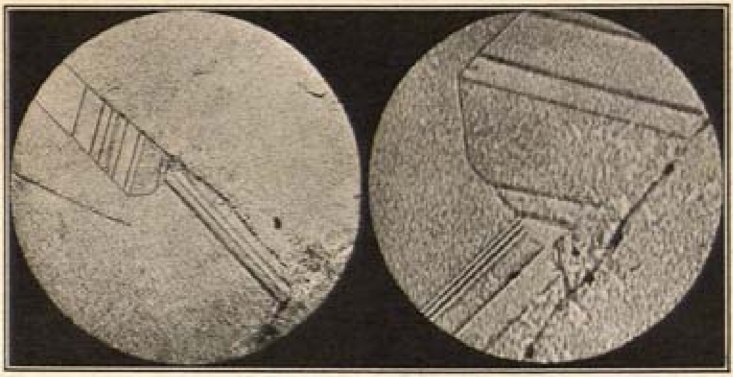

FIG. 9. 50 ×. $AgNO_3$. FIG. 10. 220 ×. $AgNO_3$.
Show twinning as the result of cold work.

Fig. 7 shows a large inclusion of the before-mentioned impurity standing out in relief and practically unattacked by the ammonia hydrogen peroxide reagent. The surface of the metal was stained as was quite common with this reagent.

Fig. 8 shows the effect of etching with silver nitrate solution. The sample was the same as in Fig. 7, but was photographed at lower magnification and shows a much larger surface. The quantity of impurity is quite evident.

Figs. 9 and 10 show a very interesting case of twinning as the result of cold work. It was recognized that the metal was brittle and could be shattered easily with a blow. As a result of cold work in preparing the surface, therefore, a number of twins were revealed. The lines have definite width and at higher magnification it appears that the lines themselves are the twins and not the metal between them.

Several other cases of twinning were to be found in this sample.

One would conclude from the last experiment that either the reheating of the metal in contact with silica, or the reduction of the initial quantity of metal by long heating (volatilization above the melting point), were responsible for the increase of the amount of enclosed material, consequently the following experiment was carried out.

A sample of the metal prepared by careful slow reduction of the pure oxide in hydrogen, was melted in the same gas at 1000° C. and after grinding and polishing as before, the surface was examined.

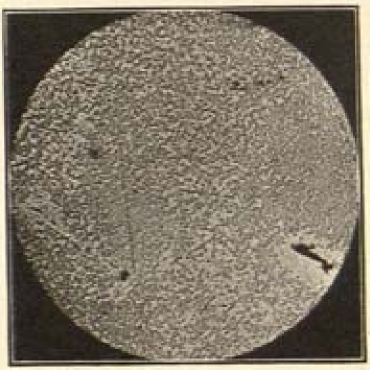

FIG. 11. 50 ×. $AgNO_3$.
Deeply etched. Shows small inclusions of graphite only.

This metal contained much less impurity as revealed under the microscope. The same sample was now reheated in a graphite boat at 1200° C. in an atmosphere of hydrogen for three hours and for one-half hour in a high vacuum. Reëxamination under the microscope showed a considerably higher degree of purity, for the surface had become of dense structure and practically free from blow holes and enclosed impurities. A few flakes of graphite were visible but no carbide or similar constituents were observed. A further indication of the high state of purity was observed upon attempting to etch the surface of the polished metal. The etching was obtained only with difficulty and long contact with the same reagents which attacked the other

samples of metal much more readily. Fig. 2 shows the picture of this metal which probably represents as high a degree of purity as is possible to obtain by the methods used.

The constituent which was present in all the other samples must be reducible under the combined action of hydrogen and graphite at high temperatures. It is probable that hydrogen alone cannot remove the impurity, but that the combined action of carbon and hydrogen does so. It is possible that the impurity was a silicide removable under these conditions.

Summary and Conclusions.

Metallic germanium is measurably volatile in hydrogen at temperatures considerably below the melting point of the metal, provided the time of heating is extended over periods of a number of hours.

Germanium absorbs detectable amounts of hydrogen when the metal is melted and cooled in an atmosphere of that gas. The quantity of hydrogen absorbed per gram of metal has been determined.

Mirrors of metallic germanium, prepared by decomposition of a hydrogen-germanium hydride mixture have been shown to be completely volatile both in hydrogen at normal pressure and in vacuo within the same temperature range. The metal in globular form made by the reduction of the dioxide in hydrogen and by carbon is also volatile under the same circumstances. Measurable volatility can be shown below 800° C.

Germanium dioxide is reduced to germanous oxide by heating an intimate mixture of the metal and dioxide in equivalent quantities in vacuo, but the reaction appears to be incomplete. Reaction begins vigorously at about 800° C. with volatilization of germanous oxide.

Metallic germanium appears to have decidedly different melting points in hydrogen and in vacuo, the presence of the hydrogen lowers the melting point appreciably.

The relative degrees of purity of metallic germanium prepared in different ways have been studied metallographically and this method of examination seems to indicate that the combined action of carbon and hydrogen is more effective in completing the reduction to metal than hydrogen alone.

A final heating of nearly pure germanium (by hydrogen), in a graphite boat in hydrogen, followed by cooling the metal in vacuo results in the production of pure germanium.

Microsopic examination of polished and etched surfaces of the metal shows an interesting case of twinning crystals of germanium produced by cold working the metal.

THE QUANTITATIVE DETERMINATION OF SELENIUM AND TELLURIUM.

By VICTOR LENHER.

(*Read by title April 23d, 1926.*)

The separation of the two element, selenium and tellurium, is not as perfect as is commonly supposed. Their chemical behavior is so similar, their precipitation out of solution is in general effected by the same order of reducing agents and their higher oxidized compounds, the selenates and tellurates, liberate chlorine with hydrochloric acid in so similar a manner that it is only by fine distinction in choice of reagents and manipulation that it is possible to perfectly separate the two elements.

As is the case with chemical elements of similar character, they are associated with each other in nature. Tellurium is associated with selenium in the selenides and selenium is always associated with tellurium and with the tellurides.

In our present commercial elements which are separated with the view of producing pure materials, there are more than traces of selenium in tellurium, and more than traces of tellurium in selenium.

Today the sole supply of these elements in the United States is as a by-product in the electrolytic refining of copper.

The *qualitative detection* of these elements is relatively simple. Fuming sulphuric acid or hot concentrated sulphuric acid give characteristic colors. Selenium gives a green color while tellurium gives a red one. These colors are attributed to the formation of $SeSO_3$ or $TeSO_3$. The colors are discharged by boiling. The green selenium color completely fades and selenium dioxide is produced. The red tellurium solution, by continued heating gradually loses its color and finally becomes colorless, and basic sulphate of tellurium is formed. The green-colored sulphuric acid solution of selenium when diluted with water gives a precipitate of bright red amorphous selenium which becomes black on heating. The red-colored sulphuric

acid solution of tellurium when diluted with water gives a precipitate of black, finely divided elementary tellurium.

This sulphuric acid reaction for these elements is practically useless for mixtures of the elements except in cases where the tellurium content is so high that the lesser amount of the green selenium does not interfere.

The *usual tests for selenium* are naturally those made in the wet way. Selenium forms a number of types of compounds, the oxidized and the non-oxidized. The oxidized types follow the oxides and acids of selenium, thus selenious oxide, dissolves in water to form selenious acid, H_2SeO_3, which in turn forms the selenites, and selenic acid, H_2SeO_4, which forms the selenates. The solubility in water of the selenites follows closely that of the sulphites. They are not, however, in any sense reducing agents.

Selenic acid which in many respects closely resembles sulphuric acid, forms salts which in their solubilities closely resembles the sulphates. There is, however, one important divergence from the chemistry of sulphuric acid. Selenic acid and all of the selenates when warmed with hydrochloric acid act as an oxidizing agent and liberate chlorine, being in turn reduced to selenious acid or to the selenites. The selenites in solution are with difficulty oxidized to the selenates, but so far as analytical results are concerned, the oxidation methods are not available. The oxidation in dry form by means of alkaline oxidizing fusion completely converts the selenite to selenate.

The most used wet method for testing selenium consists in precipitating it in the elementary form by one of the stronger reducing agents. Sulphur dioxide is certainly the most common reducing agent used and has been used since the earliest days. The solution containing selenious acid should be acid with hydrochloric acid and the sulphur dioxide can be used as the gas or as a solution in water. The selenium will precipitate as the red amorphous variety which on warming goes over into the gray crystalline form.

Hydrogen sulphide gives with selenious acid solutions a lemon yellow colored precipitate of the sulphide of selenium which is soluble in ammonium sulphide. The precipitate is not stable, but rapidly dissociates into sulphur and red selenium.

Ferrous sulphate, hydroxylamine hydrochloride, hydrazine hydrochloride, phosphorous acid, hypophosphorous acid, titanium trichloride and stannous chloride precipitate red selenium in the cold from selenious acid solutions; on warming this red variety goes over into the gray crystalline form.

Potassium iodide with either a selenite or selenate solution, when acidified with hydrochloric acid gives in the cold, red selenium which, when warmed, causes the iodine to distil and the red selenium to go over into the gray form.

Barium chloride, when added to a neutral selenite solution, gives insoluble white barium selenite, which is soluble in hydrochloric acid. Barium selenate formed by the addition of a selenate to a barium chloride solution, is insoluble in water, but when boiled with hydrochloric acid, it, like all selenates, is first reduced with evolution of chlorine and formation of selenite which dissolves in the hydrochloric acid.

Selenium as well as selenium containing compounds before the blowpipe in the reducing flame give characteristic fumes that are commonly described as having a putrid horseradish odor. A characteristic blue color is given in the oxidizing flame. The white dioxide of selenium volatilizes directly before the blowpipe without melting.

Of the non-oxidized compounds of selenium, the most important are hydrogen selenide and the selenides of the metals. The gas hydrogen selenide is formed exactly as is hydrogen sulphide by the treatment of certain selenides with dilute acids. Among the most convenient reactions are those with hydrochloric acid and sodium selenide, iron selenide and magnesium selenide. The evolved gas is extremely irritating but not particularly toxic. With the heavy metals it gives insoluble selenides. The gas is easily oxidized by the oxygen of the air and readily deposits red selenium. The soluble selenides are likewise unstable, being readily oxidized by the air with the production of red selenium.

The *more common tests for tellurium* are like those with selenium, made in the wet way, and this element also forms oxidized and non-oxidized compounds.

The oxidized compounds of tellurium follow the acids, tellurous

and telluric, which give corresponding salts, the tellurites and the tellurates. The salts of the alkaline metals with tellurous acids are soluble, all of the heavier metals form insoluble salts. It should be noted that the soluble alkaline tellurites are decomposed by carbon dioxide forming insoluble tetra-tellurite salts. Tellurium dioxide unlike selenium dioxide, is insoluble in water and while it can be formed by the oxidation of elementary tellurium, it is also produced by the hydrolysis of such compounds as the tetrachloride or basic nitrate when it appears as a white insoluble product. Indeed, the solution of any tellurium compound in hydrochloric acid is precipitated by water and by this test alone can be easily mistaken for antimony.

Telluric acid $H_2TeO_4 2H_2O$ is readily soluble in water and gives with the alkaline metals the readily soluble tellurates. With the heavier metals, the salts are insoluble. Here again, it is to be noted that the alkaline tellurates formed by oxidizing the tellurites by roasting in the air are insoluble and are possible salts of a second modification of telluric acid.

Telluric acid, or any of the tellurates, when warmed with hydrochloric acid, evolve chlorine, being in turn reduced to tellurous acid or to the tellurites. The tellurites in solution are oxidized only with great difficulty to the tellurates, hence this procedure is not available for purposes of analysis. The dry oxidation by means of an alkaline oxidizing fusion completely converts the tellurite to tellurate.

The most used wet method in testing for tellurium, is by the use of one of the stronger reducing agents when the element is precipitated in elementary form. Sulphur dioxide is naturally one of the most convenient to use. The solution should not contain more than 17 per cent. free hydrochloric acid, and preferably less. The sulphur dioxide can be either introduced as the gas or in aqueous solution. Elementary tellurium is also thrown out of solution and appears as a finely divided black precipitate.

Hydrogen sulphide gives a precipitate which is at first red brown, but quickly darkens due to the dissociation of the sulphide of tellurium, which is at first precipitated, into sulphur and elementary tellurium. The precipitate is soluble in the alkaline sulphides.

Stannous chloride, hypophosphorous acid, hydrazine hydrochlo-

ride, metallic zinc, aluminum, magnesium, precipitate black, finely divided elementary tellurium.

Titanium trichloride precipitates elementary tellurium both from the tellurites and from the tellurates.

Barium chloride precipitates barium tellurite from tellurous solutions, the precipitate is soluble in hydrochloric acid. With tellurates, a white precipitate of barium tellurate is formed which on treatment with hydrochloric acid evolves chlorine and forms the tellurite of barium, which is soluble in hydrochloric acid.

Qualitative Analysis of Complex Mixtures of Selenium and Tellurium.

A portion of the substance to be tested is treated with either aqua regia or a mixture of potassium chlorate and hydrochloric acid and the free chlorine expelled at a temperature below boiling in order to prevent loss by volatization of the chlorides of selenium or tellurium. The solution is diluted and the insoluble matter removed by filtration. Hydrated tellurium dioxide may be precipitated, but it is redissolved by further addition of hydrochloric acid. The solution is treated with sulphur dioxide either by addition of the gas or of an aqueous solution of a soluble sulphite. A precipitate indicates the presence of selenium, tellurium, or gold.

1. The precipitate can be allowed to settle, and the supernatant liquid decanted. The precipitate is warmed in nitric acid, sp. gr. 1.2 when the selenium and tellurium if present will dissolve, leaving the gold insoluble. The nitric acid solution containing the selenium and tellurium is evaporated at a low temperature with excess of concentrated hydrochloric acid to expel all of the nitric acid and then treated in strong hydrochloric acid solution with sulphur dioxide. A red precipitate, which on warming turns black, indicates selenium. The selenium precipitate is filtered by means of an asbestos filter and the solution is diluted and treated with more sulphur dioxide; black elementary tellurium precipitates if present.

2. The sulphur dioxide precipitate containing possibly selenium, tellurium or gold, may give the characteristic colors with sulphuric acid. The well washed and dried precipitate is treated with fuming

sulphuric acid in the cold or hot concentrates sulphuric acid when the green of selenium or the red of tellurium shows a color reaction.

Second Procedure.

Crude selenium or tellurium containing material is fused with five or six times its weight of potassium cyanide. Tellurium forms potassium telluride, while selenium and sulphur form selenocyanate, and sulphocyanate. The fusion is extracted with water from which the air has been removed by boiling, which will remove the tellurium as purple potassium telluride, the selenocyanate and sulphocyanate of potassium dissolving to colorless solutions. Any heavy metals remain insoluble and can be filtered off. Air is bubbled through the solution when the purple color of the telluride is discharged and elementary tellurium is thrown out of solution as a black precipitate. This can be verified as tellurium by filtering and making the sulphuric acid test.

The solution of selenocyanate and sulphocyanate which is in the filtrate from the air oxidation of the tellurium can be treated *under a good hood* with hydrochloric acid when hydrocyanic acid is set free and red selenium is precipitated. This can be converted to the gray variety of heating the solution and can be further verified by the sulphuric test.

Quantitative Methods.

Selenium and tellurium can be separated from the other metals and from the non-metals by the use of sulphur dioxide in hydrochloric acid solution. In strong hydrochloric acid, sp. gr. 1.143, selenium is precipitated and when the acid is more dilute, tellurium. Gold is simultaneously precipitated. The well washed precipitate can be separated from gold by treatment with nitric acid of sp. gr. 1.2 which dissolves the selenium and tellurium but does not dissolve gold. The solution can be carefully evaporated with hydrochloric acid to destroy the nitric and convert to chlorides. The chloride solution when it contains considerable free hydrochloric acid can be used for the separation of selenium and tellurium from each other. Since both selenium and tellurium are precipitated by sulphur dioxide, they are likely to be together and any precipitation of selenium en-

tails a separation from tellurium. These elements can be perfectly separated by sulphur dioxide if proper conditions are fulfilled. The sulphur dioxide method of selenium and tellurium was first suggested by Divers and Shimose [1] and was later modified by Keller [2] and has been studied in considerable detail by the author. It is known that the concentration of the acid is very important and that the ratio of tellurium to the concentration of the solution is an equally important factor. With hydrochloric acid having a concentration of 28.25 per cent. sp. gr. 1.143, tellurium is not precipitated by sulphur dioxide. This is the minimum concentration of hydrochloric acid which can be used, but higher concentrations can be used if the amount of selenium is small and the solution is kept cool. When working in these strong solutions, it is essential when any reducing agent is added that the solution should never be warm, since volatile selenium monochloride will be produced and will distil, giving low selenium results. With hydrochloric acid having a lower concentration than 28 per cent., tellurium slowly precipitates. A volume of 150 cc. is used in the analysis and not more than 0.25 gm. of tellurium should be present. It is likewise important that not more than 0.25 gram of selenium be present.

When concentrated hydrochloric acid is added to a strong and warm selenious acid solution and sulphur dioxide gas is passed into the solution, elementary selenium does not precipitate but the solution turns red due to the production of selenium monochloride. This selenium monochloride is so volatile that most of the selenium may be lost by distillation, when the solution is warmed, and is subsequently lost. When the concentration of the hydrochloric acid is greater than 28 per cent. a yellow or red coloration is produced, whose intensity depends on the amount of selenium which is present. Dilution with an excess of stronger hydrochloric acid which has been saturated with sulphur dioxide in the cold, is effected, with the result that the monochloride of selenium is hydrolyzed and complete precipitation of elementary selenium is effected.

A large excess of sulphur dioxide is necessary for complete precipitation of elementary selenium from this strongly acid solution.

[1] *Chem. News*, 49, 26 (1884); ibid., 51, 199 (1885).

[2] *Jour. Amer. Chem. Soc.*, 19, 771 (1897); ibid., 22, 241 (1901).

The temperature of precipitation is also of great importance. When selenium is precipitated by sulphur dioxide in the cold, it always appears as the amorphous red variety. This, when warmed, goes over into the gray crystalline variety and during this transformation there will always be occluded whatever is present in the solution—metallic salts, tellurium, hydrochloric, sulphurous, sulphuric acids of the reaction, and even water. The solids and gases cannot be removed by continued washing and the water cannot be removed without giving abnormally high results. It is therefore obvious that red selenium precipitated by sulphur dioxide cannot be transformed into the gray-black variety without obtaining high results.

The procedure recommended is as follows: The oxides of selenium and tellurium, which should not contain more than 0.25 gm. of either element, are dissolved in 100 cc. of cold concentrated hydrochloric acid. 50 cc. of this acid which is saturated with sulphur dioxide gas are added with constant stirring. When concentrated hydrochloric acid is used with a large excess of sulphur dioxide, selenium monochloride is *not* formed in the cold. The solution is then allowed to stand in the cold until the red selenium settles. It is filtered through an asbestos filter and the precipitate washed with cold hydrochloric acid, then with cold water until all of the chloride is removed and finally alcohol to displace the water and ether to displace the alcohol. It is necessary that the water be removed at once from the red selenium, since it cannot be removed later. The red selenium is dried 3–4 hours at 30°–40° to remove the ether, after which it is heated at 120°–130° for one to two hours to render the selenium perfectly dry. When any moisture is allowed to remain in the red selenium when it is converted to the black variety, high results due to oxidation will always result. Tellurium can be precipitated in the filtrate by hydrazine hydrochloride and sulphur dioxide.[3]

One of the older methods which have been recommended is to prepare the sulphur dioxide for the selenium precipitation, directly in the solution by the addition of sodium sulphite or of sodium acid sulphite. This, on account of the sulphur which may be present in elementary form, would better be replaced by sulphur dioxide gas.

[3] Lenher and Homberger, *Jour. Amer. Chem. Soc.*, 30, 387 (1908).

The use of certain reagents which will give most excellent qualitative tests for selenium such as ferrous sulphate, titanium trichloride, phosphorous acid, hypophosphorous acid, or stannous chloride, while they give red precipitated selenium, which on warming goes over to the gray variety, has not been successfully worked out as a quantitative procedure. In all cases the chief difficulty has been the occlusion of the precipitating reagent or the side products of the reaction.

The precipitation of selenium by such means as iron, aluminum, magnesium, zinc, etc., is obviously unfitted for accurate work.

Hydroxylamine hydrochloride, which was studied by Jannasch in the 90's has proven to be a most efficient reagent for precipitating selenium and for separating it from other elements. It can be used in either acid or alkaline solution. It makes possible a number of methods of separation of selenium and tellurium.

Potassium iodide is a most excellent reagent for the precipitation. It gives red selenium when added to a selenious solution containing free hydrochloric acid, free iodine being liberated at the same time. It is possible to remove this iodine by boiling when the selenium is simultaneously converted to the gray variety. Gooch and Pierce [4] prefer the titration of the liberated iodine by a sodium arsenite solution.

With selenates, the potassium iodide procedure for selenium is most excellent, red selenium is precipitated from the hydrochloric acid solution of the selenate with the liberation of correspondingly larger amounts of free iodine. This free iodine can be distilled from the solution without any difficulty and the red selenium at the same time is converted into the gray variety.

Selenic acid and the selenates can be analyzed by boiling [5] with hydrochloric acid when chlorine is evolved. This chlorine can be estimated iodometrically. Gooch and Reynolds [6] boil the selenate or selenic acid with potassium iodide and hydrochloric acid and collect and titrate the distilled iodine.

Norris and Fay [7] use the so-called thiosulphate method, which

[4] *Amer. Journ. Sc.* (4), 1, 31 (1896).
[5] *Fres. Zeit.*, 12, 287 (1873).
[6] *Amer. Journ. Sc.* (3), 50, 258 (1893).
[7] *Amer. Chem. Journ.*, 23, 119 (1900).

consists in treating a hydrochloric acid solution of selenious acid with a measured excess of standard sodium thiosulphate and then titrate the excess of thiosulphate with an iodine solution.

Selenious compounds can be oxidized by potassium permanganate to selenates. This has been used by Gooch and Clemons[8] as a volumetric procedure. A measured excess of standard permanganate is added to the acidified solution of the selenious acid followed by an excess of standard oxalic acid. The excess of oxalic acid is then titrated with permanganate after heating. All of this is done to avoid the fading end point which permanganate gives with the selenite.

Selenium can be separated with ease from the metals whose chlorides are nonvolatile. If the selenium exists as selenide, heating in a current of chlorine gas will cause the selenium to be completely volatilized as selenium tetrachloride. This can be collected in water and reduced by means of sulphur dioxide or hydroxylamine hydrochloride and weighed as elementary selenium. In the case of a selenite, hydrochloric acid gas should be used when the product is $SeO_2 2HCL$, which is volatile and from which elementary selenium can be precipitated and weighed. The selenates with hydrochloric acid gas give $SeO_2 . 2HCL$ and chlorine.

Quantitative Methods for Tellurium.

Tellurium can be determined gravimetrically and separated at the same time from most of the elements except gold and selenium by a number of reducing agents.

Sulphur dioxide is the oldest of the precipitating agents and was used originally by Berzelius. The reagent is used in either dilute hydrochloric acid solution or is added in the form of sodium sulphite or sodium acid sulphite. The same objections are made to the use of the sulphites with tellurium as in the precipitation of elementary selenium, that is, they may contain free sulphur, which is a grave criticism to their use. The great objections to the use of sulphur dioxide in dilute hydrochloric acid solution is that frequently the complete precipitation is greatly delayed. Twenty-four hours is the minimum

[8] *Amer. Journ. Sc.* (3), 50, 51 (1891).

time that such a solution must stand and it is recommended that the solution should be kept warm. It is not uncommon for the tellurium to be incompletely precipitated in that length of time. A second very serious objection to the use of sulphur dioxide is that the finely divided precipitated tellurium will superficially oxidize readily even if washed with alcohol and ether and dried at 105°. This has been noted by Schwetter,[9] Brauner,[10] Norris and Fay,[11] Crane,[12] Frericks,[13] and Lenher and Homberger.[14]

The use of hydrazine hydrochloride has been recommended by Gutbier[15] as a precipitating agent in the determination of tellurium. The reagent gives fairly good results, but as is the case with sulphur dioxide, the precipitation is somewhat delayed.

The use of hydrazine hydrochloride and sulphur dioxide has been suggested by Lenher and Homberger[16] as a precipitant for tellurium inasmuch as the reduction is almost instantaneous and the danger of oxidation during the drying is minimized. The use of the two reagents is applicable to both tellurites and tellurates.

The tellurium containing solution should have an acidity of 10 per cent. free hydrochloric acid and the solution should be as concentrated as possible, otherwise the tellurium will be precipitated in a finely divided condition and will be difficult to wash. The solution is heated to boiling, 15 cc. of a saturated solution of sulphur dioxide are added, followed by 10 cc. of a 15 per cent. solution of hydrazine hydrochloride and again 25 cc. of saturated sulphur dioxide solution. The boiling is continued until the precipitate settles in such a way that it can be readily filtered and washed. This precipitation should not take more than five minutes. The precipitated tellurium is collected on a Gooch filter and is washed with hot water until all of the chlorides are removed, after which the water is displaced by alcohol and the crucible and contents dried at 105°. This method has been

[9] *Chem. News*, 87, 17 (1903).
[10] *Journ. Chem. Soc.*, 55, 392 (1889).
[11] *Amer. Chem. Journ.*, 20, 278 (1898).
[12] *Amer. Chem. Journ.*, 23, 408 (1900).
[13] *Journ. Pr. Ch.*, 66, 261.
[14] *Journ. Amer. Chem. Soc.*, 30, 387 (1908).
[15] *Ber.*, 34, 2724 (1901).
[16] *Journ. Amer. Chem. Soc.*, 30, 387 (1908).

used in the author's laboratory for many years and with many thousands of tellurium determinations and has proven itself the best all around method for tellurium available.

Elementary tellurium can be precipitated by sugar from alkaline solution.[17, 18] The precipitation is complete but the tellurium is difficult to wash.

Hydrosulphurous acid has been studied as a reducing agent by MacIvor [19] and Donath.[20] The precipitated element always contains sulfur.

The precipitation of tellurium by means of hypophosphorous acid, titanous chloride, or by the metals is unsatisfactory on account of the various impurities which are coprecipitated. Brauner [21] has suggested that the stannous chloride reaction be made the basis of a volumetric procedure. He adds an excess of a known solution of stannous chloride, which precipitates the elementary tellurium and titrates the excess of stannous chlorine with a standard iodine solution. Brauner [22] has described a method of titration by means of potassium dichromate, the details of which have been later modified by Lenher and Wakefield [23] and which have been verified by Schrenk and Browning.[24] The details of the method are quite important. A sample of the material containing from 0.1 to 0.3 gm. of tellurium dioxide is dissolved in 10 cc. concentrated hydrochloric acid and diluted to 200 cc. with water. A measured excess of $N/10$ dichromate is added from a burette and the solution allowed to stand for half an hour. A measured excess of standard ferrous sulphate solution is then added and the surplus of ferrous salts is titrated with $N/10$ dichromate using potassium ferricyanide as an outside indicator.

Brauner [25] has used the potassium permaganate titration of tel-

[17] *Fres. Zeit.*, 11, 437 (1872).
[18] *Fres. Zeit.*, 13, 142 (1874).
[19] *Chem. News*, 87, 163 (1903).
[20] *Zeit. Anor. Chem.*, 5, 214 (1890).
[21] *Fres. Zeit.*, 30, 707 (1891).
[22] *Journ. Chem. Soc.*, 59, 238 (1891).
[23] *Journ. Amer. Chem. Soc.*, 45, 1423 (1922).
[24] *Journ. Amer. Chem. Soc.*, 48, 139 (1925).
[25] *Monatshefte*, 12, 34 (1891).

lurite and tellurate. He has worked with an excess of permaganate followed by an excess of oxalic acid and back titrates with standard permanganate. Gooch[26] and his collaborators have followed the same lines. Norris and Fay[27] add an excess of sodium hydroxide and follow with permanganate. The solution is then chilled and treated with potassium iodide and sulphuric acid, after which it is titrated with sodium thiosulphate. This procedure is modified by Gooch and Peters[28] by titrating the iodine by a sodium arsenite solution. Gooch and Morgan[29] suggest the precipitation of TeI_4 in a solution containing 25 per cent. free sulphuric acid. The end point of the titration is the complete precipitation of the iodide in a potassium iodide solution.

Gooch and Howland[30] have used the principle of boiling telluric acid with potassium bromide and diluted sulphuric acid, bromine is evolved and is absorbed in potassium iodide solution. The liberated iodine is titrated with sodium thiosulphate solution.

Tellurium or non-oxidized tellurium containing compounds, when heated in chlorine gas, yield their tellurium content as volatile tellurium tetrachloride, which is a separation from the elements which form nonvolatile chlorides.

Telluric acid or the tellurates when boiled with hydrochloric acid are reduced with formation of tellurous acid or the tellurites, with evolution of chlorine. This chlorine can be conducted into potassium iodide and the liberated iodine can be titrated with sodium thiosulphate or sodium arsenite. The tellurites or tellurates when heated in a current of hydrochloric acid gas give the volatile compound $TeO_2 2HCL$ with the tellurites and in addition free chlorine with the tellurates. The tellurium in this volatile compound can be determined gravimetrically after absorbing in water.

All of the above described methods will effect the precipitation of tellurium and afford its separation from all of the elements except selenium and gold.

[26] *Amer. Journ. Sc.* (3), 44, 301 (1892); ibid. (4), 8, 125 (1899).
[27] *Am. Chem. Journ.*, 20, 278 (1898).
[28] *Am. Journ. Sc.* (4), 8, 125 (1899).
[29] *Am. Journ. Sc.* (4), 2, 271 (1896).
[30] *Am. Journ. Sc.* (3), 48, 375 (1894).

Since gold is precipitated by the many reducing reagents which precipitate tellurium, its separation from gold in all cases must be made. This is done very simply and since selenium is in many cases co-precipitated with the tellurium, it must also be separated.

Gold is removed from a precipitate containing either selenium or tellurium or both, by treatment with nitric acid of 1.2 sp. gr., the selenium and tellurium will dissolve but the gold will not. The nitric acid solution can be evaporated with excess of hydrochloric acid at a low temperature to avoid loss of selenium and the chlorides are obtained.

When selenium and tellurium are both present in solution, the following methods are suggested:

Selenium and tellurium when together can be separated by the principle of the volatility of selenium chloride from sulfuric acid solution when treated with hydrochloric acid gas. The method was apparently first worked out by Knorr and has been somewhat modified by Scott.[31] This has been later improved by Lenher and D. P. Smith.[32] The method consists in heating a mixture of the selenium and tellurium containing material in a 150 cc. Pyrex flask in presence of concentrated sulphuric acid to a temperature of 300°–330° C. and passing hydrochloric acid gas through this acid solution. The selenium distills as chloride while the tellurium remains behind. The selenium in the distillate is collected in cold water and precipitated by sulphur dioxide while the tellurium remaining in the distilling flask is precipitated by hydrazine and sulphur dioxide after the acid is diluted to a concentration of not over 7 per cent.

The method is accurate for either high or low amounts of selenium or tellurium.

The separation of tellurium from selenium and sulphur by means of potassium cyanide is an old method. The reactions involved were known to Berzelius. As a means of separation, the method was studied by Crookes [33] and by Oppenheim.[34]

The method gives excellent results as a means of separation and

[31] "Standard Methods of Chemical Analysis," Vol. I., 423 (1925).
[32] *Ind. and Eng. Chem.*, 16, 837 (1924).
[33] *Journ. für. Pr. Chem.*, 53, 161 (1851).
[34] *Journ. für. Pr. Chem.*, 71, 266 (1857); ibid., 81, 308 (1860).

preparation of tellurium, but it is of questionable value as an accurate method of separation of the three. The cyanide separation can be conducted either by fusing any sulphur, selenium, or tellurium mixture with potassium cyanide or by treatment of the precipitated elements with a solution of potassium cyanide.

A mixture of the elements or their compounds is conveniently fused with excess of potassium cyanide when the sulphur is converted to sulphocyanate, the selenium to selenocyanate, and the tellurium to potassium telluride. The sulphocyanate and selenocyanate are readily soluble in water to colorless solutions while the telluride is soluble to a purple or permanganate color. This purple-colored solution is decomposed by bubbling a current of air through it when elementary tellurium is precipitated. This tellurium can be collected on a Gooch crucible and washed thoroughly with hot water and weighed. The results are slightly low due to loss by volatization in the fusion or by slight oxidation of the telluride to tellurite. It is possible to recover this oxidized tellurium but the procedure involves considerable manipulation. To avoid the formation of tellurite, it has been suggested, to conduct the cyanide fusion in an atmosphere of hydrogen.

The solution containing selenocyanate and sulphocyanate after treatment with air, yields red elementary selenium when treated with hydrochloric acid, evolving at the same time large quantities of poisonous hydrocyanic acid; the operation must therefore be conducted *in a good hood*. The selenium can be collected, washed well, dried, and weighed. The sulphocyanate does not interfere in any way. The small amount of tellurite formed in the fusion is found in the final solution from which it is recovered by means of sulphur dioxide and hydrazine hydrochloride.

Selenium and tellurium can also be separated by boiling the precipitated elements with a solution of potassium cyanide which will dissolve the selenium. The mechanical details of the treatment subsequently are exactly the same as when a cyanide fusion is made.

The method of precipitation of elementary tellurium by sugar in alkaline solution suggested by Stolba [35] gives all of the tellurium, but

[35] *Fres. Zeit.*, 11, 437 (1872).

on long boiling or standing a small amount of selenium separates out, hence the method has not worked successfully as a quantitative separation.

Both ferrous sulphate and phosphorous acid which precipitate elementary selenium but not tellurium have not proven satisfactory quantitative procedures.

The formation of insoluble tellurium dioxide by boiling of the acetic acid solution has proven to be of great value in the separation of tellurium from the readily soluble selenious acid. The procedure recommended by Browning and Flint [26] is to treat a dilute hydrochloric acid solution of the oxides with dilute ammonia in slight excess, followed by the slightest excess of acetic acid. Crystalline tellurium dioxide is precipitated by boiling while the selenium remains in the filtrate. The dioxide of tellurium can be dried at 105°.

The differential volatility of the bromides has been made the basis of a separation by Gooch and Pierce.[37] They dissolve the oxides in potassium hydroxide, add an excess of phosphoric acid, add potassium bromide, and distil in carbon dioxide. The bromide of selenium distils and liberates iodine which is titrated by sodium thiosulphate. The bromide of tellurium does not volatilize, hence remains in the distilling apparatus.

The separation of selenium and tellurium can be conducted with excellent results by means of hydroxylamine hydrochloride in the presence of hydrochloric acid and of certain organic acids. Hydroxylamine hydrochloride under certain definite conditions will precipitate selenium but not tellurium.

The proper concentration of hydrochloric acid, when it is used, is essential, 17 per cent. concentration or a density of 1.085 is recommended. If the acid be more concentrated, selenium may be distilled; if the acid be more dilute, the selenium precipitation will be much delayed. Further, if quite dilute hydrochloric acid be used, hydrolysis of tellurium tetrachloride takes place, with the precipitation of tellurium dioxide.

The procedure is to use a half gram or less of the mixed oxides,

[26] *Am. Journ. Sc.* (4), 28, 112 (1909).
[37] *Am. Journ. Sc.* (4), 1, 181 (1896).

dissolved in 35–45 cc. of concentrated hydrochloric acid in the cold and diluted to 100 cc. with water. To this is added 10 cc. of a 25 per cent. solution of hydroxylamine hydrochloride and the solution heated for four hours. Black selenium is precipitated and with the conditions as given the selenium will not be precipitated in the red form and is free from occluded substances as will invariably occur in the precipitation of red selenium by sulphur dioxide in the cold and then transforming by heat into the gray or black variety.

The black selenium can be brought on a Gooch filter, washed with water, then alcohol to displace the water and dried at 110°.

The filtrate is evaporated to 50 cc. on a steam bath, 15 cc. of a saturated solution of sulphur dioxide is added followed by 10 cc. of a 15 per cent. solution of hydrazine hydrochloride, then 25 cc. more of the sulphur dioxide solution; complete precipitation of the tellurium is effected in five minutes, when the tellurium is transferred to a Gooch filter, washed with water, followed by alcohol and dried at 110°.

In the presence of tartaric acid, hydroxylamine hydrochloride precipitates selenium completely but not tellurium. The manipulation is as follows: The mixture of the two oxides is dissolved in the least possible excess of sodium hydroxide, a 25 per cent. tartaric acid is added until the precipitated tellurium dioxide just redissolves, then 25 cc. more are added. The solution is diluted to 100 cc. heated to 90° and 10 cc. of a 25 per cent. solution of hydroxylamine hydrochloride are added. The mixture is kept at 90° for four hours. Selenium is precipitated and can be washed with water followed by alcohol dried at 110° and weighed.

The filtrate from the selenium is concentrated to 50 cc. and the tellurium is best precipitated by hydrazine hydrochloride and sulphur dioxide using the Lenher-Homberger method.

In the presence of citric acid, the oxides of selenium and tellurium are dissolved in sodium hydroxide, a solution of 3–5 per cent. of citric acid is added, the solution is diluted to 100 cc. and 10 cc. of a 25 per cent. solution of hydroxylamine hydrochloride are added. The selenium is then precipitated by heating to 90° for four hours, when the selenium is brought on a Gooch crucible washed with

water, and alcohol, after which it is dried at 110° and weighed. The tellurium filtrate is concentrated to 50 cc. and precipitated by the Lenher-Hamberger method.

In the separation of selenium and tellurium by hydroxylamine hydrochloride in presence of hydrochloric acid, tartaric or citric acid, it is essential that the hydrochloride of hydrazine be used and not the sulphate, since the sulphate invariably gives low results.

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THE GROWTH OF FUNCTIONAL NEURONES AND ITS RELATION TO THE DEVELOPMENT OF BEHAVIOR.

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(*Read April 23d, 1926.*)

The purpose of this paper is to indicate briefly the trend of our investigations upon the growth of the nervous system as related to the development of behavior in *Amblystoma,* and to indicate the bearing of certain of our definite results upon the problem of development of behavior and learning. Some of the more general results and conclusions may be presented under five topics.

1. The Early Behavior Pattern and its Anatomical Explanation.

The form of the behavior pattern develops according to a regular sequence of newly-acquired movements until locomotion is attained.

The earliest responses consist of a movement of the head to one side. As the embryo grows older this movement involves more and more of the trunk until finally the entire trunk bends into a tight coil. During this time the movements normally begin in the head region and progress tailward. The embryo of this coil stage can bend the body in only one direction, either the right or the left, at any particular moment. But it soon happens that a flexure which begins in the head region and progresses tailward is reversed in the head region before it has passed entirely through the trunk. A series of quick flexures in alternating directions, each passing rapidly tailward, drives the animal forward, and locomotion is perfected. During the larger part of this period nearly all movements are away from the stimulated side—that is to say, they are of the nature of avoiding reactions.

The order of sequence in the appearance of new movements is correlated with the development of specific structures in the nervous

motor system. The appearance of movement first in the anterior part of the trunk is explained by the higher development of the motor nerves in that region, and as the motor nerves increase their spread to the muscles farther tailward the movements involve more of the trunk. The movements individually progress from the head tailward because stimuli from all parts of the animal enter the motor tract through commissural cells and these cells exist only in the anterior part of the spinal cord and in the lower part of the brain. The avoiding nature of the early response is explained by the fact that afferent neurones of the first and second order pass across the motor tract of the same side and have synapse with the commissural cells which convey the excitation to the motor tract of the opposite side. The appearance of rapidly reversed flexures to produce locomotion is explained by the growth of collaterals from the motor tract cells into synapse with commissural cells in such a way that a stimulus which passes to the muscles of one side reaches a little later the muscles of the opposite side.

The mechanism of the avoiding reaction, being prerequisite to the first responses to tactile stimulation, can not be activated or determined in its origin by the responses or their behavior value. For the same reason the collaterals from the motor tract which introduce the serial reversed flexures and locomotion also cannot be activated or directed in their growth by such general agencies as exercise or experience. There is no evidence that experience or exercise even hastens the appearance of the various types of reaction, while there is very positive evidence that these factors can have no causal relation to the form of the behavior pattern during this period. The specificity of these nervous structures in terms of behavior is determined by laws of growth in which behavior-values of the patterns of response have no part.

2. Growth of Functional Neurones and the Integrity of the Organism.

In the development of the structural counterpart of the behavior pattern, neurones that are active elements in the earlier mechanisms of control extend their function by growth of their axones into new

parts, and in so doing insure the integration of the organism as a whole during development.

This is illustrated in the case of the development of the limbs, the tongue and the eye muscles, the non-functional rudiments of which are invaded by nerve fibers that grow from cells that are at the same time participating in the integration of the trunk. The relative independence of these organ systems can not, therefore, be primary. It must be secondarily attained by a process of individuation within a totally integrated system, and the development of the behavior pattern must be effected, not by an integration of independent reflexes, as is usually considered, but by a process of individuation within a total organismic system which is from the beginning of reaction integrated as a whole. The basic principle, therefore, in the development of the nervous system of vertebrates, appears to be the maintenance of the integrity of the individual while independencies are growing up within it, and are, so to speak, struggling for ascendency among themselves and for dominance over the individual.

This fact, particularly should it be found to apply to mammals, must have important bearing on psychology and education. It is in harmony with the conception of "mental configuration" as outlined by Koffka.[1] According to this psychological interpretation the first or elementary "phenomena" in consciousness are not pure sensations or independent, isolated units of reaction; they are "qualities upon a ground." This, translated into anatomical and physiological terms, means that, as actually occurs in Amblystoma, behavior develops by individuation of elements within a primary unity, and not by integration of primarily independent elements into a total pattern.

3. Progressive Mechanization of Association Systems.

The early growth of association neurones into the motor mechanism introduces unpredictable elements in behavior; but as the growth of the association neurones into the motor mechanism advances there is progressive mechanization of the association system into the motor type of organization and action.

As the embryo approaches the swimming stage, or passes it slightly, the movements are more irregular in direction with reference

[1] Kurt Koffka, "The Growth of the Mind." Translation by Ogden (1924).

ence to the side stimulated. However, if at this time the major part of the trunk be cut away from the first three or four segments, the avoiding reaction of the head piece returns to its typical regularity. This is evidence that there is antagonism between exteroceptive and proprioceptive stimuli, and it is correlated with the growth of collaterals from the axones of sensory cells of the second order into the motor tract of the same side. The original, main divisions of these axones have synapse with commissural cells, by reason of which the earlier movements are mostly away from the side touched. The sensory or association cells concerned in this response belong to the series from which Deiters' nucleus develops, the mechanized function of which in the equilibration of the body is well known.

This seems to be a clear case of progressive mechanization of an association system, the early growth of which introduces unpredictable elements of behavior whereas maturation of the structure results in stereotyped performance. This is essentially a neuro-embryological statement of conditioning of reflexes, and habit formation.

4. Growth and Learning.

There is considerable support for the hypothesis that neurones of the adult cerebral cortex grow while they function, as do those of the lower part of the brain and spinal cord in the earlier period. If this hypothesis proves to be correct it would appear that stimuli that are simultaneous, or nearly so, must necessarily become associated in the cerebral cortex through synapses that are newly formed, while they must also become associated with past experience because those newly-formed synapses which they traverse are outgrowths of the already functional system, which also has grown up according to the same principle. By this correlation of growth and function in the neurone, structural relations in the nervous system may be regarded as acquiring specificity with reference to receptor-effector functions, and in this manner structural counterparts of experience may be established, that is to say, structural systems may be formed, the action of which at any time would have the same significance to the organism as did the experience which originally excited their action.

5. A New Approach to Neurological Problems.

That nerve cells grow after they have acquired their definitive function and that such growth is a factor in the development of behavior was proposed as early as 1893 by Tanzi [2] and in 1895 by S. R. Cajal.[3] Both of these investigators, however, regarded such growth as activated by nervous function or exercise. But we find no evidence that the growth of nerve cells in *Amblystoma* is stimulated by nervous functions. Indeed, there is very strong evidence against this hypothesis. Within the motor mechanism at least the behavior value of a new performance can have no causal relation to the growth of those structures which make it possible; and forced exercise and stimulation do not perceptibly hasten the development of the behavior pattern. Contrary to Tanzi and Cajal, we believe that nerve cells grow by their own intrinsic potentiality, and that nervous mechanisms while growing acquire their specificity in behavior through the primary correlation of their growth processes with receptor and effector functions. According to this concept, the efficiency of a nervous mechanism in the sphere of adaptation depends not only upon the perfection of its receptor, conductor, and effector functions, but primarily upon its potentialities of growth. "Plasticity" becomes a function of growth. A normally growing nervous system may become perverted or asocial through experience, whereas, in a favorable environment, abnormal psychoses may be caused by arrested growth.

This conception of the relation of growth of neurones to the development of behavior is essentially different from that proposed by Cajal. It lends new interest to anatomy and embryology and opens a new approach to problems of psychology, psychiatry and education.[4]

[2] Tanzi, see Cajal (footnote 3), l.c., p. 886 (1893).

[3] S. Ramon Cajal, "Histologie du Système Nerveux," Tome 2, pp. 887–890 (1911).

[4] For the author's contributions on this subject see *Journal of Comparative Neurology*, Vols. 23, 24, 26, 37, and 41 (in press).

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MEDITERRANEAN GARIGUE AND MACCHIA.

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As indicated in a number of papers by the writer, the comparative study of types of vegetation always proves profitable in the advancement of ecology and plant geography. Our ecologic concepts can be clarified by such comparison. The Mediterranean plant associations can be studied in connection with those of southern coastal California where somewhat similar climatic conditions exist. The writer has seen the chaparral of California in the foothills of the Sierra Nevada mountains, on the hills around San Diego, and on the slopes of Mt. Tamalpais and in the course in forest botany, ecology and plant geography which he has given at the University of Pennsylvania, he has compared chaparral with garigue and macchia of the Mediterranean shores. So with this background of knowledge and with the comparative method in mind, he visited the coasts of the Mediterranean during the summer of 1923, examined these two scrub associations, took photographs and made collections of the plants that were in evidence during the summer months.

Garigue and Macchia.

Garigue is usually a somewhat open association of dwarf evergreen shrubs and trees mingling with the characteristic herbaceous plants that thrive during the summer under somewhat semi-arid conditions. Sometimes the shrubs and low trees grow close together and the intervals of soil between the plants disappear. Again the plants under sterile conditions become more widely spaced with considerable blank areas of soil. Macchia, or maqui, is an association of somewhat similar physiognomic aspect to garigue, consisting of low evergreen shrubs and trees with associated species, but it usually occurs on siliceous, or noncalcareous rocks, with soil derived from them. The constituent species are crowded more, and there-

fore the association is more nearly a closed one. Garigue and macchia are in some respects related to heath vegetation. This is particularly true of those associations which occur in the Spanish districts of Old Castile and Leon which are sometimes confused with macchia. In the tomillares, as one of these associations is called, exist *Thymus* (tomillo), *Lavandula Stoechas, Salvia* and other LABIATAE, and the other, called jarales, is characterized by the dominance of *Cistus ladaniferus, Cistus laurifolius,* and *Cistus monspeliensis,* covering thousands of square kilometers. Eastward in Southern Europe, we find a transition from macchia to the sibljak in the Balkans, where the evergreen shrubs are gradually replaced by those with deciduous leaves, such as *Paliurus australis, Phillyrea augustifolia, Rhus Coriaria, Syringa vulgaris, Viburnum Lantana* and *Zizyphus lotoides,* so that in summer macchia and sibljak have a somewhat similar physiognomy. So too we may compare the characteristic scrub association of Greece, the phrygana, where spring plants and bushes are dominant, such as *Poterium spinosum, Stachys spinosa, Verbascum spinosum,* and species of *Astragalus.*

There seems to be some diversity of opinion among plant ecologists as to the status of garigue and macchia. One group of phytogeographers believes that originally the coasts of southern Europe were forested down to the edge of the Mediterranean Sea in prehistoric times and that with the encroachment of cities, towns and cultivated areas and the removal of the forests for domestic and commercial purposes the country was denuded of its timber. As a result of this action on the part of man the sterile soils which have been reclothed with the native plants of the region have not been covered with forest trees, but in the natural process of succession have been tenanted by shrubs of evergreen character which prevail at the present time along these coasts. Other phytogeographers believe that garigue and macchia are climatic associations and have been present from prehistoric times. At the present day, however, such associations, confined originally to restricted areas determined by the stress of climatic and soil conditions, have spread gradually with the destruction and misuse of the primeval forests until they have covered extensive areas which would grow up to forests again if the

conditions became favorable once more. The writer believes that the second alternative is the one which explains best the facts as he has seen them in Southern France.

Garigue.

Back of Montpellier in southern France are limestone hills where the rock has been weathered into fragments of variable size with a few outcrops in the form of ledges and hogbacks. These limestone areas are covered with garigue. The most accessible garigue to Montpellier is at Castelnar. Here considerable areas of country are uncultivated, because they are too rough, and so the natural vegetation is supreme. The botanist is impressed with the barrenness of the soil, but yet the familiar fact appears that there are plants that will thrive under such conditions. The garigue at Castelnar is a somewhat open association, although in places the shrubs come together to form a close ground cover. The dominant shrubs arranged alphabetically are: *Cistus monspeliensis* (Fig. 1), *Paliurus australis, Quercus coccifera* and *Rhamnus alaternus.* The evergreen, holm oak, *Quercus ilex,* raises itself as a small tree above the dominant shrubs, but it is rather scattered, although it shows a lusty growth (Fig. 2). There is some evidence that it was more abundant and subdominant, but has been cut down for fuel and other purposes in a region where the wood supply is scarce. If this is the correct view as to the dominance of the holm oak, then in earlier times the country back of Montpellier was covered with holm oak forest with an undergrowth comprising the present dominant species of the garigue. The undershrubs of the present garigue that grow one to six feet high are: *Daphne Gnidium* (26 feet) (Fig. 3), *Helichrysum Stoechas* (1 foot), *Lavandula spica* (1–2 feet), *Lonicera implexa* (3–6 feet), *Osyris alba* (3 feet), *Thymus vulgaris* (1 foot), Two evergreen climbers are noteworthy constituents of the garigue, viz: *Rubia peregrina* and *Smilax aspera* (prickly) both evergreen and the shrubby vine, *Clematis Flammula.* The herbs collected by me comprise *Biscutella laevigata,* the grass, *Brachypodium ramosum, Cephalaria joppica* and *Sium erectum.* At the edge of the uncultivated garigue, the aleppo pine, *Pinus halepensis,* occurs in tall specimens (Fig. 4).

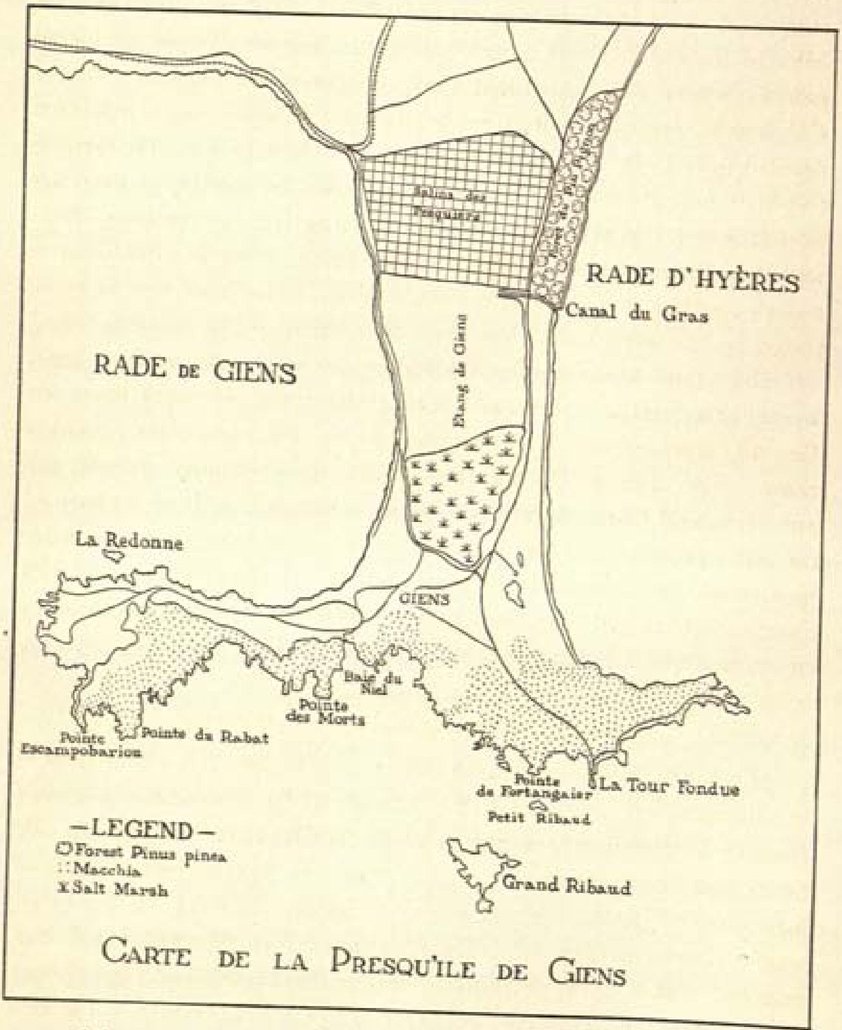
Accompanied by Dr. Herman Knoche the writer was impressed as to the physiognomy of the Montpellier garigue, by the fact that nowhere in that association was Dr. Knoche hid from sight by the shrubby ground cover (Fig. 3). In fact the shrubs and undershrubs reached only waist high. The low dwarf habit of the principal species was very noteworthy forming a continuous cover where the soil was less stony and more fertile, and thinning out into a scattered growth where the soil became more rocky, where hogbacks projected, and where on the steep hill slopes either through erosion, or the utter hardness and consequent barrenness of the soil, the constituent plants of the garigue were not offered conditions conducive to growth.

Macchia.

The macchia investigated by the writer is located on the shores of the Mediterranean at the apex of the Peninsula of Hyeres, or Giens (Presque Ile de Giens) along the bay La Tour Fondue within sight of the Isle of Porquerolles (L'Ile de Porquerolles) and the smaller island Grand Ribaud. The peninsula is T-shaped, connected by the stem of the T with the mainland (see map in text). The outer portion of the peninsula is hilly with red shale as the outcropping rock (non-calcareous). The shale rock is covered with the macchia here in undisturbed possession of the hills and extending down to the edge of the cliffs fronting the Mediterranean Sea. The long arm of the peninsula is characterized by a sandy dune-like stretch on one side, salt marshes and saltings on the other. At the saltings, the salt water is evaporated and converted into salt, which is stored in large heaps covered with red tiles for protection against the rain. Along the sandy stretch is found one of the best examples of the stone pine (*Pinus pinea*), forest along the Riviera (see map).

The taller shrubs of the macchia are the following: the tree heath (*Erica arborea*) (Fig. 5), the juniper (*Juniperus phoeniceus*) (Fig. 6), the myrtle (*Mytrus communis*), *Phillyrea media*, the pistache (*Pistacia Lentiscus*) and the holm oak (*Quercus ilex*), which show in their tops the shearing action of the wind, and where isolated they become round-topped, or low dome-shaped. Where the low thicket of constituent shrubs and undershrubs has its outer edge ex-

posed to wind action the shrubs slope in an upward direction from the ground, the dwarfest plants in front and the higher less wind-pruned ones behind. The whole scrub then appears as if skilfully



CARTE DE LA PRESQU'ILE DE GIENS

pruned by gardener's shears. The associated undershrubs fill the interspaces, or spread out on the more exposed hillslopes. Such undershrubs according to my collection comprise *Calycotome spinosa* (Fig. 8), *Cistus monspeliensis*, *Cistus salviaefolius*, *Lonicera implexa*,

and the prickly, woody climber, *Smilax aspera.* All of these woody plants in places form an impenetrable thicket. The general impression is that of a hummocky growth where the hummocks represent the rounded tops of the closely matted shrubbery (Fig. 7). The general color of the vegetation is a dark-green blending with brown and gray patches where the constituents vary in their distribution. Where *Calycotome spinosa* fronts the macchia and is wind-swept, it is of a decided gray color. *Quercus coccifera* is a dark-green color turning to gray where its branches have been denuded of foliage by wind action (Fig. 8). Where the rock roses (*Cistus*) prevail the areas dominated by them have a brownish-yellow color. *Pistachia Lentiscus* is a dark lustrous green. The maritime pine (*Pinus pinaster*) is prostrated by the wind into a low spreading shrub. The "everlasting" (*Helichrysum Stoechas*) is a shrubby growth about a foot high, woody at its base. "Stoechas" is taken from the old Greek name for Iles d'Hyeres, where this composite plant and *Lavandula Stoechas* grow. The crannies of the cliff faces support *Statice minuta var pubescens* and *Plantago subulata,* while in the rock pools at the base of the cliffs grows *Posidonia oceanica,* which torn loose from its briny habitat is rolled into balls, or aegagropilae, which with its dried and bleached leaves are piled in windrows 5–6 feet thick in the quieter embayments of the shore line.

Maritime Pine Macchia at Hyeres.

If a heath is low vegetation comprising mainly ericaceous undershrubs on a raw humus, and by extension of the idea where oak trees forming a prominent constituent of the heath converts it into an oak heath and the dominance of pine trees into a pine heath, so it is legitimate to extend the garigue and macchia concepts in the same way. Where the cork oak (*Quercus suber*) prevails we can call our macchia Cork Oak Macchia, where the maritime pine *Pinus pinaster* prevails we have a Maritime Pine Macchia. Tansley emphasizes the fact that "while maritime pine is found chiefly on siliceous soil, the Aleppo pine (*Pinus Halepensis*) forms the characteristic woods of the limestone (Fig. 4), though it is not confined to these soils." At Hyeres the dry slate hills are covered with maritime

pine (*Pinus pinaster*), which is tapped for turpentine by using clay cups to catch the resinous flow from the trees. The cork oak (*Quercus suber*) is an associate on the pine, and so is the strawberry tree (*Arbutus unedo*), the juniper (*Juniperus oxycedrus*) and the pistache (*Pistacia Lentiscus*). There are a number of tall shrubs, which form the undergrowth of these pine forests and when the pine trees thin out, they become dominant and completely cover the ground. In the dry slate hills under the pines grow the shrubs: *Calycotome spinosa* (Fig. 5), *Cistus salviaefolius, Erica arborea, Mytrus communis, Phillyrea angustifolia, P. latifolia, Quercus coccifera* (Fig. 8), and the undershrubs *Helichrysum Stoechas, Lavandula Stoechas, Lonicera implexa* and *Staehelina dubia.*

Conclusion.

Our study of the Mediterranean garigue and macchia shows that we are dealing with natural vegetation units. The garigue at Montpellier is not purely a successional association, but exists as such on the barer limestone hills. Where the soil becomes better we find that the holm oak (*Quercus ilex*) probably formed forests in prehistoric times and such areas of garigue where the holm oak is dominant may be termed Holm Oak Garigue (Fig. 2). Similarly on the exposed promontory of the Peninsula of Giens, we find the low shrub thicket dominant and here we have true macchia in the sense in which that term is used by European phytogeographers. More inland near the City of Hyeres, we find a forest in which the undergrowth consists of many of the same species as occur on the exposed promontory of the Peninsula of Giens. Here the maritime pine (*Pinus pinaster*) is dominant. We can call such an association a Maritime Pine Macchia), and if, as suggested by the presence of the cork oak (*Quercus suber*) in this forest, this tree becomes the dominant one and overshadows the shrubby and herbaceous constituents, we have a Cork Oak Macchia. Such a characterization of two of the most important associations of the Mediterranean coast enables us to classify associations which are closely related, and which naturally interdigitate as we travel along the Riviera. It enables us to call associations, garigue and macchia, which have dominant tree species by the addition of a qualifying descriptive term. Thus we have:

FIG. 1. *Cistus monspeliensis*, *Crataegus oxyacantha*, *Lavandula spica*, *Brachypodium ramosum*, etc. Garigue at Castelnar near Montpellier, France. July 6, 1923.

FIG. 2. Tall holm oak (*Quercus ilex*) with *Q. coccifera*, *Rhamnus alaternus*, etc. Garigue at Castelnar, Montpellier.

FIG. 3. *Daphne Gnidium* in the Garigue, Castelnar near Montpellier, France, with Dr. Knoche. July 6, 1923.

FIG. 4. Tall aleppo pines (*Pinus halepensis*) at edge of uncultivated garigue at Castelnar near Montpellier, France. July 6, 1923.

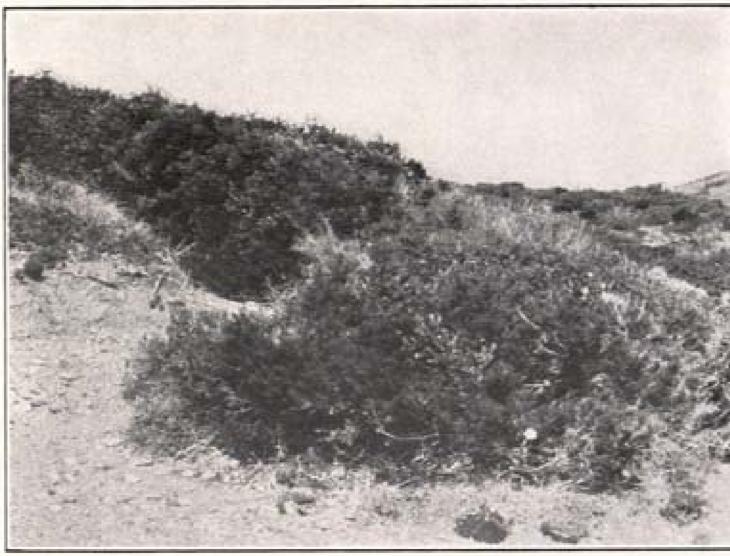


FIG. 5. Almost pure *Erica arborea* with *Calycotome spinosa*. Presqu' ile de Giens near Hyeres, France. July 9, 1923.

FIG. 6. *Juniperus phoeniceus* two feet tall in Macchia. Presqu' ile de Giens near Hyeres, France. July 9, 1923.

FIG. 7. General View of Macchia looking Seaward. Presqu' ile de Giens near Hyeres, France. July 9, 1926.

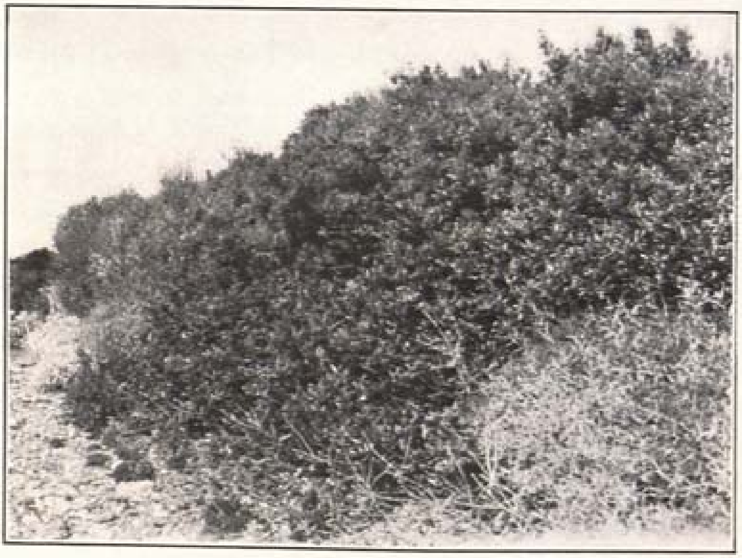


FIG. 8. Close View of Wind-swept Macchia with *Quercus coccifera*, *Erica arborea* and *Calycotome spinosa*. Presqu' ile de Giens near Hyeres, France. July 9, 1923

GARIGUE (On Limestone)	GARIGUE PROPER	Treeless.
	HOLM OAK GARIGUE	With trees.
	ALEPPO PINE GARIGUE	
MACCHIA (On Noncalcareous rocks and soils)	MACCHIA PROPER	Treeless.
	CORK OAK MACCHIA	With trees.
	MARITIME PINE MACCHIA	

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SOME PUZZLING PEPPER LEAVES.

By WILLIAM TRELEASE.

(*Read April 22, 1926.*)

While making descriptive studies of a large number of herbarium specimens of *Piper,* I have stumbled onto occasional leaf-peculiarities that puzzle me.

Piper Amalago, of Jamaica, which had been the subject of examination and publication earlier by Browne and Sloane, was given status as a binominally designated species in 1753 by Linnaeus.

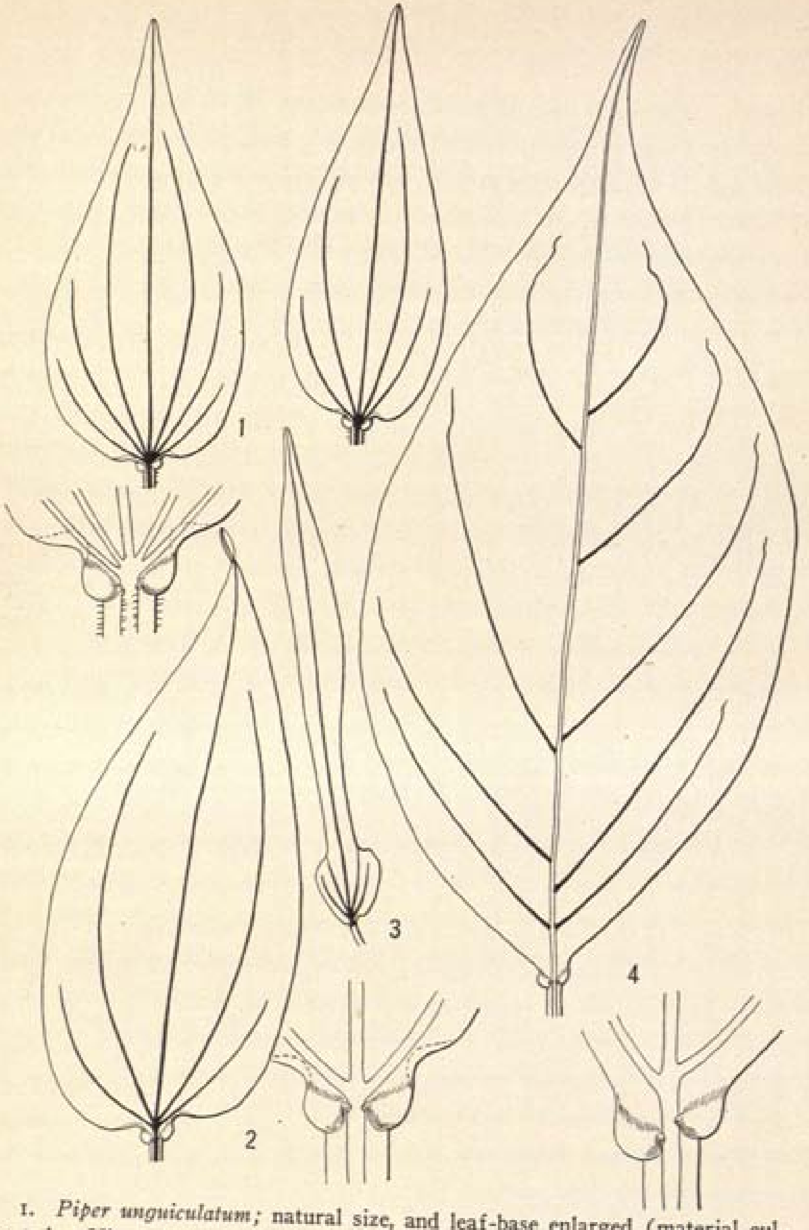
In 1798, Ruiz and Pavon described a Peruvian plant of somewhat the same aspect, which they named *Piper unguiculatum* because the leaves often seem to bear an extremely small lobe or auricle at either side of the blade where this joins the petiole.

In the same publication, Ruiz and Pavon gave the name *Piper callosum* to another Peruvian plant which has small disks—something like the glands of a cherry leaf—at either side of the blade, close to the petiole.

Piper unguiculatum may be taken as illustrative of these structures not only because it first commemorated them in a name and embodied them in a specific description, but because these facts have caused confusion between this Peruvian plant and several North American species that, though distinct, have been identified with it because of a more or less observable " unguiculate " leaf-base.

At first sight, the blade of the leaf often appears here to be prolonged on each side into a small basal lobe, somewhat as in the English oak (*Quercus pedunculata*) or as is the case much more obviously in the large leaves of *Magnolia Fraseri:* but this appearance does not exactly represent the fact.

Though sometimes cordate, usually the leaves of this pepper are rounded or gradually narrowed at base, and in either case the margin flows uniformly onto the upper side of the petiole. What appears to be a lobulation is merely the expression of a crescent-shaped fold-



1. *Piper unguiculatum;* natural size, and leaf-base enlarged (material cultivated at Vienna).

2. *Piper Amalago;* natural size, and leaf-base enlarged (the black-jointer of Jamaica—Robinson).

3. *Piper Amalago subpanduriforme;* natural size (type collection, from Jamaica—Wullschlaegel).

4. *Piper callosum;* natural size, and leaf-base enlarged (type collection of *P. Poeppigii*—Peru, Poeppig).

ing-back of a small part of the margin shortly above the base of the blade, in a way comparable with the notched tip of the pinnules in some species of *Adiantum* among the ferns. Sometimes the margin is more revolute on one side than it is on the other, so that the leaf-base appears unsymmetrical, and often it is lacking on one side or on both sides, especially in the most cordate leaves; but in general it seems to be a characteristic feature of the leaves.

The leaves of the Antillean *Piper Amalago* commonly are revolutely unguiculate in the same manner, as also are those of the related Mexican *Piper terminale* and of several as yet unpublished species of the same country. So far as I have noticed, none of the earlier printed references to these specifically mention this small but rather striking feature of their leaves; but it appears to have been observed in a number of cases if one may judge from the fact that several of them have been mistaken for the Peruvian *Piper unguiculatum*. The same feature appears on some leaves of the curious Jamaican monstrosity of *Piper Amalago* that has been called *Piper subpanduriforme*.

The leaf-base, or apparent lobule, below the inrolled margin, lying against the top of the petiole, finally appears somewhat pouch-like in all of these cases, so that revolute margin and claw cover, without enclosing, a continuous chamber or tunnel partly on the lower side of the leaf-blade and partly on the upper side of the petiole where the blade abuts on the vanishing groove of the leaf-stalk.

Small, at the beginning, when a leaf opens out from the bud, these structures sometimes progressively develop as the leaf grows, and even on the fully grown leaf the basal texture sometimes appears delicate and immature, though the revolute margin itself and the basal lobule may finally become calloused.

These species, *Piper unguiculatum* and *Piper Amalago* and its continental relatives, are of the palmately nerved group sometimes segregated as a subgenus or even as a genus under the name *Enckea*.

On the other hand, *Piper callosum* of Peru and *Piper urophyllum* of Costa Rica are of the pinnately nerved group that has been treated comparably under the sectional or generic name *Artanthe* or *Steffensia*. In the first of these species, there does not appear the cres-

centic inrolling of the margin which causes the unguiculate appearance of the Enckeas; so that the darkening callus-like areas near the base of the blade just where it joins the petiole, lie over the latter rather closely resembling the largest lobules of the *Amalago* series.

Though they appear not to have been mentioned in print, equivalent calluses occur on the leaves of the Costa Rican *Piper urophyllum*, though they are more elongated and laterally displaced here, but otherwise of the *callosum* type.

My purpose in drawing attention to these peculiarities of the leaves of a few peppers is not merely to show that in a sense they are characters usable in the differentiation of species, but to suggest to naturalists living in the tropics the question as to what they are and why they exist. This question as I put it is not entirely one of morphology or of reaction, but of Darwinian teleology as well. The structures occur too frequently to be quite accidental. They fall into that great category the teleological analysis of which furnished Mr. Darwin with most convincing arguments for the idea of correlation, or adaptation in his meaning of the word.

If they are gall-structures they can be only myco-cecidia or fungus-galls, or acaro-cecidia or mite-galls; but if so it is significant that in *Piper unguiculatum*, at least, they occur on greenhouse specimens long cultivated in European and North American greenhouses. If they are domatia in the rather ample sense in which Lundstrom used the word, they can hardly be other than acaro-domatia or mite-domiciles, in the general use of that term. If, as is not evident nor apparently probable yet, they secrete nectar from the enclosed lower leaf-surface, they would fall into Belt's group of extra-floral nectaries and Delpino's subdivision extranuptial nectaries.

Put tersely, the question might be: What *are* these *Piper* lobules or calluses; what *induces* their development; what *function* do they perform; what is their ecologic *significance?* The puzzle then remains: How HAVE THEY COME TO EXIST?

URBANA, ILLINOIS,
March 3, 1926.

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URBANA, ILLINOIS,
March 3, 1926.

THE LAST FIFTEEN YEARS OF PHYSICS.*

By R. A. MILLIKAN,

(*Read April 23, 1926.*)

With full recognition of the tendency of each generation to consider itself important and its contributions to progress unique, I feel altogether confident that the historian of the future will estimate the past thirty years as the most extraordinary in the history of the world up to the present in the number and the fundamental character of the discoveries in physics to which it has given birth, and in the changes brought about by these discoveries in man's conception as to the nature of the physical world in which he lives.

There has been no period at all comparable with it unless it be the period about 300 years ago, which saw the development of Galilean and Newtonian mechanics. This was indeed of incalculable importance for the destinies of the race. The conceptions then introduced are not only the basis of modern *material* civilization, but they were the cause of a very complete change in man's whole intellectual and spiritual outlook—in his philosophy, his religion, and his morals. But the discoveries in physics of the past thirty years justify the expectation, at least, of as great if not greater consequences—consequences, too, which are already beginning to be realized.

To appreciate how stupendous a change these discoveries have already wrought in human thought, it is only necessary to reflect that of the six basic principles which at the end of the nineteenth century acted as the police officers to keep the physical world running in orderly fashion, namely:

(1) The principle of the conservation of the chemical elements,
(2) The principle of the conservation of mass,
(3) The principle of the conservation of energy,

* This paper was prepared both for the Friday evening address of the annual April meeting of the American Philosophical Society and for the 1926 edition of Encyclopædia Britannica.

(4) The principle of the conservation of momentum,
(5) The principle underlying Maxwell's electrodynamics,
(6) The principle of entropy or the second law of thermodynamics,

there is not one the *universal* validity of which has not been recently questioned by serious and competent physicists, while most of them have been definitely proved to be subject to exceptions.

The principle of the conservation of the chemical elements went with the discovery of radioactivity. The principle of the conservation of mass vanished with the experimental discovery of the increase in the mass of the electron with speed as the velocity of light is approached. The principle of the conservation of energy suffered a change in aspect when both experimental and theoretical evidence came forward that energy and mass are interconvertible terms related by the Einstein equation $MC^2 = E$, since in that discovery the ideas of energy and of mass became completely scrambled. The principle of the conservation of momentum is denied *universality* by the quantum theory. The Maxwell equations are violated in atomic mechanics. The principle of entropy was admitted to have exceptions as soon as entropy was interpreted in terms of "probability."

Further, the speed with which new discoveries and new points of view are coming into modern physics shows as yet no abatement. Fifteen years ago it was thought that the revolution had pretty well spent its force, that the main group of new ideas had already been introduced. But a listing of the most outstanding discoveries of the past thirty years shows that the great majority of them belong exclusively to the period here in review—namely, the last fifteen years—and all of them belong at least in part to this period. The immensity of the progress made within it will be best appreciated through a rapid review of this whole list and brief comments upon the origin and the particular significance of each discovery.

1. *The Discovery of the Electron.*—This was a very gradual process covering about 150 years and participated in by many workers—Franklin, Faraday, Weber, Helmholtz, Stoney, Lorentz, Zeeman, J. J. Thomson, Lenard, Townsend, Wilson and others [1]—

[1] "The Electron," Univ. of Chicago Press, Chapters I.–III., 1924.

but the actual isolation and the exact measurement of the electron occupied the first seven years of the period in review,[2] 1910–25.

2. *The Discovery of X-rays.*—This falls clearly outside the present fifteen-year period, but practically the whole of the *quantitative working* out of the properties of X-rays and the great discovery in 1912 of their wave nature [3] lies wholly within it.

3. *The Discovery of Quantum Mechanics.*—This began at about the year 1900 with the work of Planck, but the last fifteen years have contributed enormously to it, as will appear as the enumeration of discoveries proceeds.

4. *The Discovery of the Principle of Relativity.*—Though the special principle dates from about 1905 and therefore lies within the first half of the last thirty-year period, the formulation by Einstein of the general principle belongs wholly to the period in review. Its birthday was in 1915, and its most precise and significant experimental verification through the measurement of the bending of starlight in going past the rim of the sun, the discovery of the enormous spectral shift of lines coming from the campanion of Sirius,[4] and the beautifully consistent measurements of the displacements of solar spectral lines,[5] has all been the work of the past few years. It is too early to estimate the significance of D. C. Miller's very recent observations on ether drift.

5. *The Discovery of Radioactivity.*—This belongs indeed wholly to the first half of the thirty-year period, but the definite proof that lead is a product of the radioactive disintegration of both uranium and thorium, and the application of this fact to the fixing of the minimum age of certain uraninites from the Black Hills in Dakota as 1,677,000 years,[6] to take but a single concrete case, is very new and marks an important advance in the process of elaborating a very much more definite geologic time scale than has heretofore been available.

6. *The Discovery of the Nuclear Atom* through the experiments on α-ray scattering begun about 1912 and carried on for ten years,

[2] Millikan, *Phil. Mag.*, July, 1917. See also "The Electron."

[3] Von Laue, Friedrich and Knipping, *Sitz. Ber der München Akad.*, 1912, also Jahrbuch fur Radioaktivitat u Elektronik, II., 308, 1914.

[4] Walter A. Adams, Mt. Wilson Observatory Contributions, 1925.

[5] Charles E. St. John, Mt. Wilson Observatory Contributions, 1925.

[6] C. W. Davis, *Amer. Jr. Science*, March, 1926.

mostly at Manchester and at Cambridge, England,[7] falls wholly within the last fifteen-year period and has been epoch-making in its consequences.

7. *The Discovery of Crystal Structures* through the aid of X-ray spectroscopy[8] dates from only 1913. It has completely revolutionized crystallography and opened up a new world of definite knowledge about molecular and atomic arrangements in solids.

8. *The Discovery of Atomic Numbers* (1913–1924) and the definite fixing of the total number of possible elements between hydrogen and uranium as 92,[9] both being included, is perhaps the most beautiful and the most simplifying discovery ever made. Nature never came so near surrendering herself to her lover without reserve and revealing herself in beautiful and simple grandeur as when Moseley found that all the elements fitted into a single arithmetical progression—a progression, too, which could mean nothing except that the positive charge on the nucleus of each atom moved up by unit steps from 1 to 92 in going from hydrogen to uranium—a progression which at once robbed atomic weights of their long-usurped right to act as arbiters of the chemical destinies of atoms, and restored this place to its legitimate possessor, the electrical charge of the nucleus. Some day a poet will arise who will make an epic for the ages out of young Moseley's discovery. The X-ray spectroscopists[10] and those who have recently extended the X-ray laws into the field of optics,[11] have contributed to the establishment of the complete generality of the Moseley progression, but they have but finished the structure which he designed.

9. *The Discovery that the Energy Communicated to Electrons by Ether Waves is Proportional to the Frequency of the Absorbed Waves.*—This was vaguely suggested by Planck in 1900, more specifically by Einstein in 1905, but the experimental proof of its correctness is perhaps the most momentous achievement of modern physics, and

[7] Rutherford, Geiger, Marsden and Chadwick, *Phil. Mag.*, 21, 699, 1911; 25, 604, 1913; 40, 734, 1920; 42, 933, 1922.

[8] Bragg, "X-rays and Crystal Structure," Bell, London, 1916. See also Ewald, Kristalle u. Rontgenstrahlen, Springer, Berlin, 1923.

[9] Moseley, *Phil. Mag.*, 26, 1024, 1913; 27, 1914, 703.

[10] Siegbahn, "Spektroskopic der Rontgenstrahlen," Springer, Berlin, 1923.

[11] Millikan and Bowen, *Physical Review*, 1925.

it has all come about since 1912. The achievement is momentous not merely because the equation $\frac{1}{2} mv^2 = h\nu - P$ ranks with the equations of Maxwell in its consequences, but because the relation itself is new, undreamed of in 1895, and altogether revolutionary, demanding a return to some elements of the corpuscular theory of ether waves. It was proved first very exactly in photoelectric experiments with light waves,[12] then during and after the war with X-rays,[13] and then with γ-rays. Most of the preceding discoveries were wonderful *additions* to knowledge, explorations in heretofore unknown fields but not subversive of established conceptions. This one, however, wrought havoc with existing theories and demanded a new formulation of ideas about the relations of ether physics and matter physics. Its significance for the future can scarcely be overstated.

10. *The Discovery of the Meaning of Spectral Lines.*—Bohr [14] in setting up his theory of atomic structure merely generalized the preceding relation. With unusual insight into the method of constructive science, he incorporated all the past and merely superposed upon celestial mechanics the assumption, almost inevitable (if Einstein's equation is correct) that when an ether wave is *emitted*, as well as when it is being absorbed, the foregoing relation between energy and frequency still holds, *i.e.*, that the emitted wave frequency is given by $E_2 - E_1 = h\nu$, the E_2 and E_1 being the electronic energy before and after emission. Combining this with the experimentally established Ritz-Balmer equation, he brought out sharply the unitary or atomic character of angular momentum, clearly one of the two or three most fundamental discoveries of all time, for it will presumably always be the basis of all atomic mechanics. It had been dimly glimpsed before in the work of Planck and Einstein, definitely stated by Nicholson and Ehrenfest, but from Bohr's time on quantum theory took on a definiteness, almost a visualizability before unknown.

[12] "The Electron," Chapter 10.

[13] Duane, *Physical Review*, 7, 599, 1916; 9, 568, 1916; 10, 93 and 624, 1917; de Broglie, Third Solvey Congress, 1921; Ellis, *Proc. Roy Soc.*, 99, 261, 1921; also same Jan., 1924.

[14] N. Bohr, *Phil. Mag.*, 26, –1, 476, 857, 1913. See also "The Electron," Chapter 9.

11. *The Discovery of Isotopes.*—This discovery did not begin to be made until 1913, when chemists and physicists approached it from two different angles; first, the chemistry of the radioactive elements, and, second, positive ray analysis.[15] It was completed only after ten years of work by physicists in analyzing by positive ray methods forty-six of the first fifty-five elements of the periodic table. Its significance lies in the four following facts: first, that it has resurrected completely the discredited and amazingly simple Prout hypothesis that the masses of all atoms are exact multiples of the mass of a primordial atom; second, that it has enabled us to count with certainty the exact number of positive and negative electrons inside every nucleus—positives being equal in number to the atomic weight, negatives to the atomic weight minus the atomic number; third, that the failure of hydrogen to fit exactly into the above scheme constitutes excellent evidence for the Einstein conclusion as to the interconvertibility of mass and energy; and fourth, that the difference in stability (decay-time) of radioactive isotopes suggests new possibilities in the reading of the structure of the nucleus, *i.e.*, it gives us new eyes for peering inside the tiniest organism yet found—the nucleus of the atom.

12. *The Discovery of "the Excited Atom."*—The purely theoretical reflections in 1921 of two mere youths in Denmark, Klein and Rosseland, resulting in the proof that if atoms can be thrown by impact, as experiment shows that they can, into a quantum state of higher energy than the normal—appropriately called an excited state—then unless the second law of thermodynamics is to be violated, there must be a heretofore unrecognized mechanism by which an excited atom can return to its normal state without radiating at all, but rather by throwing back all the potential energy of its excited condition through a so-called "collision of the second kind" into an electron or an atom projected from the collision with a kinetic energy that may be 100 times the average energy of molecular agitation. This is a very recent discovery of the first magnitude and of possibly immeasurable significance. It has already made it possible through the work of the experimental

[15] See Aston's Isotopes, London, 1922.

physicist[16] to see a collision-mechanism by which a negligible number of mercury atoms can absorb ether-wave radiations and transfer that energy to the act of exciting thallium atoms to radiate their characteristic frequencies. It for the first time reveals a definite mechanism, sought in vain by the best thinkers of the nineteenth century, by which the energy of either waves may be absorbed by matter and transformed into heat. It takes in one case, at least, the mystery out of the words "catalytic agent." It suggests why very minute quantities of vitamines, etc., may be the intermediaries through which very vital processes are brought about. It makes the future bright with promise for the better understanding of explosive processes. Indeed, the properties of excited atoms may be the foundations of a new era in both industrial and biological science.

13. *The Discovery of the Artificial Disintegrability of Atoms.*—This was glimpsed about 1912 through the appearance of hydrogen lines where hydrogen unless artificially produced from other elements should not have been present, and new claims of spectroscopic evidence of a similar sort are now being advanced, but the unambiguous proof is contained in Rutherford's[17] direct experiments showing that hydrogen atoms can be knocked out of other atoms by alpha ray bombardment. The method shares with that which will introduce new resolution into the study of the masses of isotopes, the promise for the future reading of the conditions of the electrons within the nucleus.

14. *The Discovery of Relativity Inside the Atom.*—It was as late as 1915 before Sommerfeld[18] began his wonderful work on the interpretation of the fine structure of spectral lines—work which began for the first time to reveal the correct principles underlying quantization, finally so penetratingly formulated by Epstein. Seldom in the history of physics have purely theoretical formulæ had such amazing successes in the field of precise prediction as have Sommerfeld's relativity-doublet formulæ and Epstein's extension of the same

[16] See Loria, *Phys. Rev.*, Nov. 1925, and *Proc. Nat. Acad.*, Dec., 1925, for review of experimental work of Franck, Caria, Donat and Loria.

[17] Rutherford and pupils, *Phil. Mag.*, 1920–1925.

[18] Sommerfeld "Atomban u. Spectrallinien," Vieweg u. Sohn Braunschweig, 1924, Chapter 6.

sort of orbit considerations to the prediction of the number and character of the multiplicity of lines found in the Stark effect. The whole interpretation of spectroscopic fine structure through changes in so-called azimuthal and inner quantum numbers is one of the great achievements of all time resulting from the interplay between penetrating theoretical analyses and skillful and refined experimental technique.

15. *The Discovery of New Experimental Techniques for Seeing Invisible Ether Waves.*—Such long-wave technique [19] has completely bridged within the past two years the gap between artificial electromagnetic waves and heat waves, and in the short-wave region hot-spark vacuum spectrometry [20] and beta ray methods of analysis have practically filled in completely the gap between the optical and the X-ray fields, while far above even the gamma rays of radium a new group of rays of well-nigh infinitely high frequency has been found. (See below.) This continuous passage of frequencies from a thousand billion billion per second, over into the zero frequency, *i.e.*, over into static electrical fields, all these waves possessing identical characteristics as to speed of propagation, as to polarization, and as to relations of electric and magnetic vectors, demands one and the same sort of transmitting mechanism or medium to take care of them all, by whatever name it may be called, whether a "world-ether" or "space," this last term meaning no longer emptiness, but emptiness endowed with definite properties, if such hybernism suits one's taste.

16. *The Discovery of New Properties in Conduction Electrons.*—The direct measurement [21] of the mass of conduction electrons, the discovery of a general increase in conductivity with the application of enormous pressures,[22] of superconductivities,[23] and the very recent proof [24] that, when intense electric fields pull conduction electrons out of metals, the energy of thermal agitation assists not at all at ordinary temperatures, but does assist at very high temperatures,

[19] Nichols and Tear, *Phys. Rev.*, 1925.

[20] Millikan, *Astro. Phy. Jr.* for 1920, and Millikan and Bowen, *Phys. Rev.*, 1923 and 1925.

[21] Tolman, R. C., *Phys. Rev.*, 1920–1923.

[22] Bridgman, *Phys. Rev.*, 1925.

[23] Kammerlingh Onnes, Contributions from the Univ. of Leiden, 1910–1925.

[24] Millikan and Eyring, *Phys. Rev.*, Jan. 1926.

all these recent discoveries, especially the last, begin to clear up the contradictions in the electron theory of metallic conduction, and to enable the quantum theory of specific heats to be applied in a new and illuminating way to the condition of the electrons in metals. The new results are full of promise for the better understanding in the near future of the moot subject of metallic conduction.

17. *The Discovery of Quantum Jumps Inside the Nucleus.*—The very recent proof [25] that gamma radiations obey the same quantum jump laws obeyed by X-rays and light rays and the still more recent proof that the initial act in a radioactive change is the ejection of an alpha or beta ray—possibly by virtue of the actual loss of mass of the nucleus through electronic settling and the transformation of this mass into the energy of the ray, following the Einstein relation governing the interconvertibility of mass and energy—this is a discovery of importance for the future understanding of one of the most fundamental processes in nature, the growth and transmutation of the elements.

18. *The Discovery that the Law of the Conservation of Momentum is Applicable to the Encounter between a Light Quant and a Free Electron.*—This very recent and very amazing discovery [26] seems to put the final nail into the Einstein conception of radiant energy travelling through space in the form of vibratory light darts of some sort, but at the same time it emphasises the apparent impossibility of the physicist finding in his present stage of development any one consistent and universally applicable scheme of interpretation. It is a discovery of the very first magnitude, one of whose chief values may be to keep the physicist modest and undogmatic, still willing, unlike some scientists and many philosophers, not to take himself too seriously and to recognize that he does not yet know much about ultimate realities.

19. *The Discovery of the Summation of Two or More Quantum Jumps into a Single Monochromatic Ether Wave.*—The very recent proof brought forth first by the properties of band spectra [27] and second by the discovery of two electron jumps through study of pp

[25] Ellis and Rutherford, *Proc. Roy. Soc.*, 1925 and 1926; Meitner, *Zeit f. Phys.*, 1925.

[26] A. H. Compton, *Phys. Rev.*, 1923, 1924 and 1925.

[27] Sommerfeld, "Atomban u. Spectrallinien, Chapter 9."

groups in line spectra,[28] that an atom can integrate the combined energy of two distinct and simultaneous quantum jumps into a single emitted monochromatic wave is of fundamental importance, because of the new light which it throws upon the nature of the act in which a ray of light is born and projected on its way through space. The discovery of two electron jumps uniting into a single monochromatic ether wave seems to preclude the possibility that there is any vibrating mechanism in the atom executing vibrations synchronously with the period of the emitted monochromatic wave. That the atom has this power of transforming, in some as yet mysterious way, the energy of every atomic shudder into a momochromatic ether wave is amazing. Whether we shall ever be able to visualize the process more definitely than we can now no one knows.

20. *The Discovery of the Failure of the Relativity Explanation of all Relativity-doublets.*—The impasse pointed out within a year [29] between the heretofore recognized causes of doublets in optics and in X-rays, an impasse which necessitated the finding of a new cause which would yield exactly the same formula as the relativity cause—a really terrible necessity in view of the extraordinary quantitative success of the purely theoretical formula following from the mere postulation of the change of the mass of the electron with speed—this impasse has apparently just been resolved within two months by two young Dutchmen, Ulenbeck and Goudsmid, who find, "mirabile dictu," that the assumption that every electron in the universe spins with one unit of angular momentum either right-handedly or left-handedly yields a formula of exactly the same form as does the relativity cause. This assumption not only saves the relativity explanation but, combined with it, it furnishes a much better correlation of all present spectroscopic facts than we have heretofore had. It represents probably a fundamental advance in our understanding of the nature of the most nearly ultimate thing with which physics deals, namely, the electron. The physics of the future bids fair to hear much of the spinning electron.

[28] Russel and Saunders, *Astro. Phys.* of 1925; Wentzel, *Zeit. F. Phys.*, 1925; Bowen and Millikan, *Phys. Rev.*, 1925.

[29] Millikan and Bowen, *Phil. Mag.*, 1925.

21. *The Discovery of Cosmic Rays*[30].—That something very fundamental is going on all through space, that nuclear transformations each of enormous energy value corresponding to the fall of an electron through as much as 30,000,000 volts, are actually taking place in all directions about us in the outer stretches of the universe and that the signals of these cosmic changes can be detected here has just been proved. It is a discovery most stimulating to the imagination. Call it the music of the spheres if you wish! Anyway man can hear it now and may some time know more about it.

Of these twenty-one fundamental discoveries at least sixteen fall wholly within the past fifteen-year period, and all of them have belonged in no small degree to it. Physics as yet seems to show no signs of approaching senility. What the future has in store, no man knows, but at present there seems to be well-nigh limitless possibilities ahead for applications even if the pace of discovery should some time slacken.

[30] "High Frequency Cosmic Rays," *Phys. Rev.*, May, June and Sept, 1926.

SAMUEL PIERPONT LANGLEY AND MODERN AVIATION.

By CHARLES D. WALCOTT

One of the most interesting periods in the development of modern aviation,—the pioneering period,—was dominated by my predecessor in office, Professor Samuel Pierpont Langley. Although he made more concrete contributions to the science of flying, perhaps the most important result of his work was the raising of the whole subject from the realm of ridicule and placing it on a solid foundation of facts and definite laws derived from years of scientific study. This change is clearly summarized in a letter from the distinguished engineer, Octave Chanute, written in 1896:

> It is significant, however, that prior to the publication of Doctor Langley's work, it was the rare exception to find engineers and scientists of recognized ability who would fully admit the *possibility* of man being able to solve the twenty-century old problem of aviation. . . . Since the publication of "Experiments in Aërodynamics," however, it is the exception to find an intelligent engineer who disputes the *probability* of the eventual solution of the problem of man-flight. Such has been the change in five years. Incredulity has given way, interest has been aroused in the scientific question, a sound basis has been furnished for experiment, and practical results are being evolved by many workers.

Langley's interest in flights began in his boyhood days, when his wonder was aroused by the mysterious power of hawks and buzzards to sustain themselves in the air and move about at will without apparent motion of the wings. His interest remained dormant, however, until 1886, when he listened to a scientific paper which caused him to conclude that the theories of the flight of birds were not based on sound facts, and he then determined to undertake a scientific attack on the problem of what mechanical power would be required to support and move through the air a given weight. This research he pursued at Allegheny Observatory and at the Smithsonian Institution for three years, studying particularly the important and dis-

puted matters of the resistances and reactions of the air on plane surfaces. In the published results of this work, entitled "Experiments in Aërodynamics" (1891), which attracted immediate attention among physicists in America and in Europe, Langley announced that it was possible to construct machines which would give such a velocity to inclined surfaces that bodies indefinitely heavier than the air could be sustained upon it and moved through it with great velocity. In concrete terms, he declared that a plane surface weighing a little over 200 pounds could be propelled in sustained horizontal flight at a speed of about 45 miles an hour by a force of one horsepower.

In 1893, Langley's second large work in this field was published under the title, "Internal Work of the Wind." He showed that the irregularities of the wind were much more pronounced than had previously been supposed, and that they offered an agency of great possible mechanical importance. He suggested that these irregularities or pulsations in the wind might largely account for the soaring ability of certain birds. This volume also attracted wide attention from physicists in this country and abroad.

As the result of these extended experimental and theoretical studies on the basic problems underlying mechanical flight, Langley was firmly convinced that from a scientific viewpoint there was nothing to prevent such flight. To test his belief, he began at once to build model flying-machines, at first small affairs of various designs powered by rubber-bands, and later steam-driven "aërodromes" of considerable size. Several attempted flights and failures, each teaching its lesson and contributing materially to progress, bring us to May 6, 1896, when aërodrome No. 5 was mounted on its launching device on top of a house boat moored on the Potomac River. The machine, weighing 26 pounds and with 74 square feet of supporting surface, had been minutely inspected by Langley and his mechanics, and everything was in readiness for another test. It was a thrilling moment, not only for Langley but for the eager watchers, among them Alexander Graham Bell. The signal was given. The little plane shot from the launching ways, rose directly in the face of the wind and soared in graceful flight slightly over 3,000 feet, when, its

fuel exhausted, it settled gently into the water and was immediately ready for another flight. The second flight, which followed directly, was equally successful, and for the first time in the history of the world, a heavier-than-air machine had moved through the air under its own power in sustained flight, guided by its own controls.

Shortly after these successful tests, Langley wrote in 1896:

> I have brought to a close the portion of the work which seemed to be specially mine—the demonstration of the practicability of mechanical flight—and for the next stage, which is the commercial and practical development of the idea, it is probable that the world may look to others. The world, indeed, will be supine if it does not realize that a new possibility has come to it, and that the great universal highway overhead is now soon to be opened.

However, in 1898, influenced in part by a natural eagerness to see a man-carrying plane in flight, and by a patriotic desire to be of service to his Government, and assisted financially by the War Department, Langley began the construction of a full-size machine to carry a pilot. Innumerable difficulties were encountered, chief among them being the impossibility of getting a sufficiently powerful engine which was not far too heavy. It was finally found necessary to construct one at the Smithsonian, and this was successfully accomplished by Mr. Charles M. Manly, the engineer who assisted Mr. Langley. The machine was completed in 1903, but on the two occasions on which trials were attempted, it failed to get into the air. These failures, however, were not due to defects in the machine itself.[2]

[2] The machine is now on exhibition in the U. S. National Museum, at Washington, bearing the following label:

"LANGLEY AËRODROME

"THE ORIGINAL LANGLEY FLYING MACHINE OF 1903, RESTORED

"IN THE OPINION OF MANY COMPETENT TO JUDGE, THIS WAS THE FIRST HEAVIER-THAN-AIR CRAFT IN THE HISTORY OF THE WORLD CAPABLE OF SUSTAINED FREE FLIGHT UNDER ITS OWN POWER, CARRYING A MAN.

"THIS AIRCRAFT SLIGHTLY ANTEDATED THE MACHINE DESIGNED AND BUILT BY WILBUR AND ORVILLE WRIGHT, WHICH, ON DECEMBER 17, 1903, WAS THE FIRST IN THE HISTORY OF THE WORLD TO ACCOMPLISH SUSTAINED FREE FLIGHT UNDER ITS OWN POWER, CARRYING A MAN.

Owing to failing health he did not undertake further trials and died in 1906 without seeing a man-driven flying machine in the air, although he had realized the dream of a lifetime when his machine of 1896 flew so successfully under its own controls.

Langley was a true pioneer. He established his own facts, deduced his own laws from them, and applied these facts and laws successfully in the actual flight of large model flying-machines. The marvellous advance in aviation in the last twenty years was stimulated by and to a large extent made possible by the pioneer research work of Samuel Pierpont Langley.

"The aëronautical work of Samuel Pierpont Langley, third Secretary of the Smithsonian Institution, was begun in 1887. By fundamental scientific research he discovered facts, the publication of which largely laid the foundation for modern aviation. Langley designed large model aëroplanes which repeatedly flew in 1896 with automatic stability for long distances. The U. S. War Department, impressed by his success, authorized him to construct a man-carrying machine which was completed in the Smithsonian shops in the spring of 1903. Attempts made to launch it on October 7 and December 8, 1903, failed owing to imperfect operation of the catapult launching device. In these trials the wings and control surfaces were badly damaged and lack of funds prevented other tests at this time. The aëroplane was left by the War Department with the Smithsonian Institution for further experiments. In 1914 (following the foundation by the Institution of the Langley Aërodynamical Laboratory) the experiments were resumed, using all available parts of the original machine. The frame and engine were the same as in the first trials; the reconstructed wings were used without the leading edge extension; the control surfaces were reconstructed; and launching pontoons with necessary trussing were substituted for the original catapult. Thus equipped, and weighing over 40 per cent. more than in 1903, with Glenn H. Curtiss as the pilot, it was successfully flown at Hammondsport, N. Y., June 2, 1914. With a more powerful engine and tractor propeller it was subsequently flown repeatedly. These tests indicated that the original machine would have flown in 1903 had it been successfully launched. After the Hammondsport flights the machine was restored in accordance with the original drawings and data under the supervision of one of the original mechanics, using all original parts available. In 1918 the machine thus restored was deposited in the National Museum for permanent exhibition. (Its 52-horsepower gasoline engine was designed by Charles M. Manly, who superintended the construction of the machine and piloted it in 1903.)

"THE MODEL AËRODROMES DESIGNED BY LANGLEY, THE LANGLEY-MANLY ENGINE, AND PHOTOGRAPHS OF THE MACHINES IN FLIGHT ARE SHOWN NEARBY"

THE TRANSMISSION OF THE VEGETATIVE CHARACTER IN *SPHAEROCARPOS*.

By CHARLES E. ALLEN.

(*Read April 22, 1926.*)

The character here discussed was first observed in one male gametophytic offspring of mating 8, made between plants of *Sphaerocarpos Donnellii* Aust. in 1919. The cultures used as parents in mating 8 were, respectively: a female clone showing a high degree of tuftedness (Allen, 1924*b*) and carrying, as its sporophytic offspring have shown, the separate-spore tendency (Allen, 1925*b*); and a group of male plants, not certainly belonging to a single clone but all recognized as typical. Among the f_1 offspring of this mating was the male clone in question (20.45) which, besides being markedly tufted, was "distinguished by a luxuriance of vegetative growth, shown especially in the size of the lateral lobes, and by a relative scarcity of antheridia and involucres" (Allen, 1924*b*, p. 575). The tendency manifested by this clone toward greater vegetative growth, combined or correlated with a tendency toward a less profuse production of sex organs than in a typical race, was provisionally designated as "vegetativeness." Clone 20.45 evidently derived its tufted tendency from the p_1 female clone. The possibility that the vegetative character resulted from a mutation is supported by the fact that this clone alone in a family of 142 was observed to display that character. However, since the p_1 male culture was not certainly a single clone, it is also possible that one plant in that culture, the male ancestor of clone 20.45, was actually vegetative; especially since at the time the parental culture was under observation the criteria of a typical race were not so sharply defined as they later came to be.

The studies to be reported here have shown that vegetativeness is genetically separable from tuftedness, in connection with which it was first observed. It is one of three atypical characters (or character-complexes), each first observed in a male clone of *S. Donnellii*

and each involving a relatively small production of sex organs and relatively great vegetative growth. The other two are polyclady, already studied on a fairly large scale (Allen, 1924*a*, 1925*a*, 1926); and semisterility (described by Wolfson, 1925), as to whose behavior in inheritance no satisfactory information is yet available. The typical condition, vegetativeness, and semisterility constitute a series differing, so far as observation has shown, only in the proportional development of reproductive and vegetative structures; semisterility being an extreme condition in which few, or at times no, sex organs appear. Polyclady, on the other hand, also involves marked structural peculiarities.

The results are here briefly reported of matings of four different female clones with the original vegetative male clone.

♀ Typical (Non-vegetative, Non-tufted) ×
♂ Vegetative, Tufted.

Mating 40: 22.3 × 20.45.
Mating 41: 20.56 × 20.45.

The results of these two matings are summarized in Table I. The classification here given is subject to modification on further study of such of the clones as still survive; it is given, however, with confidence as to its approximate accuracy.

TABLE I.

♀ Non-vegetative, Non-tufted × ♂ Vegetative, Tufted.

	Non-veg., Non-tuf.	Non-veg., Tuf.	Veg., Non-tuf.	Veg., Tuf.	Totals.
Mating 40:					
♀..........	2	—	—	2	4
♂..........	5	—	5	—	10
	7	0	5	2	14
Mating 41:					
♀..........	4	7	2	5	18
♂..........	7	1	2	9	19
	11	8	4	14	37
Totals:					
♀..........	6	7	2	7	22
♂..........	12	1	7	9	29
	18	8	9	16	51

As Table I. shows, the vegetative and tufted characters displayed by the p_1 male ancestor may reappear either separately or together in the offspring of either sex. Vegetative female clones have thus appeared (or at least have been recognized) for the first time.

Vegetative plants of either sex differ from typical plants in the number of involucres (each enclosing a sex organ) produced at the apex of a branch. On a typical plant, under conditions favorable for growth, as many as six involucres may be counted, approximately in a row across a branch near its apex; on a vegetative plant, rarely more than four involucres appear in such a row. On a typical plant the involucres are closely crowded near the apex and for some distance back, becoming gradually separated as the older portions of the thallus grow in horizontal extent, usually to a distance at the base not exceeding the diameter of a fully grown involucre. On a vegetative plant, the crowded condition disappears very shortly behind the apex, and farther back the involucres become separated more widely, usually much more widely, than on a typical plant. The vegetative tendency in males results, under conditions reasonably favorable for growth, in a larger development of the lateral lobes than in typical males, and in a more rapid extension of the area occupied by the clone as a whole. Corresponding differences in vegetative growth, if they occur, are not conspicuous in female clones; perhaps because typical females are themselves characterized by much more vigorous growth than typical males.

The statements just made apply to branches otherwise typical in appearance, whether they belong to typical or to tufted clones. On tufted branches the vegetative character is not readily recognizable; apparently the tendency in such branches toward an upright growth and the consequent crowding of involucres overcomes the tendency supplied by vegetativeness toward a greater separation of the involucres.

The differences that distinguish vegetative and typical plants are of much the same nature as differences that may appear within a single clone in consequence of varying environmental conditions; vegetative clones are therefore not so readily distinguishable from typical clones as are those marked by certain other atypical characters. This statement holds particularly for the females, and their

classification as to vegetativeness or non-vegetativeness is in some cases necessarily tentative. It is much easier to distinguish between vegetative and non-vegetative males, and, providing they are fairly healthy and vigorous, male clones can be classified as vegetative or non-vegetative with a high degree of confidence.

The possibility is not excluded that the vegetative tendency is inherited in differing degrees by different clones, somewhat as seems to be true of the tufted tendency (Allen, 1924*b*). On this point no conclusive statement can yet be made.

♀ Non-vegetative, Tufted × ♂ Vegetative, Tufted.

Mating 42: 20.68 × 20.45.
Mating 43: 20.65 × 20.45.

Very few germinations were secured of spores derived from these matings. The results, however, are given for what they may be worth in Table II.

TABLE II.

♀ Non-vegetative, Tufted × ♂ Vegetative, Tufted.

	Non-veg., Non-tuf.	Non-veg., Tuf.	Veg., Non-tuf.	Veg., Tuf.	Totals.
Mating 42:					
♀	1	1	—	—	2
♂	—	—	—	—	0
	1	1	0	0	2
Mating 43:					
♀	—	1	—	—	1
♂	—	2	—	1	3
	0	3	0	1	4
Totals:					
♀	1	2	—	—	3
♂	—	2	—	1	3
	1	4	0	1	6

In a mating between two tufted parents, it would naturally be expected that all the gametophytic offspring should be tufted, although some apparent exceptions to this rule have been found in other experiments. It may be, therefore, that the one "non-tufted" female obtained from mating 42 (Table II.) will in the course of

time produce an occasional tufted branch and thus show itself genetically tufted.

Interrelations of Characters in Inheritance.

The results of the crosses of non-vegetative, non-tufted × vegetative, tufted (Table I.) are capable of being explained by the assumption that the appearance of each atypical character (vegetativeness or tuftedness) is dependent upon a single factor. Previous results (Allen, 1924*b*) have suggested that a factorial explanation of the inheritance of tuftedness may, at least in some instances, require the assumption of two or more differential factors. The number of clones dealt with in the present experiments is too small to throw additional light upon this question. However this may be, the totals given in Table I. suggest a linkage between vegetativeness and tuftedness, or between certain factors affecting each of these characters; since the parental combinations (the first and fourth classes in the table) appear among the offspring about twice as frequently as what may be called the "cross-over" combinations (second and third classes). In considering these proportions, certain possible errors, apart from those due to random sampling, must be taken into account; particularly the likelihood that some genetically tufted clones may have been classed as non-tufted. The correction of such errors, if they occur, would shift individuals from the first to the second, or from the third to the fourth class. In one instance, therefore, possible corrections would weaken, and in the other would strengthen, the evidence for linkage. It seems probable that errors in classification have not materially affected the general nature of the results, and that a linkage really exists. The numerical relations here appearing between the respective classes of offspring (almost exactly 2 : 1 : 1 : 2) may well represent a very distant approximation to the actual ratios.

In Table III. the results shown in the preceding tables are summarized with reference to possible relations in inheritance between sex and vegetativeness, and betwen sex and tuftedness. In the former case, all four matings are included; in the latter, only two, since both parents in matings 42 and 43 were tufted.

TABLE III.

Relation of Sex to Vegetativeness and Tuftedness.

Mating.	♀ Non-veg.	♀ Veg.	♂ Non-veg.	♂ Veg.
40	2	2	5	5
41	11	7	8	11
42	2	—	—	—
43	1	—	2	1
	16	9	15	17

	♀ Non-tuf.	♀ Tuf.	♂ Non-tuf.	♂ Tuf.
40	2	2	10	—
41	6	12	9	10
	8	14	19	10

As regards sex and vegetativeness (first part of Table III.), the parental character-combinations (first and fourth classes) are slightly but probably not significantly more numerous among the offspring than are the cross-over combinations—although, if only the largest family is considered, the discrepancy is somewhat greater. There is, at any rate, no satisfactory evidence of a linkage between these characters.

As to sex and tuftedness (second part of Table III.), the figures suggest a relation the reverse of linkage; the cross-over classes are materially larger than the non-cross-over classes. Since the error most likely to occur in this connection is that of listing tufted clones as non-tufted, any correction for this error among the females would increase the present discrepancy between non-cross-over and cross-over classes, and among the males would diminish the present discrepancy. The possibility of such an error having occurred in a few cases would not seem materially to weaken the evidence offered by the present figures. However, since a linkage has been indicated between vegetativeness and tuftedness (Table I.), it is to be expected that the distribution of these two characters with reference to sex would be similar; an expectation which is not supported by the two parts of Table III.

In an earlier paper (Allen, 1924*b*), very comparable proportions were obtained among the f_1 offspring of a tufted female mated with

a typical male. At that time the suggestion was made that the preponderance of tufted over non-tufted females might be explained by an assumption of the existence of more than one factor for tuftedness; and that the apparent preponderance of non-tufted over tufted males, instead of the opposite condition found among females, may have resulted from errors in classification. In the light of later studies of the inheritance of polyclady (Allen, 1925*a*, 1926), this explanation now seems less satisfactory.

While final conclusions must await still more extensive results, the evidence of interrelations in the transmission of parental tendencies to offspring presented in the present paper, together with those indicating a partial linkage between polyclady and sex (Allen, 1926), suggest that something other than the now widely accepted explanation of linkage and "repulsion" may be necessary to account for these interrelations in *Sphaerocarpos*. The notion that linkage may in some cases result from a tendency of certain chromosomes to remain together during the reduction divisions has already been put forth as fitting the facts in *Oenothera* (Cleland, 1923) and *Triticum* (Malinowski, 1925), and a similar hypothesis may prove workable here.

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THE MECHANISM OF CHEMICAL REACTIONS.

By HUGH S. TAYLOR.

(*Read April 22, 1926.*)

The application of the Einstein Law of Photochemical Equivalence to photochemical reactions has resulted in a deeper insight into the mechanism of chemical processes. The law postulates a simple correspondence between the number of light quanta absorbed by a reaction system and the number of molecules thereby caused to react. By such studies, Warburg[1] has shown that, for example, in the decomposition of gaseous hydrogen bromide and hydrogen iodide, two molecules are decomposed for every absorbed quantum. Quite recently, this conclusion has been extended by Bodenstein and Lieneweg,[2] to show that this ratio of reacting molecules to absorbed quanta holds for liquid hydrogen iodide, is therefore independent of the state of aggregation and also of the operating temperature both in the liquid and gaseous states. To account for these experimental facts there are two proposed mechanisms, one due to Warburg:

$$\begin{aligned} HI + h\nu &\rightarrow H + I \\ H + HI &\rightarrow H_2 + I \\ I + I &\rightarrow I_2, \end{aligned}$$

the other due to Stern and Volmer[3]

$$\begin{aligned} HI + h\nu &\rightarrow HI', \\ HI' + HI &\rightarrow H_2 + I_2. \end{aligned}$$

In the former, a dissociation into atoms is postulated. In the latter, reaction between an excited molecule (HI′) and a normal molecule is assumed. Both mechanisms yield the ratio between quanta and

[1] *Sitz.-ber. preuss. Akad.*, 746 (1911); 216 (1912); 644 (1913); 872 (1914); 314 (1916).

[2] *Zeitschr. physik. Chem.*, *119*, 123 (1926).

[3] *Zeitschr. wiss. Phot.*, *19*, 275 (1920).

molecules reacting which experiment requires. A decision between the two alternatives is not yet possible, a situation therefore obtaining which is provocative of further experimental research.[4]

An analysis of the photochemical combination of hydrogen and chlorine from this standpoint by Bodenstein,[5] revealed that, in this case, a startling deviation from the Law of Photochemical Equivalence was present. Bodenstein calculated that, as many as 10^6 molecules of hydrogen chloride could be formed as the result of the absorption of one quantum of light energy. This deviation from equivalence has given rise to many explanations, many of which have been thoroughly discussed elsewhere.[6] The most persistent of the explanations cited has been that of Nernst who postulated a preliminary dissociation of chlorine by light into atoms, and then a chain of reactions which sequence may be represented by the following equations:

$$Cl_2 + h\nu \rightarrow 2Cl,$$
$$Cl + H_2 \rightarrow HCl + H,$$
$$H + Cl_2 \rightarrow HCl + Cl,$$

which sequence could continue until, by some means or other, hydrogen atoms or chlorine atoms were removed from the system by means other than those involved in the reaction chain recorded above. The most direct evidence for the possible existence of such a chain was obtained by Taylor and Marshall,[6] who succeeded in introducing hydrogen atoms into an unilluminated hydrogen-chlorine mixture and in establishing that more hydrogen chloride was produced than corresponded with the hydrogen atoms employed.

The abnormal activity of hydrogen atoms thus demonstrated is of importance in the problem of hydrogenation catalysis at the surface of such metal catalysts as nickel, copper, iron and platinum, since, as has been shown by Gauger[7] and by Wolfenden in Princeton,[8] the critical potentials of hydrogen in presence of catalytic

[4] See, Franck, Faraday Society Symposium on Photochemistry, 1925.

[5] *Zeitschr. physik. Chem.*, *85*, 297, 351 (1913).

[6] Taylor, Treatise of Physical Chemistry, Vol. II., pp. 1218–1230, D. Van Nostrand Co.

[6] Nature, *112*, 937 (1923); Marshall, J. Phys. Chem., *28*, 845 (1925).

[7] *Journ. Am. Chem. Soc.*, *46*, 674 (1924).

[8] *Proc. Roy. Soc.*, *110A*, 464 (1926).

nickel and copper indicate that hydrogen is present in the atomic condition on such surfaces. The same is true also in respect to hydrogen on iron, as some unpublished work by Kistiakowski and the writer has shown. The extent to which the presence of hydrogen atoms is of importance in hydrogenation processes has been approached from yet another angle by Taylor and Marshall [9] using hydrogen atoms produced by collision of excited mercury atoms and hydrogen molecules. By this method Cario and Franck [10] showed that collisions of the second kind occur between hydrogen molecules and mercury atoms excited by the resonance radiation, $\lambda = 2536.7$, emitted by a cooled mercury arc, hydrogen atoms thereby resulting. If such atoms be generated in presence of ethylene, carbon monoxide, oxygen, nitrous oxide, reduction of these gases readily occurs. The rapidity with which the reaction occurs suggested to the author [11] that a chain mechanism of the type met in the hydrogen-chlorine combination was involved. Thus, in the case of the reduction of ethylene, a chain of the type,

$$C_2H_4 + H = C_2H_5,$$
$$C_2H_5 + H_2 = C_2H_6 + H,$$

might occur, the second stage in the process regenerating the hydrogen atom consumed in the first stage. In this way, yields of ethane in excess of the hydrogen atoms produced by collision between excited mercury atoms and hydrogen molecules could be expected. Thermodynamic calculations suggested that both these stages were spontaneously occurring processes and, therefore, thermodynamically possible.

To account for the rapid reaction between hydrogen and oxygen to form water, two reaction mechanisms may be written, the one involving hydrogen peroxide,

$$H + O_2 = HO_2,$$
$$HO_2 + H_2 = H_2O_2 + H,$$
$$H_2O_2 = H_2O + O,$$
$$H_2 + O = H_2O,$$

[9] *Journ. Phys. Chem.*, 29, 1140 (1925).
[10] *Zeitschr. Physik*, 11, 162 (1922).
[11] *Trans. Farad. Soc.*, Symposium on Photochemistry, Oxford, 1925.

the other involving the formation of a hydroxyl radical

$$H + O_2 = OH + O,$$
$$OH + H_2 = H_2O + H,$$
$$O + H_2 = H_2O.$$

Both possibilities provide for the regeneration of a hydrogen atom in the second reaction of the sequence and therefore the possibility of a chain mechanism as in the case of ethane formation. The data for a thermodynamic analysis of these two alternatives are not available, so that other methods of reaching a decision were necessary. The second alternative appears improbable since it suggests that the affinity between an oxygen and a hydrogen atom is greater than that between two oxygen atoms. If the first alternative be correct it should be possible to demonstrate the formation of hydrogen peroxide as an intermediate stage in the process. This has now been demonstrated by Marshall on passing hydrogen and oxygen mixed with mercury vapor through an apparatus of the type described recently[12] by him. Using an apparatus of a different type, the writer and Mr. J. R. Bates have succeeded in demonstrating that the reaction may be conducted so that hydrogen peroxide is exclusively produced without any water formation. The hydrogen and oxygen saturated with mercury vapor at a definite temperature are passed rapidly through a quartz tube, 30 cm. long and 1 cm. diameter, maintained at the temperature of saturation of the mercury. Around the quartz system is built a cooled mercury arc whence the resonance radiation enters the reaction system. Table I. illustrates the type of results obtained with this method of operation.

Under certain conditions of gas flow and saturation concentration of mercury vapor the condensible product is hydrogen peroxide of 100 per cent. strength. Reduction of the speed of gas flow causes a reduction of the peroxide concentration by photochemical decomposition with the formation of water. Decomposition also occurs by interaction with mercury with the formation of water and mercuric oxide. These results, therefore, may be regarded as strong confirmatory evidence of the correctness of the first alternative and also of the possibility of a chain mechanism in the interaction of hydrogen

[12] *Journ. Phys. Chem.*, 30, 34 (1926).

atoms and oxygen. Preliminary measurements by Marshall of light energy absorbed and of reaction produced confirm this conclusion. They indicate that at least twenty molecules of hydrogen disappear per quantum of absorbed resonance radiation. The experimental work is difficult as the production of mercuric oxide complicates the measurement of light absorption. With a system containing hydrogen, carbon monoxide and mercury vapor the mercuric oxide is not produced and the optical measurements are simpler. With this system Marshall also has found more reacting molecules than absorbed quanta.

TABLE I.

Rate of Flow, Liters per Hr. H_2.	O_2	H_2O_2 Yield as CC. 0.1 *N* $KMnO_4$.
97	50	58.0
94	49	44.0
93	48	51.5
120	55	42.4
118	54	43.5
49	26	37.5
48	26	35.2
100	49	35.1
98	48	35.2
102	10	67.5
100	10	38.7

The concentration of mercury vapor was always the saturation concentration at 50° C. The arc was run at 35 volts and 18 amperes. Each run lasted 10 minutes.

Rideal and Hirst see [13] in the production of hydrogen peroxide, from hydrogen and oxygen in the presence of excited mercury, evidence that the activation process consists, not in the formation of hydrogen atoms, but in the production of excited hydrogen molecules, according to the equations:

$$Hg' + H_2 = H_2' + Hg$$
$$\text{and } H_2' + O_2 = H_2O_2.$$

They cite as further evidence in this connexion the production of hydrazine, N_2H_4, from a system containing nitrogen and hydrogen. They regard the assumption of hydrogen atoms as unnecessary in all the reduction processes studied.

[13] *Nature*, *117*, (1926).

This attitude ignores the experimentally demonstrated presence of hydrogen atoms in systems of hydrogen and mercury vapor exposed to the resonance radiation of mercury. Cario and Franck[14] showed that atoms were present in such systems at low pressures by observing on illumination the "clean-up" effect, the adsorption of hydrogen atoms on the walls of the containing vessel, an effect with hydrogen atoms first pointed out by Langmuir. The presence of hydrogen atoms in such illuminated mixtures is further confirmed by the experiments of Senftleben,[15] who showed that the illuminated mixtures possessed high thermal conductivity by reason of the presence of hydrogen atoms.

The production of hydrogen peroxide is no sufficient proof that the mechanism involves excited hydrogen molecules, since a simple mechanism involving atoms has already been suggested as an alternative, which also accounts for the high yield per quantum of absorbed energy. Furthermore, as found by Bonhoeffer,[16] hydrogen atoms, produced by Wood's method, the passage of a high tension discharge through moist hydrogen,[17] also give hydrogen peroxide on admixture with oxygen. In this case there can be no doubt that the reacting species consists of hydrogen atoms.

An entirely independent series of investigations conducted in this laboratory by Mr. W. H. Jones lend abundant support to the concept that the reduction processes in these several cases involve hydrogen atoms. If, in the hydrogenation of ethylene in presence of excited mercury atoms, the stages of progress be represented by the sequence

$$H + C_2H_4 = C_2H_5;$$
$$C_2H_5 + H_2 = C_2H_6 + H,$$

then, it should be possible to effect the combination of hydrogen and ethylene by liberating into the mixture of these gases the free radical C_2H_5 involved in the second stage of the process. If, in this manner, hydrogen and ethylene both disappear in excess of the amount of ethyl liberated, the possibility of the chain of reactions is established.

[14] Loc. cit.

[15] *Zeitschr. Physik.*, *33*, 871 (1925).

[16] *Z. Elektrochem.*, *31*, 521 (1925).

[17] *Proc. Roy. Soc.*, *102A*, 1 (1922).

The simplest method of liberating free alkyl radicals into a mixture of these gases is by decomposition of metal alkyls. At my suggestion, Mr. Jones has studied the behavior of these gases when mercury diethyl and lead tetraethyl are decomposed in their presence. These metal alkyls were chosen since they decompose in the temperature range, 200–300° C., in which hydrogen and ethylene do not react thermally in glass vessels. Furthermore, the metallic residues from the decomposition processes, mercury and lead, have themselves feeble catalytic activity. It can be shown experimentally, that hydrogen and ethylene do not combine under the conditions cited in the presence of these metals either as vapor or as deposits.

We have shown that hydrogen and ethylene readily combine in presence of decomposing mercury diethyl or lead tetraethyl. More hydrogen and ethylene disappear than would correspond to ethyl groups liberated as may be readily seen from some of the data in Table II. The main reaction product is therefore ethane; but, our

TABLE II.

CC. H_2 Taken.	CC. C_2H_4 Taken.	Grams Metal Alkyl.	CC. C_2H_5 Equivalent.	Volume after Reaction.	CC. C_2H_4 Disappeared.	CC. H_2 Disappeared.
46.6	44.4	0.105 (1)	19.2	60.4	13	
49.2	49.6	0.316 (1)	57.8	89.4	33.9	
50.4	50.1	0.023 (1)	4.2	84.7	19.5	11.65
None	95.9	0.249 (1)	45.5	50.0	80.3	—
51.0	50.4	0.209 (2)	57.8	96.5	33.8	13.0
50.2	50.8	0.388 (2)	79.8	93.9	—	—

(1) $Hg(C_2H_5)_2$; (2) $Pb(C_2H_5)_4$; (3) $Hg(CH_3)_2$. The third experiment of this series shows convincingly that more hydrogen and ethylene disappear than can correspond to ethyl groups liberated. No volume change occurs on many hours heating of hydrogen and ethylene with mercury alone under the given experimental conditions ($T = 250°$ C.).

investigations show that more complex hydrocarbons simultaneously result. This has been shown to be due to reaction involving ethyl groups and ethylene. For, in absence of hydrogen, ethylene disappears when heated with decomposing mercury diethyl. Liquid hydrocarbons, with boiling points registering over 100° C., have been recovered from the reaction, but have not yet been identified. It is

evident that reactions involving, as one stage, the addition of ethyl and ethylene

$$C_2H_5 + C_2H_4 = C_4H_9$$

are here taking place. A possible approach to the chemistry of the free alkyl radicles, of extraordinary interest to the organic chemist, is here indicated. Their major interest at the moment consists in the fact that they supply additional confirmatory evidence of the atomic mechanism of reaction in hydrogenation processes and harmonize observations on the properties of hydrogenation catalysts with those attained in the study of reactions under the influence of excited mercury.

One further aspect of the problem may be emphasised. As already stated, in systems containing oxygen there is a removal of mercury atoms in the form of mercuric oxide, so that, for reproducible working conditions, dynamic methods must replace the static method of experiment first employed in these studies. As Rideal and Hirst have pointed out, however, the reduction of reaction rate with time is not confined to systems containing oxygen but occurs also with the hydrogen-ethylene system. These authors therefore feel that the mercury vapor may be shorn of its activity by other than chemical methods. That this is not necessarily true has been established by Mr. J. R. Bates in Princeton who has shown that interaction occurs between mercury vapor and ethylene alone resulting in the production of volatile mercury organic compounds, not yet identified completely, but, apparently, of the mercury alkyl type. At the same time it has been shown that a part of the interaction between ethylene and mercury involves the production of acetylene, the excited mercury acting therefore as a dehydrogenation agent. It is this dehydrogenation process which causes the initial increase in pressure observed with excited mercury and ethylene by Olsen and Myers [18] in their study of the polymerization of ethylene and its hydrogenation by means of excited mercury atoms. Their work at low partial pressures is confirmed by operation at atmospheric pressure; practically complete disappearance of the ethylene may be achieved with the production of liquid polymers. In these experiments, the

[18] *Journ. Am. Chem. Soc.*, *48*, 389 (1926).

characteristic odor of mercury alkyls is quite pronounced, again showing the possibility of chemical interaction between ethylene and mercury.

Summary.

The intervention of hydrogen atoms in a variety of reduction processes, especially reactions conducted in presence of excited mercury vapor, has been substantiated by the results of experiments on

(*a*) The production of hydrogen peroxide from hydrogen-oxygen mixtures.

(*b*) The ratio of molecules reacting to quanta absorbed. At least twenty molecules of hydrogen disappear per quantum absorbed of a frequency corresponding to $\lambda = 2536.7$ Å.

(*c*) The sensitization of reaction between hydrogen and ethylene by thermal decomposition of metal alkyls.

THE FLASH SPECTRUM OBSERVED AT THE 1925 ECLIPSE.

By S. A. MITCHELL.

(*Read April 23, 1926.*)

The tremendous popular interest aroused by the total eclipse of January 24, 1925, is still fresh in the minds of each and every one of us. It is estimated that at least ten million people were given the opportunity of witnessing the gorgeous phenomenon. The great newspapers of the metropolitan district assert that no single event in the past decade has aroused such widespread enthusiasm. As totality lasted for the brief time of two minutes or less, and as the scientific investigations were nearly all crowded within the period of the total phase of the eclipse, it is certain that no single event in the history of man has had so many words, per minute of duration of the event, written about it as has been the case with the recent eclipse.

Ordinarily at an eclipse the most important of the scientific problems are attacked by means of the spectroscope. A prism of glass breaks up light into its colors, forming a spectrum. The spectrum is produced also by a grating. This is made by ruling with a fine diamond point on a metallic reflecting surface of speculum metal lines parallel and equidistant, many thousands to each inch. If the rulings are made on a plane surface we have a plane grating. To form a spectrum a lens must be used in connection with such a grating. If the diamond point rules a spherical concave mirror, a concave grating is the result and the lens can be dispensed with.

If the light to be examined is feeble, as is the case in stellar investigations, a prism is generally employed. With the brightest of the stars and the largest of telescopes, a second or third prism (never more than three) may be utilized to increase the dispersion or lengthen out the spectrum.

If there is sufficient light, as with the sun under ordinary conditions, and a high degree of precision is necessary, then a spectrum

is required of greatly increased length over that possible with prisms; with the consequent result that a concave grating is nearly always used for solar investigations.

With the uneclipsed sun a slit is necessary and the spectrum consists of many thousands of dark lines, each an image of the slit, superposed on a bright ribbon of light of the spectrum colors. The enigma of these dark lines discovered by Fraunhofer in 1814 became understood in 1859 by the formulation of Kirchhoff's laws. The greatest triumphs of modern astronomy are connected with the use of the spectroscope. The dark Fraunhofer lines in the ordinary solar spectrum permit us to know the materials that go to make up the sun. We know the constitution of the sun with as much certainty as if we had a representative piece of it and could make a refined analysis in one of our best chemical laboratories.

At eclipse time the spectroscope can be employed to investigate the hot gases that form the sun's true atmosphere, the chromosphere, as it is called by the astronomer, and also to try and discover the constitution of the far-flung and feeble corona. On account of the much greater strength of its light, it is possible to use with the chromosphere a much higher dispersion than is possible with the corona.

The chromosphere was first investigated at an eclipse in the year 1868 and as a result helium was discovered, twenty-seven years before it was isolated in a chemical laboratory by the celebrated Ramsay. Before the eclipse of 1870, Professor Young of Dartmouth foretold the discovery of the "flash spectrum."

The dark lines in the ordinary solar spectrum are caused by the absorption of light from the hot solar surface by the relatively cooler gases that surround the sun. As the partial eclipse progresses, and so long as there is the smallest portion of the sun's surface visible, the spectrum is the dark-lined spectrum. At the instant of totality the bright background of the sun is covered by the moon. The gases at the point where was seen the last vestige of the sun are not yet covered by the advancing moon, and as these gases are at a very high temperature, they give their spectrum which consists of bright lines on a dark background. At the very instant of totality there is a sudden change in the appearance of the spectrum, for where

there were formerly dark lines on a bright background they have now changed to bright lines on a dark background. The change is so sudden a one, the bright lines flashing out so quickly that Young, whose eye in 1870 was the first to witness it, called the appearance the "flash spectrum." This lasts only about three seconds while the moon is advancing over a relatively shallow layer. A second appearance of the flash spectrum is seen at the end of the total phase.

The flash spectrum was first photographed at the eclipse of 1893, and gratings were first employed at the eclipse of 1900. The best photograph to date of the flash spectrum was obtained in 1905.

The writer of this article has confined his investigations at eclipses almost exclusively to the photographs of the flash spectrum. All of the instruments used by him in 1925 were kindly loaned by the United States government except the concave grating itself. This was of four inches aperture, ruled with 15,000 lines to the inch and was kindly loaned by Professor F. A. Saunders of Harvard University. The same grating was successfully employed in 1905 in Spain. At the time of the eclipse, light from the sun fell upon a plane mirror mounted as a cœlostat, and by this the light was reflected directly onto the concave grating which changed the incident light into a spectrum and brought it to a focus on the photographic plate.

No slit was necessary for the reason that the atmosphere of the sun at the point of investigation is very thin. At the distance we are from the sun the shallow layer becomes almost a mathematical line. The flash spectrum consists of a number of cusps, each a colored image of the heated gases of the solar atmosphere. A measurement of the length of the cusp parallel to the solar surface readily affords a knowledge of the height in miles that each solar vapor ascends above the surface of the sun. The flash spectrum thus gives information regarding the physical constitution of the gases making up the sun's atmosphere but it also gives the heights to which these vapors ascend. There is no other method yet known to science that permits a knowledge of these solar heights—and herein lies one of the most important problems to be investigated by the eclipse astronomer.

The sun is the nearest of the fixed stars, and it is the only star

which permits us to examine its atmosphere in detail at the time of a total eclipse. A knowledge of the heights attained by the solar vapors gives information regarding the pressures under which the spectroscopic lines take their origin. At very reduced pressures in the sun's chromosphere and at the high temperature found there it is readily possible for an atom to lose an external electron and become ionized. The spectrum of the ionized atom differs very much from that of the neutral atom which has not lost an electron. In the ionized spectrum certain lines are enhanced in intensity and these are the lines which are stronger in the spectrum of the electric spark than in the electric arc. Knowledge of these things is of the very greatest importance in furthering our knowledge of the chemical atom, a quest in which astronomy, physics and chemistry are vitally interested.

It is a very thrilling portion in the life of an astronomer to take a long trip, sometimes to the ends of the earth, to make observations during the few excited moments of totality. The writer has traveled 50,000 miles to observe total eclipses of the sun. At this his sixth eclipse he regards himself as very fortunate that the moon's shadow passed over the Van Vleck Observatory in Middletown, Conn. There his friend Professor Frederick Slocum is director. Instead of being obliged to live in discomfort in an eclipse camp or small hotel on foreign soil he was the guest in the comfortable home of Professor and Mrs. Slocum. Instead of having to rely entirely on one's self for all the tools and instruments with which to erect and adjust the spectroscopes for the eclipse, a well-appointed observatory, a splendidly equipped physics laboratory and machine shop were at my disposal and every assistance needed was generously given. The focusing of the concave grating so that the cœlostat mirror and concave grating are adjusted for parallel light is a very difficult and an all-important task. Unless the focus is of the very best, unless the atmospheric conditions of seeing and transparency are of the very finest, unless the exposures at the eclipse are timed with the greatest of nicety, the resulting photographs of the flash spectrum will not be of the best quality—and at the present day in eclipse work anything short of the very best will bring little of increase to our knowledge of the sun.

In eclipse work I have had the best success in focusing the grating spectroscope by the employment of a collimator, which is a slit arranged between two concave mirrors in order to give a parallel beam of light from a slit source. The apparatus was adjusted in the basement of the Van Vleck Observatory by means of the collimator and an electric arc using Sperry carbons which give spectra rich in lines throughout the whole range of wave-length. Photographs for focus showing exquisite definition were secured. On the day before the eclipse the large box holding the grating in position and the adjusted plate-holder was carried carefully into the temporary shelter located on the outside of the dome of the 20-inch refractor. Although the focus was so carefully and satisfactorily obtained, there was one fear ever present. How would the great change in temperature affect the curvature and the focal length of the grating and the whole adjustment of the apparatus? I had never before observed a total eclipse with winter conditions. In the observatory the temperature of the room where the adjustments were carried out was about 70° F. On eclipse morning the minimum temperature was 6° below zero and at the time of the eclipse hovered around the zero point. Time did not permit a test of focus under the altered conditions of temperature—and there was nothing to do but be an optimist and hope for the best.

What a dejected crowd of astronomers we were at eight o'clock on eclipse morning when we had gathered at the Van Vleck Observatory to observe "first contact," the beginning of the eclipse. There was nothing but clouds everywhere!

A quarter of an hour later a ray of hope appeared, there was a blue streak of sky low down in the northwest—and the clouds were coming from that quarter. Would it clear off in time? Luck was with us. Fifteen minutes before totality the sun broke through the clouds. With the assistance of my colleague Dr. Harold L. Alden, the final adjustments were made on the instruments. Five minutes before totality each observer was at his station and we waited in great expectation. A cloud, very thin and very fleecy, now hung over the sun. It was not thick enough to do much damage and it was moving slowly. We hoped it too would go. When the timers called out "Two minutes," the cloud was almost gone. By now it

was beginning to get quite dark, a weird and unnatural pall coming over the landscape. The observers outside noted shadow bands flickering over the snow. At one minute before totality, with the thin crescent of the sun growing very small the atmospheric conditions seemed perfect, the thin cloud had gone!

The signal "Thirty-seconds" rang out. Everything was hushed while we waited for the zero hour, the beginning of totality. In my right hand I had a pair of binoculars over the right glass of which was a grating for observing the flash spectrum visually. When I saw it flash out, I gave the signal, "Go," totality had begun; and with my left hand I opened the shutter to begin the first exposure.

I had planned to take six photographs during totality which was expected to last 112 seconds. My assistants did their work so well that everything passed off without a single hitch.

Measurements of the flash spectrum give information of three different kinds: (1) wave-lengths of the spectral lines; (2) intensities of the lines; and (3) the heights to which the vapors ascend above the solar surface. The eclipse spectra of 1905 showed that there are no systematic differences in wave-length from those exhibited by the ordinary solar spectrum. Wave-lengths in eclipse spectra are needed mainly for purposes of identification for deriving the source of the lines. Heights and intensities are of the very greatest importance. It was from the 1905 eclipse spectra that Saha's valuable theory of ionization was confirmed experimentally. The greatest height in the chromosphere is attained by the ionized lines H and K of calcium, which rise to an elevation of 14,000 kms. above the surface of the sun. The red hydrogen line H_α reaches a slightly less elevation of 12,000 kms. The details of the flash spectrum which extends from wave-length 3200 Å. in the violet to about 7500 Å. in the red will be published at a later date.

THE PLEISTOCENE GLACIAL STAGES: WERE THERE MORE THAN FOUR?[1]

By FRANK LEVERETT,

Ann Arbor, Mich.

(Read April 23, 1926.)

It has been about 50 years since the pioneer workers in glacial geology, T. C. Chamberlin, W J McGee, J. S. Newberry, Edward Orton, and N. H. Winchell, brought out evidence that the Pleistocene Ice Age was not one of continuous cold climate, but was broken by long periods of relatively warm climate, whose fossils show conditions as temperate as now prevail. Chamberlin brought to notice a relatively young drift with a definite terminal moraine, lying back in places a considerable distance from the limits of the glacial deposits, and pointed out that the outlying, or extra-morainic drift, showed evidence of markedly greater age. In his principal paper, in the Third Annual Report of the U. S. Geological Survey, he described the outer moraine of the younger drift as the "terminal moraine of the second glacial epoch," thus throwing into a single glacial stage all the drift outside and beneath the drift of this epoch. At about the same time McGee, working in Iowa, in the extra-morainic area, found evidence in a buried soil between two tills, that there was need for the recognition of two distinct glacial stages, with an intervening warm climate stage. Winchell, also, at about the same time, brought out evidence of similar character in southeastern Minnesota and recognized two distinct drift sheets outside the terminal moraine of the last glaciation, while Newberry and Orton found buried soils both inside and outside that moraine in Ohio. Thus the youngest drift came to be recognized on the basis of topographic youth, while the others were differentiated on a stratigraphic basis.

As studies progressed it soon became evident that the top drift

[1] By permission of Director, U. S. Geological Survey.

in the extra-morainic district displays marked contrasts in the degree of erosion and weathering, inconsistent with its reference to a single glacial stage. Thus the uppermost till in southern Iowa was found by studies carried on by the writer to show markedly greater erosion than the uppermost till in southeastern Iowa and western Illinois, where proximity to the main drainage artery (Mississippi River) seems to favor rapid erosion. This drift was found to have a definite terminal moraine on its western border, and the ice sheet which formed it covered the Mississippi Valley between Clinton and Fort Madison, causing the river to take a temporary course across southeastern Iowa, outside the moraine. A buried soil was also found to separate this drift from the underlying drift, this underlying drift being the surface till of the district outside. The four drifts thus differentiated are of declared type and age, and are so considered by all students who have had opportunity to investigate them. Another differentiation of the drifts in northeastern Iowa is discussed below, their relations being problematical.

The oldest drift, which underlies the buried soil noted by McGee and Winchell, has but slight exposure in the type areas outside the second drift, so its degree of erosion is not well shown. But a long interglacial stage between these tills is shown by deep weathering of the upper part of the lower till, developing what is known as gumbotil, as well as the soil noted by McGee and Winchell. A drift in New Jersey and eastern Pennsylvania, which is tentatively regarded as of the age of the lower till of the western district and is thought by glacialists familiar with both districts to show a great degree of erosion, thus supplements the evidence from weathering. The name Jerseyan is applied to the old drift of New Jersey, and this name may eventually be extended to the oldest drift of the interior. The latter drift has already carried a succession of names—Kansan, sub-Aftonian, and more recently Nebraskan. The interglacial stage between it and the second glacial stage is known as the Aftonian. The drift of the second glacial stage was found to extend into Kansas and has come to be widely known as Kansan, while the third drift, because of wide exposure in Illinois, is known as the Illinoian. The soil and weathered zone between it and the second drift is known as the Yarmouth. A gumbotil was developed in the Yarmouth stage of

such depth as to show that that stage was one of great length, perhaps even exceeding in length the Aftonian interglacial stage. The next drift in northeastern Iowa is known as the Iowan. The drift of the latest glacial stage is known as the Wisconsin, because first clearly recognized in that State through the investigations by Chamberlin. The weathered zone developed on the Illinoian is known as the Sangamon. There is a moderate development of gumbotil where the surface is flat and drainage was imperfect, but it is a much less conspicuous feature than that developed on the Kansan drift. Between the Illinoian and Wisconsin drifts there also comes the main loess deposit. It rests upon the weathered surface of the Illinoian drift, and passes under the outer moraine of the Wisconsin drift. Its deposition appears to have preceded the culmination of the Wisconsin glaciation by only a short interval, as its surface where it is exposed beneath the Wisconsin drift shows but a slight amount of leaching and weathering.

The contrast in age of the Kansan, Illinoian, and Wisconsin drifts is clearly shown by the degree of erosion, as brought out in topographic maps of the U. S. Geological Survey. Thus the map of the Milo, Iowa, quadrangle in southern Iowa shows the great erosion suffered by the Kansan drift. Scarcely one tenth of the original surface of the drift is preserved, the rest being in valley slopes and valley bottoms. It has been estimated by a member of the Iowa Geological Survey that the average erosion, or amount of drift required to fill up the valleys is fully 50 feet.[2]

[2] The maps here named, Milo (Iowa), Vermont (Illinois), West Columbus (Ohio), and Defiance (Ohio), were shown in connection with the reading of the paper to illustrate the contrast in erosion of Kansan drift, Illinoian drift, Wisconsin drift, and the bed of the glacial lake in the Erie Basin, and the Pleistocene map of New Jersey accompanying Salisbury's report (Geol. Surv. of New Jersey, Vol. V., Pl. XXVIII.) to show the great erosion suffered by the Jerseyan, or oldest drift. As the maps are easily obtained by those interested, either in libraries, or from the U. S. Geol. Survey, it seems inadvisable to incur the large expense of their reproduction here. There are several other mapped quadrangles in each of the drifts, Kansan, Illinoian and Wisconsin, that will illustrate as well as those named, the relative degree of erosion. Thus for the Kansan drift the Chariton, Knoxville, Melcher and Pella, in southern Iowa, and the Atlanta, Braymer, Clarksdale, Gallatin, Macon, Maysville, Pattonsburg, Plattsburg, Polo, and Winston, in northern Missouri, are among the recently surveyed quadrangles which portray well

Turning now to the Vermont quadrangle in western Illinois, where the Illinoian seems to have been subjected to comparable conditions except those of length of time of exposure, it may be seen that nearly half the original surface of the drift is preserved and that the valley slopes are very narrow and bluffs much steeper than in the Kansan drift. It is estimated that the time required to carry erosion here to the degree experienced by the Kansan drift would be considerably longer than has been required to develop the present erosion features. Some glacialists would put it at not less than three times as long. The amount of material required to fill the valleys in the Illinoian drift is estimated by the writer to be less than one third as much as that for filling the valleys in the Kansan. The Illinoian drift apparently falls in the last quarter of the Pleistocene Ice Age, and is thus to be classed as one of the younger drifts. In it moraines and other glacial features are well defined and relatively well preserved, which is not the case in the older drifts. Turning to the map that has been selected to illustrate the degree of erosion of the Wisconsin drift, the new West Columbus, Ohio, quadrangle, it will be seen that valley cutting is in a very youthful stage, with parallel streams that show few branches. Another map, the Defiance, Ohio, quadrangle, represents erosion in the bed of the glacial lake in the Maumee basin. The lake waters were drawn off from this district and its erosion started several thousand years later than the time when the ice melted from the Columbus district and erosion started there. Time estimates based on the recession of Niagara Falls give the falls a period of about 25,000 years. The lake plain was drained and erosion started on it a few thousand years earlier. In all probability a period of 30,000 years is involved in developing this very

the degree of erosion. There are more than twenty quadrangles in western Illinois which illustrate as well as the Vermont quadrangle the degree of erosion of the Illinoian drift. They include the Avon, Beardstown, Canton, Carlinville, Colchester, Divernon, Edgington, Gillespie, Goodhope, Havana, Laharpe, Macomb, Milan, Monmouth, Mount Olive, Raymond, Springfield, Talula and Taylorville. Many of the surveyed quadrangles in the Wisconsin drift are so complicated by moraines and other constructional features that wide areas of till plain like those in the earlier drifts are not common. But the East Columbus, West Columbus, Delaware, and Dublin, Ohio, and the Fort Dodge, Lehigh, and Slater, Iowa, maps are largely till plain and set forth well the slight degree of erosion of the Wisconsin drift.

youthful degree of erosion, while the Columbus district probably has had not less than 40,000 years. A comparison of this stream work with that on the Illinoian drift makes it apparent that the latter has had at least three times as long a period as the Wisconsin. Glacialists have given the Illinoian an age of at least 150,000 years, and the Kansan fully a half million years. Their estimates have been based on degree of weathering as well as erosion.

In passing, it is noted that there is a striking parallelism between the four drifts of North America, just noted, and the series of drifts in Europe. In the Alps two very old drifts are present, which in respect to weathering and erosion are similar to the two old drifts of this country. There are two markedly younger drifts, differing from each other in weathering and erosion about as our Illinoian and Wisconsin drifts and showing similar preservation of moraines and other glacial features. In northern Europe two old drifts are present which bear similar evidence of age to the two old drifts of the Alps and of North America. There are also two younger drifts in which moraines and other glacial topographic features are as well defined as in our Illinoian and Wisconsin drifts. The main loess deposits in both districts are also between the third and fourth drifts, as they are here between the Illinoian and Wisconsin drifts. In the classification of northern European glacial formations given by James Geikie, six glacial stages are presented, but the last two now appear to be only the later phases or substages of the last glacial stage. The conditions are similar in the last or Wisconsin stage in America. This is divisible into early, middle, and late Wisconsin substages. It is not thought that these are separated by warm climate substages, such as separate the four glacial stages. They are regarded merely as times of marked readvance of the ice border, following times of considerable recession.

We now turn from the consideration of these four drifts of declared type and age, concerning which there is general unanimity of opinion, to one which has been a subject of dispute and disagreement almost from the time it was differentiated. We refer to the Iowan drift of northeastern Iowa and its probable correlatives. The Iowan drift was differentiated from the underlying Kansan drift by Samuel Calvin and his associates on the Iowa Geological Survey in the 1890's,

and descriptions of it appear in county reports of that Survey. It is represented to be a relatively thin deposit blanketing the eroded and weathered Kansan, but of insufficient thickness to conceal the erosion features of that drift. The main drainage lines on the Iowan drift are thought to follow the courses that had been developed by drainage on the Kansan drift. It is represented to have a decidedly fresher aspect than the Kansan drift, and to show remarkably little leaching, the expression "calcareous to the grass roots" being used to indicate this feature. The Iowan drift thus stands as the third drift of the western part of the glaciated district, as the Illinoian does for the eastern part. But it has not been correlated with the Illinoian by the persons who differentiated it from the Kansan. Instead it has been given a close connection with the main loess deposit, and separated from the Illinoian by the Sangamon interglacial stage. The Iowan drift and loess have also been regarded by these students as of pre-Wisconsin age, for as indicated above the loess underlies the outer moraine of the Wisconsin drift in Illinois. It has also been found beneath the Wisconsin in central Iowa. If it is granted that the Iowan drift stands for a glacial stage between the Illinoian and Wisconsin stages, there were five glacial stages in America. The Iowan drift also as commonly interpreted was laid down in very close juxtaposition with the loess. This interpretation carries with it the implication that the loess pertains to a glacial stage, though its fauna seems to show a temperate climate during its deposition.

It was the prevalent opinion at the time the Iowan drift was differentiated, that the main loess deposit was laid down in water lanes between tongues of ice, as graphically pictured by McGee in his classic paper on northeastern Iowa in the Eleventh Annual Report of the U. S. Geological Survey. As a consequence the Iowan drift was made to occupy the tracts where loess is thin or wanting and not present where the loess is thick. This mapping is now known to be incorrect, and the real limits of the Iowan drift are yet to be determined. The loess is now interpreted on good grounds to be a wind deposit, and not a glacial outwash. It carries land fossils of temperate climate species, which seem inconsistent with the reference of the loess to a glacial stage. While the view held in the 1890's made the loess a full correlative of the Iowan drift, Calvin in his latest

writings made it a close successor, laid down as the Iowan ice was melting. This view is adopted by Alden and Leighton in a special report on the Iowan drift in the 1915 Annual Report of the Iowa Geological Survey. The pertinence of this view is now in question. The Iowan drift carries features suggesting that it was deposited long before the time of the main loess deposition.

In the Iowan area the till has but little surface exposure, being generally covered by 2 to 4 feet of wind-deposited loamy material. Because of this covering but little was known of the character of the till surface until recent extensive grading of highways gave opportunity to study it. It had been noted by the present writer, and also by Alden and Leighton, that a pebbly concentrate is in places present beneath the surface loam indicating erosion of the till before the deposition of the loam. But it was not realized that this is the common condition of the till surface. A trip over the Iowan area in 1925, in company with State Geologist Kay and others, was taken by the writer back and forth over several newly graded highways, and we found that the concentrate is conspicuous on nearly every hillside slope. The pebbles are scattered over the crown of the ridges, but more abundant as one passes down the slope. Judging from the few coarse stones embedded in the till, it was the writer's impression that this concentrate represents several feet of erosion. Alden and Leighton, in the report above cited, have suggested that this concentrate is mainly a product of wind action, and that it was more rapidly developed than by ordinary slope wash. On this point, however, they bring no supporting evidence. The stronger development on the lower part of the slopes than on the crown of the ridges is in keeping with development by slope wash. The wind action should have the greatest effect on the most exposed part, near the crown of the ridge. It is also a question whether wind action would develop such a concentrate as rapidly as slope wash under conditions of climate such as this region has experienced. How varied these conditions have been is a matter on which further light is needed.

The possibility that this concentrate is on Kansan drift instead of Iowan was given due consideration in the field and decided in the negative. The drift under the concentrate presents the moderately weathered aspect of the Iowan, and lacks the deep weathering char-

acteristic of the Kansan drift. As a result of this trip the writer was more fully convinced than before of the presence of a definite sheet of post-Kansan drift in the type area of the Iowan, though there seem to be areas of considerable extent in which it is wanting, or represented only by scattered boulders. The drift where aggregated in kames or gravelly knolls may reach a thickness of 50 to 75 feet, but in the plain areas where it is composed of clayey till it rarely exceeds 20 feet. The Kansan gumbotil beneath it was noted in a number of places.

The Iowan drift seems to become thinner and more patchy in passing northward into the northern tier of counties in Iowa and in the neighboring part of Minnesota. In a distance of 20 miles in the southern townships of Mower County, Minn., neither the writer nor any member of the party in the trip in 1925 was able to find a single exposure of Iowan drift, unless it is represented by a few boulders scattered over the Kansan drift surface. But there are strips of gravelly drift in southern Minnesota in which material fresh enough to be classed as Iowan is present. Other gravels show complete leaching to a depth of several feet. The logical interpretation seems to be that two drifts of widely different age are each represented by gravel deposits, and the younger is tentatively referred to the Iowan. A similar dwindling of the Illinoian drift sheet was noted the past season in studies on the east side of the Scioto lobe in Ohio. From the latitude of Columbus northward the Illinoian drift is reduced to scattered boulders and occasional small patches of till, but to the south of this latitude it gradually increases in amount and becomes a heavy deposit near the southern end of the lobe. The deficiency in the northern part of the lobe seems referable to inactivity of the ice sheet both in Ohio and in Minnesota. That part may have received less nourishment than parts to the south.

Aside from the type area, there appears to be Iowan drift exposed west of the Des Moines lobe of Wisconsin drift in northwestern Iowa and neighboring parts of Minnesota and South Dakota. It probably underlies the Wisconsin drift in the Des Moines lobe between the two areas of exposure, but as yet it has not been noted. This western area has a definite moraine, in places 20 to 25 feet high, along much of its border for a distance of 200 miles, from Florence,

S. Dak., to Odebolt, Ia. Both at the north and the south it passes under the Wisconsin drift. There is also a conspicuous amount of outwash sand and gravel along the border, and gravelly knolls are not infrequent in the moraine. These features seem to indicate considerable activity of ice movement and drainage. This is perhaps due to a nourishment by winds from the west, which on rising to the ice lobe became cooled and precipitated their moisture as snow.

Inside the terminal moraine this drift seems to be very scanty, so much so that certain members of the Iowa Geological Survey have expressed doubt of a post-Kansan ice invasion in this district. Over wide areas the post-Kansan erosion features show but little modification by this later ice invasion. Here and there a few knolls have been dumped in the post-Kansan valleys, but the valleys are generally not noticeably obstructed by the later drift. This drift was included in the Wisconsin by Leverett and Sardeson in their report in Bulletin 14 of the Minnesota Geological Survey. But later studies by Leverett brought out evidence of deeper weathering than seems consistent with Wisconsin age. The Iowa portion of this drift carries a coating of loess which seems to have antedated the Wisconsin ice invasion. The loess is several feet thick in Iowa but becomes reduced to only two or three feet in Minnesota and does not form so continuous a coating as to the south. Exposures along the outer moraine near Sheldon show an older loess beneath the post-Kansan drift, which is tentatively referred to the Loveland clay, widely exposed in southwestern Iowa and neighboring parts of Missouri and Nebraska.

The present writer interpreted a thin drift in northwestern Illinois to be Iowan and described it under this name in Monograph 38, U. S. Geological Survey, published in 1899. But later studies have led him to interpret part of it as of early Wisconsin age. A similar view has been expressed by Leighton, though the limits he places differ somewhat from those of the writer. The occurrence of a drift in that district referable to a glacial stage between the Illinoian and the Wisconsin is now considered by the writer as improbable. The drift to which the name Iowan is thus restricted lies wholly within the limits of what has been termed the Keewatin field of glaciation.

Some explanation seems necessary as to the significance to be

attached to the terms Labrador, Patrician, and Keewatin, as applied to parts of the Laurentide area of glaciation. In some of the discussions of these parts the idea seems to be presented that each district furnished an independent field of ice accumulation and radiation. While it is possible that in the closing part of the ice retreat there may have been separate dispersion areas in these districts, and while similar conditions may have affected the early stages of generation of the great ice cap, there is substantial evidence of a confluence at the culmination of the glacial stages, with a confluent field of control of the direction of ice movement. The writer's studies in the north-central states have shown clearly that the ice sheet in the Wisconsin stage of glaciation made a great growth westward from the Labrador peninsula and had a late culmination in the western part of the Laurentide area. This supports an early view of Chamberlin, brought out in the controversy as to the cause of the Driftless Area, that arose in the 1870's, for he regarded the Dakota lobe and the Des Moines lobe as roundabout derivatives from the common ice mass north of the Great Lakes. It is now known that in the early part of the Wisconsin glacial stage there was a southwestward ice movement from the Labrador peninsula as far as central Illinois, and this formed the early Wisconsin moraines. In the middle part of the Wisconsin stage there was a southward ice movement from the Patrician district south of Hudson Bay across the Great Lakes basins. There was at that time an extensive southwest movement from the Superior basin that deposited the red drift of eastern Minnesota. Following this the strong flow from the Keewatin district of central Canada brought in the gray limestone-bearing drift that overlies the red drift of eastern Minnesota. The culmination of the movement into the Dakotas and Iowa appears to date from this late part of the Wisconsin stage. At this time the ice from the Labrador peninsula barely filled the Ontario, Huron, and Superior basins, and was forming the Port Huron morainic system. The Labrador part thus had a shrinkage to be measured in hundreds of miles. But the shrinkage of this part seems to have been due to lack of snowfall rather than to an amelioration of the climate. It is thought that the western districts were being nourished at the expense of the eastern, as the ice-sheet expanded in the west. The time required for the expansion

above outlined must involve some thousands of years, and it has been found that the early Wisconsin moraines are perceptibly older than the late Wisconsin, as shown by the toning down of the surface contours and degree of weathering.

It now becomes of interest to inquire into the method of growth of the Illinoian ice sheet, and see whether it was similar to that of the Wisconsin. In this stage we find that the earliest movement was southwestward from the Labrador peninsula to the full limits of the Illinoian drift in western Illinois and southeastern Iowa, and that its limits are roughly concentric with those of the early Wisconsin drift. It appears also that this was succeeded by a southward movement through the Lake Michigan basin that extended over much of eastern Illinois and western Indiana, and whose western limits are found in the system of morainic ridges bordering the Kaskaskia Valley. This movement seems to mark a middle Illinoian, to correspond to the middle Wisconsin movement. It seems but natural that westward growth such as we know affected the Wisconsin ice sheet should also have occurred in the Illinoian stage and given the ice movement into Iowa that brought in the Iowan drift.

The lack of gumbotil on the Iowan drift has been cited by Kay, and also by Leighton, in conferences with the writer, as an evidence that it is not to be correlated with the Illinoian drift, on which some gumbotil has been developed. The point would be stronger if the gumbotil were not so largely dependent upon summit flats, and if the Iowan had not inherited good drainage slopes, which, as above noted, have favored the development of a conspicuous pebbly concentrate. In northeastern Iowa a slope toward the Mississippi favored rapid erosion both in the Kansan and in the Iowan, while in northwestern Iowa and southwestern Minnesota an equally well defined general slope toward the Big Sioux and the Missouri valleys is found. In that district the gumbotil is wanting on the Kansan as well as on the Iowan drift.

In view of all the features of the Iowan drift, taken in connection with the fact that it stands as the third drift of the western district, as the Illinoian does of the eastern, and that each district has but four drifts, the writer raises the question whether there really were more than four Pleistocene glacial stages in North America, or

whether the Iowan drift should be regarded as a late phase of the third glacial stage. Features of the Iowan drift and its relation to the loess seem to demand further critical field study.

It remains to say a few words concerning the studies now in progress which look toward a better understanding of the eastern equivalents of the western series of drifts in this country, and especially the equivalents of the first and second drifts. Reference has already been made to the Jerseyan drift of the Atlantic coast as a probable equivalent of the oldest drift of the western field. A very old drift, which is tentatively correlated with the Jerseyan, has been noted at various places beneath the Illinoian drift as far southwest as southern Illinois, and outside the limits of the Illinoian drift in southeastern Missouri. It is so old that the clay has become kaolinized to a marked degree. This drift appears to be represented in a very deeply weathered drift beneath the Illinoian drift at Covington, Ky., which was first noted by Chamberlin and Salisbury some 40 years ago as a drift of great age. Scattered erratics, including boulders of large size, have recently been found in eastern Kentucky, at distances of 30 to 40 miles outside the well-defined till deposits and up to altitudes that seem difficult to bring them within the reach of ponded waters such as are known to have occupied parts of the district in which they occur. These may prove to be of early glacial age, and be all that is left of whatever drift was laid down. Their derivation, as determined by members of the Canadian Geological Survey, seems to have been from the vicinity of Ottawa. The erratics found in the old drift in southeastern Missouri include Huronian quartzites from east of the Superior basin. In both cases they seem to show a southwestward movement from the direction of the Labrador peninsula, similar to the early Illinoian and the early Wisconsin movements, and of similar extent to the Illinoian movement.

There is an old drift exposed in northwestern Pennsylvania which has a more advanced degree of weathering and greater erosion than the Illinoian drift, but whether it is a correlative of the Jerseyan drift remains to be determined. The writer plans to make a careful study of this drift and of the Jerseyan the coming field season, with a view to clearing up their relative ages. In studies pursued in the

1890's the writer came to think that the degree of preservation favored Kansan rather than Jerseyan age, but the Jerseyan was not carefully studied by him at that time and the inference may prove incorrect. There are outlying boulders in western Pennsylvania, in the vicinity of Pittsburgh, that may prove to be Jerseyan, if the better defined sheet of drift farther north is not.

Data on ice movements furnished by the distribution of copper and copper-bearing rocks in the drift indicate that at some time prior to the Illinoian glacial stage there was a southward movement from the Superior basin through the Huron basin into central Ohio. This is so out of harmony with the early southwestward movement into southeastern Missouri, as well as with the Illinoian ice movement, as to suggest a different glacial stage, presumably the Kansan stage. Such an interpretation will be strengthened if the old drift of northwestern Pennsylvania proves to be of Kansan age.

The Illinoian drift is exposed outside the Wisconsin from central Ohio westward, but to the east it may have been completely overridden by the later ice movement. It is thought by Fuller to be represented in the deposits on Long Island and it may have a slight exposure in New Jersey, immediately outside the Wisconsin drift. The drift was reported by Salisbury to have a less aged appearance there than to the south. This matter will be given attention the coming field season. Search will also be made for exposures of Illinoian drift in Pennsylvania. Its limits in eastern Ohio can not be far inside the border of the Wisconsin drift, for gravel trains from it are found along the valleys of eastern Ohio and along the Ohio below the mouth of Beaver River.

Summing up the evidence from the eastern district, it appears that the first and second drifts have only scanty exposure outside the limits of the later drifts, compared with the exposure of the Kansan in the western district. One drift, thought to be the Jerseyan, has a similar extent to the Illinoian drift and it is referable to a similar direction of ice movement. The Kansan may be exposed in northwestern Pennsylvania, but elsewhere in this eastern district it seems to be completely covered by later drifts. It may have been brought into this district from the north by an ice movement that is out of harmony with the movement in the three other glacial stages, which

seems to have been from the northeast. Finally, the limits of the Illinoian drift, from central Ohio eastward, may be not greatly different from those of the Wisconsin.

A suggestion as to the cause for the much greater extension of the ice sheet in the western district in the first and second stages than in the later ones is here offered, though it is recognized to be difficult to demonstrate. It probably depended upon a better relation to moisture-laden winds. If the Cordilleran ranges stood relatively low in early Pleistocene time, as seems probable, the ice sheet may have been more bountifully nourished by the moist winds from the Pacific than in the late Pleistocene, and thus have had the greater extension in these stages.

Note.—A recent extremely valuable book by Prof. A. P. Coleman, entitled "Ice Ages, Recent and Ancient," which deals with each of the several glacial periods, as far back as the Huronian, contains a few statements concerning the relation of the Keewatin and Labrador parts of the Laurentide ice sheet which are not in harmony with the interpretations given in this paper. Thus, on p. 16, Coleman says: "The Labrador ice sheet probably began later than the Keewatin ice sheet, but was in existence when the latter reached its maximum dimensions and then coalesced with it." But no supporting evidence is presented by Coleman, and the present writer knows of nothing that will bring support to this view. In fact, all the evidence seems to support the view that the Labrador ice sheet was the first to become prominent.

THE PRESENT CONDITION OF KNOWLEDGE ON THE COMPOSITION OF METEORITES.

By GEORGE P. MERRILL.

(*Read April 24, 1926.*)

For a number of years the writer has been devoting a portion of his time to the study of meteorites with reference to their composition, both mineralogical and chemical, and their structure. In all cases especial attention has been devoted to the presence—or absence—of sundry elements heretofore reported, and to such structural peculiarities as may be ascribed to secondary causes. The results here given relate mainly to composition and are not wholly my own, but in the brief time at my disposal I shall not attempt to discriminate.

It is now but little over 100 years since the German, E. F. F. Chladni, placed the study of meteorites on a truly scientific basis, by establishing beyond question their ultra terrestrial origin. Since his time chemists and mineralogists have made abundant contributions to the problem, and produced a by no means inconsiderable literature. As may be readily comprehended by any who have kept track of the advances in the sciences—particularly in chemistry and mineralogy—the early analyses and mineral determinations were poor. Analytical methods were imperfect and chemicals were by no means in a condition of desirable purity. Indeed, it was not until the introduction of the microscope—until the modern method of micro-petrology was developed—that satisfactory results were achieved. One great drawback, even since this introduction, is the tendency on the part of the collectors to hold the material so precious that not enough can be made available for study. Meteorites, in order to gratify these collectors, have been divided and subdivided until often no one collection holds enough for full and satisfactory investigation. It was the absurdity of the situation thus stated, that led me to formulate the following as suggestive of my feelings: *I would rather not have*

a thing, and know what I have not than to have it and not know what I have. Analyses have been published which were made on less than a gram of material and with no assurance that this was representative. As will be noted later, in going through the entire literature I was able to find only about 100 analyses of meteoric stones which were sufficiently accurate and complete to warrant their utilization in the tables I shall show.

Very early in my studies I was struck by the fact that while the meteoric stone belongs to a very basic group of rocks—mainly peridotites, with a few pyroxenites and some that might be classed as basalts—reported analyses showed frequently the presence of elements that had never been reported from this class of terrestrial rocks and which from what is known of mineral association one would scarcely expect. It was then with a view of settling this doubtful question that my first investigations were undertaken. Whenever it was possible samples were obtained from the identical stones in which these doubtful elements were reported, as well as from others which had never before been analyzed. Thin sections were cut and studied and particular pains taken to select for the chemical analyses material that represented each mass as a whole. The analyses were made with greatest care by the best and most experienced man available[1] and inasmuch as this branch of the work was not my own I think I may truthfully say they are among the best that were ever made and materials were selected with discrimination.

So much in the way of explanation. The elements that have thus far been found in meteorites, so far as determined, are as follows:

Aluminium	Iridium	Potassium
Argon	Iron	Radium
Calcium	Magnesium	Ruthenium
Carbon	Manganese	Silicon
Chlorine	Nickel	Sodium
Chromium	Nitrogen	Sulphur
Cobalt	Oxygen	Titanium
Copper	Palladium	Vanadium
Helium	Phosphorus	
Hydrogen	Platinum	

[1] Dr. J. Edw. Whitfield of Philadelphia.

The elements considered doubtful which had been reported on one or more occasions were as below: Antimony, lithium, arsenic, tin, gold, zinc and lead. Other elements looked for and not found were: barium, strontium, fluorine and zirconium. Tests for these were made with the greatest care and in no instance was a single analysis accepted as sufficient. Moreover, the amount of material utilized was sufficient to give one confidence in its truly representative nature.

While searching for these doubtful elements attention was also directed to the possible discovery of others and a confirmation of the reported occurrence of other rare elements. The results fully confirmed the presence in traces of copper, vanadium, platinum, iridium, palladium and ruthenium, the last named being reported for the first time. Platinum and the allied metals it should be stated were reported as occurring in traces only.

Although the elemental composition of meteorites is in essential agreement with that of allied terrestrial rocks the mode of combination of these elements is in many cases markedly different, a difference which can be accounted for only as due to a deficiency in oxygen in the medium in which they were formed. The following is a list of those minerals characteristic of meteorites which are also found in terrestrial rocks: *Olivine:* the orthorhombic pyroxenes *enstatite, bronzite* or *hypersthene;* the monoclinic pyroxenes *diopside* and *augite;* the plagioclase feldspars *anorthite, labradorite,* or *oligoclase;* the phosphate *apatite;* the oxides *magnetite, chromite* and *quartz;* the sulphide *pyrrhotite;* rarely the carbonate *breunnerite,* and various forms of carbon including *graphite* and *diamond*. The following are found only in meteorites: the nickel-iron alloys *kamacite, tænite,* and *plessite;* the nickel and iron phosphide *schreibersite;* the iron monosulphide *troilite;* the iron and chromium sulphide *daubreelite;* the iron protochloride *lawrencite;* the calcium and titanium or zirconium oxysulphide *osbornite;* the calcium-sodium phosphate *merrillite;* the iron and nickel carbide *cohenite;* the carbon silicide *moissanite* (doubtful); an isotropic mineral believed to be a re-fused plagioclase and called *maskelynite;* and a form of silica, *asmanite*.

Concerning the minerals mentioned it may be said that asmanite is a form of silica probably identical with tridymite; breunnerite, a ferriferous carbonate of magnesia has been reported in but a single

meteorite, that a highly carbonaceous stone which fell in 1864 in Orgueil, France. The probable original nature of this needs verification in my opinion. Carbon occurs in the amorphous form and crystallized as graphite and in microscopic form as diamond; cohenite a carbide of iron and nickel is a common constituent of meteoric irons; daubreelite, a sulphide of iron and chromium, though frequently reported is less common. Of the feldspars, mention need be here made only of the isotropic variety, maskelynite. Lawrencite, the *bete noir* of collectors, is an iron chloride so susceptible to oxidation that when present in quantity it may result in the complete destruction of the meteorite if an iron, or hopelessly obscure structures, if a stone. Merrillite is a phosphate of calcium and sodium, the discovery of which was one of the results of the work I am here recording. The metallic constituents, as is well known, are alloys of iron and nickel known by the names of kamacite, tænite and plessite. The metal is of interest, being soft and malleable when cold and having the general properties, of a wrought iron, *i.e.*, an iron, produced by smelting at low temperatures. It is of further interest in that it undergoes a granulation on heating at a temperature of bright redness. On complete fusion and recrystallization, in the case of an octahedral iron, it assumes more the character of ordinary cast iron. It is, I believe, a product of reduction of the chloride, presumably in an atmosphere of hydrogen. Oldhamite, the calcium sulphide has been reported in but few instances, but this, probably on account of its ready oxidation, passing over into the hydrous form gypsum. Schreibersite, the iron phosphide is an almost invariable constituent of meteoric irons as is also troilite a mono-sulphide of iron, a form usually regarded as an end member of the pyrrhotite series of iron sulphur compounds. Of the remaining minerals, silicates and oxides, all are characteristic of terrestrial rocks and may be passed over here. A word should however be said regarding the gases in meteorites the determinations of which, by various workers,[2] are given in the following table.

[2] See R. T. Chamberlin, "The Gases in Rocks," Carnegie Inst., 1908.

GASES IN STONY METEORITES.

Meteorite.	H_2S.	CO_2.	CO.	CH_4.	H_2.	N_2.	Total.	Analyst.
Guernsey, Ohio	....	1.80	0.13	0.06	0.95	0.05	2.99	Wright
Pultusk, Poland	....	1.06	.06	.06	.52	.04	1.75	"
Parnallee, India	....	2.13	.04	.05	.36	.04	2.63	"
Weston, Conn.	....	2.83	.08	.04	.46	.08	3.49	"
Iowa Co., Iowa	....	.88	.05	.....	1.45	.12	2.50	"
Cold Bokkeveld	....	23.49	.61	.82	.10	.21	25.23	"
Dhurmsala, India	....	1.59	.03	.10	.72	.03	2.51	Dewar
Pultusk, Poland	....	2.34	.19	.27	.64	.09	3.54	"
Mocs	....	1.25	.07	.09	.45	.07	1.94	"
Orgueil	(SO_2) (48.03)	7.40	1.14	.87	.....	.33	57.87	"
Allegan, Mich.	tr.	.21	.19	.01	.08	tr.	.49	Chamberlin
Estacado	tr.	.24	.25	.03	.31	.01	.84	"
Average of 12 analyses	4.00	3.77	.24	.20	.50	.09	8.80	

GASES IN IRON METEORITES.

Meteorite.	H_2S.	CO_2.	CO.	CH_4.	H_2.	N_2.	Total.	Analyst.
Lenarto	....	0.13	0.00	.....	2.44	0.28	2.85	Graham
Augusta Co., Va.	....	.31	1.21	.....	1.14	.51	3.17	Mallet
Tazewell Co., Tenn.	....	.46	1.31	.....	1.35	.05	3.17	Wright
Shingle Springs, Cal.	....	.13	.12	.....	.67	.05	.97	"
Cross Timbers, Tex.	....	.11	.19	.....	.99	.....	1.29	"
Dickson Co., Tex.	....	.29	.34	.....	1.57	.....	2.20	"
Arva, Hungary	....	5.92	31.91	.....	8.57	.73	47.13	"
Cranbourne, Aust.	....	.04	1.13	0.16	1.63	.63	3.59	Flight
Rowton, Shropshire	....	.33	.47	.....	4.96	.62	6.38	"
Toluca, Mexico	tr.	.12	1.32	.04	.27	1.10	1.85	Chamberlin
Average	....	.78	3.80	.02	2.36	.30	7.26	
Average omitting Arva meteorite	....	.21	.67	.02	1.67	.24	2.83	

The high content of sulphur dioxide in the Orgueil stone and that of carbon dioxide in Arva iron are considered abnormal and are omitted in making the averages.

Radium.—Sundry attempts at the determination of the radioactive properties of meteorites have been made by use of photographic plates, but with results by no means satisfactory. Strutt,[3] working by what is known as the Emanation method, was the first to demonstrate its presence in determinable quantity in the stone of Dhurmsala. Later Messrs. T. T. Quirke and L. Finkelstein[4] ex-

[3] *Proc. Roy. Soc., A.*, Vol. 77, March, 1916, p. 480.

[4] *Amer. Jour. Sci.*, Vol. 44, 1917, pp. 237–242.

amined a considerable number of stones and irons and have shown that "the average stony meteorite is considerably less radio-active than the average igneous rock, probably less than one-fourth as radio-active as an average granite, and that the metallic meteorites are almost free from radio-activity." [5]

As is well known meteorites are roughly classed as: (I.) Siderites or iron meteorites, (II.) siderolites or stony iron meteorites and (III.) aerolites or stony meteorites. There are transitional forms but we will not enter into the matter of classification here. The average composition of the all-metal forms as selected by Farrington [6] from available analyses is in the following table:

AVERAGE COMPOSITION OF IRON METEORITES.

	Per cent.
Fe	90.85
Ni	8.52
Co	0.59
P	0.17
S	0.04
C	0.03
Cu	0.02
Cr	0.01
Total	100.23

This needs no comment other than that the presence of the elements mentioned as occurring in traces, would doubtless appear in this analysis had they been looked for with sufficient care.

The average composition of the stony irons is a difficult matter to decide inasmuch as they present great variability. That of the variety pallasite as given by Tscherwinsky is shown in the following table. These figures I should state are not the result of direct analysis, but derived through an elaborate series of weights and measurements.[7]

[5] Inasmuch as meteorites are looked upon as representative of the class of rocks constituting the earth's interior it would seem that this is an important matter for consideration by those who lay so great stress upon radio-activity in connection with certain geological problems.

[6] Field Museum Natural History publication, No. 151, 1911.

[7] The proportional amounts of olivine and metal were determined and from their known percentage composition these figures were obtained by calculation.

Average Composition of Pallasites.

SiO_2	20.08
FeO	7.42
MgO	23.41
Fe	43.33
Ni	4.91
Co	0.27
	99.42

The average mineral composition is given as olivine 51.06 per cent., nickel-iron 48.94 per cent. In both of the cases it is obvious the rarer constituents were not looked for.

Average Composition of (I.) Stony Meteorites, (II.) Terrestrial Peridotites, (III.) Rocks of the Earth's Crust.

Constituent.	I.	II.	III.
Silica (SiO_2)	38.68	37.78	59.93
Titanic oxide (TiO_2)	.18	0.58	.74
Tin oxide (SnO_2)	None	....	....
Zirconium oxide (ZrO_2)	None	....	.03
Alumina (Al_2O_3)	2.88	3.11	14.97
Ferric oxide (Fe_2O_3)	....	2.41	2.58
Chromic oxide (Cr_2O_3)	.47	0.19	.05
Vanadium oxide (V_2O_3)	Trace	....	.02
Metallic iron (Fe)	11.98	....	....
Metallic nickel (Ni)	1.15	....	....
Metallic cobalt (Co)	.07	....	....
Ferrous oxide (FeO)	14.58	18.36	3.42
Nickel oxide (NiO)	.48	0.18	.03
Cobalt oxide (CoO)	.06	....	....
Lime (CaO)	2.42	3.06	4.78
Barium oxide (BaO)	None	....	.11
Magnesia (MgO)	22.67	28.38	3.85
Manganous oxide (MnO)	.29	0.31	.10
Strontium oxide (SrO)	None	....	.04
Soda (Na_2O)	.87	0.68	3.40
Potash (K_2O)	.21	0.32	2.99
Lithia (Li_2O)	Trace	....	.01
Ignition (H_2O)	.75	3.79	1.94
Phosphoric acid (P_2O_5)	.26	0.10	.26
Sulphur (S)	1.80	....	.11
Copper (Cu)	.014	....	....
Carbon (C)	.15	....	....
Chlorine (Cl)	.08	....	.06
Fluorine (F)	None	....	.10
Carbonic acid (CO_2)	(?)	0.75	.48
	100.044	100.00	100.00

In computing the average composition of stony meteorites but 99 analyses were at the time (1916) found sufficiently complete and

[a] TABLE SHOWING ELEMENTS OF METEORITES (STONES) ARRANGED ACCORDING TO PERIODIC LAW AND PERCENTAGE AMOUNTS OF SAME CALCULATED FROM COL. 1.

Average Composition as given in Mem. Nat. Acad. of Sciences, Vol. 14, 1916, p. 28.

Series.	Group 0.	Group 1.	Group 2.	Group 3.	Group 4.	Group 5.	Group 6.	Group 7.	Group 8.
1		H = 1 0.084%							
2	He = 4				C = 12 0.15%	N = 16	O = 16 36.298%		
3		Na = 23 0.645%	Mg = 24.4 13.67%	Al = 27.1 1.527%	Si = 28.3 18.153	P = 31 0.112%	S = 32 1.80%	Cl = 35.46 0.08%	
4	A = 39.9	K = 39.1 0.174%	Ca = 40.1 1.729%		Ti = 48.1 0.108%	V = 51.0 Trace	Cr = 52.1 0.321	Mn = 55 0.24%	Fe = 55.9 23.31 Ni = 58.7 1.524 Co = 59 0.17
5		Cu = 63.6 0.014%							Ru = 101.7 Trace Pd = 106.5 Trace
6 7 8 9									
10									Pt — 195.2 Trace Ir — 193.1 Trace
11 12									

Note: 97.16 per cent. of the elements occur in Series 2, 3 and 4 and in Groups 2, 4, 6 and 8.

accurate to make them available. These yielded the results shown in Column I. of the table on page 121. In Column II. is shown the average composition of terrestrial peridotites and in Column III. the average composition of the rocks of the earth's crust as given by Clarke.[8] The most striking difference it will be observed lies in the relative amounts of silica, alumina, magnesia and iron.

Some years ago at the suggestion of the late Doctor G. F. Becker, I tabulated these figures in elemental form according to the periodic law as shown in the table on page 122. I do not know that Becker made any use of my material, and I present it here without discussion as of only general interest. It will be noted that upwards of 97 per cent. of the elements in meteoric stones occur in series 2, 3, and 4 and in groups 2, 4, 5, and 8 forming a striking contrast with those given in the similar table by Clarke[9] showing the distribution of the terrestrial elements.

In total known weights the three classes of meteorites mentioned are as follows: Irons 168,975,572 grams; stony irons 5,252,534 grams; stones 9,012,199 grams; or roughly 93 per cent. by weight are metallic, 2 per cent. are stony irons, and 5 per cent. stones. Below in Column I. is given the average composition of meteorites as calculated by Farrington[10] using the method of Clarke in 1891.[11]

Average Composition of Meteorites.

Constituents.	I.	II.
Fe Ni Co	75.31	94.16
MgO	6.33	1.60
FeO	4.55	0.88
CaO	0.65	0.12
SiO	11.07	2.33
Al_2O_3	0.74	0.14
All other constituents	1.35	0.77
Total	100.00	100.00

The method though the best that had thus far been suggested is acknowledgedly defective in that it is an average of analyses made

[8] "Data of Geochemistry," *Bull. U. S. Geol. Survey*, No. 491, 1911, p. 32.
[9] Bull. 616, U. S. Geol. Survey, 1916.
[10] Field Museum Publication, Geol. series, No. 151, 1911.
[11] Bull. U. S. Geol. Survey, No. 78, 1901.

regardless of the proportional amount of the various materials. I have thought therefore it might not be uninteresting to present the figures in Column II. representing the calculated composition of such a body as could be assumed to result from the combination of all known meteorites in the above relative portions in one homogeneous mass. It is scarcely necessary to add that the enormous preponderance of metal over all other constituents is due to assumed greater resistance of metallic to stony forms and their arrival on the earth in larger masses, and that the actual average composition is probably more nearly that given by Farrington. It may be added that though some 20,000,000 meteors of sufficient size to be evident after nightfall as a shooting star enter our atmosphere daily, the average annual find of meteorites, as shown in the accompanying table is but four.

ANNUAL FALLS OF METEORITES SINCE 1880.[12]

Year.	No.	Year.	No.
1880	3	1903	6
1881	2	1904	3
1882	4	1905	4
1883	3	1906	2
1884	3	1907	3
1885	4	1908	3
1886	7	1909	3
1887	6	1910	7
1888	0	1911	3
1889	5	1912	3
1890	6	1913	1
1891	2	1914	3
1892	3	1915	2
1893	4	1916	5
1894	3	1917	5
1895	3	1918	2
1896	4	1919	2
1897	6	1920	3
1898	3	1921	6
1899	5	1922	1
1900	4	1923	2
1901	3	1924	2
1902	6	1925	2

The geographic distribution of all known falls and finds up to 1925 is given in the accompanying tables:

[12] The table includes only indubitable cases of the finding of meteorites seen to fall.

Geographic Distribution of Meteorites in North America up to 1925.

Alabama	11	Maryland	3	Oregon	3
Alaska	1	Michigan	5	Pennsylvania	5
Arizona	7	Minnesota	2	South Carolina	5
Arkansas	2	Mississippi	3	South Dakota	2
California	7	Missouri	11	Tennessee	18
Colorado	9	Montana	1	Texas	24
Connecticut	1	Nebraska	9	Utah	2
Florida	2	Nevada	1	Virginia	10
Georgia	15	New Jersey	1	West Virginia	2
Idaho	1	New Mexico	10	Wisconsin	6
Indiana	6	New York	6	Wyoming	1
Iowa	4	North Carolina	22		
Kansas	18	North Dakota	3	Canada	11
Kentucky	16	Ohio	6	Mexico	44
Maine	4	Oklahoma	1	Central Amer.	3
				Total	324

Table Showing Approximate Number, Kind, and Geographic Distribution of Meteorites up to 1925.

Country.	Irons.	Stones.	Stony Irons.	Totals.
North America	209	102	13	324
South America	30	16	6	52
Europe *	29	225	8	262
Africa	25	26		51
Australia †	32	17	5	54
India	3	95	2	100
Japan	3	12		15
Siberia	10	6	2	18
All others	7	17	1	25
Totals	348	516	37	901

* Including Great Britain and Ireland.
† Including New Zealand and Tasmania.

All known meteorites are composed of volcanic materials, and none has shown any traces of animal or vegetable life, unless the carbonaceous matter is to be so considered. This, however, is a wholly unnecessary and, indeed, unwarranted assumption. Nothing in the nature of a terrestrial sedimentary rock, a sandstone, shale or limestone or a metamorphic like a schist or gneiss, has yet, so far as known, come to us from space, nothing in content of silica, alumina, lime, or alkalies corresponding to the granites and nothing of the nature of a true vein. Further, and this seems the more singular when theories of earth history are considered, nothing that can with

certainty be ascribed to a meteoric origin has been found in terrestrial beds of any geological horizon but the most recent.[13] If such have fallen during earlier periods, they must have been of a quite different type, or, what is more probable, become so thoroughly decomposed or otherwise altered as to be unrecognizable. The meteoric origin of the socalled *Tektites* I regard as yet unproven and they are therefore ignored for the present.

[13] This fact was noted by Olbers nearly 90 years ago. Ward's statement as to the Pliocene age of the Lujan mesosiderite seems contradicted by its having been found in "an undisturbed Quaternary formation."

TEMPERATURE SENSATIONS.

By HENRY C. BAZETT.

(*Read April 22, 1926.*)

Temperature sensations have been investigated for many years, but there are no records of actual measurements of the temperatures accompanying them in the tissues.

We have made such measurements of the temperatures in the skin, fat, and muscles, using thermo-couples made in needle form similar to those previously used by Lefèvre and others, but have used them to determine the variations that accompany different sensations.

The needles consist of a steel tube 0.35 mm. or more in diameter and with a central constantan core, and temperatures are read by determining the galvanometer deflection, using a standard couple at a temperature near to that being determined and calibrating empirically. A brass cover protects the needle from the air and allows the depth to be read. The error in reading the temperature of the thermo-couple is small, but owing to the great differences in heat conductivity between the steel and the tissues the estimation of the tissue gradient has an error. When the needles are oblique so that the temperature change along the needle is small, this error is negligible, but if the needle is inserted vertically for only a short distance it may be considerable. Consequently measurements have often been made using an oblique needle and controlling the actual depth by x-rays, but at other times vertical needles have had to be used (where the depth can be directly read), and in such cases a considerable error occurs in the first few mm. depth. In the curves given later the data observed with vertical needles have been corrected. The correction used has been arrived at by comparing the apparent temperatures at such depths when read with needles of varying diameter, the error

being greater the larger the needle, and extrapolating the curve obtained to determine the probable temperature, if the needle diameter had been infinitesimal. From such data an empirical correction formula was derived. All the data thus obtained are probably accurate to within 0.1 to 0.2° C., except perhaps in the case of values obtained with vertical needles at depths of less than 4 mm.

The temperature in the limb muscles are much lower than is generally realized and much below deep body temperatures. The curves shown illustrate the sort of temperatures found in the forearm. The upper two curves illustrate the gradients observed in two subjects in the hot weather of last June. Depths are plotted in mm. as abscissæ and temperatures as ordinates, the needles being introduced vertically and gradually withdrawn. Even in the hot weather the temperature at about 20 mm. depth is much below rectal temperature. Under these conditions there is a flat area with little gradient just superficial to the deep fascia, and the gradient in the subcutaneous tissues is also slight. Both subjects were uncomfortably warm. The same subjects on another day gave the lower two curves, subject 4 having the steepest curve, the higher rectal temperature and complaining of cold. In this case there was now no plateau superficial to the fascia and the gradient in the subcutaneous tissue was steep. On the hand the other subject felt comfortable, and, though the general gradient was steep, the normal plateau superficial to the fascia was present.

Such relationships were common. Thus on another occasion a normal curve with a plateau superficial to the fascia was obtained in the thigh with a room temperature of 22.8° when the subject had been sitting in a damp bathing dress for 43 min.—subject comfortable. A second curve taken similarly in the arm after 85 minutes, when the subject was rather cool, was steeper and no plateau was present. The first curve is normal and the plateau is present, the arm curve is steeper than normal and the plateau absent. After swimming for 20 minutes the subject was very cold and 14 minutes later a third curve was obtained showing an exaggerated gradient, no plateau, a fall of deep body temperature with a rise of muscle tem-

perature accompanying shivering. Shortly after this the shivering stopped, the subject felt comfortable, but the rectal temperature was low and actually falling; a fourth curve was then obtained in the arm 40 minutes after the swim, showing a low temperature level, but a normal type of curve associated with the warmer sensation; the plateau was again present. A fifth curve was lastly obtained in the thigh one hour after the bath and accompanying a comfortable sensation a curve was obtained similar to the first though at a rather lower temperature level. In other experiments after swimming a plateau type of curve even flatter than any of the above has been found associated with a sensation of a warm glow, even though the deep body temperature was 0.5° C., or more below normal.

Sensations of warmth seem therefore to be associated with a general diminution of gradients. Sensations of cold were associated with steep gradients and particularly with the disappearance of the plateau superficial to the deep fascia. Whether these changes are the causes or the results of the sensations it is at present impossible to say.

To investigate the question further we have therefore directed our attention to the changes to be observed on point stimulation with a v. Frey æsthesiometer of the skin end organs sensitive to heat and cold. Stereoscopic x-ray photographs were used to determine the actual positions of the couples and photographic records were made of the changes in temperature observed when a metal point was brought in contact with the skin for a short time. In one experiment two needles were used both at about 2.0 mm. deep, just beneath a warm spot, and both gave similar results. Comparison was then made with the temperature changes occurring on the surface of the skin with the application of such a point. The surface change followed a simple curve that might be anticipated, but at a deeper level the changes were more complicated. In spite of the nearest cold point being somewhat to one side a sensation of cold was recorded soon after a stimulus at 20° C. was applied and much before a recordable change at 2.0 mm. depth. The temperature of the skin remains below normal for several minutes if a point at 20° C. was

applied for only a few seconds. With rise of temperature following the stimulus an after sensation of warmth was considered present by the subject. In a similar experiment, where a 28° stimulus instead of one of 20° was employed a sensation of cold was experienced in the period when the temperatures were rising. With a stimulus of 38.5°, a sensation "hot" much preceded any temperature rise in the needle at 2.0 mm. depth. In this case the needle at this depth showed a slight initial fall of temperature and after this a marked rise, occurring in two steps.

The end organs for warmth appear therefore to be situated considerably superficial to 2.0 mm. That the lag in the deeper needle is due to the tissues rather than to the needle and galvanometer is indicated by the almost complete absence of lag in the surface temperature records.

While the temperature changes recorded in the more superficial layers follow relatively simple curves and only show slight tendencies to step like changes this is not true of deeper needles. Some records show very complex curves and this is particularly true at the greater depths. This presumably implies that heat conduction depends to a considerable extent on movement of heat by the blood stream, so that it is much affected by vasomotor changes. We believe the initial fall of temperature, which is often observed with a warm stimulus, if the needle is a few mm. deep, to be due to vasodilation and passage of cooled blood back to deeper venules.

Sometimes the curves obtained show a similar paradoxical change with stimulation by cold, a deep needle showing an initial rise of temperature.

As the result of such experiments we judge the end organs sensitive to cold to lie not far from 0.5 mm. deep, while those for warmth (on which we have as yet done few experiments) seem to be slightly deeper, almost certainly much less than 2.0 mm. deep, and probably in the neighborhood of 1 mm. If this is true they should lie in the dermis and not in the subcutaneous tissue as has been previously suggested. In order to work at these small depths we have had to

alter our technic and we are now working with wire loops made of wire 0.06 mm. in thickness, and they have given curves similar to those previously obtained with needles. With these loops we hope to be able to localize changes more accurately and possibly to determine whether it is the gradient or the direction of the temperature change that forms the stimulus to the end organ.

The work has been done with the coöperation of Dr. B. McGlone, who should be equally credited for any success attained.

Our thanks are also due to the Ella Sachs Plotz Foundation for assistance towards the expenses.

NULLIPORE VERSUS CORAL IN REEF-FORMATION.

By WILLIAM ALBERT SETCHELL.

The presence of nullipores (or corallines) as well as corals as components of a coral reef was recognized by Darwin and noted for particular reefs in the Indo-Pacific region (1842, etc.). Dana (1849, 1872, etc.) also mentions nullipores (as included under the term coral) but neither he nor Darwin seem to have considered the association of nullipores with corals as of significance in any way except possibly as contributing towards bulk. Semper (1863) and Sir John Murray (1880) have practically disregarded nullipores in their theories, although the latter was certainly in a position to be aware of their existence and to a certain extent at least of their prevalence and striking association with corals on the reefs of Tahiti and elsewhere. Murray regarded sediments, especially of foraminifera, as important in building up reef foundations from deep water to the lower depth limit of reef-forming corals. Alexander Agassiz (1888) realized that calcareous algae were important in reef formation, particularly as contributors to bulk. The true relation of nullipores to coral in reef formation began to be visualized during the Funafuti Expeditions (1896, 1897, and 1898). The data obtained by these expeditions from the point of view of coral reef growth and formation constitute the most considerable and most exact data available for discussion of coral reef theories. The Funafuti Expedition emphasized the "Lithothamnion belt," forming the outer and exposed broad margin of the atoll reefs. It also emphasized the cementing function of the Lithothamnia (or nullipores) all through the reef, binding the disconnected coral materials together. It determined that below 180 feet in the main boring there was a pronounced change in the structure of the reef and that below 637 feet the proportion of magnesium to calcium (due to nullipores) increased enormously. While the two shallow borings (each less than 180 feet) agreed with the main boring as to the character of the upper reef, of looser structure, where corals seem to predominate in bulk, they reënforce the suggestion of the results of the main boring that below 200 feet the nullipore constituent clearly predominates.

A most important observation was made by the Funafuti Expedition in the Gilbert Archipelago in determining that the only visible component of Onoatoa Atoll was nullipore (chiefly *Porolithon craspedium* (Foslie) Foslie. J. Stanley Gardiner, who accompanied the first Funafuti Expedition, added much to our knowledge of the situation in eastern Indian Ocean during the Percy Sladen Expedition in H. M. S. *Sealark* (1905, 1906). He found that the atolls of the Chagos Archipelago (*Nature*, Vol. 72, 571, 572, 1905) are apparently constituted of nullipore reefs (*Porolithon craspedium* probably the chief builder). The presence of corals at the Seychelles, but absence of reefs, he attributes (*Nature*, Vol. 73, pp. 184–186, and pp. 294–296, 1905, 1906) to the lack of "cementing nullipores." He also found nullipores to be the chief reef-forming organisms in the Maldives and Laccadives (quoted by Foslie in "The Fauna and Geography of the Maldive and Laccadive Archipelagoes," Vol. 1, p. 463, 1903).

Marshall A. Howe ("The Building of Coral Reefs," *Science*, N.S., Vol. 35, pp. 837–842, May 31, 1912) has summarized the nullipore situation and has brought out the salient points most clearly and there is little to add to his most admirable exposition except in emphasis of his position. Howe has called attention to Bigelow's report (*Proc. Amer. Acad.*, Vol. 40, pp. 557–592, 744, 1905) on the calcareous pebbles making up the Challenger Bank off Bermuda, in depths of 180 to 300 feet.

Professor E. L. Mark has kindly given me samples of calcareous pebbles of the same collection dredged from the Challenger Bank in 1903. These pebbles or concretions vary from a few inches to possibly a foot in their large diameter. On cutting, they are found to be formed about a small shell or fragment of a shell, by layer after layer of nullipore (various species of Melobesieae), until the relatively huge mass of nullipore results.

The Funafuti reports (p. 173) call attention to the fact that there were found "everywhere scattered through the rocks, organisms, and fragments of organisms, encrusted with successive layers of a foliaceous Lithothamnion, till irregular nodules from 1 to 2 inches, or even more, in diameter, have been built up." The indications are that such nodules, formed of layers of nullipores, alternating irregu-

larly with layers of *Polytrema,* have been important in reef formation in all parts of the world.

My own experiences at Tutuila of the Samoan group in 1920, at Tahiti of the Society group (1922), and on Oahu of the Hawaiian group (1924) have led me to bring forward the relation of nullipores as reef builders and reef formers, particularly in the Indo-Pacific region.

Rose Atoll is built up, according to Mayor (cf. Setchell, Carneg. Inst. Wash., Pub. 341, pp. 242, 243, 1925) of nullipores (*Porolithon craspedium*) and the exposed fringing reefs of Tutuila (cf. Setchell, ibid., pp. 34, 35) owe their existence, form, and growth characteristics particularly to the nullipore, *Porolithon onkodes* (Heydr.) Foslie. The island of Tahiti, however, shows reef formation of all forms except, naturally, that of true atoll, in most characteristic and instructive fashion. I have classified these reefs elsewhere (Carneg. Inst. Wash., Yearbook, 21, pp. 180–187, 1923) as exposed fringing reefs, protected fringing reefs, and barrier reefs. I have also called attention to what I have called incipient exposed fringing reefs and to barrier banks as possible incipient or undeveloped barrier reefs. Elsewhere I shall publish further details tending to support these ideas. It is sufficient here to call attention to the fact that nullipore action is not only the controlling factor in each form (or type) of reef or bank but that there is also a definite nullipore specificity due to ecological and growth form peculiarities, for each type of reef or bank as well as for depth.

Porolithon onkodes (Heydr.) Foslie is a surface builder and through its influence the exposed fringing reefs of both Tutuila and Tahiti have been built out as shelves, adding to their bulk below the surface by coral growth held together and in place by the cementing nullipores (Melobesieae and calcareous Squamariaceae). The protected fringing reefs of Tahiti were probably exposed fringing reefs at first, extending later after being protected by the formation of barrier reefs, by corals of vertical growth forms and by cementing nullipores. The barrier banks of Tahiti have arisen in an encircling zone in water of 30 or more fathoms, by the growth of nullipores almost exclusively, until within a few fathoms of the surface. One of the reef-formers here is *Lithothamnion Dickiei,* said to have prob-

ably formed an entire bank in the neighborhood of Papeete. Over a considerable portion of the shores of Tahiti, the barrier banks have become coral (with cementing nullipore assistance) reefs until near the surface, when the pavement nullipore (*Porolithon onkodes*) has rounded them off above and assisted in their preservation and extension in width. On certain sectors of the Tahitian coast the barrier structures are still in the form of banks, due probably to inhibition of their growth rate, or time of inception, by some factor, probably connected with the volcanic history of the island.

The nullipore relation is known in atoll reefs, such as Onoatoa, Rose Atoll, and the Chagos. These reefs are due chiefly to *Porolithon craspedium* (Foslie) Foslie as both reef-former and reef-builder. This nullipore is not only a surface organism (particularly a cumatophyte or surge plant) but it undoubtedly grows much deeper (exact depth not known at present). The encircling atoll reefs when in the "bank" stage allow of full sweep of water over them, which possibly explains the larger depth relation of this nullipore. The lowest portions of an atoll reef probably are (or at least may be) formed largely by nullipores of simple encrusting form, but few data are available as to specific forms. From Funafuti, one of the species from about 250 feet of depth is *Lithothamnium funafutiense* Foslie.

Finally, I may state that a study of the nullipore relation leads to the following suggestions:

1. The nullipore relation removes the depth limit assumed for reefs supposedly depending upon "reef-forming corals." Subsidence or other type of gradual change of sea level theories are unnecessary, since living nullipores have been obtained from a depth of 1,200 feet at Funafuti and even, as Howe indicates (loc. cit., p. 841) as deep as 350 fathoms or over 2,000 feet in Florida waters.

2. The second assumption, practically of all coral reef theories, is that of the interconvertibility of different types of reef. My studies at Tahiti indicate that the nullipore control not only renders this unnecessary as an assumption, but also indicates the improbability of its occurrence in the sense in which Darwin and others have postulated it. Fringing reefs, barrier reefs, and atoll reefs show

peculiarities of nullipore species and growth form and action, each more or less peculiar to the particular type of reef form.

In closing his article on "The Building of Coral Reefs," Howe says: "Much evidence has accumulated tending to show that the importance of corals in reef building has been much overestimated and that the final honors may yet go to the lime-secreting plants." It seems to me that the final honors can now be bestowed and, without minimizing the contributions of corals, there may be added:

1. That without nullipores no "coral reefs" can be or would have been formed;

2. That the biological depth limit founded on coral peculiarities may be abandoned;

3. That reef interconvertibility not only is an unnecessary assumption, but for most barrier and atoll reefs it is thoroughly improbable that they arose from fringing reefs through a period of gradual subsidence;

4. That the final evaluation of the fact that coral reefs are commonly formed on shores where change of sea level has taken place, is still to be made, but it seems probable that these changes of sea level took place before rather than during the growth of the reefs and are incidental rather than causal in reef-formation;

5. That the animal components of the reef of next importance after the nullipores are the various encrusting species, especially of *Polytrema,* a genus of the Foraminifera. In the upper 150 feet of the main boring of Funafuti, corals constitute only one fifth of the bulk while below that their remains are much altered and represent a less considerable element, in all probability being debris from higher levels. As fillers, sand (shell and coral fragments and Foraminifera) and shell and coral rubble form elements of reef structure and Murray (1880) was inclined to attribute to these the building up of reef formations to the level where coral growth becomes possible.

6. That barrier and atoll reefs originate at depths below the limits for growth of reef-forming corals as a result of zonal ecologic conditions and rise towards the surface, the fairly uniform depth of lagoon and moat, respectively, being in these cases another expression of zonal control.

THE PREHISTORIC PERUVIANS.

By CHARLES W. MEAD.

When Pizarro began the conquest of Peru in 1532 the Inca Empire included the greater part of what is now Ecuador, Peru, Bolivia, and also the northern part of Chile down as far as the Maule river in the thirty-seventh degree of south latitude. Thus it extended from north to south a distance of 2,200 miles. It varied greatly in breadth. In very early times a stone age people lived in various localities on the coast. True paleoliths, like those of Europe, have been found in considerable numbers at Arica and Taltal, in northern Chile, particularly at Taltal where the lowest strata of graves, where they are found, contain nothing but paleoliths.

Many centuries before the rise of the Inca Empire the so-called megalithic people flourished. All our knowledge of this people is derived from such of their works as are still extant. They were the builders of Tiahuanaco, and similar megalithic remains. Among the best known of these megalithic structures are *Sacsahuaman,* on the hill above Cuzco, *Ollantaytambo,* at *Concacha* near *Apurimac, Chavin, Huaraz* and *Quelap* in *Chachapoyas.* Remains of this kind are widely distributed over the whole country, suggesting that the megalithic people were a more or less homogeneous people. Prescott well says of them: "Who this race were and whence they came may afford a tempting theme for inquiry to the speculative antiquarian. But it is a land of darkness that lies beyond the domain of history."

Yet due to recent archæological research we know that there were three great centers of culture in Peru in prehistoric times: the region about Trujillo, Nazca, and Tiahuanaco. There is good reason to believe that they flourished, at least in a portion of their duration, at the same time, for we find forms in pottery and ornamental motives in each that also appear in the other two. The characteristics of their arts were however entirely different.

In the northern coast or Trujillo art, realism prevailed. Animal

and vegetable forms in terra cotta, without conventionalization, vases that were evidently intended as portraits, and well executed scenes from their daily life, and even landscapes painted on their pottery vessels.

The art of the Nazca region does not show the wonderful modeling found at Trujillo. It is inferior in this respect to that of many parts of Peru, but in wealth of color it surpasses all other regions, and conventionalization runs riot in their painted decorations.

The art of Tiahuanaco is best illustrated in work in stone. The best and most characteristic example is the carving on the great monolithic gateway at Ak-Kapana. The central figure represents some god, holding a staff in either hand. The art motives are the human figure, the condor and the puma.

We know nothing definitely about the rise of the Inca Empire, but it seems probable that in the beginning it resulted from the joining of two Andine cultures, that of Tiahuanaco and the Urubamba Valley. This seems to be borne out by forms and ornamental designs of pottery, from burial places in the coast valleys, which are often in the styles of both Cuzco and Tiahuanaco.

The Incas domesticated the llama, which they used as a beast of burden. This gave them a great advantage over their enemies, as it enabled them to transport supplies to a great distance. By conquest and confederation they gradually overran the entire country. It is generally believed that they finally conquered the northern coast region about 1,400 of our era.

The formation of the country is such that they had all degrees of temperature, from the burning heat of its deserts to the perpetual winter of the highest cordilleras. The strip of land along the coast is largely a desert where rain rarely falls. At intervals there are small fertile valleys, watered by streams that come down from the mountains to the Pacific Ocean. The mountains mostly run in two parallel ranges: the eastern known as the Andes, the western as the Cordillera. North and east of Lake Titicaca are the Bolivian Andes or Cordillera Real.

Their government was a pure despotism. The Inca, as the representative of the sun, was at the head of the priesthood and of the army, making all the laws, and appointing judges to enforce them.

In short, he was a superior being, owning everything, and the source of all power in the empire. No one could approach him unless barefoot and carrying some token of homage. He was supposed to allot to each person or to each family sufficient land for their support, who could not part with any of it, nor could they acquire more from their neighbors.

It is impossible to determine the number of reigning Incas, as the list of names given by the different old chroniclers vary in number from 8 to 102. The Inca, Huayna Capac, died in 1525, only 7 years before the advent of the Spaniards.

Cieza de Leon says that more than 4,000 souls, women, pages, and other servants, together with immense riches were buried in the tomb with the Inca Huayna Capac, and adds the somewhat doubtful statement: "As soon as Huayna Capac was dead the lamentations were so great that the shouting rose up to the clouds, and the noise so stupefied the birds that they fell from a great height to the ground."

When Pizarro entered the country he found it divided against itself. When Huayna Capac was dying he decreed that his illegitimate son Atahuallpa, by a princess of Quito, should inherit the ancient Kingdom of Quito, the rest of the empire he settled on his legitimate son Huascar in Cuzco. This arrangement was satisfactory to neither son, and they were engaged in a bitter war when the Spaniards arrived.

The Inca prince was well trained for the position of Inca. He and other princes of the blood were obliged to undergo severe training to prove their strength, courage and general fitness to govern the empire. They were made to fast for a number of days with only a small amount of food and water, as such a fast might be necessary in times of war. They were obliged to run a race over a distance of a league and a half. Garcilasso says their parents and relations would intercept the runners, encouraging them, and telling them it was better to break their hearts in the race than to come off with dishonor.

They were also divided into two equal parties: one to garrison the fortress, and the other to assault it. The next day they changed stations. They had to show their dexterity in archery, throwing stones at a mark with a sling, casting the lance and dart, and were

also obliged to learn how to make all implements of war, and their clothing.

If we divide the range of the world's culture into enlightened, civilized, barbarous, savage, and presavage, the Peruvians, at the time of the Conquest, come under the head of barbarous people: if one defines barbarism as a stage in which powerful nations were founded, and systems of record developed.

It is not uncommon for a barbarous people to reach a high development in one of the arts, as for instance in basketry; but the Peruvians excelled in many directions. They produced great architects, as shown in many of their structures, and great engineers, who built aqueducts hundreds of miles long for irrigating the desert coast lands. They made pottery with beautiful lines and colors, and textiles which, in technique and decorations, have never been excelled. They invented the Quipu, an efficient instrument for keeping their accounts. They had a well-organized government.

These things seems to entitle them to be classed as a civilized nation; but the other side of the picture is not so agreeable. We are told in one paragraph that the Inca was a most beneficent ruler, and in the next that he was a savage, who being offended at an individual, immediately proceeded to destroy the village to which the offender belonged, killing men, women, and children. After reading Prescott's "Conquest of Peru" one is left with the impression that the Incas, at the time of the Spanish invasion, were making remarkable strides toward becoming a highly enlightened nation. We now suspect that they had reached the highest development it was possible for them to attain, and were, in fact, going backwards at the time Pizarro entered the country.

Historical contact with almost every eastern nation has been claimed for Peru. In this way it has been sought to account for many of the arts of the Peruvians; but none of these claims have been substantiated, and it is now generally conceded that they developed in their own country and owe nothing to any outside influence.

Again Mexico and Peru flourished at the same time, but it is improbable that they knew of each other's existence. Certainly their arts developed along very different lines. The character of their

civilizations was entirely different, for while the Peruvians were much superior in agriculture, the textile arts, and in such public works as roads and aqueducts, they fell far short of the Maya in the higher intellectual culture: more particularly in astronomy, and in the invention of hieroglyphs as a means of communicating thoughts by visible symbols.

The prehistoric Peruvians, like the Indians of the country today, were of moderate stature: the men measuring between 5 ft. 2 in. and 5 ft. 3 in. The women about 2 in. less.

Peruvian dwellings were of several kinds. On the coast, and in the warm valleys they were generally of cane, supported by posts of algaroba wood, and often plastered with mud. Sometimes made of adobe. In either case the roof was a mat of reeds, or thatch of ichu grass laid over sticks. In cold districts stone was often used in building their huts.

Father Cobo and Cieza de Leon have given us good accounts of their clothing worn at the time of the Conquest. The dress of a man consisted of a breech-cloth, over which a poncho, with or without sleeves, called *uncu*. The outer garment, called *yacolla,* was thrown over the shoulders. When dancing or at work two of the corners were tied together at the left shoulder.

In some localities the women wrapped themselves in a large piece of cloth, which hung under the arms. The edges were pulled up over the shoulders, and fastened with a *topu* or pin. A broad belt, called *chumpi,* encircled the waist. The outer garment, called *lliclla* was shawl-like. It was thrown over the shoulders, and fastened over the breast with a pin. These pins have very large heads, some in the form of a spoon, with which they ate their roasted and ground corn. Others had flat heads, with a thin edge which they could use as knives.

On going to sleep, at night, they did not undress: the men threw off the *yacolla,* and the women the *lliclla.*

When any foot covering was used, it was a sandal, made either of llama hide or of braided vegetable fiber.

Agriculture was carried on in a strictly scientific way, often under great natural difficulties. In many parts there was little arable

land. To remedy this shortage the hillsides were made into terraces, and soil laboriously carried up.

In planting, a stout stick was used. On the northern coast this stick was shod with copper. This copper point was shaped much like a chisel, and had a socket at the upper end into which the handle was driven.

They had no plough-share, but Garcilasso says that sometimes a pointed stick was drawn through the earth by a number of men on a rope: women following to break up the clods. For manure they used guano or a sardine which they could procure in immense numbers.

Besides maize, potatoes, sweet potatoes, tomatoes, beans, mandioca, squashes, oca, quinoa and two varieties of cotton, we know that a variety of fruits were cultivated.

Maize was the staple food in localities where it could be raised. It was boiled, or roasted and ground into meal. A bag of this meal is often found with a mummy. It is the principal food, carried on journeys, by the present Indians. A spoonful of this meal and a swallow of water now and then is all they require.

In very cold regions, where corn cannot ripen, quinoa takes its place, or in the neighborhood of Lake Titicaca a small variety of potato is grown. This potato is frozen and pressed to free it from moisture, and thus prepared it is called *Chuñu*. It is a tasteless food, but the only way the potato can be preserved in this climate.

The coast peoples subsisted quite largely on fish. The sea all along the coast abounded in a great variety of excellent fish. They captured these fish in nets, by hook and line, and with spears having detachable points of stone or copper to which were fastened long cords or strips of llama hide, by which the point could be recovered after it had left the shaft.

The list of animal foods is a short one. The herds of wild vicuna and alpaca on the mountain belonged to the Inca. The flesh of the deer, and in some localities the guinea-pig, peccary, and the *vischacha,* a large rodent, ducks and geese were the principal animal food.

In many localities the flesh of the guinea pig is the only meat.

It is roasted or made into a thin stew, highly seasoned with Chili peppers.

Hunting implements were the same as those used in war, the bow and arrow, the club with stone or copper head, a spear, sometimes cast with a throwing stick, and the bolas.

Narcotics.—The dried leaves of the coca plant (*Erythroxylon coca*) were chewed, with a little lime, exactly as the betel nut is chewed in the East.

Chicha, a kind of beer, generally made from maize, was the national drink when the Spaniards entered the country, and has lost none of its popularity since that time.

Metallurgy.—The Peruvians worked gold, silver, copper and lead. The objects fashioned show that casting in moulds, beating up tall cups from a single piece, soldering and even plating or gilding one metal with another were understood.

They had also discovered the art of making bronze. They found that a combination of copper and tin made a much harder and more serviceable tool than one of copper alone.

I have spoken of the characteristics of the pottery in the different sections of the country.

We are indebted to these old potters for quite a part of the knowledge we have of things familiar to them in their daily life. They have left us models of their houses, of their costumes, animals and vegetables. Their painted decorations show women weaving, and fishing and hunting scenes.

The early Spanish chroniclers were not interested in such things, and could not imagine that future generations would be.

The Conquistadores entered the country with but two ideas; the acquisition of gold and the spreading of the Catholic religion.

As in other parts of the world every important act was in conformity to a ritual. When the earth had been prepared for planting the people sang certain songs. The substance of these songs was taken from the word *hayllis*, which means triumph, as if they triumphed over the earth and took fruit from it.

Another festival was held, by the highland people, when the corn appeared above the ground. Sacrifices of young llamas, barren

ewes, and male llamas were offered, and the deity petitioned not to allow the crop to be destroyed by frost.

The principal festival of the sun, called *Yntip Raymi* was celebrated in Cuzco, soon after the Summer solstice. All of the principal captains of the army, and the lords of the different provinces assembled on this solemn occasion to do honor to their god, the sun, by virtue of whose heat and light all living creatures were generated and sustained.

Early on the appointed day the Inca arrived, followed by the whole population of the city. They watched for the rising of the sun, and as his first rays were seen a great shout broke forth from the multitude. The Inca offered a libation to the sun from a large golden vase, filled with the fermented liquor made of maize. He drank from the vase himself, and gave what remained to his royal kindred. After this ceremony they all went in procession to the temple. Later the high priest offered a sacrifice, generally a llama. He opened the body and sought from the appearance which it exhibited to read the future.

They had made considerable progress in surgery and medicine. Trephining was done with a piece of obsidian or a sharp stone. After the advent of the Spaniards the medicine men used a piece of a broken bottle, a knife, chisel, or any sharp implement.

In Peru, where clubs with star-shaped heads of stone or copper, and slings for throwing stones were in common use, fracture of the skull must have been a common occurrence and trephining often resorted to in such cases. It was also done for other reasons, probably some religious belief.

Amputation of the foot was a common surgical operation in the coast region, judging from the number of pottery human figures in museum collections, that have lost one or both feet.

In the mythological fables of Peru we find variants of the Biblical accounts of the great flood and of the virgin birth.

Christoval de Molina wrote the Inca account of the great flood between 1570 and 1584.

In the life of Manco Capac, who was the first Inca, and from whom they began to be called the children of the Sun, and to worship the Sun, they had a full account of the deluge. They say that all people and all created things

perished in it, insomuch that the water rose above all the highest mountains in the world. No living things survived, except a man and a woman, who remained in a box, and when the waters subsided, the wind carried them to Huanaco.

The Peruvian variant of the virgin birth was written by Francisco Avila, cura of San Damian, in 1608.

The god *Uira-cocha* caused the virgin goddess, *Cavillaca*, to conceive by dropping before her the fruit from a *lucuma* tree. To her own astonishment she gave birth to a son. She assembled all the gods to find out who was the father, by the test of the child recognizing him.

Uira-cocha came disguised as a wretched beggar. The child went at once to him. *Cavillaca* was so ashamed and enraged at the thought of such a character being considered the father of her boy that she snatched up the child and fled to the sea. *Uira-cocha* resumed his godlike form and pursued her, calling to her to turn back and look at him. She was soon out of sight, and when she reached the shore of Pachacamac she entered the sea with her child, and immediately they were turned into two rocky islets, which may still be seen.

THE PEOPLING OF THE EARTH.

By ALEŠ HRDLIČKA.

(Read April 23, 1926.)

At the annual meeting of this Society in 1921 the speaker had the pleasure of presenting a discussion on the subject of "The Peopling of Asia"; and in dealing with that key-problem brief notes were added on the peopling of other parts of the earth. To-day he is able to add the results of three additional large trips abroad, the last of which in the year just passed took him through the Mediterranean and the Red Sea to India, Ceylon, Java, Australia and South Africa.

These trips have enlarged the horizon. They brought many new detailed facts. But their main result, it is gratifying to state, was that the essentials given in 1921 were in all important respects corroborated. Without further preliminaries, it is now possible, with fuller confidence, to make the following statements:

Man's Origin.—Just where on the earth the first beings that could be called human came into existence, is as yet uncertain; but the weight of present evidence, so far as the known varieties of man are concerned, points most towards western and southwestern Europe.

The Cradle of Man.—By the "cradle" of man is meant the location of the nursery of human kind, the region where the infancy and early childhood of man was passed. Here again, and that even more than with the origin of man, the mass of indications to date is found to point to western and southwestern Europe, with probably an early extension of the species on the one hand towards Central Europe and on the other over the watershed of the Mediterranean.

The idea that the cradle of man lay in Central Asia, still supported in some quarters, may be characterized as merely an idea, based on collateral rather than critical anthropological reasonings and without to this moment a single item of material evidence. All found thus far in Central Asia connected with earlier man, relates to his post-glacial extensions and hence to a man already late in history, nearly

fully fledged and approaching man of modern times. The infancy of the human race belongs to the earlier half of the glacial period, and of man of this period not a vestige of substantial evidence of any sort exists as yet outside of the above-mentioned parts of Europe.

It is strange what a hold fixed ideas have on most of us. Were it a question of any other family of mammals, the region which gave us not only the mass of the remains of these mammals but also that in which alone were found their earlier representatives would inevitably be taken for the probable original home of that family. Only with man this law does not seem to apply and he forcibly is being led into a region which to this moment has shown not a sign of such an existence—simply because such a placement would fit reasons based on imperfect and irrelevant evidence and conceptions.

Human Differentiation.—Human differentiation into races, varieties and possibly even species may rationally be dated from the earliest time of his separation into localized groups. The process doubtless began even before man was full-fledged. But of what was accomplished in the earlier times we know as yet next to nothing. The forms are gone, and their known skeletal remains are still so few in number that no conclusions of value are possible.

The Neanderthal Man.—It seems probable, however, that by the time the last or Würmian glaciation was approaching, man existed in only one general form, known as the Neanderthal. This form is seen persisting for a very long time, several if not many scores of thousands of years, into the beginnings of the postglacial or recent time. Some students incline to view this important and already fairly well known form of humanity as a separate species perhaps a side branch of the main human stem which came into existence in the dim past, developed a characteristic type, never weaned itself from this type and perished completely some time after the last glaciation, without leaving descendants.

Most of this, it may now be confidently said, is erroneous. The Neanderthal form is a necessary stage of man's evolution; it is not uniform in type either as to the skull or skeleton; it shows plain indications of progressive differentiation towards modern man; and it is met with in a more or less dilute but still recognizable form in later humanity, even down to the present day. Moreover a human

strain as long lasting and as widely spread as the Neanderthal could not completely disappear, like a mere animal species, through any known agencies. Should we agree that Neanderthal man in Europe and neighboring regions became extinct and that his place was taken by the so-called *Homo sapiens,* who presumably came from another source somewhere in Asia, we should be obliged to assume another Neanderthal-like phase in those quarters. For man could not possibly have bridged the gulf from his precursor or anthropoid characteristics to the type of *Homo sapiens* without passing through a phase similar to that of Neanderthal man.

The probabilities are that the latest Neanderthal man, due to the vicissitudes of the last glacial invasion, became much reduced in numbers in Western Europe, and that his place was eventually taken by the transitional Aurignacian man, who was nearing the modern human type. The latest developments in Central Europe and elsewhere make it probable that while the Neanderthal type was declining in the west, portions of it which had meanwhile extended into and possibly beyond Central Europe, developed gradually into the Aurignacian man, who, spreading once more westward, reoccupied most if not all the sites of his Neanderthal forefathers. At one time it was supposed that the Aurignacian man might have developed to the south of the Mediterranean; but the evidence for this view is unsatisfactory.

Differentiation of Postglacial Man.—A comprehensive survey of both preglacial and postglacial remains of man, as known to-day, leaves the impression that until after the last glacial invasion man multiplied but slowly and irregularly, and occupied but a smaller part of the Old World, with the rest of the earth as yet unpeopled. The great wonder is, in fact, that man sustained himself at all during the hundreds of thousands of years of his earlier development, from the first human to the latest Neanderthal forms, against nature, disease and his own kindred. But following the last glacial invasion there is clearly a relatively rapid and ever surging advance in culture; and man evidently for the first time in his history becomes capable of furnishing such a surplus of numbers that needs ever greater extension of his domain. It was during these earlier postglacial times that we witness his spread in all favorable directions—eastward into

and beyond Central Europe, southeastward into Palestine and much further; and southward at least as far, it seems, as Northern Rhodesia.

It was doubtless during this earlier half of the postglacial time that the foundations were laid for man's differentiation into the older human stocks or races the progeny of which exists to-day. There is no evidence that since these times any human race worthy of the name has perished.

The Old Races.—The oldest human physical stocks constitute what we know as the main strains of humanity. They are the yellow-browns, the negroid and the "whites." These strains assumed in the course of time, during the latter half of the postglacial age, the basic characteristics which mark them one from the other; and each developed in turn a number of variants or secondary races, which, while differing more or less amongst themselves and also from the old native stock, retained nevertheless sufficient in common to be recognizable as to their sources and relations. These secondary races are as follows:

The yellow-browns peopled the central, eastern and northern Asia. Here they differentiated into a number of sub-types, which give the modern Asiatics such as the Mongols, Tungus, Chinese, etc. As pressure of population increased and resources diminished, more northeastern contingents pushed out still further northeastward—towards America; others forged southward into Malaysia, later into Madagascar, and, mixed already with other elements, into Micronesia and Polynesia. Still others endeavored to overflow the Himalayas to the southward. And eventually when other roads were blocked the northern masses turned back westward, towards Asia Minor and Europe, as the Mongol invasions.

Intermediately between these and the Europeans appear a considerable body of "semi-Mongolic" peoples known as the Finno-Ugrians and Tatars, extending from the Baltic to and over the western half of Siberia and Central Asia.

America, according to all indications, received a number of already distinct though in most respects closely related sub-types of the older yellow-brown stock, besides eventually developing some of its own.

The distinguishing negro characteristics developed, it seems certain, in the heart of Africa. But from far back the negroids appear in two main strains, the short, or pigmy or negrillo, and the well developed negro. The shorter type differentiates in turn into the negrillo proper and the bushman with the related hottentots and "strandloopers." From this type, which at one time was probably much more prevalent than now, an offshoot called now the negrito, proceeded in an eastern direction, skirting evidently the southern coast of Asia and reaching as far as the Philippine Islands.

The regular negro developed, in numbers at least, evidently somewhat later than the short, and has not as yet differentiated into as distinct sub-types as the latter; though localized differences are well known.

The "whites," probably before reaching a status when they could be fully characterized as such, began to extend especially in the southeastern direction, and must have reached not merely Asia Minor with the Caucasus and Persia, but also India and probably even Java and Australia. Their furtherest stream which retains to this day numerous primitive characteristics that approach it to the uppermost Mousterian and the Aurignacian man, are the Australians. Subsequent developments of the whites take place in India, Asia Minor and Northern Africa to form the Dravidian-Hamitic and Semitic types; while those remaining in Europe differentiate gradually into the Mediterranean, the Central or Alpine, the Nordic and the Slavic types.

For much of this the speaker's 1925 journey has furnished further corroboration.

One of the most satisfactory results of the trip relates to the Negritos. As brought out in the 1921 discussion, one of the major problems in anthropology is the presence of the Negrito in the Philippines, the Malay Peninsula, the Andamans and elsewhere in the far southeast. He is there—a clear but enigmatic type without connection in any direction. His nearest relatives are apparently the Pygmies of Central Africa—there is nothing else with which to connect him; but a great unbridged space has till now separated the two. The problem has been—how did the Negrito get to his present homes. If he extended from Africa, he must have left traces of his passing

in Arabia and India, from which however there has come hitherto no clear evidence of his presence. However, such traces, so far at least as the Indian coast lands are concerned, the speaker became satisfied, do exist. They occur in Parganas (northwest of Calcutta), in at least one area along the eastern coast, here and there among the Dravidians, and along larger parts of the western coast, more especially in the Malabar Hills. This brings unmistakeable traces of the Negrito a long way more to the westward and so much nearer to Africa, making his derivation from that continent so much the more probable.

Another major problem of anthropology has always been that of the Australians together with the Tasmanians. Data obtained on this subject were rich beyond expectation, including the essential determinations on approximately 1,000 well identified skulls of Australians and most of the known crania from Tasmania. The data throw very interesting and to some extent new light on the constitution of both of these peoples. According to these observations, the Australian aborigines deserve truly to be classed as one of the more fundamental races of mankind, and yet it is a race which shows close connections with our own ancestral stock—not with the Negroes or Melanesians (except through admixture), but with the old white people of postglacial times. They carry, however, some admixtures of the negroid blacks, which is more pronounced in some places than in others.

As to the Tasmanians, the indications are that after all they are but a branch of the Australians, modified perhaps through this particular admixture and in their own country. Both peoples have lived, and the Australians of the northwest live largely to this day, in the palæolithic stage of stone culture. They are still making unpolished stone tools, which in instances resemble the Mousterian implements of later European palæolithic types—though they are capable also of a much higher class of work.

The third problem of much importance to anthropology is that of the presence to this day in different parts of Asia of living remnants of the older yellow-brown stock or type from which was derived the American Indian. On this point also new light of importance was gained on this journey. In the southern slopes of the Himalayas are found to-day many Tibetans, as well as other Mongoloid tribes

who at some time in the past overflowed the range but could get no further southward. Among these, but more particularly among the Tibetans, one finds to-day true American Indian types, so true that if they were transplanted into America nobody could possibly take them for anything but Indian. They, men, women and children, resemble the American Indian in physique, in behavior, in dress and even in the intonations of their language.

Finally interesting observations were brought from the journey relating to the formation in far-away colonies of what eventually promise to become new types of the white man. They relate to Australia and South Africa. The older population in Australia shows a perceptible trend towards the formation of a fine type of tall, lithe, efficient man, resembling in many respects the older stock in America; while in South Africa the mixture of the older Boer population with the English, together with other conditions, is favoring the development of another good, newer white type, somewhat stockier than the English, less tall and lanky than the Australian, but according to all indications a favorable type of considerable promise.

Nothing of the above nature, notwithstanding some mixture with the natives, is taking place in the Dutch colonial possessions, or in India. This is due to the fact that European man in those countries is in small numbers, and in general lives there only temporarily without raising an acclimatized progeny.

THE PEOPLE OF THE MAIN AMERICAN CULTURES.

By ALEŠ HRDLIČKA.

(*Read April 24, 1926.*)

It is generally agreed that the main precolombian American cultures, from north to south, were those of the " Moundbuilders " and the Pueblos in what are now the United States; the Toltecs, Aztecs and Mayas, in Mexico and Central America; the Chibchas, Chimu, Nascas, Kechua and Aymara in South America.

This selection is imperfect; it is not based on exact scientific determinations; it is possible that other groups on a critical study would be found to have the right to be included in this list; but the groups mentioned are the best known, and they are those who produced the most impression on the precolombian American developments of a material nature, particularly in the way of construction.

The earthwork and architectural achievements of the " Moundbuilders," Mayas, Toltecs, Aztecs and Incas, were in fact of such a nature and magnitude that the people who produced them became in many minds dissociated from the ordinary American Indian, and were believed to have been different " races." To this day we often in reading encounter the " race of the Moundbuilders," " the Aztec race " and similar expressions.

A more advanced view, to which even some serious scholars of our days incline, is that several, if not all, of these old native culture-groups were influenced by accessions from outside of the American continent. Thus the idea of the Chinese (with later Japanese) connections along the western coasts is very strong; and there are other suggestions (southern Asiatics, Egyptians, white men). Most recently there comes from France (Rivet, Verneau) a recrudescence of the notion that the western parts of the continent received some of the Pacific islanders, and, Rivet adds, even Australians.

The facts are, in brief, that for no one of these contentions or suggestions is there any physical proof. The people of our main

aboriginal cultures were just Indians and, so far as known, nothing but Indians. The culture developments were, according to all indications, not due to different blood, but to propitious conditions. So far as physical anthropology goes, there has never been found reliably a trace of any other precolombian population either in North or South America than the Indian. The Moundbuilders, the Aztecs, Toltecs, Mayas, Incas, all were but Indians. If ever there had taken place any contact of other people—and this is by no means improbable—this contact was so small that while it may have influenced culture it left no traces of physical nature that could to-day be clearly ascertained. Cranial resemblances to other peoples, believed in originally by Quatrefages and after him by Ten Kate, Rivet and even Sullivan, are resemblances based in all probability on old basic relationship, or are demonstrably individual variations and constitute no proofs of racial admixture.

The builders and bearers of the principal precolombian American cultures were however not all of one type of the Indians. The Indian population developed doubtless not from a single pair, nor from a single immigration, but from repeated small comings or dribblings over of eastern and northern Asiatic tribes which, though evidently all parts of the older yellow-brown race, differed already in type, language and other particulars. It is still possible to recognize several of these pre-American types of the Indian, and their distribution is not only of much interest but also probably of chronological significance. They are, roughly, (1) the older dolichocephals, represented by many of the tribes from South America to Mexico and California; (2) the older brachycephals, the "Toltec" type of Morton, extending over the Antilles, Yucatan, parts of Central America and of Ecuador, and down the coasts of Peru to north of Arica; (3) the later dolichocephals, represented by the Algonkin tribes with most of the Iroquois; and (4) the latest brachycephals, represented by the Athapascan tribes, reaching with interruptions in a narrow stream from Alaska to northernmost Mexico. In addition to these there are recognizable several other types, such as that of our Gulf States, that of the Sioux, etc., which are apparently of indigenous development.

We may now proceed with the enumeration of the types of the

Indian concerned in the development of the foremost aboriginal cultures:

The Moundbuilders were partly of the "Toltec" or the Gulf types, partly of Algonkin and perhaps even Siouan derivation (Cahokia mounds, etc.).

The Pueblos, at base, are mostly the older western dolichoids, but with here and there (especially among the Hopi) a strong to dominent element of the older brachycephals.

The original Aztecs belonged, it seems certain, to a branch of the older dolichocephalic type; but the "Aztecs" of the empire found by Cortez were a conglomerate of several branches of the older dolichoids with several groups of the older or Toltec brachycephalic peoples.

The Mayas were, according to all indications, a remarkably pure sub-type of the old brachycephals.

The "Incas," like the empire Aztecs, were a conglomerate. The coast population (Yungas or, more locally Chimus, Pachacamac, Nazcas, etc.) was, barring some intrusions from the mountains, of the Maya type and same derivation; while the mountain people were essentially composed of several branches of the old dolichoids, with here and there a more or less perceptible admixture of the coast people.

In every one of the groups under consideration there has also been admixture of the types, and doubtless some localized physical "specialization."

This is about all that needs now to be said on the question under consideration. We may summarize by saying that it appears to be the older brachycephalic type that has developed the higher cultures—Toltec, Maya, coast of Peru, perhaps over one half of the moundbuilders, and an important part of the Pueblos. But the Aztecs, Aymara, most of the Pueblos, and perhaps the main element in the Kechua, were of the older dolichoid type. The newer dolichoids gave us the bulk of the Iroquois with their relatively high culture; and the newer brachycephals are responsible for some of the cultures of the northwest coast.

There appears therefore, except probably in the case of the older

brachycephals, no special connection between the cultures and the physical type of the Indians.

It may be added that all the Indian types here dealt with are also represented—though apparently least with the old and most with the newer brachycephals and the older dolichoids—among the "savages" of the two Americas.

UNIVERSAL ATOMIC VOLCANISM AND THE MILLIKAN COSMIC RAYS.

By MONROE B. SNYDER.

(*Read January 20, 1926.*)

It is at this hour, on the 20th of January, 1905, twenty-one years ago, that I presented before the American Philosophical Society the first account of my discovery of a new cosmic force due to the explosive transmutation of atomic elements of an order other than terrestrial radio-activity. The title of my paper was "Universal *Celestial* Radio-activity" in deference to the only transmutation then known, and hence to my primary belief that radio-activity in the stars might differ widely from the changeless form, and hence account for the facts. Subsequently in order to emphasize the difference from radio-activity, I named the unknown process of transmutation, and the accompanying force, "radio-action," and so taught the subject. Only, last of all, after the force had been found to account precisely for the volcanism of the earth did "atomic volcanism" seem to be the proper designation for the process and the force wherever acting.

The hypothesis of explosive atomic transmutation favored by the relative position of the nebulous material ejected, its resulting form, the resulting photometric effects, the resulting visible line spectra, and the apparent transformation of the chemical elements involved, was merely an hypothesis, incapable of being brought to a test, until one day in August, 1904, when my intensive study of the conditions of the production of the line spectrum of hydrogen, always from the start assumed as the final element of the stellar atomic transmutation, suddenly completed itself in the conception precisely and briefly expressed as "electroture." Temperature, or the degree of energy due to the random motion of particles, was not capable of explaining the actual phenomena of star spectra. Kirchhoff's law had utterly failed to account for the helium spectrum in the heavenly bodies and that meant the failure of temperature.

But the electroture, or the degree of the orbital energy of the electrons producing spectra of different line frequency, of different spectral series, and of different character per element, rescued the problem from mere mathematics to nature. It was then plain that as the degree of explosive transmutation of atoms varied, the degree of the orbital energy, the line frequency, the electroture, varied with it for each spectrum involved. Electroture then became the real key to stellar atomic volcanism, and permitted definite application of the principle of compound probabilities to the spectroscopic evidence. It was thus that the practical truth of the hypothesis was established.

The investigation of the force of atomic volcanism has necessarily, during the long stretch of years, been pursued by the Newtonian Method of Science, and hence outside the pale of scientific authority. With results insisting on comprehensive publication I am, this evening, confronted by a double demand: First, the call for some brief publishable account of the complexities of atomic volcanism, and, secondly, the decree for a just appraisal, by means of atomic volcanism, of the recent triumphant experimental discovery by Millikan of the precise order of the penetrative radiation, which, in more or less unsatisfactory ways, has received the attention of science for more than a score of years.

A mere catalogue of a few results of the progress of my investigation is now the only feasible plan: 1904 finds the famous line 4686, then supposed to be due to hydrogen, and now to helium, as preëminently associated with stellar volcanism, and so reported in 1905. Nineteen hundred and nine brought definite evidence of Radium Emanation as participating in an explosion in a star of the great nebula of Orion, and also disclosed both laboratory evidence and celestial evidence of explosive transmutation of atoms up the rare gas group through what was later found to be by steps each of a mass loss of 46 hydrogen units. Nineteen hundred and seventeen challenged me to find deductive proof of this explosive transmutation of the inert gases, already verified by induction. This immersed me in a need for solving the Atomic Table Problem on assumption of whole number hydrogen steps. Here I met my first pronounced opposition from the accredited atomic weight of Calcium

of the chemists. The matter was vital, and it is to my colleague, Professor E. Rowland Hill, and his reliable mathematical training, that science will always owe gratitude for the unbiassed review of my work, and the judgment that only the proposed path should be followed. With ease, the autumn months of 1917 found the true atomic weights derived from the atomic numbers for the first 39 elements. Zirconium brought another battle with the chemical authorities, which so sidetracked my attempts that it was only by August 3, 1918, that I could complete the solution.

The completed Table gave me the true atomic numbers and true atomic weights of all the known and unknown elements whose true placing in the compartments could be inferred. This Table has removed all discrepancies between the atomic numbers and the corresponding atomic weights; has placed Uranium as number 96 instead of 92; permitted my discovery of the only terrestrial rare gas then unknown; established a precise constant difference of atomic number and of atomic weight in the atomic sub-groups, and thus cleared up many chemical and physical relations, and, above all, furnished the complete and final statement of the exact order of the atomic transmutation which we designate as atomic volcanism.

Application of the Table to the new star of 1918 in Aquila enabled me to derive full explanation of many of the details of the spectroscopic observations, and particularly, the reasons for the different order of spectra for different novæ. Similarly has the table revealed the mysteries of the meteorites. Incidentally five different orders of the transmutation of atoms in nature have been disclosed in the earth and the meteorites.

Through the labors of my son Professor John A. Snyder the entire body of the earth sciences of geology, mineralogy, and of geophysics generally, has shown the earth to be one of the heavenly bodies and one of the best observed. My son has also been particularly successful in showing that the terrestrial volcanic action is but a miniature of that in the solar system, and in the universe of stars and nebulæ.

It seems convenient to conclude this section with

A Summary of Universal Atomic Volcanism.

1. *Atom formation* is a ceaseless process of star-life. Under the progressive pressure of gravitation within the star, the atoms are built up in successively greater stages of mass and energy according to a marvelous structural plan exhibited by The Fundamental Periodic Table of the Chemical Elements.[1] While the electron and the proton are the ultimate electrical units of the one element universe, the immediate units of the hydrogen structure of the atoms are the molecules known as the stable H_2, or hydron, and the less stable H_3, or hydrion.

2. *Explosive transmutation of the atoms* in the stars and up the atomic groups, through great steps, major and minor, of mass and energy loss, results from a decided lessening of gravitational pressure on the nascent atoms, consequent to stellar rotation, or to change in the star's gravitational field.

Atomic volcanism thus, for instance, by major step, explodes Tellurium into Selenium, and Selenium into Sulphur, and by minor step, Sulphur into Oxygen, as the mouths of volcanoes testify.

Neighboring transmutation of atoms acts along the atomic series through small steps of mass change, either to next group or next but one, owing to the slow change of pressure and of internal atomic energy attending the declining effects of volcanism.

3. *Volcanic energy has a multiform expression* through the orbital and projectile speeds of electrons and atoms, which results in motion, magnetism, electricity, heat, and other forms of radiation classed as light, visible and invisible.

4. *Atomic volcanism is a universe-wide phenomenon* due to the conditions of atomic structure and of atomic change attained under gravitational action in every rotating and revolving star.

5. *The might of the volcanism of a star* depends upon the star's mass, state of aggregation, and kind and amount of its explosive atoms brought into action through variation of the gravitational field. The star may now expel a tiny cloud of gas, and now eject a pair of giant suns.

6. *Atomic volcanism distributes the masses and energies* of the stars, the nebulæ, the sun, the planetary and satellite systems, and

[1] "The Fundamental Periodic Table of the Chemical Elements," Copyright 1919, 1921, 1923, 1924. By M. B. Snyder, filed in Congressional Library, Washington.

the comets, as well as builds up and renews the continents, oceans, and atmosphere of the life-bearing earth. Atomic volcanism is, in brief, the cause of all intrinsic variability in the heavenly bodies.

Universal gravitation aggregates, and universal volcanism distributes, both the star masses and the elements in them.

The Millikan Cosmic Rays.

Hitherto I have chiefly directed attention to the visible changes in the atoms themselves which accompany the world force of atomic volcanism. I have also referred only to that radiation which is expressed in the visible line spectra, although the structure of the atom and its widely varied radiation constitute but one stupendous problem. This problem stood forth too varied and vast to permit one easily to walk round it and tell the towers thereof. But immediately I had learned of the existence of the Millikan invisible cosmic rays, I realized that they could be accurately accounted for only by the marvelous transmutative energy released by the atomic volcanism active in all stars. As all visible stellar radiation is the final result of the explosive transmutation of the atoms, kept in action by the atom circulation systems of the rotating stars, so the invisible light of the highest frequency and penetration must be due to the same stupendous nuclear changes in the stellar atoms.

In the precise discovery by Robert Andrews Millikan of a spectral gamut of invisible cosmic light, of an observed penetration of hitherto unimagined order, we are in the presence of the most important revelation of atomic radiation of all time. It is only his colossal plan of constituting deep snow-fed mountain lakes of different levels a part of the equipment of the physical laboratory that could reveal the final actuality of the cosmic rays; their definite range of mass absorption coefficients, disclosing a true spectral order; the marvelously exact determination of the highest observable penetration of these rays; their evident production of the observed softer rays due to the Compton effect; the ceaseless equal action from all directions of these cosmic rays at all hours, day and night, and the rigid logical deduction that these rays from all the wide heavens must be due to nuclear atomic transformation, and, as Millikan says, "enormously more energetic than are those taking place in any radio-active changes which we know anything about."

Radio-activity, as my atom table shows, is accompanied by loss at each step of either 4 or 6 hydrogen atoms, whereas major atomic volcanism proceeds by individual steps of the loss of 46 hydrogen atoms, approximately ten times that of radio-activity, or, it would seem, one hundred times the energy loss of atoms at the same atomic level. In the absence of any proper publication of my discovery, and of my wide verification, of the atomic volcanism due to the immense mass loss of 46 hydrogen units at each step of atomic transmutation in the stars, we need not wonder that Millikan fails to give final decision as to the specific origin and nature of the cosmic rays, nor marvel that the eminent English physicist and astronomer, J. H. Jeans, not only gracefully retires from the problem of the exact origin of the cosmic rays, but, in emphasizing their complete absorption in the stars, fails to see that the atom transmutation must take place at different levels within the stars, and that the stellar penetrative rays, thus produced, cannot suffer the dire destruction he depicts.

It was not only the high energy of this cosmic radiation, but the possibility that Millikan's observation of the uppermost degree of its penetration had something to do with my ultimate stellar atomic number 143, that led to decided emphasis of the volcanismic explanation of the cosmic rays. Strangely enough, too, Sommerfeld, in his recent fourth edition of "Atombau," had put profound emphasis on the point that there was *yet to be solved* the great problem of determination of the limit of the atomic system, a problem which had incidentally come up in my work[2] five years ago and had then led to my published indication that the highest stellar atom possible must be number 143. Mulling these considerations over with Dr. Carleton D. Haigis, my colleague at the Victor Talking Machine Company, he suggested that the Kaye-Owen relation, showing the absorption coefficient of the K radiation to be, approximately, inversely proportional to the fifth power of the atomic number, might be applicable. Comparison of Barkla's value of the mass absorption coefficient of Molybdenum with Millikan's upper coefficient for the new rays brought the astounding result of number 142.5, or within

[2] "The Fundamental Periodic Table of the Chemical Elements," Copyright 1919–1921. By M. B. Snyder, filed in Congressional Library, Washington.

0.5 of my 143, as the atomic number sending forth this ultimate cosmic radiation. Assuming the absolute accuracy of the fifth power relation thus incidentally shown, I computed comparison of Millikan's highest coefficient with each of the eighteen mass absorption coefficients of the K characteristic radiation of as many elements determined for unit density, by Barkla and other observers, as shown in Kaye's list, and, for sixteen of these, found an average of 142.6, and for two of the best of these, namely Copper and Antimony, a value of 142.8, instead of the utmost possible number 143. From the observed coefficients of Cerium and Barium, extraordinarily high values resulted for the ultimate element. These point to a hitherto unsuspected admixture with Cerium and Barium of minerals belonging to the subgroups of these elements.

Perhaps I ought to indicate that the limiting atomic number, 143, had been determined by me by four wholly independent methods before this application of the ultimate number to the cosmic rays. By a reversal of the logic, this successful application may, of course, be taken to be the fifth verification of the existence of the limiting atomic number 143 in nature. If N_z represents atomic number 143, N_e that of the terrestrial element whose mass absorption coefficient is to be compared, C_z the coefficient of N_z, and C_e that of N_e, the simple and accurate law is: $C_z = C_e \times N_e^5/N_z^5$. I naturally inverted the previous computation and derived as many coefficients for the terrestrial elements as I cared to find, and also determined the degree of Millikan's approach to observation of the most penetrative cosmic radiation possible.

We do expect Millikan accuracy, but a simple calculation with use of the best comparison coefficients known shows that his maximum penetration coefficient is just one one hundred thousandth, or one in the fifth decimal place, short of absolute perfection, an accuracy in such a field that is hardly less than uncanny. It is Millikan's supreme accuracy of observation, joined with the unexpected accuracy of the fifth power law, and with the previously demonstrated accuracy of my ultimate element, number 143, that results in the following rigorous deduction: The highly penetrative cosmic rays, with reliably observed absorption coefficients ranging from .18 to .30 per meter of water, are the limiting radiations of the

K series of the X-rays, and are due to the atomic volcanism, or explosive transmutation, with mass loss of 46 hydrogen units, of each of the upper 15 stellar elements, from atomic number 143 down to atomic number 129. Thus the cosmic rays observed by Millikan[3] constitute the most penetrative range, of the K radiation of the X-rays, existing. These rays are the ultimate invisible light emitted by the ultimate atoms.

An inference by Millikan that "the frequencies of these cosmic rays do not extend over into the X-ray region of frequencies" seems to require further study. For, below the lowest elements concerned in the observed cosmic frequencies there are still 33 other elements, able to furnish this form of radiation, before atomic number 96, or Uranium, is reached. It becomes, then, an interesting problem to determine whether this missing band of cosmic radiation is somewhere absorbed, or is yet to be disclosed by observation.

The Accepted Atomic Table with its false atomic numbers and long periods falsely varying from 18 to 32, and widely adopted by chemists, physicists, and astronomers, cannot determine a true stellar terminal element, nor many of the other vital relations, and has now accordingly, let us hope, reached the utmost limit of its career.

It is not possible briefly to describe all the implications of the rare and radiant atomic number 143. And yet it seems fitting to reason from effect to cause and find that this stellar element, Ultine, has, among other things, in a new and emphatic manner, established the validity of my entire Fundamental Periodic Table of the Atoms, whose seven systems of long periods of exactly 18 atoms each, and whose true atomic numbers and whole number atomic weights, have disclosed the exact order in which Universal Atomic Volcanism exerts its mighty forces in the heavens and in the earth.

Such theoretical and observational labors on atoms and their radiations are not destined to remain matters of pure science alone. For several years my son and I have been planning to use the magnetic and electric disturbances emitted by the explosive transmutation of the terrestrial atoms as means of predicting both the confined explosions of the earthquake and the freer explosions of the

[3] Millikan, *Proc. National Acad. Sc.*, 1926, 12, 48.

volcano, and thus of contributing to the amelioration of the catastrophes most dreaded by mankind.

And now that the Millikan cosmic rays have been, unequivocably, shown to have their origin in the same order of atomic transmutation as that which is peculiar to volcanic action, and there has, also, been added to instrumental equipment such efficient means of testing for radiations as the Millikan recording electroscopes, the prediction of volcanoes and earthquakes, and of their degree of violence, should promptly become a field of successful scientific effort.

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UNIVERSAL ATOMIC VOLCANISM AND THE ULTIMATE ATOM.

By MONROE B. SNYDER.

(*Read April 23, 1926.*)

In a recent paper on "Universal Atomic Volcanism and the Millikan Cosmic Rays" I briefly indicated the applicability of the ultimate atomic number 143 to an exposition of the nature of these rays. Here it is proposed to discuss the origin and important relations of the final atom in some detail.

The recent work of Rosseland, Bohr, and Sommerfeld on the ultimate atom, although done without knowledge of my earlier result, points to the interesting reality of this inference, and to the probability that all students of general atomic relations are finally to be brought face to face with the problem. While largely but suggestive of the existence of the ultimate atom, the touch given the problem by these investigators is of the highest importance.

I find that about four years after my first solution[1] of this problem of the ultimate atom, Dr. Rosseland[2] in 1923, from studies of radioactivity in relation to atomic size, comes to the conclusion that there must be a limit to the atomic system. From a supposed approach of the electronic orbits to the nucleus of increased size at Uranium he reaches the inference that atomic number 92 marks the limit. Somewhat later in the same year, Bohr[3] from the quantum relation $N/k = hc/2\pi e^2$, by assuming the factor $k = 1$, derived the value for $N = 137$. While regarding this number as indicative of orbital limitation about the atomic nucleus, Dr. Bohr neither discusses nor applies this maximum value due to the quantum theory. Sommerfeld,[4] however, in the recent fourth edition of "Atombau," October 1924, essays discussion of the whole subject. In the first place by assigning ½ to the k factor, a proceeding in violation of Bohr's indication, he derives 68.5 for the limiting number, and suggests that this atomic number falling so near the end of the rare earths, the K-shell must no longer be capable of existing. "The K-electrons,"

he says, "would fall into the nucleus, in that they approach it spirally." Furthermore Sommerfeld upon the hypothesis of the mutual perturbations of the electrons entertains "the enticing assumption" that possibly the atomic number, 92, may be the limit. Let us permit Sommerfeld to deliver his own closing opinion: "Whatever the decision may be," he says, "the problem of the periodic system is in any case only then solved when not only the termination of the individual periods within the system, but also the termination of the entire system at Uranium and equalling 92, can be explained." "As we saw at the close of section 5 of chapter 3, we have not yet succeeded in theoretically explaining the termination of the periods with the numbers 2, 8, 18, 32. On the other hand the termination of the entire system doubtlessly presents the more difficult and the more unapproachable problem. In this paragraph it is intended less to suggest the solution than the existence of the problem."

That the problem of finding the limiting member of the atomic system was at this late date of 1924 a real one for Sommerfeld is at least encouraging to our arrival at the solution [5] of the problem some three to five years earlier. Inasmuch, also, as Sommerfeld [6] has critically adverted to the length of the periods of the Periodic Table, I must here clearly indicate that it was the accurately determined reasons for limiting each of the short periods to 8, and each of the long periods to 18, and in no case to 32, as demanded by the Accepted Periodic Table, that necessarily brought me to the problem of deriving the exact atomic number of the ultimate atom.

The conception of a limit to the system of atoms naturally presents itself to many as the height of absurdity, and yet the fact that this limit has now been seriously mooted in science suggests that finally every student of atomic structure must deal with this problem. I realized this necessity in 1919, for I find that the first copyrighted edition of that year of my "Fundamental Periodic Table" shows the sub-group of the rare gases extended toward the ultimate atom as far as it is possible for any of them to exist in the stars. The first attempt to determine a limit was, however, by means of a study of the electronic speeds necessary for the production of the limiting frequency of the K series of the X-rays. For

this high frequency of the electrons whirling about the nucleus of Uranium the speed came out at about two thirds of the velocity of light. For a speed equalling that of light I found that the atomic number mounted to 141. Taking all the uncertainties of the data used in this computation into account I finally adopted atomic number 143, or the eighth member of the Chlorine sub-group and the last of the seventh long period as shown by my Periodic Table, as the real ultimate atom. It accordingly received the name, Ultine, in my second copyrighted edition of the Periodic Table of 1921.

TABLE I.

I.	II.	III.	IV.	V.	VI.
		Resonance Potential (Calc.)	(Obs.)	Ionization Potential (Calc.)	(Obs.)
2	Helium He				
10	Neon Ne				
18	Argon A	11.55	11.5	15.40	15.4
		1.65	1.6	2.20	2.1
36	Krypton Kr	9.90	9.9	13.20	13.3
		1.65	1.6	2.20	1.8
(54) 54	Xenon Xe	8.25	8.3	11.00	11.5
		1.65		2.20	
72	Astron An	6.60		8.80	
		1.65		2.20	
• (86) 90	Radon Rn	4.95		6.60	
		1.65		2.20	
108	Pleon Pl	3.30		4.40	
		1.65		2.20	
126	Akron Ak	1.65		2.20	
		1.65		2.20	
144	....	0.00		0.00	

$$11.55 \times 4/3 = 15.40$$
$$1.65 \times 4/3 = 2.20$$

The second solution of the problem of the limiting atom was due to an astrophysical study of the formation and explosive transformation of the successive members of the rare gas group at the surface of stars. This solution required the massing of astronomical data gathered from a number of distinct fields, and therefore can receive but little further attention here. I must, however, not fail to say that the apparently mythical rare gases Pleon and Akron of my table, respectively atomic numbers 108 and 126, have justified

the cumbrous method then used in inferring them, and that they clearly point to the non-existence of the element number 144, just a whole period of 18 elements beyond the ultimate inert gas, Akron.

The third and fourth proofs of the limitation of the atomic system will now receive detailed statement. They are based on observations by Dr. G. Hertz and Dr. R. K. Kloppers [7] of the first resonance potential and the ionizing potential of several members of the sub-group of the inert gases.

One of the most important revelations of "The Fundamental Periodic Table" has been the constant differences in atomic number and in atomic weight characterizing the sub-groups of the elements. These constant structural differences in atomic number and in mass have suggested that some of the physical properties dependent upon atomic structure should also follow changes marked by a constant difference. Accordingly my test of the accuracy of the observations of the first resonance, or excitation, potentials of Argon, Krypton, and Xenon, was to examine the decreasing potentials for constancy of difference. It was in fine harmony with the well-accredited superior method and great accuracy of these observations that I found, as shown in column IV. of Table I., a constant difference of 1.6 volts. Reference to Hertz's [8] previous work revealed the fact that the first resonance potential of Argon had been observed as 11.55 volts. The decrease, then, to Krypton, 9.90, gave a difference of 1.65 volts, and this difference applied down the sub-group of the rare gases, column III., resulted in the non-existent atomic number 144 of zero resonance potential, or in an impossible atomic number precisely one greater than the ultimate atom, number 143.

Perhaps I ought here to remind those still believing in the authority of the Accepted Periodic Table that no valid reason is assignable for the discontinuous change from 18 elements per long period to 32 as there used. In passing it must be stated that the rare gas Astron, atomic number 72, owes its discovery to the completion of my Table, August 3, 1918. In accord with the early prediction of Ramsay and Travers [9] many of the properties of Astron have readily been derived from those of its congeners. While the stellar members of the rare gas sub-group can never be subject

to laboratory test, this has not prevented several important properties of Pleon and Akron from becoming known.

In addition to the resonance potentials mentioned, Hertz and Kloppers also observed the ionization potentials as quoted in column VI. Here the difference is not precisely constant. From the difficulties encompassing such observations I inferred that one might fairly divine the probable constant difference, and this attempt is represented in column V. The assumed constant difference differs by but one-tenth of a volt from the first difference which is the more easily observed with accuracy. I was not a little surprised that the final issue of applying the assumed difference should be exactly the same as in the case of the first resonance potentials. Even with the slight element of hypothesis here entering I incline to believe in the absolute validity of the resulting ionization potentials of column V. as set opposite each rare gas of the sub-group. Thus incidentally the ionization potential of each of these rare gases is exactly predicted. And here is also deduced the atomic number of a non-element which is one greater than number 143 of the ultimate atom, and for which the ionization potential becomes zero.

In this connection, it is interesting to note that the ionization potential of Radon, or Niton, has been predicted by Turner[10] from a discussion of quantum defect as 27.5 ± 1.5 volts, and by Glockler,[11] by use of the Accepted Periodic Table, as 10.0 ± 0.9 volts. The review of the atomic radius of Radon in relation to Eve's rule by Glockler indicates clearly that there is a progressive decrease of the ionization potential, just as the Hertz-Kloppers' observations, and my interpretation, also show, in the rare gas sub-group. The interpretation of these observations, by means of my "Fundamental Periodic Table" as set forth in Table I., places the predicted ionization potential for Radon at 6.6 volts. This result for Radon, as well as for the ionization potential of each of the other rare gases of the subgroup, is with confidence submitted to any future accurate observational test.

On general structural considerations there ought to be some quantitative relation between the ionization potentials and the resonance potentials of the rare gases. But I was not prepared to find the fact that the ionization potentials of column V. are exactly

four thirds times the resonance potentials of column III. I have as yet found no theoretical reason for this curious ratio, although convinced that such should exist.

The fifth test of the validity of the derivation of number 143 as the ultimate atom has been an incidental product of the comparison of the K series X-ray mass absorption results of Barkla with the maximum mass absorption of the cosmic rays as observed by Millikan.[12] In the earlier paper, I have already stated the general results of this comparison by means of the proportionality of the mass absorption of an element to the inverse fifth power of its atomic number. The comparison, in all its implications, seems important enough to merit indication of the specific details.

No one has yet, so far as I know, set forth the final explanation of the physical processes acting in the mass absorption of X-rays. The comparison of the mass absorptions mentioned has, however, shown that the inverse fifth power law of atomic number applies with astounding accuracy in the case where the X-rays absorbed are of the maximum or limiting frequency of each K series. The Moseley law then becomes absolutely precise, and, simultaneously, the law of mass absorption of the X-rays reaches its five half power stage for the same maximum frequency. With these two assumptions, Kaye's [13] deduction of the law of the inverse fifth power of the atomic number becomes thoroughly exact.

Moseley's law, as used by him, in the *Philosophical Magazine* of 1913 and 1914, is $\lambda^{1/2} \propto 1/(N - a)$, where λ = wave-length, N = atomic number, and a is the constant of about 3.5. This formula, however, for the limit of frequency becomes accurately $\lambda^{1/2} \propto 1/N$, or $\lambda \propto 1/N^2$. A careful examination of the best observations of the K series of the elements shows that it is this simple form of the Moseley law that is steadily approached as the frequency increases. The mass absorption coefficient has been observed to vary nearly as the five half power of the wave-length absorbed. It, therefore, is valid to infer that at the minimum wave-length this relation becomes exact. If μ represents the mass absorption coefficient for water, or unit density, and ρ the density, the general coefficient is μ/ρ. For the water absorption, of the limiting frequencies, $\mu \propto \lambda^{5/2}$. But it was found above that $\lambda \propto 1/N^2$ for limiting X-rays of the K series, and as

these are used in the absorption experiments, the absorption formula becomes $\mu \propto (1/N^2)^{5/2}$ or $\mu \propto 1/N^5$. The application of this inverse fifth power law to the comparison of the mass absorptions of terrestrial and celestial X-rays, of the limiting frequency of the K series, should then proceed with full confidence in the precision of the results. In the actual use of this law in the computation of the atomic number, 143, of the ultimate atom its precision will also fully appear.

TABLE II.

$$C_z \propto 1/N_z^5, \quad \text{or} \quad C_z = k/N_z^5 \qquad (1)$$

$$C_e \propto 1/N_e^5, \quad \text{or} \quad C_e = k/N_e^5 \qquad (2)$$

From (1) and (2),

$$C_z/C_e = N_e^5/N_z^5 \qquad (3)$$

Whence,

$$C_z = C_e(N_e^5/N_z^5) \qquad (4)$$

or

$$C_e = C_z(N_z^5/N_e^5) \qquad (5)$$

or

$$N_z = N_e(C_e/C_z)^{1/5} \qquad (6)$$

or

$$N_e = N_z(C_z/C_e)^{1/5} \qquad (7)$$

The problem is now that of comparing the mass absorption coefficient of the ultimate celestial element, yielding cosmic rays, with the mass absorption coefficient of each of a series of terrestrial elements as observed by Barkla through use of X-rays of the K series, and recorded in column IV. of Table III. According to the Kaye-Owen law the mass absorption coefficient of an element varies, as shown above, proportionally with the inverse of the fifth power of its atomic number. For simplicity in printing, this relation will be expressed on the following plan: If N_z represents the highest atomic number possible, namely 143, N_e the atomic number of the terrestrial element whose mass absorption coefficient is to be compared with that of the former, and C_z and C_e, respectively, the mass absorption coefficient of N_z and N_e, the law mentioned suggests the relations set forth in Table II. In this Table the fundamental relation, (3), between the four given quantities readily assumes each of the four explicit forms following it.

The application of these relations has produced results which are exhibited in detail in Table III. Column I. of Table III. states the "Cosmic" or accurate atomic numbers of the elements here under consideration, and, by courtesy, the usual erroneous atomic numbers of Tungsten—Uranium, as prefixed. Column IV. reproduces the list, quoted by Kaye, of Barkla's observations of 1909

TABLE III.

I.	II.	III.	IV.	V.	VI.	VII.
At. No.	Element.	Series.	C_x(Obs.)[14]	C_z .0018 C_x (Calc.).	C_z .0017905 C_x (Calc.).	C_z .0018 N_x (Calc.).
24	Chromium	K	15.3	13.517	13.446	146.6
26	Iron	K	10.1	9.055	9.011	146.1
27	Cobalt	K	7.96	7.501	7.462	144.8
28	Nickel	K	6.58	6.254	6.221	144.4
29	Copper	K	5.22	5.248	5.22*	142.8
30	Zinc	K	4.26	4.429	4.406	141.9
33	Arsenic	K	2.49	2.750	2.736	140.2
34	Selenium	K	2.04	2.369	2.356	138.8
35	Bromine	K	1.9	2.049	2.039	140.8
37	Rubidium	K	1.32	1.552	1.544	138.4
38	Strontium	K	1.16	1.358	1.351	138.6
42	Molybdenum	K	0.81	0.823	0.819	142.5
47	Silver	K	0.46	0.469	0.467	142.4
50	Tin	K	0.35	0.344	0.343	143.5
51	Antimony	K	0.31	0.312	0.310	142.8
53	Iodine	K	0.29	0.257	0.256	146.5
56	Barium	K	0.26	0.195	0.194	151.4
58	Cerium	K	0.248	0.164	0.163	155.3
74 78	Tungsten	K		0.037	0.037	
78 82	Platinum	K		0.029	0.029	
82 86	Lead	K		0.023	0.023	
83 87	Bismuth	K		0.022	0.021	
90 94	Thorium	K		0.015	0.015	
92 96	Uranium	K		0.013	0.013	
74	Cosmium	K		0.049	0.048	
76	Hafnium	K		0.042	0.042	
143	Ultine	K	0.0018		0.0017905*	

and 1912 of the mass absorption coefficients, produced by the K series of X-rays, for unit density, of the elements set opposite. In this column also the same coefficient of utmost value, as observed by Millikan, naturally assumes its place opposite Ultine of atomic number 143. Column VII. records the calculated atomic numbers of the ultimate atom as derived from the terrestrial absorption values of column IV. and Millikan's maximum absorption value of .0018 for the cosmic rays. By applying, for example, the cosmic absorption value and the absorption value for Copper in formula (6) of Table II., we have $N_x = 29(5.22/.0018)^{1/5} = 142.8$, or a number within .2 of the theoretical atomic number, 143, of the ultimate atom. The first sixteen similar results of column VI. furnish an average value of 142.6 for the calculated highest atomic

number. This outcome discloses not only the approximate precision of the Millikan observation used, but when all the natural uncertainties are considered, the high degree of accuracy of Barkla's difficult observations.

Dr. Bohr in 1923 theoretically derived the atomic number 137 for the ultimate atom, and has not submitted his result to any test. In 1921 I had announced my theoretically derived atomic number 143 of the ultimate atom, and have now by the foregoing statistical test shown the validity of the prediction. This result, therefore, in and by itself challenges acknowledgment as an established fact of physics. But when the universe wide reality of explosive atomic transmutation shall become generally known, this outcome need not be discredited because it also has most intimate relations with the theory of universal atomic volcanism.

The remarkable deviations of value for the computed ultimate atomic number which result from the use of Barkla's observations of the absorption of the assumed Barium and Cerium were evidently due to a similar cause, the absorption coefficient for Barium being about .07, and that for Cerium about .09 numerically too large. It is noteworthy that at the time of these absorption observations the next heavier elements of the Cerium and Barium sub-groups, now known respectively as Hafnium and Cosmium, were wholly unknown. The fact that atomic volcanism, or the explosive transmutation of atoms of the sub-groups, should produce a natural commingling of elements in a sub-group, a condition probably responsible for the inexact estimates by Barkla, was also wholly unknown.

The foregoing success in computing the ultimate atomic number to a high degree of approximation led to the use of the same Millikan value of .0018 in deriving the theoretical mass absorption coefficients of column V. This calculation was extended to the heavier elements for the K series for which the absorption has not yet been observed. And it was a simple step to derive also the K absorption for the newly discovered elements, Hafnium and Cosmium. As illustrative of this theoretical derivation, the Copper coefficient, with use of formula (5) of Table II., becomes $C_e = .0018 \times (143/29)^5 = 5.248$.

The next step was, of course, to assume the mass absorption coefficient of Copper, as observed by Barkla, to be accurate, and with use of the ultimate atomic number, 143, in formula (4) of Table II., to find that $C_z = 5.22(29/143)^5 = .0017905$. This theoretical maximum mass absorption coefficient for the K series of the X-rays differs from the Millikan value of .0018 by but .00001, and emphatically approves the high accuracy of the recent American experimental work on the cosmic rays.

Both from experimental experience, and from the results of this discussion, Copper has been shown to be eminently fitted for a special determination of its mass absorption coefficient to the highest degree of accuracy. With the Copper coefficient brought to the highest precision it would be possible easily thus to secure a satisfactory derivation of the mass absorption coefficients of all the elements known and unknown. The coefficients of the elements here considered, as recorded in column VI. of Table III., have been derived by use of the above maximum coefficient based upon Copper 5.22 of Barkla. They are probably the most accurate available for these elements. It should, hence, be interesting to make a detailed comparison of these results of column VI. with those of columns IV. and V.

That, hitherto, there has been no theory by means of which the experimental values of the mass absorption coefficients could be tested is shown by the incidental manner in which W. H. Bragg and W. L. Bragg [15] in the latest edition of their classical work have quoted Barkla's Table of 1909, recording the erroneous value of 0.41 for the mass absorption coefficient of Silver, instead of the more accurate value of 0.46 for the same element as given by Barkla in 1912. Barkla's papers show the early difficulty encountered in Silver, and the justice of the later correction. Kaye, indeed, has understood Barkla's preference for 0.46 and incorporated it in his list of coefficients. It is, therefore, significant that with use of my ultimate atomic number of 143, and the absorption coefficient of .0018 by Dr. Millikan, the result for Silver is found in Table III. to be 0.469, and with use of the same ultimate atomic number and the computed ultimate absorption coefficient dependent on that of Copper 5.22, the result for Silver is 0.467. Both of these values are

in close agreement with the value of 0.46 of Barkla, and, therefore, the test of this theory seems justified. The value of 0.41 for the mass absorption coefficient of Silver having thus been shown to be erroneous, it needs no further perpetuation.

The application which has here been made of the atomic number 143 of the ultimate atom to the elucidation of the nature of the cosmic rays could not have produced a decisive result but for the remarkable accuracy with which Millikan has determined the mass absorption coefficient of the most penetrative of these penetrative rays. It was indeed also the other complex and logical work on these rays that placed Millikan first in the long line of investigators to furnish not merely an hypothesis of, but an irrefragible proof of, the cosmic origin, and the all-sided celestial approach of this notable radiation. And yet despite the precision and conclusive character of Dr. Millikan's investigations, providing unequivocal evidence of the cosmic origin of the long-discussed penetrating rays, the cloud of historic uncertainty still persists in the recent German discussions of Hoffmann [16] and Behounek,[17] claiming these rays to be of radioactive character. Hess,[18] also, in reviewing these discussions, and the work of Millikan and associates, in a paper on "Die Ursprung der Höhenstrahlung," does not seem to appreciate the finality of the assignment of these rays to celestial origin, else his title would not have doubtfully dealt with "The origin of the sky-rays," nor his closing words emphasized the unknown nature of these rays.

Profound recognition is, indeed, to be accorded the painstaking balloon work of Gockel, Hess, and Kolhörtster, of 1910–1913, notwithstanding the degree of indefiniteness which had to cling to the deductions from these observations. And nothing less than profound recognition is to be accorded the host of observers and theorists, who from every angle for a quarter of a century have studied this strange penetrating radiation in search of a final solution.

It is now, however, enough to know that Millikan has proved these rays to be of cosmic origin, and to be invariable day and night, proved their terrestrial transformation to be in consonance with the Compton effect, and, besides, determined their maximum mass absorption coefficient with such precision that it has permitted complete identification of the nature and intimate origin of these cosmic

rays, as ultimate X-rays of the K series, due to the ceaseless atomic volcanism, or the explosive transmutation of heavy atoms, in the stars.

The theory of atomic volcanism so unwillingly and yet necessarily injected into these papers on cosmic rays and the ultimate atom should receive due criticism when it has achieved the publication sought as a unit investigation. But since atomic volcanism is historically associated with my discovery and proof of the ultimate element, and since I have naturally pointed to logic which is largely effective only through unpublished investigations, it must not be supposed that this unfortunate necessity suggests more than a preliminary toleration of the theory of universal atomic volcanism. The tie between the ultimate element and this theory was too intimate to be wholly ignored, and yet the ultimate atom may also be considered with regard to its own independent claims.

The atomic number 143 having been shown to belong to the ultimate atom, it follows that the development of my "Fundamental Periodic Table," in that it is responsible for its suggestion, has a rightful claim to validity. Since this final atomic number appears at the close of the table, and only in consequence of the special order of its development, there is reason to regard this order as the true order of nature. The atomic number 143 belongs to the Chlorine sub-group, and is the seventh Chlorine analogue, each of which marks the ending of a "long period" of 18 elements. If, then, to the atomic number 17 of Chlorine there is added the 7 times 18 atomic numbers of the other elements of the Chlorine sub-group, the result is number 143 for the last and most remarkable of all the atoms.

Returning still further into the history of the subject, it is to be noted that it was my discovery in 1904 of the distributive force of nature, which I call Atomic Volcanism, that led to the solution of the Periodic Problem of the atoms in 1918, and thence to the inference and publication, in 1921, in my second copyrighted Periodic Table, of the atomic number 143, as marking the ultimate atom.

This paper reviews five different methods of inferring and deriving the ultimate atomic number 143 as guided by a solution of the Periodic Problem of the elements, two of these being based on the

Hertz-Kloppers' observations on resonance and ionization potentials of rare gases, the fifth computing this number approximately by comparison of the highest mass absorption coefficient of the cosmic rays with sixteen terrestrial coefficients by means of the law of the inverse fifth power variation of the atomic number. Attention is drawn to the simultaneous accuracy of the Moseley law and the five half power law of absorption at the convergence of the K series of X-rays here considered. A method is shown of utilizing the ultimate atomic number in computing the mass absorption coefficients of the elements. The ultimate atomic number by its relation to the most penetrating of the cosmic rays is, under the physical laws and observations at hand, shown to certify these rays to represent the convergent radiation of the K series of X-rays. That these rays are due to the continuous explosive transmutation of the atoms, or to atomic volcanism, in the stars, is an inference supported by unpublished investigations.

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FURTHER STUDIES ON THE ALLOTROPHY OF GERMANIC OXIDE.

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Within the past several years it has been recognized that germanium dioxide can be obtained in at least two distinctly different modifications, one of which is insoluble in water and decidedly inactive toward aqueous solutions of both acids and alkalis, and the other a soluble form which possesses all of the properties commonly known for this metallic oxide. At the same time, recent investigation has also disclosed the probable existence of two forms of the soluble oxide, but as yet no method has been devised for their isolation.[1]

A brief summary of the work already carried out on the allotrophy of the oxide is as follows:

Germanium dioxide in aqueous solution when carefully evaporated yields a residue which is partly converted to an insoluble form by heating to any temperature between 225° and the melting point which lies near 1100° C. The major portion of oxide so treated, however, remains soluble in pure water, and may be removed from the insoluble fraction by repeated extraction of the residue with hot water.

The insoluble fraction, when heated above the melting-point, is converted into a meta-stable glass which is easily and completely soluble in pure water.

Study of the yields of insoluble oxide under different conditions of preparation indicated that the temperature of maximum velocity of transformation of the soluble to the insoluble form was about 380° C.

When the time of heating of the soluble oxide was varied at constant temperature, the yield of insoluble oxide increased in such a

[1] Müller and Blank, *J. Amer. Chem. Soc.*, 1924, 46, 11, 2558.

manner as to indicate that the conversion could never reach 100 per cent., and for this reason and because the yields varied greatly with different preparations of the oxide (by evaporation), it seemed probable that three allotropic forms exist and that the oxide obtained by evaporation of aqueous solutions is really a mixture of two soluble forms, one of which has an easily measurable velocity of transformation, while the other either does not change at all or does so at a scarcely measurable rate.

The glassy form of oxide prepared by heating any preparation of the oxide to above the melting-point (1100° C.), possesses no definite melting-point but is a true glass. It softens far below the melting-point of any other form of the oxide, and is completely soluble in water. Samples of this glass have been preserved since the foregoing investigation and have spontaneously devitrified to an opaque white glass resembling porcelain. This is also completely soluble.

The insoluble form of oxide which can be conveniently called the alpha or stable form is chiefly distinguished by its extraordinary inertness toward alkalis and acids, especially in its inactivity toward hydrofluoric acid which dissolves any other preparation of the oxide with a hissing noise and evolution of much heat (a fact noted by Krüss and Nilson as early as 1887). After fusion of the inert alpha form, all of the commonly known properties of the oxide are regained.

The following paper consists mainly of a further study of the comparative properties of the several forms of germanium dioxide with special regard to the following considerations:

(*a*) Preparation of specially purified germanic oxide, from which single stock of pure material all of the insoluble or alpha form was prepared in considerably larger quantity than in previous experiments.

In this operation it was also deemed advisable to prepare the oxide from an entirely different source in order to find out whether the formation of the insoluble modification had been influenced by the presence of some unknown constituent in the original zinc oxide residues which had been previously used as the source of germanium.

(*b*) Preparation of workable amounts of insoluble oxide in which a given sample of the soluble form is shown to be capable of complete transformation to the alpha form by repeatedly fractionating off

successive yields of the latter from the same sample of the oxide until the residual soluble oxide had been reduced to a very small fraction of initial amount.

(*c*) Solubility of the insoluble or alpha oxide.

(*d*) Determination of the densities of the several forms of oxide.

(*e*) X-ray spectral examination of various preparations of the oxide which may be regarded as definite proof of allotrophy on the part of germanium dioxide.

The *x*-ray spectroscopic data and interpretation of the same are entirely due to the work of Dr. R. W. Wyckoff of the Geophysical Laboratory of the Carnegie Institution of Washington, D. C., to whom the writer is deeply indebted for his kind coöperation.

Preparation of Material.

The germanium dioxide used in all of the experiments here described was obtained from a smithsonite ore from Livingston County, Kentucky. The ore itself is low in germanium content, but a considerable amount of germanium oxide in crude state was obtained from large volumes of zinc sulphate mother liquors which came from this source, the same having been prepared from waste zinc oxide which was converted to sulphate mainly for the recovery of its germanium content. The recovery of germanium from smithsonite ore from this locality has been described in detail in a previous paper.[2]

Starting with a fairly high grade of germanium dioxide containing only a small amount of arsenic and perhaps traces of other metals, the following procedure was carried out for complete purification. The oxide was dissolved in a large volume of hot water, and after addition of hydrochloric acid to six normal concentration, the whole was converted to sulphide. The sulphide precipitation was carried out in such a way as to discard the first fractions of sulphide thrown down by hydrogen sulphide, for the small amount of arsenic present showed a strong tendency to concentrate in these fractions. The combined masses of white sulphide were converted to the ammonium thio-salt by dissolving in dilute ammonia and ammonium sulphide, and the dilute solutions of the latter were carefully acidulated with

[2] Müller, *J. Ind. Eng. Chem.*, 1924, 16, 6, 604.

dilute hydrochloric acid in which the easily decomposable thio-arsenate was converted to sulphide and the much more stable thio-germanate mostly escaped decomposition. The filtrates were then treated with enough concentrated sulphuric acid to produce about six normal concentration of acid, and after saturation with hydrogen sulphide under pressure, masses of pure white germanium sulphide were filtered off and washed. This fractionation, first described by Truchot, "Les Terres Rares," was repeated several times, and the sulphide obtained was then introduced into water and boiled to effect hydrolysis and elimination of much of the sulphur as hydrogen sulphide. The mass was then treated with nitric acid, and by frequent remoistening with the same, followed by ignition, the whole was converted to oxide. This oxide was converted to the tetrachloride by distillation in presence of constant boiling hydrochloric acid in a current of chlorine, and the chloride so obtained was hydrolyzed by collecting in receivers containing water. The major part of the oxide separated in white crusts from the diluted acid in the receivers and was filtered off on buchner funnels and washed with cold water. Much germanium, of course, remained in the acid filtrates, but it should be noted that these were discarded as less pure fractions, while only the solid fractions separating from the hydrolysing chloride were used for the preparation of the final product. The product of this hydrolysis of the tetrachloride may be considered free from arsenic and could not have contained any impurities other than small amounts of chlorine due to incomplete decomposition. It should be borne in mind that the original fractionation of the sulphide by partial decomposition of the mixed thio-salts was continued until no test for arsenic could be obtained in the selected germanic sulphide, using a method previously described by the writer for detecting small amounts of this common contaminant of germanium preparations.[3]

The chlorine present in the washed "hydrolyzed" oxide was detected by treating the acidified aqueous solution of a gram sample with silver nitrate, and the bulk of oxide was then repeatedly treated with water, followed by evaporation to dryness and ignition. The removal of the last of the chlorine was a long and tedious operation,

[3] Müller, *Amer. Chem. Soc.*, 1921, 43, 2549.

but was considerably aided by igniting the oxide in a current of superheated steam until the escaping steam on condensation gave no further test for chloride. The oxide was then ignited and finally dissolved in water, filtered to remove a small residue of insoluble oxide, and the solution was evaporated to dryness in a platinum dish on a steam-bath.

It should be noticed that the complete dehydration of this final yield of oxide was not undertaken, as the high temperature required to effect the expulsion of all water results in a partial conversion to the insoluable or alpha form.

For this reason the mass of oxide was dried at 100° to 105° C. in air, removed from the platinum dish, and after powdering in an agate mortar, was preserved in this condition. The final yield of purest material amounted to about 20 grams and was exclusively used for all of the following experimental work.

Preparation of Alpha or Insoluble Oxide.

A portion of the pure soluable germanium dioxide, prepared as above described, and weighing 11.3420 g. was dissolved in about 1,500 cc. of water contained in a well-seasoned pyrex flask. Solution was slow but complete after a number of hours heating to the boiling-point. The clear solution was decanted, in about one-quarter liter portions, into a weighed platinum dish and there evaporated to dryness after complete transference of the solution to the platinum vessel. The dish was then heated in an electric oven to the temperature of maximum velocity of transformation for some hours (See Table 1). The dish was then re-weighed, giving total oxide dried at this temperature. The dish and contents were then introduced into a two-liter pyrex beaker and digested with about 1,500 cc. of water which was maintained at or near the boiling-point for several days. On cooling and allowing to settle for some time, the clear supernatant liquid was syphoned off from the dense residue of undissolved oxide, using a small alundum syphon filter constructed of a small alundum thimble and a 2 mm. bore glass syphon tube attached. Most of the clear solution was removed without disturbing the mass of oxide on the bottom of the beaker. The syphon was then raised out of the beaker and the residue again treated with a large

volume of water, repeating the heating and use of the syphon until nearly all of the soluble oxide was removed. The residual insoluble oxide was finally transferred to an 11 cm. filter paper and was thoroughly washed with boiling water, after which the major part of it was washed from the filter paper into a weighed porcelain crucible (100 cc.). This operation gave two portions of insoluble oxide—by far the greater amount together with water in the weighed crucible—and a small amount remaining attached to the filter. These quantities were determined separately, the first by simple evaporation and ignition, and the second by a slow charing of the filter paper, with frequent moistening with nitric acid, and final ignition to oxide. In this way it was possible to save most of the insoluble oxide throughout the series of experiments without introducing the ash of filters or the products of the reducing action of the same upon the insoluble oxide.

The combined syphonates and wash-waters were collected in a large pyrex beaker in which the volume of the solutions was reduced by rapid evaporation. After this, the solution was transferred to the same weighed platinum vessel for recovery of the soluble fraction of oxide. The whole operation above described was then repeated with the "evaporated oxide," again fractionating off the yield of insoluble oxide, produced by again heating to the temperature of maximum velocity of transformation.

As seen in the table which follows, 11.3420 grams of completely soluble oxide as a starting-point was converted to 10.5678 grams of insoluble oxide, representing 93.17 per cent. of the initial quantity. A careful examination of the remaining soluble fraction which weighed 0.7909 grams failed to show any chemical difference existing between this oxide and a sample taken from the combined yields of insoluble oxide, for when the latter was fused to a glass and subsequently dissolved in water, the solutions of both possessed identical properties.

From the results shown in Table I it appears that highly purified germanic oxide can be converted to the insoluble modification by dissolving the soluble form of the oxide in water, evaporating to dryness and exposing the residue to a temperature of 350° to 400° C. for some hours, finally extracting the unconverted fraction by re-

TABLE I.

PREPARATION OF INSOLUBLE GERMANIC OXIDE.

No.	Wt. of Soluble Oxide, gms.	Yield of Insoluble Form, gms.	Hours Heated.	Temperature C.	% Yield of Insoluble Oxide Formed.	Conditions of Evaporation of Aqueous Sol.
1..	11.3420	1.3230	48	340	11.66	On water bath 100°.
2..	10.0635	0.4926	120	350	4.89	Rapidly boiled till dry in plat. dish.
3..	9.5700	0.4897	25	350	5.11	Same as in (2).
4..	9.1287	1.6666	96	360	18.26	Slow evap. at 80–90°.
5..	7.4445	1.5031	24	400	20.19	Slow evap. at 75–80°.
6..	5.9400	0.9000	10	400	18.52	Constant temp. 60° C.
7..	4.8963	0.5379	26	395	10.98	Constant temp. 90–95°.
8..	4.3700	0.6840	72	400	11.08	Water-bath at about 90°.
9..	3.6890	0.5756	24	400	15.60	Slowly on bath at 80°.
10..	3.1120	0.3416	3	400	10.97	Water-bath at 90°.
11..	2.7700	0.4435	24	410	16.00	Water-bath at 80°.
12..	2.3243	0.4751	24	400	20.44	Water-bath at about 75°.
13..	1.8460	0.3966	24	400	21.48	Constant temp. 68–70°.
14..	1.4440	0.2768	24	400	19.16	Constant temp. 50–55°.
15..	1.1662	0.1913	24	420	16.42	Constant temp. 80–82°.
16..	0.9680	0.0640	12	400	6.61	Constant temp. 98–100°.
17..	0.9116	0.0304	24	400	3.33	Dried at 95° for 3 days.
18..	0.8759	0.1760	24	400	20.10	Constant temp. 70–72°.
19..	0.7909					
		10.5678	Total insoluble oxide = 93.17%			

peated treatment with hot water. By regulating the temperature at which the initial evaporation of the aqueous solution takes place, it is possible to convert about one-fifth of the total residue of soluble oxide to the insoluble form. The best yields were obtained by evaporation at low temperatures and then suddenly raising the residue to the temperature of maximum velocity of transformation—about 380° to 400° C. From the widely differing percentage yields obtained, it is evident that the conditions under which the evaporation of germanic oxide solutions are carried out greatly influence the effect of the final heating of these residues. (Observe experiments 2, 3, 16, and 17, as compared with the much higher yields of the insoluble oxide in all cases where evaporation was carried out at lower temperatures.)

In several experiments (not shown in the table), in which the solutions of oxide were driven rapidly to dryness by violent boiling the yields of insoluble oxide became negligible in quantity—the

finely divided non-adherent oxide so produced remaining in the water soluble condition.

It is important to note that a single sample of oxide can be practically all converted to the insoluble form by repeating the process upon the constantly decreasing yields of soluble fractions. In the case at hand, the combined insoluble fractions obtained by eighteen operations amount to 93.17 per cent. of the starting product. Fractionation was not continued beyond this point because it was advisable to compare the properties of the remaining small amount of soluble oxide (0.7909 g.) with the insoluble oxide prepared from it.

For this purpose approximately the same weight of insoluble oxide from the combined insoluble fractions was taken, and after fusing to a glassy mass at 1100° to 1200° C. in a platinum boat, was dissolved in water. Portions of this solution were compared with the solution of the soluble fraction, working with aliquot portions of each solution at the same concentration. Both of these solutions showed exactly the same behavior with all the reagents commonly used for the detection and estimation of germanium, and hence must have been chemically identical. The use of the spectroscope, however, did indicate an appreciable amount of sodium and a trace of potassium in the solution prepared from the soluble oxide residue, while only traces of sodium and no potassium could be found in that prepared from the solution of the melt from the insoluble form. This was doubtless due to the long-continued evaporation of the solutions of soluble fractions in pyrex vessels.

Solubility of the Alpha Form of Germanic Oxide.

The total yield of insoluble germanium dioxide from the above described experiments amounted to 10.5678 g. of which 9.2229 g. had been obtained free from filter ash or other impurity. The latter amount was placed in a pyrex flask fitted with ground pyrex return condenser attachment and treated with boiling water for a period covering several weeks to remove traces of soluble oxide. The digestion was continued until 100 cc. portions of filtered supernatant liquid showed the same amount of dissolved oxide. The residual mass was then thoroughly washed with boiling water and washed from the filter into a silica dish in which the mass of oxide was brought to

dryness. All of the water used was thrice redistilled, using a block tin condenser, distilling first from alkaline permanganate, then in presence of a little sulphuric acid, and finally alone. The first portions of distillate were of course rejected.

About 2 g. of the insoluble oxide were placed in a well-seasoned pyrex flask of about 250 cc. capacity and digested with water for over two weeks in a thermostat. The temperature was kept at 25.0° C. (± 0.01° C.) with continuous agitation. Just before taking off samples of the filtrate the agitation was discontinued, and after the dense undissolved oxide had settled, about 200 cc. were syphoned off through a dry filter and caught in a stoppered bottle of known weight. The solution was weighed and then evaporated to dryness in platinum and the residual oxide weighed after ignition to full redness.

The solubility of the same oxide was determined at 100° C. in much the same manner, with the added requirement of a steam jacketed filter and syphon for the removal of the solution at 100° C. Results were as follows:

100 g. water at 25° C. dissolve 0.00045 g. of oxide (± 0.0000.2).

100 g. water at 100° C. dissolve 0.00117 g. of oxide (± 0.00002).

From the above results it will be noted that the alpha form of germanic oxide is about 1000 times less soluble than the soluble modification, and like the latter, about doubles its solubility between the ordinary temperature and the boiling-point of water.

Densities of Different Forms of Germanic Oxide.

The densities of the various forms of oxide were determined through the use of anhydrous toluene, prepared by distillation of the latter over sodium and redistillation of the anhydrous liquid alone. The complete insolubility of all three forms of oxide in toluene had been previously established by allowing the oxide samples to remain in toluene for several days and subsequently evaporating 10 cc. portions of the filtered liquid to dryness in platinum. No weighable amount of residue was obtained.

Three forms of oxide were obtained as follows: Eight grams of the insoluble oxide were ground in an agate mortar until thoroughly mixed and divided roughly in half. One-half was then dried to

constant weight at about 400° C. and used for determination of the density of the insoluble modification.

The other half was fused to a clear glass at 1350° to 1400° C. in a capsule made of thin platinum foil, after which the rapidly colled glassy oxide was obtained in a single piece by stripping off the platinum foil. The clear glass was then reduced to powder in a diamond mortar. This was used for determination of the density of the glass. The oxide used in the above experiments was recovered almost entirely by pouring off the toluene from the pyknometer in each case and mixing and fusing the recovered oxide to glass after which the yield was again divided in half and used for the preparation of the "evaporated" and "hydrolyzed" forms of the oxide. For this purpose one-half of the fused or glassy form was placed in pure water in which it was completely soluble, and the aqueous solution was evaporated in platinum to dryness at 80° to 90° C. and finally at 150° to 200° C. in an air oven. (Higher temperature could not be used because of the formation of more or less of the insoluble form.)

The other half of the glass was placed in a distilling bulb under a little 20 per cent. hydrochloric acid, and the mixture distilled at about 100° C. allowing a little hydrochloric acid gas to enter the flask from time to time. In this way most of the germanium passed over as tetrachloride below the boiling-point of the acid in the bulb, and the oily tetrachloride was caught in a receiver containing pure water. The major part of the germanium separated as the "hydrolyzed" oxide, the white crusts of which were removed by filtration. The solid mass so obtained was washed with a little cold water and finally dried at 100° C., remoistening and drying several times, followed by re-evaporation at 150° to 200° C., as in the case of the evaporated oxide. This was used for determining the density of the "hydrolyzed" form.

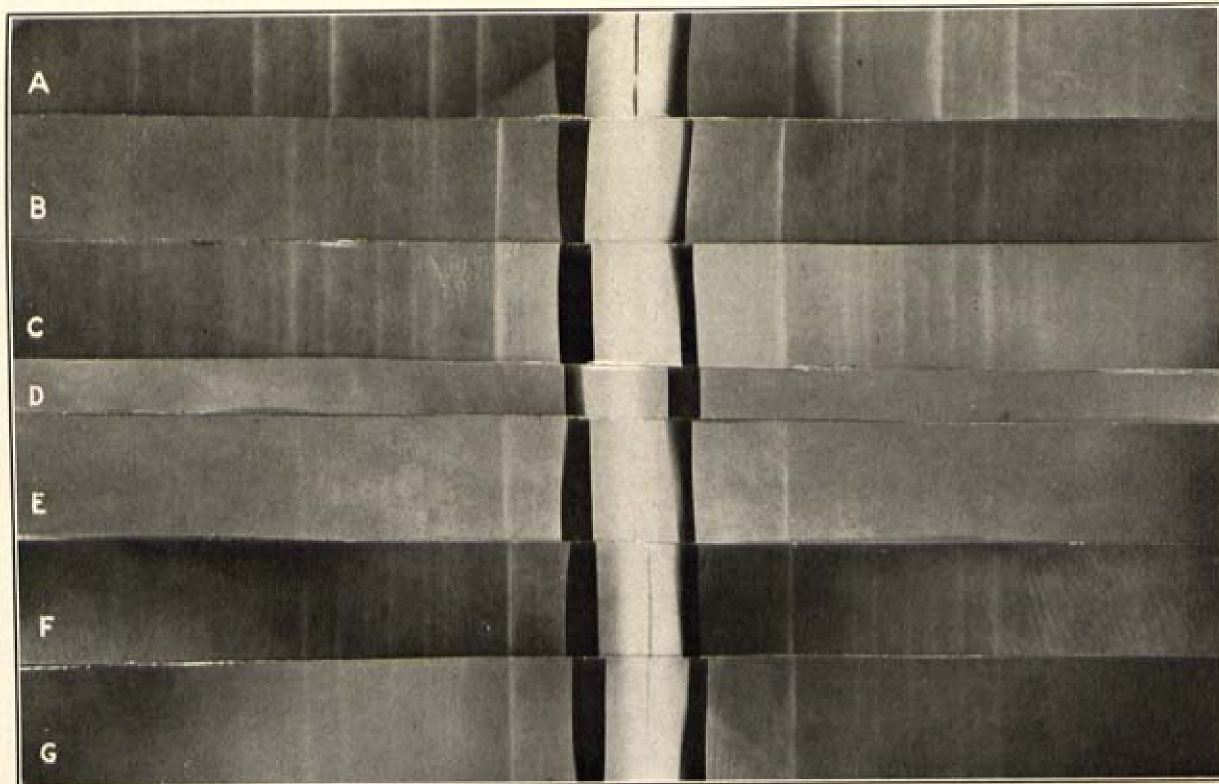
The following results express the means of two determinations for each form of the oxide:

Insoluble or alpha form..............................6.0039—$D^{24°}_{24°}$

Soluble "evaporated" form..........................3.5205—$D^{24°}_{24°}$

Soluble Glassy form..................................3.3037—$D^{24°}_{24°}$

Soluble "hydrolyzed" form..........................3.6128—$D^{24°}_{24°}$



X-Ray Spectra of Germanic Oxide Indicating Two Allotropic Modifications.

From the above results it is seen that the stable or alpha modification not only conforms to the expected property of possessing a greater density than any metastable form of the same substance but that this value of 6.0039 is not far from double the density of the metastable glassy form which was produced by simply melting the same sample.

The other two preparations were as before stated prepared from glassy (fused insoluble oxide), by subsequently dissolving in water and evaporating to dryness or distilling off the tetrachloride into pure water from hydrochloric acid.

It is thus evident that all these forms can be obtained from the same mass of insoluble oxide and that their respective densities are distinctly different from each other.

X-Ray Spectroscopic Examination.

Samples of alpha, "hydrolyzed," "evaporated," and glassy germanium dioxide above obtained, together with similar preparations which had been prepared by Müller and Blank about three years previously, were examined by Dr. R. W. Wyckoff at the Geophysical Laboratory, Washington, D. C. The X-ray spectrographs obtained appear in order as follows:

(*a*) Alpha germanium dioxide (insoluble form).

(*b*) Germanium dioxide prepared by melting the alpha form (1100° to 1200°), dissolving the melt in water and distilling off the tetrachloride into water, washing the solid product of "hydrolyzed" oxide, drying at 105° C.

(*c*) "Evaporated" oxide made by fusing the alpha form and evaporating its aqueous solution to dryness on water-bath, finally drying at 105° C.

(*d*) Glassy form prepared by fusing the alpha form.

(*e*) Old sample of glassy oxide which had spontaneously devitrified after over a year standing.

(*f*) Old lot of "hydrolyzed" oxide after about three years' standing.

(*g*) Old lot of "evaporated" oxide after about three years' standing.

From the above diffraction patterns, quoting the interpretation of Dr. Wyckoff, "all except (*a*) and (*d*) appear identical both in the position and in the relative intensities of their diffraction lines." "The five preparations of the soluble oxide—(*b*), (*c*), (*e*), (*f*), and (*g*)—are essentially crystalline, and consist of the same modification of germanium dioxide. These might, of course, be composed of two or more modifications present in practically the same relative proportions."

"The powder photograph from sample (*a*) is totally different from that given by the five preparations just mentioned, and therefore the structure of this, the alpha form, is totally different from that of the soluble form."

The photograph of sample (*d*) shows a more or less uniform blackening without evidence of diffraction lines. This was taken from the sample of the insoluble or alpha form after fusing to a glassy mass at 1100° to 1200° C. It is a true glass. (*e*) is interesting because it shows the effect of the spontaneous devitrification of the same glass on long standing and likewise shows that the devitrification results in formation of the same pattern as that of the soluble modifications and not that of the alpha form.

From these considerations and the foregoing data it is interesting to note that any sample of germanium dioxide, soluble or insoluble, may be converted to a true glass of much lower specific gravity than the original sample by simply fusing the oxide at any temperature above 1100° C. and that this metastable glass may then be dissolved in water and subsequently be converted to either the alpha form or a metastable soluble modification, both of which are shown to be crystalline but of different structures respectively.

It has already been mentioned that a third crystalline form of germanic oxide probably exists which is soluble in water and so far not separable from the soluble oxide preparations obtained by evaporating aqueous solutions of germanic oxide. This follows from the peculiar fact that different conditions in the temperature of evaporation before finally raising the oxide to the temperature of maximum velocity of transformation results in widely varying yields of the alpha form from a single sample of the oxide.

If a third form does exist, no method has been devised by which

such soluble forms may be separated, but it is possible to prepare two samples of the soluble oxide by evaporating under conditions which favor a maximum yield of the alpha form and under those conditions favoring a negligible yield of the same, and then subjecting these "evaporated" oxides to x-ray spectral examination before they are heated to transformation temperature. This may show that the photographs, (B), (C), (E), (F), and (G), represent the combined patterns of these two forms, and at the same time disclose the existence of trimorphism in the case of germanium oxide which would be analogous to the familiar behavior of titania, as seen in rutile, anatase and brookite. Examinations of such preparations of soluble germanium dioxide are now being made by Dr. Wyckoff, the results of which will appear in the near future.

Summary and Conclusions.

1. Germanium dioxide in a high state of purity can be converted to an insoluble or alpha modification, remarkably inert toward all of those reagents which are commonly reactive with the previously known oxide.

2. The preparation of germanium oxide from widely different sources does not have any influence on the preparation of the alpha or insoluble oxide.

3. The solubility of the alpha form has been determined.

4. The densities of the alpha form, the fused oxide or glassy form, and several other preparations of soluble germanic oxide have been determined. The alpha form is by far the most dense form of the oxide, possessing a density of 6.0039 as compared with 3.3037 for the glassy or fused oxide.

5. Through the kind coöperation of Dr. R. W. Wyckoff of the Geophysical Laboratory, Washington, the various preparations of oxide have been examined. Their x-ray spectrographs show the alpha form to be of totally different diffraction pattern from any form of the soluble oxide.

Philadelphia, Pa.,
April 23, 1926.

THE METABOLISM OF URIC ACID.

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Introduction.

Uric acid is of interest to at least two groups of students:

1. To the biologist: As later paragraphs will show, uric acid is an important product of substances in the nuclei of cells. The "chromatin" of the biologist is called "nucleoprotein" by the chemist.

2. To the physician: Uric acid enters into the interest of the medical student in different ways:

(*a*) It is used in diagnosis of certain lesions connected with the kidney. Thus, in bichloride poisoning, uric acid is not passed into the urine from the blood, but is "retained" as the term is used and the degree of retention is a measure of the damage to the kidney.

(*b*) It is doubtless intimately involved in gout and may be the cause of this disease.

(*c*) It is found in kidney stones and for this reason holds an important place in urology.

(*d*) Its insolubility in body fluids, slightly changed from the normal, is probably responsible for its deposition in the blood-vessels of old age. Since uric acid and its salts, the urates of sodium and ammonium, are soluble in alkali, certain waters, called "lithia waters," "carbonated waters," etc., have been sold and hydrotherapeutic sanitaria have long been sought by sufferers from kidney diseases. The fact that the Government has suppressed advertisements of such waters as cures for uric acid diseases indicates that this function is held in disrepute.

Slides were shown during the presentation of this paper showing advertisements in well-known, standard journals published in Europe, proving that such restrictions are not imposed abroad.

The Origin of Uric Acid.

We have said that uric acid is a product of the metabolism of the nuclei of the cell. The question remains, what substances are used

by the body in making the chromatin (nucleoprotein)? There are three chief substances in chromatin, leaving aside protein, namely (1) phosphoric acid, (2) glucose and (3) two sorts of nitrogenous substances, one of which gives rise to uric acid when burned. We should look, then, for substances in the body containing these three materials, or from which they could be derived. Such a substance is realized in lecithin, a phosphorized fat occurring in active cells; the structure of lecithin, compared with that of nucleic acid, the acid of nucleoprotein, which is a salt, protein being the basic part, is shown in the following scheme:

Lecithin contains:	Nucleic acid contains:
1. Phosphoric acid.	1. Phosphoric acid.
2. Organic substances:	2. Organic substances:
a. Glucose-derivative (glycerol).	*a*. Glucose-derivative, or glucose itself.
b. Nitrogenous substances: Cholin, a substituted ammonium hydroxide.	*b*. Nitrogenous substances: (1) Pyrimidin. (2) Purin (precursor of uric acid).

THE COMPOSITION OF URIC ACID.

In order to show the manner in which the chromatin of the cell is composed, it is necessary to resort to the following diagrams:

Nucleoprotein
"chromatin"
(a salt, having, as all salts do)

Basic part	Acid part
Protein. (A simple protein like protamin)	Nucleic acid (Composed as follows): Nucleotid I, Nucleotid II, Nucleotid III, Nucleotid IV

Each nucleotid is linked with its fellow by a simple oxygen bond. Each nucleotid, in its turn, is composed as follows:

Phosphoric acid	Glucose	Nitrogenous substance.

It is possible to remove the phosphoric acid, in which case, one has a "nucleosid":

Glucose	Nitrogenous substance.

Finally, one may cleave the nucleosid and obtain the nitrogenous substance free from glucose. Of the purins which occur in the cell, there are two, namely, *adenin* and *guanin*. Guanin is partly oxidized, adenin not at all, while uric acid has three atoms of oxygen:

$C_5H_5N_5$ .... Adenin
$C_5H_5N_5O$ .... Guanin
$C_5H_4N_4O_3$ .... Uric acid.

The conversion of cell-purins into uric acid is done by means of enzymes which first cause the loss of nitrogen (compare the amount of nitrogen in uric acid with that in adenin, or guanin); secondly, they cause the oxidation of the remainder of the purin; this causes the formation of *oxy-purins*. From adenin, the oxy-purin, hypoxanthin is formed; from guanin, xanthin. Xanthin may form, also, from hypoxanthin. The relations with uric acid are as follows:

$C_5H_4N_4O$ .... Hypoxanthin
$C_5H_4N_4O_2$ .... Xanthin
$C_5H_4N_4O_3$ .... Uric acid.

The enzymes causing the loss of nitrogen ("dem ainases") are found in all tissues, but the ones causing the oxidation of adenin to hypoxanthin and of guanin or of hypoxanthin to xanthin and xanthin to uric acid occur only in the liver. Hence the liver is the organ in which uric acid is made.

Uric Acid, Abnormally.

One disease in particular is intimately connected with uric acid metabolism, namely, gout. In the United States, gout does not occur as frequently as it does in Europe and especially in the British Isles. A tentative reason may be the prevalence of chilling winds, laden with dampness; for it is known that such conditions, in which the body heat is rapidly withdrawn by the excess moisture of the air, are augmentative of gout. A perhaps more potent reason is that alcohol taken with meals tends to cause a retention of uric acid. In the United States, alcohol is used, when used at all, as a beverage and not taken with meals as frequently as in Europe. In order to account for gout, it is necessary to show that there is an increased amount of uric acid in the blood, from some source. The excess uric acid injures the kidney tissue and that organ, which normally is responsive to changing amounts of the acid in the blood, becomes irresponsive. As Folin has shown, excess uric acid, as for instance, when injected artificially into the blood, causes swelling and other pathological states in the kidney. Eating meat, free from substances with a large proportion of nuclei in the cells, tends to cause uric acid to be lost from the body in the urine. Such substances as the following contribute to the uric acid of the body:

Sweetbreads, liver, steak, veal, ham, chicken, beans, lentils.

The following are low in uric-acid-producing substances:

Fish, potatoes and vegetables other than legumes.

Uric acid is deposited in the kidney, bladder and ducts belonging to the urinary system. These deposits are called "calculi." While alkalies, as we have said earlier, dissolve uric acid and its salts outside the body, the solutions must be of such a strength that they injure the tissues of the body when injected into the body for the purpose of dissolving the calculi. Hence it is quite improbable that the medicinal waters aid in the cure of uric acid stones. Nor is it possible to correct for uric acid abnormalities by keeping the urine in an alkaline state, as may be done by the administration of fruits and fruit-products. Moreover an alkaline urine is conducive to the development of bacteria.

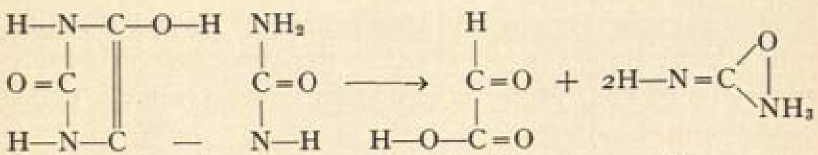
The Fate of Uric Acid.

No problem in physiology has been quite so baffling as that concerning the disappearance of uric acid. It was questioned for a time whether any destruction of the substance occurred in the human body. Experimental proof seemed to show that man and the higher apes resembled one another in that they did not destroy uric acid. Now, however, it seems certain that uric acid is destroyed in the body and especially in the blood. It has been known for some years that uric acid may be converted with comparative ease into a somewhat similar substance, *allantoin*, by causing uric acid to become oxidized under controlled conditions. Allantoin is uric acid minus a molecule of carbon dioxide; that is, the acid has lost one carbon atom. The excretion of allantoin in various animals was intimately studied by Andrew Hunter and reported in the *Proceedings of the Royal Society of Canada*. Allantoin is decomposed into urea and excreted as such into the urine.

Tests for Allantoin.

In order to follow the destruction of uric acid it has been hitherto necessary to resort to a quantitative method, requiring a prolonged interval of time and many manipulations. No test, readily applied, has been described. The Wiechowski method involves such a long time that its use is limited. The desideratum of a reliable qualitative and quantitative test is recognized by everyone and there has been much work directed towards deriving such methods.

The writer, taking advantage of a familiar procedure, known as the test of Adamkieviczs, proposes the following method for recognizing allantoin: Conversion of allantoin into urea and glyoxalic acid and conjugation of the latter with an indol substance to form a colored compound readily recognized. The equation representing the conversion of allantoin into the two substances mentioned is as follows:



Allantoin   Glyoxalic acid   Two ureas.

The glyoxalic acid is then conjugated with indol, a commercial preparation, to form a colored substance, indicative of allantoin. The sensitiveness is at least 1:1000.

The test does not lend itself to adaptation as a quantitative method, although for rough approximations it may be used.

It is hoped by this or other qualitative and quantitative method to follow the destruction of uric acid and the disposal of the products. Perhaps, then, a means can be found for artificially causing the destruction of uric acid in pathological states.

THE NEWER KNOWLEDGE OF THE PHYSIOLOGICAL ACTION OF ULTRA-VIOLET RAYS.

By ALFRED F. HESS, M.D.,

New York.

The essential importance of ultra-violet rays in medicine has just begun to be appreciated. The action of these rays, as distinct from the visible radiations of the sun, has been known for many years, but physiologists have only recently become fully alive to their significance in relation to normal and pathologic conditions of man. This is all the more surprising in view of the fact that plant physiologists have laid great stress on the rôle of the invisible or "chemical" rays of the sun in the biologic processes of the vegetable world. Some twenty years ago, the physiologist Hertel carried out striking experiments in this field, which demonstrated the marked abiotic power of ultra-violet rays—their ability to destroy bacteria within a period of sixty seconds. About the same time, Finsen showed that the improvement or cure of lupus could be brought about by means of irradiations from the carbon arc lamp, and that this remarkable effect was due to the ultra-violet rather than to the visible radiations emitted from this source. Rollier's excellent results in cases of bone and glandular tuberculosis by exposing the body to the sun have likewise been attributed largely to the ultra-violet rays. However, these various experiences failed to focus the attention of biologists on this aspect of physiology. It was not until it could be shown objectively in man and in animals, by means of the roentgen ray and by chemical analyses of the blood, that a nutritional disturbance—rickets—came about as the result of a lack of the ultra-violet solar rays, and could in turn regularly be prevented or cured by these irradiations, that their importance in physiologic and pathologic processes was fully appreciated.

These rays constitute less than 1 per cent. of the total solar radiations, and it is therefore all the more remarkable that they should prove to be essential to the well-being of man. The young, rapidly growing infant thrives better when deprived of the visible rays than when deprived of the ultra-violet rays of the sun. It is an illustration in another field of what we have recently become sensible

of in regard to nutrition—the lack of relationship, one may almost say the inverse relationship, between abundance of supply and the indispensability of food constituents. The vitamines furnish a striking example of this principle. The law of the vital importance of the minimum applies to the radiations of the sun—those rays which are furnished in smallest amount and in least intensity are nevertheless indispensable.

What is known regarding the action of these short radiations may be summed up in a few words. It has been repeatedly shown that they possess exceptionally little power of penetration; that the dust or the moisture of the atmosphere suffices to absorb the shorter ultra-violet rays and prevents from reaching the surface of the earth; that mist, fog and smoke intercept their progress to a greater or less degree. This is true even of the tenuous skin that surrounds the hen's egg. Ordinary window glass filters out all but the longer and less potent of these rays, allowing the passage only of denatured sunlight, which still retains all the semblance of the beneficent radiance of the sun.

The relationship of rickets to the ultra-violet rays has already been referred to. Indeed, the most reliable index of the activity of these rays on the animal organism is the biologic response of rickets. The reaction of this disorder affords a valuable criterion for the study of the physiologic action of these rays; and the utilization of this procedure, both in man and in animals, during the last five years, has been our main source of knowledge in regard to this important aspect of physiology and pathology. Rickets is characterized by a disturbance in the mineral metabolism, which is manifested by an alteration in the structure of the bones and a diminution of the inorganic phosphorus or of the calcium of the blood. Both of these abnormal states are rectified when the infant or animal is exposed to the sunlight or to the ultra-violet radiations from an artificial source. How this remarkable action is brought about remains to be determined, and constitutes one of the fundamental questions in the biology of the cell. So widespread is this action of the sun's rays that there is a seasonal tide in the percentage of phosphorus in the blood of infants in the temperate zone—an ebb and flow corresponding to winter and summer. These changes constitute the action of sunlight in relation to rickets.

The beneficent radiations are highly specific; a difference of about 25 millionths of a millimeter determines whether the rays are of specific curative value, or whether they are inert in relation to rickets. Furthermore, there is a marked seasonal variation in the ultra-violet radiations of the sun. They are weak during the winter months, and in the early morning and evening—poor not only in quantity but in quality. It is largely this difference in quality which accounts for the fact that rickets prevails throughout the temperate zones and is almost non-existent in the tropics. If we compare the actual amount of sunshine during the five winter months in the various cities of the United States and Europe with the five corresponding months in some cities of the tropics and West Indies, we find that there is no real difference in the amount of actual sunshine; the difference lies in the quality or intensity of the ultra-violet radiations which is so much greater in the tropics due to the smaller annual fluctuation in the zenith distance of the sun. The dominant factor in relation to the activity of solar ultra-violet rays is not quantity but quality.

There is likewise an indirect action of the invisible rays of the sun, as has recently been brought out by the observations of Hess and Weinstock, as well as by Steenbock—a power in ultra-violet radiations to produce an antirachitic factor in plants, in vegetable oils, etc., endowing them with the potency to prevent rachitic changes in bones. Refined wheat flour, dried milk, vegetables and other foods can be rendered rickets-protective by short exposures to the radiations from the mercury vapor lamp. (Chart 1.) A series

CHART 1.

FEEDING IRRADIATED AND NON-IRRADIATED COOKED SPINACH.

Weights.	Rickets-Producing Diet.	Spinach (10 g.).	Rickets.	Blood P. Inorganic.
64–89....	Low Phosphorus No. 84	Irradiated (½ hr.—1 ft.)	None	3.24 mg. %
54–60....	" " " "	" " " " "	"	
34–58....	" " " "	" " " " "	"	
56–84....	" " " "	" " " " "	"	
50–60....	" " " "	Non-irradiated	Moderate	1.83 mg. %
48–64....	" " " "	"	"	
32–60....	" " " "	"	Marked	
50–60....	" " " "	"	"	

of experiments has shown that *the chemical substance which is activated by the rays is the cholesterol in animal foods or its counterpart, the phytosterol in vegetable foods.* It has long been known that cholesterol is present in almost every animal cell and phytosterol in almost every vegetable cell. For this reason cholesterol has been the object of study for many years; however, physiologists have been unable to associate it specifically with any organ or with any normal or pathologic function of the body. It is, therefore, of peculiar interest that cholesterol, which is inactive in its ordinary state is found to acquire antirachitic potency after having been subjected to ultra-violet radiations. (Chart 2.)

CHART 2.

FEEDING IRRADIATED CHOLESTEROL AND PHYTOSTEROL.

Rat Wt. (g.).	Rickets Diet.	Substance Fed.	Result.	Blood P. (Inorganic).
50–60 44–40	Low Phosphorus No. 84	0.25 cc. Cholesterol (1% in water) *Irrad.* ½ hr. 1 ft.	No Rickets " "	4.80 mg.
48–50 44–50 44–50 40–46	Low Phosphorus No. 84	0.25 cc. Cholesterol (1% in water)	Sl. " " " Mod. " " "	3.64 mg.
40–50 48–42	Low Phosphorus No. 84	0.25 cc. Phytosterol (1% in water) *Irrad.* ½ hr. 1 ft.	No " " "	3.31 mg.
30–46 50–54 38–58	Low Phosphorus No. 84	0.25 cc. Phytosterol (1% in water)	Mod. " " " " "	2.70 mg.

As is well known, cod-liver oil is also a specific for rickets. How are we to associate a common activity to two such divergent agents as fish oil and ultra-violet radiations? At first this riddle seemed most mysterious and confusing, but now that we know that ultra-violet rays activate cholesterol the solution is simple. In the first place, the superficial layers of the skin are rich in cholesterol which readily explains the mode of action of these rays whether coming from the sun or from an artificial source. Furthermore, it has been found that the oily part of cod-liver oil is inactive in relation to rickets and that the effective moiety is the so-called "non-saponifi-

able fraction" of which cholesterol forms an important part. This cholesterol is composed largely of inactive cholesterol, but partly of the specific activated form which the cod has consumed in its food, but which has the solar rays as its ultimate source of energy. It will be seen, therefore, that we are supplying the same substance to the infant, whether we give cod-liver oil or whether we expose its body to the ultra-violet radiations of the sun or the mercury vapor lamp.

An interesting example of antirachitic activation in nature is furnished by cocoanut oil. It has been found that almost the sole vegetable oil which possesses antirachitic value is the oil of the cocoanut; olive oil, cotton-seed oil and linseed oil are practically inert in this respect. A recent experiment readily explains this peculiarity. It was found that cocoanut oil is antirachitic only when it has been prepared from copra which has been dried in the sun; that which has been kiln dried is just as inert as other vegetable oils. In other words, the copra has been activated by the tropical sun.

In closing, the question may be raised as to the relation between activated cholesterol and the vitamines. Has a vitamine been prepared in the laboratory by means of subjecting cholesterol to ultra-violet radiations? At the present time this question is purely academic. There is no agreement as to the definition of a vitamine, nor as to what substances should be included in this ever-increasing group. It is quite probable that with increased knowledge as to the chemical constitution of the vitamines it will be found that they do not constitute an entity and do not belong together. Whether or not we regard activated cholesterol as a vitamine, it is of interest and would seem to be of physiologic significance to have elaborated by means of ultra-violet irradiation a substance of essential importance for the nutrition of the growing animal.

DISCUSSION OF THE KINETIC THEORY OF GRAVITATION III.

Some Experimental Evidence Supporting Theory; Continual Generation of Heat in Some Igneous Rocks and Minerals. Relation of This to the Internal Heat of the Earth and Presumably of the Sun.

BY CHARLES F. BRUSH.

(*Read April 23, 1926.*)

At the Minneapolis meeting of the American Association for the Advancement of Science I had the honor to outline "A Kinetic Theory of Gravitation,"[1] which is in substance briefly as follows:

The ether is assumed to be endowed with vast intrinsic kinetic energy in wave form of some sort capable of motive action on particles, atoms or molecules of matter, and propagated in straight lines in every conceivable direction so that the wave energy is isotropic. The waves are of such frequency, or otherwise of such character, that they pass through all bodies without obstruction other than that concerned in gravitation and the slight heating effect described in the present paper, and perhaps other slight effects. Distribution of the ether's energy is assumed to be uniform throughout the universe except as modified by the presence of matter.

Each particle or atom of matter is regarded as a center of activity due to its energy of translation initially derived from the ether. There is continual absorption and restitution of the ether's energy, normally equal in amount; but the ether is locally robbed of as much of its energy as is represented by the mean kinetic energy of the particle or atom. The particle or atom thus has a field of influence extending in all directions, or casts a spherical energy shadow, so to speak, the depth or density of the shadow varying with the inverse square of distance. The energy shadow of a body of matter is the

[1] *Science*, March 10, 1911; *Nature*, March 23, 1911.

sum of the shadows of its constituent parts. The energy shadows of two gravitating bodies interblend, so that the energy density between them is less than elsewhere, and they are pushed toward each other by the superior energy density, or wave pressure, on the sides turned away from each other.

That the ether really *is* endowed with vast intrinsic energy in some form or forms is the belief of many eminent physicists, and it seems highly probable that all energy has its source and destination in the ether; that is to say, that energy in all the various forms in which we observe it, comes in some way from the ether and is energy of the ether. This view does not in any manner conflict with the principle of conservation of energy. In this connection I beg to propose the hypothesis that the ether is abstract energy—energy pure and simple—*free energy*.

In support of my contention that etherial energy is the cause and essence of gravitation, I wish to emphasize particularly, what seems to me an obvious fact, that the energy acquired by a falling body comes from the ether, and is restored to the ether when that body undergoes negative gravitational acceleration.

In this connection I cannot do better than quote Lord Kelvin's description of the collision of two very large bodies through the influence of mutual gravitation. In his "Popular Lectures and Addresses" (Vol I., 413–417) he says:

"To fix the ideas think of two cool solid globes, each of the same mean density as the earth and half the sun's diameter, given at rest, or nearly at rest, at a distance asunder equal to twice the earth's distance from the sun. They will fall together and collide in exactly half a year. The collision will last for about half an hour, in the course of which they will be transformed into a violently agitated incandescent fluid mass flying outward from the line of motion before the collision and swelling to a bulk several times greater than the sum of the original bulks of the two globes. . . . The time of flying out would probably be less than half a year when the fluid mass must begin to fall in again towards the axis. In something less than a year after the first collision the fluid will again be in a state of maximum crowding towards the center, and this time even more violently agitated than it was immediately after the first collision; and it will again fly outward, but this time axially towards the places whence the two globes fell. It will again fall inwards, and after a rapidly subsiding series of quicker and quicker oscillations it will subside, probably in the course of two or three years, into a globular star of about the same mass, heat and brightness as our present sun.

Undoubtedly this is substantially what would happen under the conditions named: The two cold bodies would acquire *from some source external to themselves* the vast energy represented by the heat of a sun, heat sufficient to maintain enormous radiation millions of years with little diminution. And this vast accumulation of energy would occur in half a year, largely in the *last few days* before collision. There is, to me, no conceivable source of this energy other than the ether. It may be argued that the two cold bodies, as a gravitating system, initially possessed all this energy in the form of "potential energy of position." This is a most convenient expression, but it affords no explanation of the source of the energy until, as I pointed out at the Washington meeting, we take the energy-endowed ether into partnership as an essential part of the system. Certainly the energy could not be resident in the two cold motionless globes. For a homely illustration, think of two golf balls joined by a stretched thread of rubber; they form an attracting system and possess "potential energy of position" or separation, but the energy does not reside in the balls, it is in the stretched rubber thread.

Later in his description Lord Kelvin says:

> "If, instead of being at rest initially, . . . each globe had a transverse velocity of three quarters (or anything more than 0.71) of a kilometer per second, they would escape collision, and would revolve in ellipses round their common center of inertia in a period of one year, just grazing each other's surface every time they came to the nearest points of their orbits." (Assuming of course that the globes were sufficiently rigid to escape disruption by tidal forces.)

The globes in falling from aphelion to perihelion would gather the same amount of energy that they did in the case of collision, where their motion was arrested and their kinetic energy was thus converted into heat; but without collision the vast energy acquired during positive acceleration from aphelion to perihelion would disappear during negative acceleration from perihelion to aphelion, and be transformed back to the ether whence it came, with complete restoration of all initial conditions.

The sun and planets of the solar system, and the planets and their satellites, because of the excentricity of their orbits, continually go through the same kind of cycle described by Lord Kelvin, differing from that only in degree. For instance, the earth in its six months'

passage from aphelion to perihelion falls about 3,000,000 miles toward the sun, and gains in orbital velocity about 5/8 mile per second. It thus acquires new kinetic energy from the ether which, if it could be manifested as heat, would be sufficient to evaporate all the oceans, lakes, and rivers, heat the dry earth to vivid incandescence, and vaporize much of it; the earth would become a miniature sun. And all this energy is restored to the ether during the next half year while the earth is moving from perihelion to aphelion.

With the idea in mind that a falling body gathers energy from the ether, and restores all of it to the ether when raised the same distance against gravitation, *by any means*, homely examples are at once suggested; thus, a stone thrown upward and falling again, does it in the reverse order, and a common clock pendulum goes through, and repeats the cycle with almost the regularity of a sun and planet.

In the theory of gravitation under discussion, the only new postulate is that some or much of the ether's intrinsic energy is *kinetic* and consists of some sort of isotropic wave motion or energy flux, whereby a disturbance at any point in the free ether is ultimately felt everywhere else, diminishing in intensity, of course, with the inverse square of distance from the seat of disturbance.

It is not difficult to conceive of kinetic energy in the ether quite apart from matter. Radiation is one form of such energy, and when once launched in the ether it is persistent and quite independent of its source. Interstellar space is alive with wave energy radiated from countless suns, and at points far removed from any single sun this energy is approximately isotropic. This known isotropic wave energy in the ether of space is unsuitable in kind and too feeble to play any appreciable part in gravitation, and I call attention to it only for the purpose of showing that one sort of free isotropic wave energy in or of the ether in celestial space is a known phenomenon.

Isotropic ether wave energy exists everywhere in any closed space at uniform temperature, an evenly warmed room for instance. In such case every part of every surface of objects in the room as well as of the enclosing walls, ceiling and floor radiates and partly reflects exactly as much heat as it receives from other radiating surfaces. (If this were not so, there would be local heating or cooling which we know never occurs.) This becomes obvious when we re-

member that radiation, absorption and re-radiation between warm bodies is not qualitatively conditioned on temperature difference, but goes on just the same when temperatures are equal.

Emission and absorption of radiation by matter demonstrates an intimate interrelation between ether waves and atoms.

We know that different trains of light waves may pass through the same point in any number of directions without obstructing or interfering with each other in the slightest degree, and this with confidence is assumed to be true of the waves or trains of waves concerned in gravitation.

Perhaps the ether waves concerned in gravitation are not the transverse kind known to us, but are longitudinal or otherwise consist in an energy flux which, by reason of its universal presence, has not been manifested except by gravitation. It seems quite possible however that they are transverse electromagnetic waves of *extremely* high frequency, *far* beyond the frequency of the gamma rays from radium. Since the original paper was written it has been found that very high-frequency ether waves, on account of their frequency, may embody great energy; and the higher the frequency, the more readily do they pass through matter without absorption.

The foregoing synopsis of the theory under discussion is principally quoted from the first "Discussion"[2] written in 1914.

Gravitation Waves and Heat.

Heat is often defined as an agitation of atoms and molecules of matter, and measured by the total kinetic energy of such agitation. The agitation consists partly in internal vibrations of the elastic atoms and molecules and spinning about their various axes, and partly in a very rapid translatory motion among themselves. Thus they are supposed to dart about in every conceivable direction, constantly colliding with each other and rebounding or glancing in new directions. The kinetic energy of this translatory motion constitutes *sensible* heat (not total heat) and is the measure of *temperature*. Anything (such as absorbed radiation) which stimulates the internal vibration of atoms or molecules likewise increases their translatory

[2] *Proc. Am. Phil. Soc.*, Vol. LIII., No. 213, January–May, 1914.

velocities by the increased violence of rebound after collision, and thus increases their temperature; and *vice versa.*

All the above is known to be true of gases and vapors (kinetic theory of gases), and is generally believed to be true of liquids and solids.

The "*mean* free path" and the "*mean* velocity" between collisions of the molecules of many gases under stated conditions have been computed. But it has also been shown mathematically that the higher and lower velocities, and the longer and shorter paths differ greatly from the means, and may in each respect vary twenty or more times in amount. Doubtless this is true also of liquids and solids.

Certainly the "free path" of atoms and molecules in solids must be very short, but quite as certainly there must be some space for movement because we know that the atoms or molecules of solids are not in contact. And diffusion of contiguous metals into each other proves migration of the atoms or molecules just as in gases, though vastly slower, as we should expect from the extreme shortness of their free paths.

From the fortuitously wide variation in velocities and free paths of the billions of vibrating atoms or molecules in their heterogeneous movement, it follows that collision frequencies must also vary greatly, from instant to instant, everywhere in a body of matter.

Probably the postulated gravitation waves are not confined to one frequency, but have a wide range of frequencies as do the well-known X-rays.

With the foregoing in mind it is easily conceivable that some kinds of matter may have atoms or simple molecules or complex molecules of occasional vibration frequency corresponding with some gravitation wave frequency, whereby fortuitous resonance can, for brief instants, be established at various points. This would result in a slight increase of vibrational activity and a cumulative rise of general temperature, perhaps sufficient to be detected.

A body of such matter, with some thermal insulation, would become and remain permanently warmer than a neighboring body similarly circumstanced, but not endowed, or less endowed with the permissive heat-generating quality.

The above hypothesis has been my guide in a very large amount of research work in this field. Commenced many years ago, it has been pursued intensively during the past year, and during the last eight months I have had the most promising success as indicated by the title of the present paper.

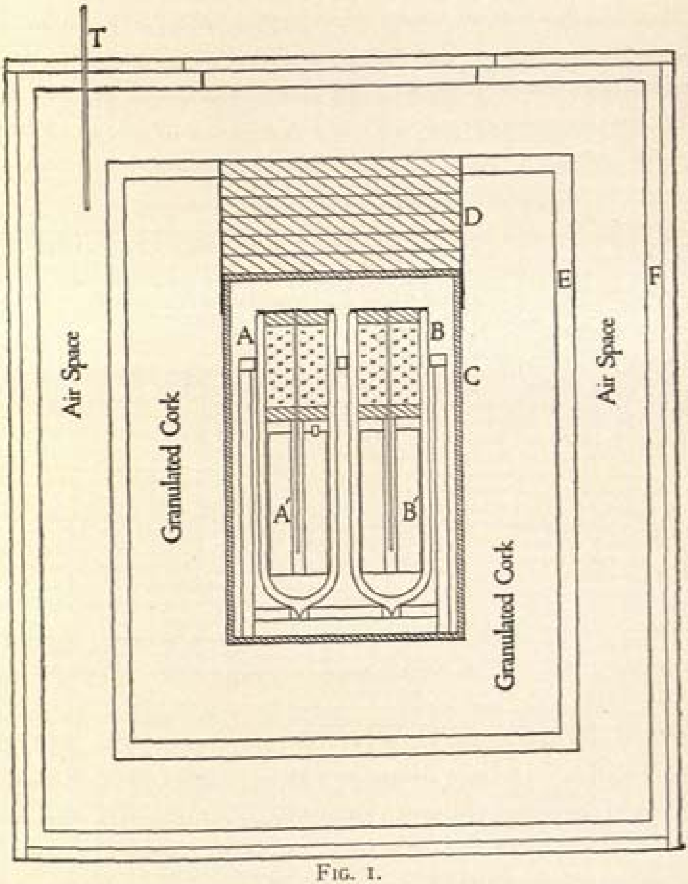


FIG. 1.

In the work of many years ago, several forms of apparatus were tried, but the one about to be described was finally adopted, and with slight modifications has been used in the work of the past year.

Figure 1 is a diagram of the apparatus employed. *A B* represent two large silvered Dewar vacuum jars selected to have very

nearly equal thermal insulating efficiency. They are supported in a wooden rack inside a thick copper cylinder *C*, packed in granulated cork in a wooden box *E*. *D* is a paper extension of *C*, packed with layers of felt by removal of which and the loose copper cover of *C* easy access is had to the Dewar jars. The copper cylinder weighs 23.5 kg. and its functions are, by reason of its large thermal capacity and high conductivity, to protect the Dewar jars from any rapid change of temperature, and from temperature stratification.

The box *E* is surrounded by a much larger wooden box *F* lagged with a thick layer of felt. A long resistance wire is strung back and forth in the air space between the boxes at the bottom and four sides of *E*. Electric current controlled by a thermostat warms the wire, whereby the temperature of the air space may be maintained very nearly constant as many days or weeks as desired. A thermometer *T*, easily read to hundredths of a degree, indicates the temperature of the air space.

Returning now to the core of the apparatus: *A′* is an airtight cylinder of thin copper, 15 cm. high and 6.4 cm. in diameter, provided with an open axial tube also of copper. A small round opening at the top of *A′* permits the introduction of a weighed quantity of water, after which the opening is tightly corked to prevent any change of temperature by evaporation of the water. *B′* is another copper cylinder just like *A′* except that it has a removable top to permit the introduction of the substance whose thermal behavior is to be investigated. The high thermal conductivity of these copper cylinders prevents temperature stratification within them. The Dewar jars are filled above the copper cylinders with layers of felt, and granulated cork, and covered with waxed cardboard carefully sealed on to prevent temperature difference inside the jars which would follow unequal loss or gain of moisture by the felt and granulated cork. A small thin glass tube, flanged at top and closed at bottom, is located in the axis of each Dewar jar and extends from the waxed cover nearly to the bottom of the enclosed copper cylinder. The glass tubes contain the ends of thermo-electric couples of fine constantan, copper and iron wires, 1 iron-constantan and 1 copper-constantan junction at the bottom of each tube. The leading-out

wires are copper, and connect the thermo-couples with a reflecting galvanometer having the customary reading telescope and scale.

In using this apparatus, the metal to be tested, in the form of bars or a cylinder with suitable axial bore, was placed in the copper container B', and a carefully weighed quantity of water just sufficient in thermal capacity to equal that of the metal (or other substance) under test was placed in the copper container A'. Then the whole apparatus was assembled as shown, the "air space" was raised slightly above room temperature by the heating wire before described and thereafter kept at nearly constant temperature by the thermostatic device already mentioned. Galvanometer readings were then made several times daily until they became constant, which usually occurred in four or five days.

Several metals were tested in this manner, but in no case was there found any observable temperature difference between the contents of the Dewar jars until hardened steel was tried. The steel was found to be considerably warmer than its surroundings, but the excess of temperature very slowly declined, though still observable at the end of some weeks. This was the initial discovery of an important phenomenon not before known, the "Spontaneous Generation of Heat in Recently Hardened Steel." I investigated this phenomenon extensively during the next few years, and published several papers on the subject.[3]

About a year ago I resumed work on the present subject and have followed it intensively ever since. Some small changes were made in the apparatus of Fig. 1: The copper containers A', B' were silver plated and highly polished, and the central tube of each was tightly corked at bottom and top, the upper cork having a small hole at its center in which the small glass tube containing the thermocouples fits snugly; this to prevent air circulation. A very long-stemmed precision thermometer, easily read to half a hundredth of a degree, and passing through cover of box F, layers of felt in D and cover of copper well C, was installed to keep track of temperature

[3] *Proc. Am. Phil. Soc.* (May–July, 1915), Vol. 54; *Phys. Rev.* (2) (1917), Vol. 9; *Proc. Am. Phil. Soc.* (1917), Vol. 56; *Proc. Royal Soc. Lond.* (1917), *A* 93, joint paper with Sir Robert A. Hadfield; *Proc. Royal Soc. Lond.* (1918), *A* 95, joint paper with Sir Robert A. Hadfield and S. A. Main; *Proc. Am. Phil. Soc.* (1918), Vol. 57.

inside the copper cylinder or "well." All thermometers are read with a telescope.

It was found that when the thermo-couples were completely short-circuited outside the calorimeter, the galvanometer often gave small deflections of either sign when there happened to be a change in room temperature and air currents prevailed. This was traced to slight temperature differences between some of the several joints of somewhat different metals in the galvanometer structure. This source of error was nearly, but not quite eliminated by enclosing the galvanometer with a closed vertical cylinder of thick copper having a small hole in its side for viewing the mirror.

When, in the regular course of work, the smaller deflections are under observation, the thermo-couples are short-circuited after each reading, the galvanometer is tested for error as above, and suitable correction, if any, is made in the reading. Such corrections are never more than a very small fraction of the deflection. The galvanometer is of the swinging-coil type with powerful permanent magnetic field. Its working circuit is opened and closed by an all-copper knife switch located well away from the observer and lamp.

Many metals have been tested in addition to those of years ago, ranging from tungsten, of great density and high atomic weight, down to aluminum of small density and low atomic weight, and also carbon in the form of graphite, of still less density and atomic weight. But in no case was any generation of heat detected.

Next, several simple and complex alloys were tried. Some of these generated appreciable heat; but in every instance this was traced to oxidation.

Meanwhile, a campaign on minerals and rocks was planned, particularly igneous rocks, for the following reasons: It is generally believed that many millions or hundreds of millions of years ago the earth was an incandescent molten globe; and that it has gradually cooled to its present thermal condition by radiation of heat from its surface. But there is ample reason for the further belief that the interior of the earth is still very hot, hot enough to melt the most refractory rocks were they not kept rigidly solid by the enormous gravitational pressure to which they are subjected. Escape of in-

ternal heat certainly must still be going on by slow conduction through the earth's cool crust, and radiation into space. As Lord Kelvin has expressed it (Thomson and Tait's "Natural philosophy," Appendix D, "On the Secular Cooling of the Earth"),

"The fact that the temperature increases with the depth implies a continual loss of heat from the interior, by conduction outwards through or into the upper crust. Hence, since the upper crust does not become hotter from year to year, there must be a secular loss of heat from the whole earth."

This clearly indicates that the earth is continually radiating heat into space faster than it receives radiant heat from the sun. Yet there is much geological evidence that the earth's surface has not become colder by more than a very few degrees, if any, in millions of years.

Several hypotheses have been proposed by eminent physicists to account for the maintenance of the earth's internal heat. Rutherford ("Radio-active Substances and Their Radio-actions," Section 260) estimates that the radio-activity of the materials of the earth's crust is sufficient to account for it. This, however, involves the assumption of a rather small temperature gradient in the crust, based on the evidence of a few deep mines and borings on the land areas. But we have no means of knowing what may be the temperature gradient in the beds of the oceans, which form very much the greater portion of the earth's crust.

My own thought was that the maintenance of the earth's internal heat might perhaps be due, in part at least, to a continual small generation of heat in some of its constituents by gravitation ether waves in the manner already outlined; and possibly this might be sufficiently large to be detected.

This surmise has been supported by the result of experiments with some basaltic rocks and volcanic lavas, and some minerals; that is to say, unmistakable generation of heat has been observed, some of which, at least, is thought to be due to the postulated gravitation ether waves.

Presumably an ideal material for experimentation would be some of the very hot molten magma of the earth, quickly cooled to prevent crystallization and segregation of its constituents. Of course

this is quite unobtainable; but perhaps some basalts and lavas do not differ from it very greatly. They consist of complex igneous silicates, and mixtures of silicates.

I have observed some generation of heat in a basalt from Lintz, Rhenish Prussia. This is very fine grained, nearly black and extremely hard and tough. Following is a careful analysis of this rock:

TABLE I.

Analysis of Basalt from Lintz, Rhenish Prussia.

Silica	43.80
Alumina	16.24
Ferric Oxide	7.18
Ferrous Oxide	5.09
Calcium Oxide	11.32
Magnesium Oxide	9.97
Potassium Oxide	1.56
Sodium Oxide	2.98
Loss below 105° C.	.74
Loss at red heat	.94
	99.82

A trace of manganese was found.

Let us consider the origin of basaltic rocks. My thoughts on this subject run as follows: When the earth's surface, for a depth of many miles, was still in a molten state, cooling at the surface gradually formed a pasty crust greatly torn and crumpled by tidal action. As cooling progressed, most of the large family of siliceous minerals crystallized out of the liquid magma as lowering temperatures suitable for their formation were reached. In due time (millions of years) the surface of the thickening crust became solid and comparatively rigid, and doubtless had greater density than the still liquid magma some miles beneath it. As cooling further progressed, and the solid crust thickened, lateral shrinkage caused cracks to occur in the crust from time to time, here and there, over the earth's surface. Whenever a considerable crack or fissure occurred, the molten magma from miles below welled upward through it, owing to the greater density of the crust above, doubtless enlarging the fissure by scouring action, and spread laterally over the solid earth crust; in many cases covering hundreds and even thousands of

square miles, as in Idaho, Oregon and Washington, and sometimes a mile or more in thickness as shown by the Snake River canyon in Idaho.

The extruded molten magma, thus spread over large areas of comparatively cool earth crust, and exposed to direct surface radiation, must have solidified quickly, and with little segregation of its constituents by crystallization: Hence some basalts from great depths may nearly represent the original fluid magma of the outer shell of the earth.

Surely there must be very many large fields of basaltic rock on the beds of the oceans, because the period of such formations long antedated the appearance of condensed water on the earth.

Dense volcanic lavas are much the same in character and composition as basaltic rocks, though probably in most cases extruded from lesser depths.

Experimental Work with Some Basalts, Lavas and Minerals.

After some preliminary work with the apparatus of Fig. 1 just as described, a modified procedure was adopted and adhered to, as follows: Each rock or mineral was crushed (not ground) to coarse-sand size, with numerous siftings, until it all passed through the sieve. Then the dust and very fine grains were removed by a much finer sieve and rejected. This left a mixture of coarse, medium and small grains much better adapted to close packing than if the grains were of uniform size. The crushed material was then spread in a thin layer and left exposed to the air of the laboratory for several days to acquire room temperature and normal hygroscopic condition.

The copper containers A', B' of Fig. 1 were removed, and a weighed quantity of the ground material was poured directly into one of the Dewar jars and gently rammed down to reduce its volume to minimum. A closely-fitting waxed card-board disc with a small hole at its center, was placed on top of material to prevent, or greatly retard migration of moisture between the material and the felt and granulated cork above it in case of any difference in hygroscopic condition. Next, the small glass tube for the thermo-junctions was inserted through the central hole in the disc, the felt covering and

granulated cork added, the small tube worked downward to final place, and all sealed in as usual.

If a cylindrical mass of crushed material as above described generates heat, loss of heat occurs not only through the walls of the containing Dewar jar, but also to a small extent in the axis of the cylinder by conduction upward through the central small glass tube and its contained thermo-wires; and this heat must be supplied by slow conduction through the material closely contiguous to the tube. Undoubtedly a larger heating effect would be observed in the apparatus if there were some air space between the tube and the crushed material, through which transfer of heat from a larger surface of material to the tube could be made by convection.

Prior to removal of the copper containers *A′ B′*, fine white silicious sand, previously ignited in presence of air to destroy any organic matter and ferrous iron that might be present, was compared with water in the then usual manner, without the slightest observable generation of heat. Hence this material was used thereafter as the standard for comparison. Nine hundred grams of sand was found a convenient quantity, and filled about five-eighths of the other Dewar jar, which was equipped with waxed cardboard disc, central small glass tube, felt and granulated cork, and sealed as already described.

None of the rocks and minerals subsequently tested for heat generation differed much from the sand in specific heat, and in each case a weighed quantity was used just sufficient to equal the sand in thermal capacity.

Subsequent procedure was as follows: The pair of Dewar jars, one loaded with sand, the other loaded with the material to be tested, were placed in the copper well of the calorimeter and covers put in place, all as shown in Fig. 1. During the next many hours "room temperature," "box temperature" (in the air space) and "well temperature" (in the copper well) were observed from time to time, and temperature controls (room and box) were so manipulated as to bring about substantially constant well temperature as soon as practicable, usually in a day or two. After a few hours, galvanometer deflection readings were commenced. Electrical connections were such that if the material being tested happened to be at first a little warmer than the sand, the deflection was right-handed (plus);

if a little cooler, the deflection was left-handed (minus). But this made no difference in the amount or sign of the final permanent deflection, if any.

Thereafter, during a whole experiment, the temperature and galvanometer readings were taken and recorded three or more times daily. Temperature equilibrium was usually reached within a week, the time depending on the initial temperature difference, and for confirmation, readings were continued several days thereafter.

All the igneous rocks tested, and some minerals, remained more or less warmer than the sand with which they were compared.

In several experiments, after temperature equilibrium was reached, the thermo-couples in the Dewar jars were reversed; this did not at all affect the amount of galvanometer deflection, but of course changed its sign, showing that the couples were evenly balanced. Occasionally the entire contents of the Dewar jars were exchanged; but this did not affect the result, thus showing there was no systematic error due to difference in the jars.

All the basalts examined contained more or less "Olivine" disseminated throughout their mass in very minute or invisible crystals. When finely powdered they were distinctly greenish in color (Olivine is green). When the fine powder was ignited in air it lost its green tinge, and became reddish in color, by peroxidation of its ferrous iron.

Olivine is a ferrous metasilicate with magnesium silicate $(Mg, Fe)_2 SiO_4$. The ferrous oxide is so loosely bound by the small amount of silica combined with it, that it cannot withstand the action of free oxygen at red heat. But I hoped it was stable at room temperature. To answer this important question the device shown in vertical section in Fig. 2 was used.

In Fig. 2 *a* is a glass tube about 2 cm. diameter, prolonged downward by a much smaller and longer tube *b*, which extends nearly to the bottom of a small beaker *c* partly filled with mercury as shown by the dotted line. *d* is a plug of cotton, and *e* is a tightly fitting cork.

The large tube between *d* and *e* was filled with the material to be examined for oxygen absorption, finely ground to expose very large

grain surface, and the cork *e* was sealed airtight with melted wax. When oxygen from the enclosed air was absorbed, mercury gradually rose in the tube *b* for many hours.

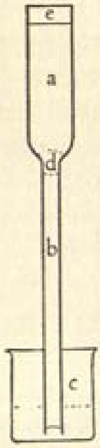


FIG. 2.

All the basalts examined as above, indicated more or less oxygen absorption, doubtless with some slight evolution of heat. Absorption was very large in the case of an "Olivine Basalt" from Jefferson County, Colorado. This basalt, when tested in the large calorimeter of Fig. 1, indicated spurious generation of heat, gradually diminishing from day to day but not ending during the full course of the experiment. This is what prompted investigation of all the basalts and lavas as above. The Lintz basalt (Table II) contained very little Olivine.

When a crushed basalt, ready for use, is ignited in presence of air, its ferrous metasilicate, at least on the surface of its grains, is destroyed by peroxidation.

To surely prevent absorption of oxygen by crushed basalts and minerals containing ferrous metasilicate, the following scheme was adopted: The stem of a very long-stemmed small glass funnel was worked downward through the center of the crushed material in its Dewar jar nearly to the bottom. Then 120 grams of somewhat viscuous mineral oil was poured slowly into the funnel, keeping the latter nearly full to avoid entrained air. In an hour or two the

oil gradually displaced the air between the grains of crushed material and rose nearly to the top of the charge, and in a few hours more, by capillary action, oil coated every grain not actually submerged. After withdrawing the funnel, the hole left by the stem was tamped full of the surrounding material. The oil employed was the "Ponderol" used by druggists for medicinal preparations. It was water-white, perfectly neutral, odorless and tasteless. Heated to 160° C. it did not change color, gave off no gas bubbles and fumed but slightly.

The sand in the other Dewar jar, used for comparison, was flooded in the same way with the same amount of oil to preserve equality in thermal capacity.

None of the lavas tested indicated any absorption of oxygen, and hence were not treated with oil. According to analysis in Encyclopedia Britannica, Kilauea lava contains an unusually large amount of ferrous oxide, but doubtless this is combined with a larger proportion of Silica than in Olivine, and is thus rendered stable.

TABLE II.

Material Tested.	Temperature Excess, degrees C.
Basalt, Lintz, Rhenish Prussia, strongly ignited	.0127
Basalt, Lintz, Rhenish Prussia, with oil	.0155
Lava, Basaltic, Kilauea, Hawaiian Islands	.0115
Lava, "Scoria," Millard Co., Utah	.0100
Lava, "Scoria," Otumba, Mexico	.0127
Clay, Burned	.0136
Albite, Na, Al, Si_2O_8	.0060
Olivine, $(Mg, Fe)_2SiO_4$, with oil	.0084
Wollastonite, Ca, SiO_3	Not observable
Cryolite, Na_3AlF_6	Not observable
Limestone, Ca, CO_3	Not observable
Silica, Fused	Not observable

Table II. shows *comparative* values thus far obtained. The last column gives temperatures computed from galvanometer deflections. Of course the figures in fourth decimal place are uncertain.

Following the above tabulated tests a basalt, containing a fairly large amount of Olivine, from Fort William, north shore of Lake Superior, was tried (with oil). But before completion of the experiment the Dewar jar collapsed. Enough was learned, however,

to indicate that this Olivine basalt was generating little more than one-half as much heat as did the Lintz basalt.

The burned clay of Table II. may be regarded as an artificial igneous rock, and is classed with them. It consisted of a specimen of clay used in the manufacture of Portland cement. After levigation, drying and moderate ignition, it was light yellow in color. After heating an hour or two to about 1100° C. (in presence of air) it came out of the furnace a greatly shrunken, hard-burned, chocolate-colored brick. This was crushed and sifted for use as usual. Table III. is an analysis of this clay before burning. Probably the iron was mostly in the ferrous condition, as is usual with clays, prior to the first ignition.

TABLE III.

Silica	57.63
Alumina	17.95
Iron oxide	5.38
Lime	7.80
Magnesia	4.64
Loss on low ignition	2.90
	96.30

In Fig. 3, the performance of the Lintz basalt of Table II. is plotted in a temperature difference curve. Only that portion of the

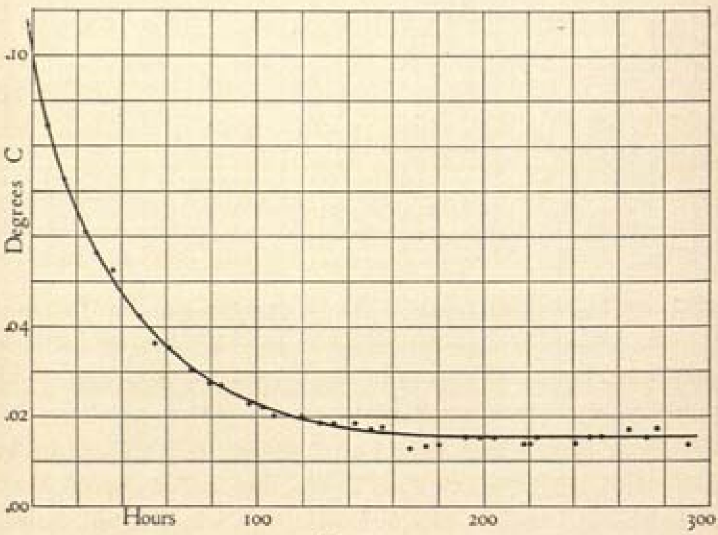


FIG. 3.

observed curve lying below one-tenth degree is shown, as this is the significant part. The neutral sand for comparison is taken as zero. The low points in the curve lying between one hundred and sixty-five and one hundred and eighty-five hours, are due to a temporary small rise of temperature in the "copper well" occurring late in the previous day; and the high points between one hundred and forty and one hundred and sixty hours, and between two hundred and sixty and two hundred and eighty hours are due to small drops in well temperature many hours earlier. There is always a lag of about one half day in the effect of changing well temperature, as is to be expected.

Whenever a substance under test happened to be initially at a little lower temperature than the sand, its temperature curve was, of course, a rising one; and if the substance was generating heat, the curve crossed the zero line and rose above it. Such a curve always had a shape notably different from that of Fig. 3; it was steeper in its earlier stages. This was because heat generation *retarded* falling temperature and *hastened* rising temperature.

Estimate of the Rate of Heat Generation in the Lintz Basalt.

The Dewar jars used in the experiments of Table II. were tested and selected as follows: 8 commercial jars of 1 liter capacity, 28 cm. deep, were partly filled with ice-water to precool them, and placed side by side in a rack. Then each jar was emptied and recharged with 600 cc. of ice-water just after thoroughly stirring with much ice, and the jar was closed with a large cork.

After an hour or so, the water in the first jar was well stirred with a thin strip of wood previously cooled in ice-water, and the temperature of the water in the jar was taken with a precision thermometer and noted, together with the time, and the jar was recorked. All the jars were thus treated in turn. The initial temperature was in most cases about 1° C. Similar temperature readings were made every few hours for several days.

The two best jars, very nearly alike in efficiency, were chosen for use, and their performance was plotted in a curve which showed everywhere that half the temperature difference between the water

and the outside air (very steady) was covered in the next thirty-one and one half hours. I see no reason to doubt that this ratio would have continued until equality was reached. Presumably also, the same ratio would hold if the conditions were reversed; that is, if the water were warmer than the outside air.

The thermal value of the inner skin of a Dewar jar was computed equal to 25 grams water, so that the total warming (or cooling) body equaled 625 grams of water.

From the above data in accordance with the usual logarithmic law of heat transfer, the thermal conductivity constant of the jars was computed and found to be 13.7 calories per hour per degree C.

Nine hundred grams of the basalt maintain a temperature difference of .0155° C. (Table II.) which indicates heat generation at the rate of $.0155 \times 13.7 = 0.212$ calories per hour for the contents of the jar; or $\frac{0.212}{900} = 2.36 \times 10^{-4}$ calories per hour per gram of basalt.

Taking the specific heat of basalt as 0.199, the time required for the basalt to raise its own temperature 1° C. if all escape of heat were prevented would be $\frac{0.199}{2.36 \times 10^{-4}}$ = eight hundred and forty-three hours, or about thirty-five days.

While the above method of estimating the rate of heat generation in the Lintz basalt is the only one at present available, the result found is certainly several times too large, for the following reason: The cylinder of cold water in the Dewar jar had little or no temperature gradient between its periphery and its axis because of its easy convection; but the cylinder of basalt and oil must have been continually much warmer in its axis, where its temperature was measured, than at its periphery where the generated heat was being lost, because of the very slow conduction of heat from its central portion to its outer surface.

Having no available data from which to compute the radial temperature gradient in the basalt and oil, we can only guess at the correction to be applied to the value of heat generation found above. But we cannot be very greatly astray if we assume one hundred and twenty-two days, a third of a year, as the time required for the Lintz

basalt to generate sufficient heat to raise its own temperature 1° C. At least this will indicate the order of magnitude of heat generation.

The Observed Generation of Heat Cannot Possibly be Due to Radio-activity.

Rutherford tabulates a long list of igneous and sedimentary rocks from widely-separated localities, showing their relative radio-activities. Three basalts appear in the list, the most active of which is below the average of all the rocks. I have compared the radio-activity of the Lintz basalt and the sand, with pitch blende and impure uraninite photographically as follows: Several short lengths of thin brass tubing 2 cm. inside diameter, 1.2 cm. long, were prepared with ends machined truly plane. One end of each was coated with a thin film of beeswax, and tightly pressed on a disc of very thin, mineral-free filter paper on a piece of plate glass, thus forming a shallow cup with paper bottom.

The minerals were crushed and sifted to the usual grain size, and 4 grams of each was placed in the cups and shaken down. An X-ray plate in its holder with film side up, was covered with a card-board rack (not in contact) provided with 15 round holes in which the cups fitted freely. The sand and basalt cups were placed on the film side by side, and left there, in different positions, eight, four and two days. The pitchblende and uraninite were exposed twelve, six, three and one and a half hours, all in complete darkness. Then the plate was *very evenly* developed, fixed, washed and dried.

The plate eight days under the basalt showed the faintest suspicion of darkening; the sand showed nothing. The uraninite, exposed one and a half hours, gave well-marked blackening, estimated to be at least 4 times greater than the basalt, exposed 128 times longer (eight days), or 500 times more activity. The pitchblende was rather more than twice as active as the uraninite, the one and a half hours' exposure being a little blacker than the three hours' exposure of uraninite.

Thus it appears that, compared in this way, the pitchblende was at least 1000 times more radio-active than the basalt. The pitch-blende was not analyzed, but presumably contained about two-thirds

its weight of uranium. This would raise the above ratio to 1500 for uranium.

Rutherford computed the heating effect of 1 gram of uranium to be 7.2×10^{-5} calories per hour.

We have already found the apparent heating effect of 1 gram of basalt to be 2.36×10^{-4} calories per hour. But as before pointed out, this is much too high. If we apply the same arbitrary correction as before, we find heating effect of 1 gram of basalt to be 6.8×10^{-5} calories per hour. This is close to the heating effect computed by Rutherford for uranium. And we have found uranium to be 1500 times more radio-active than the basalt. Hence radioactivity of the basalt can account for only 1/1500 part of its heat generation.

The computed rate of heat generation in the Lintz basalt, 3° C. in a year, is extremely large; and it is thought that some or much of it may be due to the very large area of new surface created by crushing, and the severe shocks throughout the grains incident thereto, whereby a slow rearrangement or incipient crystallization and regrouping in the surface layer of molecules and even in the grain mass of this complex rock may occur with some generation of heat, analogous to the spontaneous generation of heat in recently hardened steel. Doubtless basalts and lavas are particularly susceptible to such action because they are in a condition of suspended crystallization arising from their comparatively rapid cooling after ejection.

If the suggested action occurs, several days, weeks, or even months may be required to reach entirely stable condition. This very important point will be determined by retesting after a lapse of several months.

The observed generation of heat is many times more than sufficient to account for the maintenance of the earth's internal heat if the generation goes on at great depths and under great pressures, and if we accept the very small temperature gradient and low thermal conductivity usually assumed for the earth's crust. But we know little or nothing of the temperature gradient in great masses of igneous rocks, and in volcanic regions. In this connection it would be of much interest to make deep borings in some of the great and

very thick fields of basaltic rocks, and ascertain their temperature gradient.

Nor have we any knowledge of the thermal conductivity of the lower igneous rocks (all igneous) of the earth's crust, at the high temperature, and under the great pressure to which they are subjected.

It seems highly probable that large areas of the ocean floors consist of ancient igneous rocks and more recent basalts and volcanic lavas, only thinly covered with sediment. The heat generated in these floor rocks, and conducted through them from still hotter regions below, must be absorbed by the cold water above them and rapidly transferred by convection to the ocean surface, from which much of it is radiated into space and lost.

It seems to me quite possible that the great ocean currents of warm water are produced in this way, and have their origin in comparatively shallow waters over large areas of volcanic activity, where the earth's hot interior is covered with less than the usual thickness of poorly conducting crust.

Take for instance the Gulf Stream: This appears to originate in the large volcanic region comprising the West India Islands and the Caribbean Sea; and the steady current westward doubtless prevents much sedimentation, and even tends to scour and keep the ocean bottom clean. The warmed water finds its way into the Gulf of Mexico, and thence in a comparatively narrow and swift stream northeastward between Florida and the Bahama Islands, whence it spreads fan-shaped into the North Atlantic Ocean. On its way to the Arctic region, the prodigious amount of heat carried, as compared with that of the general ocean, profoundly tempers the climate of Northern Europe. The water returns from the Arctic region in a broad cold stream on the deep floor of the Atlantic Ocean to the region of warming. I hope to develop this phase of my subject at length in a future paper.

Internal Heat of the Planets.

Let us make the reasonable assumptions that the other planets have substantially the same composition as the earth, and that they

have reached stable thermal condition as the earth appears to have done.

The exterior planets receive comparatively little heat from the sun; and if their internal heat is maintained in the manner supposed, their surface temperature must be largely conditioned on the ratio of their mass to their radiating surface. Mars is smaller than the earth, and consequently colder. But the giant planets, Jupiter and Saturn, have a much larger mass-surface ratio than the earth, and certainly have a much higher surface temperature, as evidenced by the fact that they are covered with dense clouds of vapor. Presumably they are too hot to permit the condensation of water.

Heat of the Sun.

The mass-surface ratio of the sun is about 27 times greater than that of the earth; and if generation of heat takes place there at the rate observed here in igneous rocks, it would account for much of the sun's heat, though far from all of it. But we know little or nothing of the sun's interior, and it is readily conceivable that gravitational generation of heat there, under the prevailing conditions of enormous temperature and pressure may be very much faster per unit of mass than in the earth, and could then fully account for maintenance of the sun's heat.

Cleveland, April, 1926.

Supplement.

July 30, 1926.

Since presenting the foregoing paper I have carefully retested the basalt, lavas and clay of Table II., using the same specimens after intervals of several months as contemplated in one of the latter paragraphs of the paper; and as then thought not unlikely, have found some large changes in the rate of heat generation, doubtless due to the causes suggested. This, in itself, is a very interesting phenomenon.

The strongly ignited Lintz basalt after six months retained less than 10 per cent. of its early heat generating activity. This specimen included all the fine stuff and dust incident to crushing, and had

been briefly ignited at very high temperature, almost fusion. The Lintz basalt with oil (not ignited) retained about 30 per cent. of its initial activity after three months. Another lot of Lintz basalt was crushed to very much coarser grain size than formerly, and all small grains and dust were removed by sifting. The coarse material was then maintained at a steady temperature of about 345° C. continuously for a full week, then slowly cooled. It is thought that during this long-continued moderate heating the basalt reached stable condition. Forty days afterward it was placed in the calorimeter and its rate of heat generation measured. This came out 20 per cent. (or a little more) of the value of the freshly crushed basalt and oil as given in Table II. Probably the latter will decline to similar value when it reaches stability.

The Kilauea lava almost completely lost its heat generating property after eight months. This is a basic lava comparatively low in Silica and easily fusible.

The Utah lava retained forty-five per cent. of its freshly crushed activity after nine and a half months.

The Otumba lava retained rather more than fifty per cent. of its activity after seven months.

The two latter lavas were very spongy in structure, and weathered to deep iron-rust color; differing greatly from the Kilauea lava in these respects.

The burned clay, after eight months, retained a little less than thirty per cent. of its freshly burned and crushed activity. This clay was part of a lot prepared about a year ago by washing free from all gritty particles, drying and moderately igniting; not heating sufficiently to sinter or densify it at all.

I have recently tested some more of the clay, in its unburned (but formerly ignited) condition, after nearly a year's exposure to the atmosphere of the laboratory. There can be little doubt that this was in stable condition. It gave nearly three times as rapid heat generation as did the burned clay after eight months. Apparently the burning was highly detrimental. I am preparing for test some more clay from the same bank, washed and air dried, but not ignited.

THE PRESENT STATUS OF THE HITTITE PROBLEM.

By GEORGE A. BARTON.

(*Read April 23, 1926.*)

The Hittite problem became a problem just fifty years ago. Until that time the Hittites were thought to have been only a small Palestinian tribe, knowledge of which was derived from the oft recurring list of peoples whom the Israelites drove out of the Holy Land: "The Canaanite, the Hittite, the Amorite, the Hivite, and the Jebusite." After the decipherment of the Egyptian inscriptions it was learned that Egyptian monarchs of the nineteenth dynasty had relations with a people that they called Kheta. Similarly, when the secret of Assyrian writing had been recovered, it was learned that the Assyrian kings fought a people whom they called Khattu. Gradually, too, during the nineteenth century rock-carvings were found scattered over northern Syria and Asia Minor, on which were pictured men with extremely aquiline noses, wearing boots with up-turned toes and peculiar tall caps, often accompanied by inscriptions in a peculiar hieroglyphic character. In 1876 it occurred to the Reverend A. H. Sayce (afterwards Professor at Oxford) that the Kheta, Khattu, and Hittites were all one and that it was they who made the rock-carvings and inscriptions just mentioned—an inference which subsequent discoveries have in the main justified.

These Hittite rock-carvings have been found at Hamath in Syria, at Carchemish on the Euphrates, at various points in ancient Cappadocia, Lycaonia, and Phrygia, on the Lydian mountains west of ancient Sardis, as well as in the mountains near Smyrna. They have been found at Marash, Sendjirli, and at other points, including the city of Asshur. Beginning with the attempt of Professor Sayce in 1880 to decipher this hieroglyphic Hittite writing, eight different attempts [1] have been made to discover the clue to it, but as yet that has not been successfully accomplished.

[1] These attempts are as follows: A. H. Sayce: "The Boss of Tarkendemos" in the *Trans. of the Soc. of Bib'l. Arch.*, VII, 248 f.; E. F. Peiser, "Die hetitischen

With the discovery at El-Amarna in Egypt of an archive of clay tablets written in the Babylonian cuneiform script in the winter of 1887–1888 a new approach to the Hittite problem was opened, although it was not recognized at the time. Among the tablets in this archive there were several letters from Dushratta, a king of the Mitanni, a people closely associated with the Hittites, to kings of Egypt. While most of these were written in the Semitic Akkadian, one of them—the longest letter of all—was written in the Mitannian language.[2] Two other letters of the collection were from a ruler of Azarwa,[3] and were written in a tongue that turns out to be identical with the Hittite. Some years later an archive of Assyrian tablets was found a few miles to the northeast of the ancient Cæsarea in Cappadocia, from which it was learned that as early as 2200–2300 B.C. the Assyrians had established trading stations or colonies in the country afterward occupied by the Hittites and that these colonies maintained correspondence with their home country in the Assyrian language and the Babylonian script—a fact which now throws some light on our Hittite problem.

The real key to the Hittite problem was, however, discovered by the late Professor Hugo Winckler of Berlin, who in 1906 discovered at Boghaz Koi, the old Hittite capital, situated a few miles east of the river Halys in Asia Minor and about two-thirds of the distance from the Mediterranean to the Black Sea, a large archive of tablets written in the cuneiform script of Babylonia. A number of these texts were in the Sumerian and Akkadian languages—the languages of Babylonia—but the majority were in the language of the Hittites

Inschriften, ein Versuch ihrer Entzifferung nebst einer weiterer Studien vorarbeitenden methodisch geordneten Ausgabe," 1892; P. Jensen, "Grundlagen für Entzifferung der (hatischen oder) cilischen(?) Inschriften," in *Zeit. der deutsch. Morganlanden Gesell.*, XLVIII, 1894, and *Hetititer und Armenier*, 1898; C. R. Conder, *The Hittites and their Language*, 1898; A. H. Sayce, "The Decipherment of the Hittite Inscriptions," in the *Proceedings of the Society of Biblical Archæology*, XXV, (1903); R. C. Thompson, "A New Decipherment of the Hittite Hieroglyphs," in *Archæologia*, XX, (1913); A. E. Cowley in *The Hittites* (The Schweich Lectures for 1920); and Dr. Carl Frank, *Die sogenannten hettitischen Hieroglypheninschriften*, Leipzig, 1923. The different ways of attacking the problem are outlined in the writer's *Archæology and the Bible*, 4th ed., p. 75 ff.

[2] Cf. F. Bork, *Die Mitannisprache*, Berlin, 1909.

[3] Cf. Knudtzon, Bugge, und Torp, *Die zwei Azarwa-Briefe, die alteste Urkunden in indogermanischer Sprache*, Leipzig, 1902.

themselves. On some of the tablets were lists of Hittite words in one column, opposite to which in other columns were their Sumerian and Akkadian equivalents. Here, then, was a key to the long-lost Hittite tongue. The lock did not, however, yield immediately to the touch of the key. This was due in part to the fact that Professor Winckler, to whom by right of discovery the privilege of interpreting the tablets belonged, was soon attacked by the long and distressing illness from which he died; also, in part, to the broken and fragmentary condition of these Hittite vocabularies, and to the fact that the words contained on the remaining fragments of these ancient dictionaries were not the words in most common use in the other tablets.

After the death of Professor Winckler the task of editing the cuneiform tablets from Boghaz Koi was committed to two Assyriologists, the Bohemian scholar Friedrich Hrozny, and the German, H. H. Figulla. They had copied a considerable number of the texts and were making progress toward the interpretation of them when the Great War broke out in 1914. The credit of having first successfully applied the key found by Professor Winckler to the Hittite language belongs to Professor Hrozny. Taking as his starting point the work done on the Azarwa letters by Knodtzon, Bugge, and Torp, he gradually disentangled the intricacies of the Hittite language. This, as a skilled Assyriologist he was able to do, in part because the script was derived from Babylonians, or from people who had derived their culture from Babylonia, the texts contained many well known Sumerian and Akkadian words. The Hittites used these words just as the peoples of western Europe often employed Latin phrases. In duplicate texts the thought is often expressed by a Hittite word, so that one by comparison can obtain the nucleus of a reliable vocabulary. In No. 56 of the *Mitteilungen der deutschen Orient-Gesellschaft* (December, 1915) he announced that Hittite belonged to the Indo-European family of languages. This was followed in 1917 by the publication of his "*Die Sprache der Hethiter*," in which convincing proof of the thesis was set forth.

In demonstrating the Indo-European groundwork of the Hittite language, Hrozny but confirmed a shrewd guess of Professor Jensen,

made more than twenty years earlier. In some respects Hrozny's work was open to criticism. He is a Semitic philologist and has not a broad training in Indo-European philology. Under the circumstances it was inevitable that his pioneer work should contain some mistakes. What pioneer work does not? In the main, however, Hrozny's work stands, and to him belongs the credit of having broken the pathway for other workers in the field. Other scholars have since joined in the labor. Otto Weber, E. F. Weidener, E. Forrer, and H. Ehelof have participated in the publication of texts, while E. Forrer, Johannes Friedrich, A. Götze, and Ferdinand Sommer, the eminent philologist, have participated in the labor of explaining the facts of the language and in the interpretation of texts. The Orient-Gesellschaft has published six volumes of cuneiform texts from Boghaz Koi, the Berlin Museum, fifteen, and the British Museum, one. The Hittite laws and a number of chronicles and religious texts have been interpreted, and the literature grows apace. More recently the study has been taken up by some American Scholars, as Professor R. J. Kellogg of Ottawa University, Kansas, Professor Sturdyvant of Yale, and the present writer with his pupil, Dr. E. A. Speiser.

It should be noted that the tablets and fragments found at Boghaz Koi numbered about ten thousand, but many of these were broken so that often what was a single tablet has become five, ten, and in some instances twenty fragments. The original archive contained between five hundred and a thousand documents. These were chronicles, treaties, stories, letters, incantations and other religious texts. These texts were written during the supremacy of the great dynasty founded by Shubbiluliuma, which reigned at Hattushash, or Hittite City, on the site of Boghaz Koi from about 1400 to 1200 B.C. In these tablets there is material written in eight different languages, as follows:

1. There are examples of the Sumerian language of ancient Babylonia, in which so much of the thought of the early inhabitants of that country has been expressed.

2. There are chronicles, stories and treaties in the Akkadian, or Semitic dialect of the Babylonians, and phrases from both the Sumerian and Akkadian besprinkle texts in the other languages.

3. The great body of the material is in the language spoken by this ruling dynasty at Hattushash, which we call Hittite, but which they called "Kanish." Of this language more will be said below. Proof will there be offered that the structure of this language is Indo-European.

4. A number of quotations—about 700 words altogether—are said to be in the Luvish or Luyyish language. There is one bi-lingual text, Luvish and Kanish. The tablets containing Luvish are much broken, however, and many of the lines are incomplete. Luvish seems, nevertheless, to have been an Indo-European dialect closely akin to Kanish. The verb-endings were the same as in Kanish; it made a middle-passive form in *ari* like Kanish. Thus we have in Luvish *vashantari*, "to come" or "be brought." It also appears from the Hittite laws that the Luvish people were so closely akin to the Hittites that they were accorded privileges similar to those enjoyed by the Hittites themselves.[4]

5. In eighteen places in the Kanish texts proverbs are quoted in a language which is called *hat-ti-li* or Hittite. Scholars have agreed to call this language Proto-Hittite. From the examples which we have, it is clear that Proto-Hittite was not an Indo-European language. The facts seem to indicate that people of the Indo-European stock had conquered a non-Indo-European people called Hittite and were, at the time from which the Boghaz Koi tablets come, ruling them: that the name Kanish belonged to the ruling, Indo-European stock, while the name Hittite belonged to the subject, non-Indo-European stock.

6. Twelve quotations in these texts—about 3500 lines in all—are said to be in the Hurri language. The linguistic phenomena presented in this Hurri material show that the Hurri dialect was closely akin to, if not identical with the language of the Mitanni in which Dushratta, king of the Mitanni wrote to a king of Egypt one of the letters of the El-Amarna collection. These dialects are not members of the Indo-European family, but, as Bork[5] has shown, are apparently related to the Caucasian group of tongues.

7. Four or five examples of a language which is called "Balish"

[4] See the Code §§ 5, 19, 20, 21 in the writer's *Archæology and the Bible*, 4th ed., pp. 369, 370.

[5] *Die Mitannisprache*, passim; cf. especially pp. 72–82.

are also found in the texts from Boghaz Koi. They consist of Proverbs and are given both in Balish and Kanish, or what we call Hittite. A number of words in Balish are identical with words in Luvish and Kanish. It seems impossible at present to determine whether these words have been borrowed or whether Balish may also be an Indo-European dialect.

8. Finally in four tablets we find bits of the Manda language. It is found in connection with a people called Kikkuli from the land of Mitanni who appear to have been dealers in horses and horse-trainers. Six or seven hundred years later, in the time of Esarhaddon of Assyria, a people called by the same name, Manda, overran the region between the two rivers, where, at the date of the Boghaz Koi tablets, the Mitanni lived. Fifty years later they came again, and Herodotus calls them Scythians.

In view of the fact that a number of these languages belong to a different linguistic stock than the Kanish, and that this is the case with Proto-Hittite itself, it may well be that the hieroglyphic Hittite mentioned above, which still defies our attempts to decipher it, may prove to contain material in a non-Indo-European tongue.

Of all these dialects we are especially interested in the Kanish, which we are accustomed to call Hittite. To that we now turn. A study of the forms of its pronouns, nouns and verbs shows that in structure it is related to the Indo-European group of languages. The word-material, on the other hand, appears to be of non-Indo-European origin to a greater degree than is the case in most of the languages of that group.

As pronouns are as a rule the most *sui generis* parts of speech and are least likely to be borrowed, we begin with a few examples of pronouns. The relative pronoun with which we may compare the Latin is as follows:

Hittite.	Latin
N. kuis (neut. kuit)	N. qui
G. kuēl	G. cujus
D. kuēdani	D. cui
A. kuin, (kuit)	A. quem
Ab. kuēz	Ab. quo

Plural.

N. kuyēs or kuēs; kui or kuye	N. qui
G. kuēl	G. quorum
D. kuēdas	D. quibus
A. kuyus, kue	A. quos
	Ab. quibus

Indefinite Pronoun.

Hittite: kiski	Latin: quisque

Of the personal pronoun we submit a somewhat wider comparison, as follows:

PERSONAL PRONOUNS.

First Person.

	Sanskrit.	*Avestan.*	*Greek.*	*Hittite.*	*Latin.*
N.	ahám	az^{e}m	ἐγώ	ūg	ego
A.	mā́m, mā	mąm, mā	ἐμέ. μέ	ammug mu	mē
I.	máyā				
D.	máyam, me	māv^{o}ya, mē	ἐμοί. μοί	ammug mu	mihi mī
Ab.	mát	mat		ammēdaz	mē
G.	máma, me	mana, mē	ἐμοῦ. μοῦ	ammel	meī
L.	máyi			ammug mu	
	Pl.	Pl.	Pl.	Pl.	Pl.
N.	vayám	vaēm	ἡμεῖς	uēs	nōs
A.	asmā́n, nas	ahma, nō	ἡμᾶς	anzās	nōs
I.	asmā́bhis				
D.	asmábhyam, nas	ahma^{i}byā, nō	ἡμῖν	anzās	nōbis
Ab.	asmát	ahmaṭ		anzedas	nōbis
G.	asmā́kam, nas	ahmāk^{e}m, nō	ἡμῶν	anzēl	{nostrūm / nostri}
L.	asmā́su			anzās	

Second Person.

N.	tvám	tūm, tū	σύ	zig	tū
A.	tvā́m, tvā	thwąm, thwā	σέ	tug	tē
I.	tváyā	thwā			
D.	túbhyam, te	ta^{i}byā, tē	σοί	tug	tibi
Ab.	tvát	thwaṭ		tuedaz	tē
G.	táva, te	tava, tē	σοῦ	tuēl	tuī
L.	Tváyi			tug	
	Pl.	Pl.	Pl.	Pl.	Pl.
N.	yūyám	yūž^{e}m	ὑμεῖς	sumēs	vōs
A.	yuṣmā́n, vas	vō	ὑμᾶς	sumēs	vōs

I.	yuṣmā́bhis				
D.	yuṣmábhyam, vas	ḫšmāvᵃya or yūšmaoyō	ὑμῖν	sumās	vōbīs
Ab.	yuṣmát	yūšmaṭ		sumedaz	vōbīs
G.	yusmā́kam, vas	yusmakam, vō	ὑμῶν	sumēl	{vestrūm, vestri}
L.	yuṣmā́su			sumās	

Of nouns we submit as examples of Hittite declension, declensions of *antuḫsas*, 'man', Gr. ἄνθρωπος;[6] *watar*, 'water,' Ger. 'wasser;' *paḫḫar*, 'fire,' Gr. πῦρ; *tēkan*, 'earth,' Gr. χθών (?).

"Man."	"Water."	"Fire."	"Earth."
N. antuḫsas	N. watar	N. paḫḫar	N. tēkan
G. antuḫsas	G. wetenas	G. paḫḫuenas	G. taknas
D. antuḫsi	D. weteni	D. paḫḫueni	D. takni
A. antuḫsan	A. wātar	A. paḫḫar	A. tēkni
Ab. [antuḫsaz]		Ab. paḫḫuenaz	Ab. taknaz
I. [antuḫsit]	I. wetenit	I. [paḫḫuenit]	I. taknit

Plural

N. antuḫses	N. witār		N. takān
G. antuḫsas			G. taknās
A. antuḫsus	A. witār		D. taknās
			A. takān
			Ab. taknāz
			I. taknit

Similar declensions of other nouns could be presented. It is evident, however, that the examples presented are Indo-European both in word-material, in the number and nature of the cases, as well as in the case endings.

As examples of the conjugation of verbs we select the following stems: *es-* 'be' (cf. Latin *esse*); *dā(i)-* 'set,' 'place' (cf. Skr. *dhā-*, Gr. τίθημι); *dā-* 'take' (cf. Lat. *do*(?), Gr. δίδωμι(?)); *ep-* 'take'; *pa-*, *pi-* 'give'; *oḫ-* 'see' (cf. Gr. ὄψ, Lat. oculus).

[6] A comparison of É. Boisacq's *Dictionnaire étymologique de la langue grecque*, p. 63 will show that the connection between *antuḫsas* and ἄνθρωπος is much closer than appears on the surface.

	"Bee."	"Set."	"Take."	"Take."	"Give."	"See."
				Present		
				Singular		
1.	esmi	teḫḫi	daḫḫi	epmi	peḫḫi	ūḫḫi
2.	———	daitti	datti	epsi	paitti	autti
3.	eszi	dāi	dāi	epzi	pāi	aūszi
				Plural		
1.	esueni	tiyaueni	———	ebbueni	pēyaueni	aummeni
2.	esteni	———	datteni	epteni	pēsteni	autteni
3.	asanzi	tiyanzi	dānzi	abbanzi	peyanzi	———
				Preterite		
				Singular		
1.	esun	teḫḫun	daḫḫun	ebbun	peḫḫun	ūḫḫun
2.	esti (-ta)	———	———	epti (-ta)	paisti	———
3.	esta	dāis	dās	epta	pais	aūsta
				Plural		
1.	esuēn	———	———	ebbuēn	peyauēn	aummēn
2.	estēn	———	———	epten	pesten	———
3.	esir	tiēir	dāir	ebbir	peyer	auir
				Imperative		
				Singular		
2.	es	dai	da	ep	pāi	au
3.	esdu	———	dau (daddu)	ebtu	pāu	ausdu
				Plural		
2.	estēn	daistēn	———	ebtēn	pēstēn	———
3.	asandu	tiyandu	dāndu	abbandu	pēyandu	austen
				Part.		
	asanza			abbanza	peyanza	
				Infinitive		
	———				peyauvar	auwas
				Supine		
	essuwanzi			ebbuvan(zi)	peyauvan(zi)	

Such paradigns could be multiplied. In addition to such forms as are given it should be noted that the Kanish or Hittite forms a passive or middle stem by the use of the letter *r*. This feature it shares with the Latin and Celtic languages, the only members of the Indo-European family in which this phenomenon was previously known. Thus, from pa- 'go' we have *pa-an-ta-ri-it* 'were driven' (KBo, V, No. 6, i, 28); *pa-an-ga-ri-it*,' were brought' (KBo, V, Y, ii, 1); *is-du-wa-ri-a*, 'to be left over' (KUB, XIII, No. 4, iv, 46, 47, and 66). (The last stem appears to be the same as that of the Gr. *ἵσταμι*,

the Lat. *sto*, Skr. *tiṣṭhati*, Zd., *hista'ti*, which appears also in nouns: Lat. *status*, Skr. *sthita-ḥ*, Zd. *stāta-* [7]). Latin examples of this passive in *r*, such as *amari*, 'to be loved,' and *audiri*, 'to be heard' will occur to every one. Examples of passive formations in *r* in Celtic are the following from the Irish: *carthir*, 'I am cleansed' (root *carth-*); *gaibir*, 'I am taken' (root *gaib-*); *benir*, 'I am smitten' (root *ben-*); *berir*, 'I am boiled' (root *ber-*).[8]

In view of these phenomena and such as these there can be no doubt but that the later Hittite language of Boghaz Koi, which they called Kanish, belongs, in its main grammatical structure, to the Indo-European family of languages, although these phenomena present a number of difficult problems to which attention will be called in a moment. When we come to the vocabulary we are confronted by a great mixture. The word-stuff is to a considerable degree of non-Indo-European origin, and at times we are confronted with the use of postpositions instead of prepositions. While this non-Indo-European element is very real, it would be easy to overrate its importance. The writer's belief from his own studies is that ultimately it will be recognized that a much larger part of the vocabulary is of Indo-European origin than is now supposed.

The place of Hittite or Kanish in the Indo-European family is not easy to determine. Some phenomena (especially parts of the vocabulary) speak for a fairly close relationship with the Aryan branch of the family. Many more features seem to indicate a tolerably close relationship to the Greek; while, as we have noted, the formation of the passives presents a feature shared by Latin and the Celtic dialects only. The Hittite tenses also raise a difficult question. So far as we can see Kanish possessed but two tenses, a present and a preterite, while the other leading members of the Indo-European family possess six or seven. In Hittite we possess our earliest dated Indo-European material. It had previously been supposed that the further back we go in time the more closely we should find the Indo-European languages resembling one another, but the phenomena presented by Hittite upset all our theories.

[7] The Sanskrit and Zend forms are quoted on the authority of Boissacq. The identity of the stem *is-du-* with the Indo-European stem *sta-* was first suggested by Dr. E. A. Speiser.

[8] These examples are taken from Padersen's *Vergleichende Grammatik der keltischen Sprachen*.

It has been suggested by two scholars [9] that Hittite or Kanish was the first to split from off the Indo-European group, and that it is not so much a sister language of the other members of that group as a cousin. There is much to be said for this view. It is well known that in the Semitic and Hamitic languages there are but two tenses, one denoting incomplete action, employed to express actions in present and future time; the other completed action, used to express what happened in past time. There are not wanting indications that the tense-systems of the Indo-European tongues may have been developed from a similar beginning. In Greek, for example, the tenses denote not so much time as the kind of action, the present and imperfect signifying action in progress—moving on as in a line; the aorist that movement occurred at some moment—a point of time; the perfect expressing completed action. From the phenomena of Hittite it would seem that we are justified in assuming that here we have the survival of an early stage of the development of Indo-European speech, when as yet the tense-system was at the same stage of development as that preserved in the Semitic and Hamitic languages.

It is too early for much attention to have been given to Hittite syntax, but, when it is studied, it will be found to present features familiar in other Indo-European dialects. Just one example will be noted here—the Hittite method of expressing a condition contrary to fact in past time. In the treaty of Mursilis, king of Hittite-city (Hattushash), with Kupantakal of Myra we find the following, (Col. i, line 63 ff. Cf. KBo. V, no. 13, line 20): *[ma]-a-an tak-kan* BET A-BI-KA MAT-KA-*ya* U-UL *ar-ḫa da-a-ir ma-na-at [d]a-mi-e-da-ni ku-e-da-ni-ik-ki pe-i-e-ir* A-NA MAT-TI *ma-an da-ma-a-i-in ku-in-ki* BEL-*an i-ya-nu-un:* "If they had not deprived the house of thy father of thy country or given it to some other, I would have made some other lord over the country." This sentence corresponds in structure almost exactly to the structure of the Greek supposition in past time contrary to fact. The Greek expresses the protasis by the particle εἰ and a past tense of the verb; the apodosis a past tense with the particle ἄν. Hittite expresses the protasis by a past tense introduced by *mān takkan* (*takkan* being the Hittite equivalent

[9] Forrer and Sturdyvant.

of the Greek εἰ) and the apodosis by the past tense and the particle *mān* (the equivalent of the Greek ἄν). The one difference is that the Hittite employs the particle *man* (ἄν) in both clauses.

We have left ourselves no space in which to speak further of the underlying ethnic type revealed in Hittite portraits—a type which we find extending from Asia Minor to Assyria with a branch extending to Palestine—and which the Boghaz Koi texts teach us was of non-Indo-European and of non-Semitic stock. Overrun in the Hittite country by Indo-Europeans, and in Assyria and Palestine by conquering Semites, partly Indo-Europeanized in the one country and quite Semitized in the others, this race imposed its facial type and somatic peculiarities upon all three peoples. It is often called in consequence the "Semitic" type, but that was originally more nearly identical with the Hamitic. All this is, however, another story, which the writer hopes to treat elsewhere.

THE AZTECS AND THEIR PREDECESSORS IN THE VALLEY OF MEXICO.

By ZELIA NUTTALL.

(Read April 24, 1926.)

The discovery and study of the extremely ancient pre-Aztec remains of clay vessels and fragments of figurines of an archaic type found buried in the soil under the vast lava bed that occupies an area of many miles at the southern extremity of the Valley of Mexico, are of recent date.

It is true that, as far back as 1861, (in a footnote on page 67 of his work on the Popol Vuh) the French Abbé Brasseur de Bourbourg wrote: "A singular proof of the existence of ancient towns buried under lava is found in the Pedregal. . . . A wide stream issues from under the lava, its waters rolling fragments of pottery and terra-cotta vessels which undoubtedly proceed from habitations buried under the lava. How many Pompeiis and Herculaneums the lavas of Mexican volcanoes may have covered!" In Paris, at the Trocadero Museum, a small collection of clay heads labelled "of the archaic type" and proceeding from a hill near Tacuba have, it appears, been on exhibition since 1881. They seem, however, to have been overlooked by Mexican archæologists and, as far as can be ascertained no publication has been made concerning them. My first acquaintance with clay heads of the archaic type dates from shortly after my purchase, in 1902, of property so close to the lava field that a portion of this extends into my orchard.

On a walk past a quarry close by where lava was being extracted, to be used as building material, I noticed some children playing with small clay heads which they allowed me to examine and buy, for my interest was great on observing how different they were from the familiar Aztec type of clay figurines. Although I then asked the workmen to let me know when, on blasting and removing rock, they came across other specimens, years elapsed before they brought me

more than some potsherds found under the lava. In 1906 however one complete seated figurine and several heads came to light and thus I gradually became familiarized with an archæological type of which no specimens were then on exhibition at the National Museum.

In 1909 during a short stay in Cuernavaca I called on my esteemed and learned friend the late Bishop Plancarte, who showed me his splendid archæological collection. It was a thrilling experience for us both when, on seeing in a case a group of archaic clay heads which he had collected in the states of Morelos, Guerrero, Hidalgo and Mexico, I expressed joyful surprise and told him that I had come across the same strange type in Coyoacan. Independently we had both come to the same conclusion, namely that our specimens antedated any Aztec remains. Before long the Bishop paid me a memorable visit and I had the pleasure of showing him my specimens and then conducting him to the quarry to see the exact spot from which the latest finds had been extracted. In his book entitled "Tamoanchan," published in 1911, the kindly old bishop describes his pleasure at having his opinion that the type was pre-Aztec so unexpectedly confirmed by my specimens. He also tells of our agreement to inform each other of any new finds we might make and how, in 1910 I reported that I had come across figurines and heads, identical with those in our respective collections, in Panuco, near Tampico.

During the celebration of the Centenary of the Independence of Mexico, in 1910, several of my American colleagues were my house guests and to them I showed my specimens, telling them of Bishop Plancartes' and my researches and our plan to issue our publications on the subject simultaneously. Mine never was completed for, in March 1911, I left Mexico expecting to be absent from my home for a couple of months, but remaining away for six years and a half on account of the unsettled conditions that prevailed. During this interval, however, the International School of Archæology was organized in Mexico and the first systematic stratigraphical investigations of the sub-soil of the Valley of Mexico was excellently made by Drs. Boas, Tozzer and Gamio who carried out fruitful researches at Teotihuacan and with Dr. Spinden, found and identified the same

archaic type near Atzcapotzalco and vicinity under strata containing vestiges of other cultures.

Mr. Niven, who, during several years made excavations in the same region, found and sold many specimens derived from these different strata but, by inventing names of by-gone civilizations and attributing, arbitrarily, the various types to these, he and his associates have impeded the advancement of scientific truth. Previous to my return to Mexico, in 1917, Señor Gamio had discovered, by tunnelling under a twenty-foot-deep stratum of lava at the quarry of Copilco, three burials which he carefully left *in situ*. The skeletons (the skulls of which are of a comparatively modern Indian type) are imbedded in sandy soil, baked hard by the heat of the lava-flow and are surrounded by clay vessels of a plain coarse type. A great quantity of potsherds and fragments of figurines of the archaic type were also found at Copilco, which is situated at a distance of about two miles from my property. I had often felt the wish to excavate under the portion of lava bed in my own orchard and about two years ago, asked Señor Gamio to aid me in doing so, by supplying me with two of his workmen trained in archæological work. It thus came about that under the auspices of the Department of Anthropology and with the collaboration of the estimable geologist Señor Diaz Lozano, excavations were made to the depth of 17 feet under the lava on my property, the result being the discovery of an ancient river bed. Immediately under the lava was a layer of hard baked sand in which were extremely friable scattered human remains, seemingly pertaining to persons who had met their death by drowning.

Under alternating strata of sand and gravel and "pockets" of the latter, at a depth of between 15 and 17 feet there is a uniform stratum of coarse gravel containing quantities of much water-worn and discolored potsherds among which I found two archaic figurines and fragments of flaked obsidian with a dull surface and a patina which unquestionably indicate a great antiquity.

On making a deep excavation at the end of my garden, at a distance of about 250 feet from the orchard, we found the same river-bed and, at the same depth, the identical layer of gravel containing potsherds and obsidian fragments.

This river-bed, yielding mute testimony of the extremely ancient and prolonged occupation of this valley by a race which made and used great quantities of pottery is of particular interest to me because in 1910 near Atzcapotzalco, at a distance of at least 25 miles from Coyoacan I had found, at the same depth, waterworn pottery and figurines under a gravel bed. The figurines, of which I subsequently showed screen illustrations during a lecture I gave in Washington, are of a peculiar type which recalls that associated with the prehistoric finds in Michoacan. The specimens I and two friends found *in situ* in the gravel pit were all of the same type, a fact that led me to name this "the sub-gravel type." Within a few weeks Mr. C. C. James, an Englishman and collector, reported to me that about two miles further north than the old gravel pit, on making a 16-foot-deep trench in a dry river-bed, he had found my sub-gravel type in a similar stratum but mixed with others of the familiar archaic type.

There is another remarkable type which I have only found in a limited area which is covered with a deep stratum of "Tepetate," a kind of pumice which when falling in showers during the volcanic eruption must have converted day into night. I have reserved for the last a mention of what I consider the most important discovery that has ever been made in Mexico and possibly in America, namely the cone-shaped, three-storied structure at Cuicuilco, for the uncovering of which we owe a debt of gratitude to Dean Cummings of the University of Arizona. His publications on this archaic monument, in which there is not a single worked stone and whose foundations lie twenty-five feet deeper than the lava flow that surrounded it, are familiar to you. There is however a point concerning it to which I would like to particularly draw your attention. The visiting and local geologists whom I have taken to Cuicuilco and consulted there about the sandy deposits on the terraces and summit of the structure have been unanimous in conjecturing that it must have been submerged for a prolonged period, and that it must have been surrounded by water when the molten stream of lava flowed around it, for nowhere did the latter come in direct contact with the stones that face the sloping walls. It has been suggested that possibly owing to a great volcanic disturbance some body of water situated in the vast upland plains or in the crater of one of the volcanoes of the

Ajusco or Toluca range may have emptied itself into the Valley of Mexico which forms a basin, the only outlet of which lies to its north, towards the Valley of Teotilmacan.

A convincing proof that this valley had undergone a vast inundation after it had been inhabited for countless centuries came to light when, a few years ago, Señor Gamio had a tunnel made running from the eastern side of the great pyramid of the Sun to its center. This revealed that the entire structure is artificial, consisting of sun-baked clay containing enormous quantities of potsherds.

It is therefore evident that the recent, and therefore not generally known discoveries of gravel deposits containing potsherds situated under deep accumulations of sand and under the Pedregal or under a stratum of clay at Atzcapotzalco (two localities that lie twenty miles apart) of alluvial deposits on the terraces and summit of the Cuicuilco monument and of great quantities of potsherds in the clay of which the pyramid of the Sun is constructed furnish proof that the region of the Valley of Mexico which, according to our foremost botanists, is the home of the teozintle, the native grass from which maize was developed by cultivation, had been inhabited for countless centuries by a race of people who had practiced the art of making pottery, of flaking obsidian, of cultivating the most valuable of food plants and had built the archaic structure at Cuicuilco.

These discoveries demonstrate that the various ancient myths and traditions were founded on terrible realities when they tell of a succession of cataclysms that overtook the ancestors of the native race. The first was a flood from which only few survivors escaped, who in order to insure their safety in case of a recurrence of the same disaster, built, of mud, a great artificial hill on which the entire population could take refuge and escape drowning. The lava flow that surrounds the Cuicuilco structure, covers the ancient river bed on my property and the burials at Copilco and spreads over an area of many miles, as well as the adjoining deposits of "tepetate" prove that after an interval which, according to native tradition, lasted for several thousand years, the Valley of Mexico became a center of great volcanic activity. It is obvious that after the first cataclysm, small bands of survivors must have abandoned the cradle of their

civilization; migrated northwards and southwards; founded settlement after settlement during their search for a region as fertile as their ancient homeland and spread their culture and the cultivation of maize among the more primitive tribes they may have encountered.

Their successors in the Valley of Mexico seem to have been the Otomis who increased and multiplied until, at the time of the arrival of the Aztecs, they were in occupation of the region.

We have the authoritative statement of Dr. Daniel G. Brinton, in his introduction to the Maya Chronicles, that "the Mayas and Aztecs, though differing radically in language, had legends which claimed a community of origin in some indefinitely remote past." He tells us also that "it cannot be denied that the Mayas, the Kiches and the Cakchiquels, in their most venerable traditions, claimed to have migrated from the north or west, from some part of the present country of Mexico."

I have the permission of Señor Manuel Gamio to mention here that during his expedition to Guatemala he recently found there, between 14° and 15° N., even at a depth of six feet, archaic figurines and potsherds exactly similar to those buried under the lava in the Valley of Mexico. He and other archæologists also report that, in the same region, there are truncated conical structures, obviously more ancient than those of pyramidal form, which recall the archaic Cuicuilco truncated cone.

These proofs of a prolonged occupation by the archaic poeple, of precisely this belt in Guatemala, is particularly interesting because they substantiate certain facts I am going to submit at the meeting of the International Congress of Americanists in Rome, next September, which indicate that in this region the 260-day period, named the Tonalamatl, which forms the basis of the Maya and Mexican Calendar systems, was a natural division of time that cannot have been unobserved by its ancient inhabitants.

History seems to have repeated itself, for after a prolonged residence therein, the archaic people were evidently forced to migrate owing probably to volcanic disturbances and to a scarcity of food products caused by the plagues of grasshoppers which have periodically recurred in Guatemala, Chiapas and Southern Mexico from time immemorial. The present one has lasted two years. Notwith-

standing the energetic campaign, led by experts, that has been made by the Mexican Government to exterminate these destructive insects, their northward advance has not been arrested and they are now devastating the States of Veracruz and Oaxaca, reducing their productiveness to less than one half. It was in the region situated between 16° and 18° N., occupied by the Maya Kiches, who never claimed to be autochthonous, that, at some remote period a branch of the once archaic people, carrying with them their 260-day period, established themselves. It seems to have been in the region containing the great ruined metropoli such as Copan, Quirigua and Palenque that a conventionalized set of ideas evolved or was introduced. Communal life was evidently organized on a large scale and a ruling caste was instituted with a taste for building great monuments and erecting, periodically, carved stelæ which entailed an infinite amount of labor by a submissive population.

The Toltec culture hero and his small band of celibate followers who appeared in the high plateau of Mexico at an era corresponding to the third century of the Christian era and were also great builders, may well have been members of the ruling caste in search of a fertile region suitable for colonization.

Communication, by land, between tribes living in widely separated portions of the Continent seems to have been more constant than has been supposed. There can be no doubt that for many centuries there was inter-communication between the peninsula of Yucatan and Panuco, near Tampico, by boats keeping close to the coast.

Ancient Aztec traditions record how, at a very remote period, Huastecas under a leader named Huastecatl landed at Tampico and settled there, founding a colony that was densely populated at the time of the Conquest. Their dialect is closely akin to that of the Tzendals of Tabasco, the nearest Maya race to the south of them. The landing at Panuco of another band of colonists, the Olmecas, under their leader Olmecatl is also somewhat obscurely recorded and these are believed to have proceeded to Cholula and Teotihuacan and settled there.

That from ancient times there was a trade route from Panuco to Teotihuacan is indicated by the fact, stated by the governor of

Teotihuacan in 1580, that the cotton the Indians used for clothing came from the region of Panuco.

It was at this same place, which, being situated well in the mouth of a great river, afforded a safe landing place and harbor, that the Toltec culture hero Quetzalcoatl arrived and re-embarked, his subsequent return to Chichen-Itza being a matter of history. For many years I shared my esteemed friend Dr. Brinton's view that the Toltecs were a mythical people. Now I am inclined to believe, especially as Sahagun was told by his native informants that they were the first inhabitants of this country, that they were descendants of the ancient maize-growing, pottery-making people who were well-nigh destroyed by volcanic disturbances in the cradle of their civilization, and that they returned to this as colonizers countless centuries later, bearing with them the highest degree of aboriginal culture that was reached and which they had attained during centuries of residence in favorable surroundings.

They spoke the Nahuatl or Aztec language, which is a treasure house of knowledge, for it contains thousands of descriptive names of the natural products and plants of Mexico and Central America. Sahagun states that the Nahuas who spoke the Nahuatl tongue most clearly were the Chichimecs who claimed to descend from the Toltecs.

According to the native historian Ixtlilxochitl, the Chichimecs descended from a lord named Chichen, but a Friar Andrés, quoted by Chavero relates that, having often spoken with the Indians of Panuco and Tampico and inquired about their origin, they told him that they had originally come from a city named Chichen. The Mexican element in the art and architecture of Chichen-Itza has been clearly demonstrated by Drs. Morley and Spinden; so has the Maya element in the columns found at Tula, the first colony founded by the Toltec colonists. The influence of Maya art is also discernible in the so-called temple of Quetzalcoatl at Teotihuacan the facade of which is decorated with full-face great masks of Tlaloc and projecting serpent's heads. In recent lectures given at the leading Mexican scientific societies I presented data which seem to establish that this remarkable structure, which has water symbolism and marine shells carved all over it, is none other but the temple, recorded as " most

beautiful" which was erected by the fifth Toltec king Mitl, eleven centuries ago, in honor of the goddess of water.

After an era of great prosperity which lasted for centuries, the Toltec state succumbed to what appears to have been great volcanic disturbances which brought about violent climatic changes and finally a drought that, according to Ixtlilxochitl, lasted twenty-five years. Obliged to undertake foraging expeditions in order to obtain food, the Toltecs resorted to violence and warfare and after having suffered from famine and pestilence were vanquished by their enemies, forced to abandon their capital and, dividing into small bands, migrated, some going south, returning to Tabasco, Yucatan and Guatemala, or going as far as Nicaragua where, to this day, there are towns bearing Aztec names.

Later on, in the Valley of Mexico a new center of culture arose and under the poet-king Nezahualcoyotl, a descendent of the Toltecs, science and the arts flourished and the beautiful Aztec language reached its highest perfection. By that time, however, the Aztecs had arrived in the Vâlley of Mexico from the North bringing with them a proof of their originally southern and Toltec ancestry, namely the Nahuatl language and the Tonalamatl or 260-day period. Although they recognized Teotihuacan as the "matrice of cities" or metropolis, the Aztec name for which is given as Totecuacan in Molina's dictionary, they did not establish their capital there, but regarded it as the great religious center to which, up to the time of the Conquest, Montezuma and the Aztec priesthood resorted every twenty days.

Bearing in mind the fate of their predecessors the Aztecs evidently sensibly chose an island in the lagoon as their future residence and thus insured for themselves facilities for the cultivation of food plants, and independence from any drought that might occur on the mainland.

All evidence seems to indicate that the Aztecs also came from the region of Panuco and were related to the Huastecs from whose name theirs may possibly have been derived, as the latter may well have been Hue-azteca or "the ancient Aztecas." The most important testimony that has been preserved concerning the origin of the Aztec

rulers is the statement made by Montezuma to Cortes, as recorded by Cervantes de Salazar who was a personal friend of Cortes. The following is a translation of Montezuma's words which convey his sincere conviction, to which he sacrificed himself and his country:

> . . . I regard you not only as friends but also as very near relatives, for my father told me and I also heard his father say so, that our ancestor and the kings from whom I descend, were not natives of this country but immigrants who came with a great lord who, shortly after, returned to his native land. As they were the most powerful they assumed the rulership of this country which was of the Otomis. At the end of many years this great lord returned for them but they did not want to return to the land they came from, having married here and having children and authority, which made them like this country and enjoy the place, which were certainly strong reasons in their defence. That lord left, much discontented with them and, before his departure told them that he would send his sons to govern and maintain them in peace and justice and in the ancient laws and religions of their forefathers and that, if they did not submit willingly they would be compelled to do so by force of arms. For this reason we have always believed and expected that some day those from those regions would come to subjugate and rule us. Therefore I believe that you are they, on account of the direction you came from and the fact that your great lord and emperor who sent you had remembrance of us.

Montezuma's admission that he was a descendant of men who, to the indignation of their leader, had married native women and had children by them, reveals that for generations his forefathers had been of a mixed race. This explains certain incongruities discernible in their civilization which, in 1864, led the eminent German anthropologist to state: "The Aztecs seem to have been the last offspring or heir of an extremely ancient and admirable civilization which it had no share in creating or developing and only imperfectly assimilated. In its hands the ancient culture was rapidly deteriorating and becoming mixed with barbaric elements."

In conclusion: Recent archæological discoveries in the Valley of Mexico reveal that in remote antiquity this portion of the high plateau which is the home of the teozintle, was inhabited for a very long period by a race which had attained a degree of primitive civilization, made pottery, modelled figurines, employed flaked obsidian knives and built a truncated conical structure faced with unworked stone which was surrounded by a lava flow at a period that geologists estimate from 2,000 to 5,000 years ago. Driven from their

habitat some of the survivors of the cataclysm or their descendants seem to have migrated southward and to have established themselves in Guatemala where between 14° and 15°, archaic structures, figurines and pottery identical with those of the Valley of Mexico have been found, also plain stelæ. This region, in turn, seems to have been occupied for an extremely long time and the 260-day period of the Maya and Mexican Calendar naturally originated there.

As this was also a volcanic region, subjected to periodical devastation by the invasions of grasshoppers entailing loss of crops, famine and pestilence, history evidently repeated itself and migrations occurred, obviously northward and, in time, the descendants of the archaic people who had carried maize to Central America[1] drifted back to the high plateau of Mexico, bringing with them the Tonalamatl or 260-day period that originated in Guatemala. The foregoing data, substantiated by the facts I shall submit to the International Congress of Americanists that is to meet in Rome next September throw fresh light on the connection between the Maya and Aztec people and establish, I venture to believe, the unity of their culture and common origin.

[1] One of the intriguing mysteries of the New World, which baffles botanists, is that while the teozintle is recognized as the ancestor of maize none of the intermediate stages between maize and its relatives have been found.

An explanation of this hiatus is forthcoming if it is assumed that during thousands of years the food plant was cultivated by a sedentary people in a limited area until maize was developed. The region became uninhabitable and was abandoned for centuries. The intermediate types perished or reverted to the hardy primitive one which alone was fitted to thrive without cultivation.

Survivors from the cataclysm forced to migrate, became wandering agriculturists whose existence depended upon the quantity and quality of the seed their crops produced, a fact which would lead to the utmost care being used in its cultivation with a resulting, ever increasing and rapid improvement of the stock. The history of the development of maize is inseparable from the history of the origin and development of civilization on the American Continent, and there can be no doubt that the recent archæological discoveries made in the Valley of Mexico have thrown unexpected and new light upon both problems.

ON THE STRUCTURE OF *PALÆASPIS* AND ON THE OCCURRENCE IN THE UNITED STATES OF FOSSIL FISHES BELONGING TO THE FAMILY PTERASPIDÆ.

By WILLIAM L. BRYANT.

(*Read April 24, 1926.*)

The family Pteraspidæ includes a very ancient group of so-called Ostracoderms belonging to the order Heterostraci. Amongst them are the oldest true fishes yet discovered in which are preserved indications of sense organs and viscera. Three genera are known, *Pteraspis, Cyathaspis,* and *Palæaspis;* one of these, *Cyathaspis,* being represented by various species from the Lower Ludlow of England, the Wenlock Limestone of the Island of Gothland, the upper Silurian of Galicia, from rocks supposed to be of Niagaran age of New Brunswick, and as I shall presently show from the Silurian of New York State.

The Pteraspidæ survived till lower Devonian times and thus during most of their career were contemporaneous with the ancient monorhinal Anaspids and Cephalaspids whose systematic position is now rather well understood from studies upon the remarkable fauna of the Christiana area in Norway.

The recent works of Johan Kaier upon the Downtonian Fishes of Norway, and of Stensiö upon the cranium of the primitive Arthrodire, *Macropitalichthys,* have gone a long way towards clearing up the prevailing confusion as to the relationships between groups of primitive fishes, which had resulted in almost as many schemes of classification as there were authors.

Kaier[1] having demonstarted that the families of the Anaspidæ and Cephalaspidæ have little in common with the other so-called Ostracoderms, proposes to include them together with the Cyclostomata in a single great branch or class which he terms the Monorhina.

[1] "The Downtonian Fauna of Norway: I. Anaspida," J. Kaier, Videnskap. Skrifter. I. Mat.-Naturv. Klasse, 1924, No. 6.

He considers that the most important difference between cyclostomes and fishes is the peculiarity that in the former the paired olfactory nerves run into the hypophysial sac which thereupon functions as an unpaired nasal sac, while in all higher Craniata from the fishes upward they constantly end in paired nasal sacs.

He thus revives Haeckel's old scheme of classification; while the rest of the Ostracoderms with paired nasal sacs including the Cœlopidæ, the Psammosteidæ, the Pteraspidæ and the Drepanaspidæ, he places as true fishes with the Diplorhina, believing that they belong to the same ancestral stem from which the Elasmobranchs were derived.

The discovery of well-developed jaws in the Anaspidæ shows, according to Kaier, that the presence or absense of these elements can no longer be regarded as of fundamental importance in the classification of these highly specialized forms and he therefore argues that the Class Agntha of Dean and Woodward should be abondoned.

The late Dr. Traquair had previously shown the structural affinities of the Pteraspids and their allies with the primitive, soft bodied Cœlolepidæ, and had long ago expressed the opinion that all of these forms must have been derived from the Elasmobranchs.

Stensiö while doubting that the agnathous Ostracoderms are related either to Elasmobranchs or to the Arthrodira has recently shown that an ossified skeleton probably existed in the ancestral Elasmobranchs which has gradually disappeared in their descendants.[2]

His more recent studies on the sensory canal system in Pteraspids[3] seem to have convinced Stensiö that these so-called Ostracoderms are closely related to the Cyclostomes, a conclusion with which I cannot agree in view of the apparently well developed semicircular canals, the reduction of the branchial apparatus, which whether or not it was developed in the form of gill pouches never consists of more than seven on each side; and most of all on account of the olfactory organs which are apparently developed as in true fishes. It is quite true, however, that these ancient creatures as might be ex-

[2] "On the Head of the Macropitalichthyids," E. A. Stensiö. *Field Mus. of Nat. Hist. Geolog. Series*, Vol. IV., No. 4, 1925.

[3] "On the Sensory Canals of *Pteraspis* and *Palaæaspis*," E. A. Stensiö, *Arkiv För Zoologi utgivet av K. Svenska Vetenskapsakademien*, Band 18 a, No. 19, Stockholm, 1926.

pected have retained many primitive features, including a sensory canal system that can be best compared with the Cyclostomes; although in many respects similar to that in fishes.

It must be admitted that the Ostracoderms are such highly specialized creatures and had even in Silurian times diverged so far from their ancestral stock that their origin is exceedingly difficult to trace.

Pteraspis, the typical but most highly specialized genus of the family Pteraspidæ is found only in Great Britain and in Northern and Central Europe. It includes the largest known forms and the only one in which the scales of the anterior caudal region have been preserved.

Palæaspis, the only genus of Pteraspids hitherto recognized in the United States, was first discovered many years ago by Claypole in the Salina of Pennsylvania. The genus is known abroad by a single species from the Lower Old Red Sandstone of Monmouthshire.

The material upon which this paper is based consists of a large number of fossil fishes from Pennsylvania, mostly collected by the late Gilbert van Ingen of Princeton University and preserved in its Museum; a collection from New York State also made by Professor van Ingen and now belonging to Princeton University; and a number of specimens from New York State belonging to the New York State Museum.

The Pennsylvania collections all come from within the limits of a great formation of red and purplish shales and sandstones to which the name of Bloomsburg Red Shale has been given. It probably is equal to, in part at least, the Vernon Red Shale of New York State Salina, and it certainly falls within the limits of the Salinan series. The lower part of this series is apt to be developed as a heavy sandstone, well seen in the vicinity of Bridgeport, Perry County, Pennsylvania, and therefore called Bridgeport Sandstone by Claypole in his "Report on the Geology of Perry County."

The middle portion forming by far the larger part of the formation is red shale; sometimes with thin seams of sandstone, but usually a thick section of rather incoherent bright red shales that easily weather to a sticky mud.

The upper part of the formation consists of alternating beds of

red shales with thin seams of yellowish limestone which increase in thickness and purity until, toward the top of the formation, they become gray limestone with intercallated thin beds of red shale.

The formation is succeeded conformably by a series of gray limestones containing Leperditia of two or three species, which Professor van Ingen thought should be correlated with part of the Tonoloway Limestone of Maryland.

It is toward the upper half of the formation that the Palæaspid beds are found. They are met with in a number of outcroppings in various localities in Perry County and it is probable that several of the occurences are of exactly the same horizon. There is, however, one section on the Scheible farm one mile east of Alinda, Perry County which establishes the fact that Palæaspid remains occur in three distinct horizons. The lowest of these is followed by 1,238 feet of shale before the second horizon is reached; while 452 feet above the latter is seen the highest horizon. This highest bed is about 1,100 feet below the Tonoloway Limestone as seen in a nearby quarry.

Fossils belonging to the family Pteraspidæ have been found at only one other locality in the United States. This is at Guymard, southwest of Otisville, Orange County, New York. Here the Erie Railway passes through a deep cut showing a complete section of the Shawangunk Grit at about one mile west of Otisville.

After passing through the cut which is at right angles to the strata which strike N. E. and dip about 30° to 35° N. W., the railway curves to the southwest and runs approximately along the strike of the beds for several miles as it descends the slope of the Shawangunk Mountain past Guymard and on to Port Jervis. It has a somewhat undulating course which is due to the topography, now cutting back into the mountain side, and now running out around a hump on the slope. These prominences are caused by the exposures of a quartzite of gray, olive and reddish colors, that lies above the Shawangunk Grit. This formation is considerably over 100 feet in thickness. It was named by Professor van Ingen the Guymard Quartzite because of its excellent exposures in this vicinity.

Toward the upper part of the Quartzite there are some thin beds of red shale that seem to be prophetic of the type of sediments so characteristic of the overlying Longwood shale. It is in fact difficult

to determine just where the limit between the Guymard Quartzite and the overlying Longwood should be drawn. The Longwood seems to be the equivalent of the High Falls to the north and the Bloomsburg of Pennsylvania to the South.

In these lowermost beds of red shale there occur remains of two species of *Cyathaspis* which I propose to describe in this paper.

The above account of the stratigraphy of the New York and Pennsylvania Palæaspid beds was furnished to me by Professor van Ingen in 1920, a few years before his lamented demise and was based upon his own field notes, and personal investigations.

That Cyathaspids occur in even earlier rocks near Otisville is rendered probable by the discovery of fragmentary shields in the thin black layers of shale in the upper portion of the Shawangunk grit.

There is some doubt as to the age of this formation which carries an abundant Eurypterid fauna. Considered by Schuchert and others as of Medina age the discovery of Eurypterids in the Shawangunk was taken by Clarke and Hartnagel as evidence that it really belonged in the Salina. The later discovery of Eurypterids in lower formations again raised doubts as to the age of the Shawangunk. The presence of *Arthrophycus* in this formation gives considerable weight to the theory that it should be included with the Medina, and this is the view adopted by Schuchert.

Dr. Hartnagel now feels that "in a sense this is probably the correct interpretation although it is quite likely that the formation represents a transgressing shore line and that therefore the *Arthrophycus* as well as the sediments may rise in the series and consequently not be of the same age everywhere."[4]

The fragmentary shields from the Shawangunk to which I above refer as being probably those of Cyathaspids were figured by the late Dr. John M. Clarke in his account of the Eurypterid fauna of that formation.[5] These fragments were considered by Dr. Clarke to be parts of Phyllocarids of a type hitherto unknown, but to me they seem almost certainly to belong to Palæaspids. The resemblance not only in form but in ornamentation to the anterior portions of

[4] Letter to the author, March 22, 1926.

[5] "The Eurypterid Shales of the Shawangunk Mountains in Eastern New York," *New York State Museum Bulletin* 107. p. 309: Plate 8, Figs. 14–21.

Cyathaspid shields is sufficiently striking to warrant a reëxamination of the specimens and if possible the preparation of thin sections which would at once settle the question.[6]

Palæaspis Americana Claypole.

A large number of specimens of this species collected by Professor van Ingen are preserved in the Museum of Princeton University. They appear to have been pretty well distributed through the Bloomsburg shale as a number of different horizons are indicated by the labels. Due to the permeable nature of these shales many of the specimens are only moulds or casts, the actual integument having been dissolved away; but there are some in which the shields are in part exceedingly well preserved and show perfectly the details of the ornamentation so suggestive of the markings on the epidermis of one's hand and fingers.

As Claypole has well described not only the superficial ornamentation but the microscopic structure of the shield which is characteristic of the family,[7] I shall only remark that the gracefully disposed whorls of ornamentation are really flat-topped placoid scales of vasodentine fused into meandering ridges. It is probable that the lines of ornamentation of the shield, more tortuous in front than behind, have some relation to the disposition of the sensory canals and pit organs. The superficial character of this ornamentation is well shown on Plate I., Fig. 1.

So far as I have been able to ascertain, there are only two elements in the armor of *Palæaspis*—a dorsal and ventral shield. I have seen no indications either of a distinct rostral, or of the postero-lateral plates which Claypole described. It is possible that lateral plates may occur and that in adult specimens they may be so firmly fused as to obliterate the sutures, but I have not been able to make them out in any of the numerous specimens which have come to my notice and I must accordingly doubt their existence; first, because there is

[6] Dr. Ruedemann informs me that the specimens in question have been lost and he suggests that they may possibly have come from the same beds in which were found the Cyathaspids, as is indicated by Clarke's note that "they have been found only in the gray shale lying at the top of the grit and black shale series."

[7] *American Naturalist*, Vol. 18, p. 1224.

no indication of them in the disposition of the lines of ornamentation, and second, because in both *Pteraspis* and *Cyathaspis* the laterai plates have their origin far forward in the vicinity of the orbits and not at all as Claypole showed in his figure.

The dorsal shield of *Palæaspis Americana* is sub-oval in form and gently arched, the tip of the rostrum slightly depressed. The orbits are located well forward, near the angle of the snout. Their position is indicated by rounded notches in the shield which is depressed on either side of the orbit. A series of curved parallel ridges follows the contour of the eye on the dorsal shield. Between the orbits and the tip of the depressed beak is another pair of less conspicuous notches which probably marks the position of the nasal openings. In one specimen I at least believe I have seen the impressions of the cartilaginous nasal sacs.

The location of the pineal body well behind the orbits can be determined by a median elevation on the outer surface of well preserved shields, but there is no perforation.

Behind the pineal a pair of >-shaped pits may be seen on the inner surface of the shield, which have been correctly interpreted by Woodward and others as the impressions of ridges upon the auditory capsules. These markings are well shown in Fig. 1 of Plate III.

We are thus enabled to infer from the widely separated orbits and nasal sacs, that the forebrain of these fishes was much better developed than in the monorhinal Cyclostomes; while the rigid roof over the hind brain and the prominences above the semicircular canals indicate a rather well developed neurocranium posteriorly. The pineal although strongly developed did not perforate the head shield and, therefore, could not have functioned as a median eye.

On either side of the visceral surface of the dorsal shield there is a series of six or seven parrallel elongated impressions originating near the margins and directed obliquely postero-laterally. The first pair of these extends from just behind the orbits nearly to the pineal. There can be no reasonable doubt that these impressions indicate the location of the gill pouches. There are seven of these on each side. They may be seen in the specimen shown in Plate III., Fig. 1, as well as in that illustrated in Plate I., Fig. 1, where the shield has

been broken away exposing a natural mould from the visceral surface. Just within the margin of this mould may be seen a further series of small round pits, each marking the termination of one of the gill pouches. I can only surmise that these represent the openings of the gill sacs into a common branchial duct beneath the shield. There is, however, no indication of a lateral foramen in the shield of *Palæaspis* such as occurs in *Pteraspis*.

I can find no traces of sensory canals on the external surface of the shield. These may have opened through minute pores into the fine grooves between the ridges which cover the outer surface and as may be seen by the section (Plate I., Fig. 2) of a *Cyathaspis* shield which they agree with in this respect, these grooves are nearly roofed over by projecting arms of the ridges.

Two specimens, however, have come under my observation which are suggestive in this respect.

In one of these, Plate III., Fig. 1, which is a natural mould of the inner surface of the shield a pair of ridges symetrically disposed arise near the pineal pit and running forward and outwards terminate at the margin of the shield just in front of the orbits. These unquestionably indicate the location and direction of the supra-orbital canals together with part of the pineal line of the lateral sense organs. As there are no indications of sensory canals in the middle vascular layer of the shield I imagine that the sensory canals must have traversed the basal lamellae. This supposition is strengthened by another specimen seen on Plate IV., Fig. 3. This is the visceral aspect of a fragmentary shield, on which are shown as surface stains a number of branching double canals, these stains having apparently filtered through the inner layer of the shield. The entire dorsal sensory canal system in *Palæaspis* has recently been explained in an excellent paper by Stensiö and hence need not be further treated here.[8]

The ventral shield is oval and slightly emarginate in front while the ornamentation consists of fine, sub-parallel longitudinal lines. I am not certain whether or not the ventral shield formed the lower border of the orbits, although I have so indicated it in my restoration of *P. bitruncata*.

[8] "On the Sensory Canals of *Pteraspis* and *Palæaspis*," op. cit.

I have seen no certain indications that would point to a squamation of the caudal portion of the fish, nor any fin rays. There is no spine attached to the posterior end of the dorsal shield as in *Pteraspis*. There are, however, associated in the same beds with the Palæaspid remains and sometimes closely adjacent to them, small detached spines of similar structure and ornament, which I suggest may have been located in the mid-line of the back of the fish just behind the dorsal shield. They would then have corresponded to the enlarged fulcral scales which one sees in the perhaps nearly related but later Drepanaspidæ. I have figured on Plate II., Figs. 2 and 4, two of these spines but I do not know to which of the two species of *Palæaspis* they pertain.

Palæaspis Bitruncata Claypole.

Claypole did not fail to perceive a second species of Palæaspid in the Bloomsburg Shale. Unfortunately in his published figure he incorrectly oriented the dorsal shield which is shown upside down. This fact and the imperfection of his specimens may have misled Woodward, Eastman and others into the later supposition that it

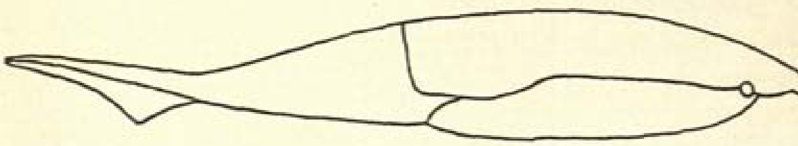


Fig. 1. *Palæaspis bitruncata* Claypole. Restoration of lateral aspect. The tail is hypothetical.

was the ventral shield of *Palæaspis americana:* while Patten[9] who published a restored drawing from a cast of the neural surface of the dorsal shield of this species, suggests that it may have been the male form of *P. americana*. As I have never seen any indications of sexual variations in the body form either in the Ostracoderms or in the Antiarchi I cannot agree with this interpretation. Neither have I observed the lateral wings or cornua which his figures show. Figure 1 is a hypothetical restoration of this more slender species.

I have figured on Plate II., Fig. 3, a mould of the inner (neural)

[9] "Evolution of the Vertebrates and their Kin," Philadelphia, 1912, p. 365, Fig. 244 *B*.

surface of the dorsal shield of this form. The plate is crushed or folded longitudinally nearly at the median line but shows well a profile of this species, including the depressed snout, the truncated hinder end and the lateral contour. The pineal, orbital notches, and the hypothetical semi-circular canal pits are preserved in this specimen though not well shown in the photograph, and hence there is no doubt that the specimen represents the dorsal shield. It will be seen that there are no indications of lateral plates and that the flanks of the shield deepen posteriorly. On Plate III., Figs. 3 and 5 I have figured the ornamentation of the snout region which appears to be somewhat finer, with less complicated whorls, while the ridges are not so flat and are more widely separated.

The orbits are located at the angle of the only slightly rounded snout. Their position is indicated in Plate III., Fig. 4, which shows as well the pineal and the >-shaped notches.

The impressions of the branchial pouches are well shown in a somewhat weathered natural mould from the inner surface of a dorsal shield of this species figured in Plate III., Fig. 2. There are apparently seven of these on each side.

The collections of Princeton University contain several slabs upon which may be seen groups of individuals of both of the above species, all oriented in the same direction as though so disposed by the action of tide or stream.

The presence of *Lingula* in these deposits as well as the association of *Cyathaspis* in the Otisville formation with the remains of Eurypterids and of *Arthrophycus* militate against the assumption that these fishes are fresh water forms. The Eurypterids in both the Bertie waterline and the Pittsford Shale are now known to be associated with typically marine organisms. In the latter formation I have found trilobites and brachiopods in the same beds with the Eurypterids, and Ruedemann has recently described a new marine fauna from the waterline with many delicate forms which can hardly have been transported thither according to the theories of O'Connell and Grabau.

CYATHASPIS WARDELLI RUEDEMANN.

1916. *Anatifopsis wardelli* Ruedemann. New York State Museum Bulletin 189, p. 102: Plate 32, Figs. 1–12.

Some years ago Mr. H. C. Wardell, while collecting Eurypterids for the New York State Museum, secured a number of peculiar fragmentary fossils from the shaly layers interbedded with Guymard

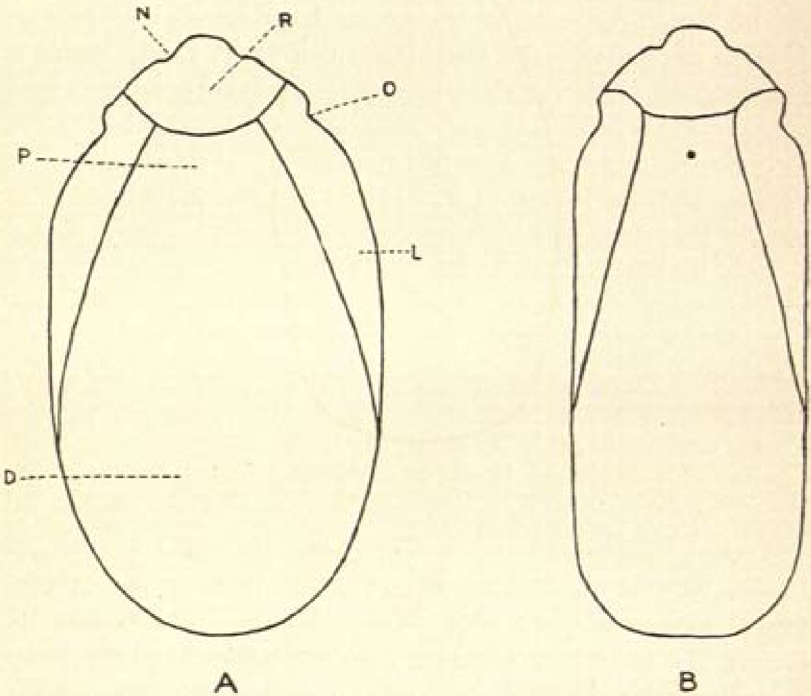


FIG. 2. Outline of dorsal shield of (*A*) *Cyathaspis wardelli* Ruedemann; (*B*) *Cyathaspis van ingeni* Bryant; *D*, Central disc, or median dorsal; *L*, lateral cornua; *N*, narial opening; *O*, orbit; *P*, pineal; *R*, rostral plate. The heads are shown as though crushed flat.

Quartzite not far below the Longwood shales. These were studied by Ruedemann who suggested that they might be the shells of a palæozoic barnacle and accordingly placed them in Barrande's genus *Anatifopsis* as a cirriped crustacean.

Later feeling that these fossils might after all pertain to Ostracoderms he sent specimens to me for examination with the result that

a thin section of the plates immediately established the fact that they belonged to the Heterostraci. Afterwards Professor van Ingen visited the locality and collected a number of better preserved specimens which show that we have here the Pteraspidian genus *Cyathaspis,* represented by two species.

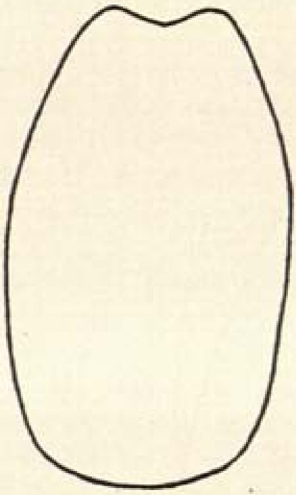


FIG. 3. *Cyathaspis wardelli* Ruedemann. Outline of ventral shield. From a nearly perfect specimen in the Museum of Princeton University.

Unlike *Palæaspis,* the dermal armature consists of five plates, Figs. 2, 3. On the dorsal surface there is a large central disk flanked on each side by a lateral plate or cornua; while the snout is covered by a short azygous rostral plate not hollow as in *Pteraspis.* A single large ventral plate is loosely articulated with the laterals. In the European species traces of a short median spine have been observed at the posterior end of the central disc.

Cyathaspis wardelli, Plate II., Figs. 5, 6; Plate IV., Fig. 1, is a small oval form averaging less than 30 mm. in length. Its body is wide, the snout slightly depressed, the dorsal shield gently arched from side to side. The prominent orbits are further emphasized by the superficial striæ of the shield and the notches for them are contained within the lateral plates. The rostral, Plate IV., Fig. 1, is short and rounded in front with a slight depression at the beak, on either side of which are gently rounded eminences in which the nasal

openings may have been located. It is limited entirely to the dorsal side and not produced below to form a hollow cone as in *Pteraspis.* The hinder contour of the rostral is demarcated by a well-defined suture and by the direction of the superficial striæ which run transversely parallel to the curving suture line.

The pineal body is situated behind the eyes and at a median point well within the central disc. The paired >-shaped furrows on the inner surface of the shield referred to in my description of *Palæaspis* as indications of vertical semi-circular canals are also conspicuous in well-preserved specimens, *i.e.*, Plate II., Fig. 6. Seven gill pouches on each side may be counted in one specimen belonging to the Princeton Museum. There seems to be no postero-median spine on the central disc.

The lateral plates are articulated by firm sutures to the rostral in front and to the central disc on the side. They are widest in front and gradually taper behind as the curved sides approach the straight suture line. They do not extend so far back as in European species.

The ornamentation of the lateral plates consists of sub-parallel anastomosing lines which curve around the orbits and gradually straighten out behind until they run regularly fore and aft. On the central disc the ornament is somewhat involved in front but runs into more or less longitudinal striæ behind, some of which diverge towards the outer posterior extremities of the shield. The minute structure of the superficial ornament of this species is well shown on Plate I., Fig. 2, where the ridges are seen to be flat-topped or T-shaped denticles of vasodentine fused into meandering lines. Only the outer and middle layers of the shield appear in this illustration, the inner laminated layer having been broken away.

The ventral shield (Fig. 3) is oval, slightly emarginated in front which suggests that the mouth must have been situated close beyond. The ornamentation consists of nearly straight parallel lines running fore and aft.

Some of the foregoing elements are easily recognized in Ruedemann's plate;[10] where Fig. 4 is the emarginate front of a ventral shield. Fig. 6 shows a crushed dorsal shield with the right orbit preserved. In the original specimen the right lateral suture can be

[10] Op. cit. Plate 32, Figs. 4, 6, 7, 11, 12.

easily discerned although not well shown in Ruedemann's figure. The original of Fig. 7 is apparently a detached lateral plate of the left side broken off behind the orbit and figured upside down. Figs. 11 and 12 show the cancellated middle layer of the shield.

I have seen no indications of sensory canals on any of the specimens, nor have any caudal scales or spines been discovered so far as I know. The tail in all of these forms is unknown but as Schmallhausen has pointed out on purely mechanical grounds, there is every reason to suppose that it was heterocercal.

Cyathaspis van ingeni Sp. Nov.

A hitherto unnoticed species of *Cyathaspis* occurs in the Guymard Quartzite near Otisville, New York for which I propose the above name in memory of the late Professor Gilbert van Ingen of Princeton University who contributed much to our knowledge of the Palæozoic formations in Pennsylvania and who made the collections upon which these studies are based.

The body form of *Cyathaspis van ingeni* (Fig. 2, *B*); is long and slender the width of the dorsal shield being contained nearly two and a half times in the length, which averages about 30 mm. Seen in profile (Plate II., Fig. 1), the shield is greatly arched longitudinally, while the snout bends sharply downward. It is rather narrow in front with a slightly depressed beak. The orbits are prominent as rounded notches in the laterals and are placed well back behind the rostrum. The rear end of the shield is rounded.

The lateral plates do not extend much more than half way along the central disc being received in an excavation of the latter, which is vase-shaped, the posterior portion of the central plate widening to continue the line of the outer border of the laterals.

The rostral is short, its posterior suture line being easily distinguished in well-preserved specimens. (Plate IV., Fig. 2.) It articulates with the central disc as well as with the front ends of the laterals. The suture lines between the central disc and the laterals are easily visible in front but are more completely fused behind, so that they are difficult to make out. The ornamentation is closely similar to that of *C. wardelli*.

The ventral shield is long and somewhat arched. It is narrow and emarginate in front, widening out behind. In one specimen a large portion of what may be a lateral plate is firmly fused to the margin of the ventral plate and bends sharply upwards. This element may, however, simply be an upturned fold of the ventral plate and this seems the more probable because there is no visible eye notch as should be seen in a lateral plate. No evidences of appendages or caudal squamation can be found in any of the rock in which the fossils are contained.

When first found, the remains of the Pteraspidæ were described as the internal shells of some cephalopod related to *Sepia*. Later they were considered by Roemer to be crustaceans, by some they were compared with fossil sponges, while even recently as I have shown they have been mistaken both for Phyllocarids and for cirriped barnacles.

Obscure and difficult to interpret as are the fossils here discussed, we have another striking instance of the surprising migrations in Siluric times of such lowly and rapidly evolving creatures as these primitive chordates. Loaded with unwieldy and cumbersome armor, they yet managed to distribute themselves over thousands of miles from one continental border to another, altering but little their specific characters. They were succeeded in Upper Devonian times by even more specialized relatives, the flounder-shaped *Drepanaspis* and *Phyllolepis*; and as Hussakof and I pointed out some years ago,[11] the latter of these typically European genera is now known in New York State by a few fragmentary remains from the Portage group.

EXPLANATION OF PLATE I.

FIG. 1. *Palæaspis americana* Claypole. Forepart of the dorsal shield showing snout, orbital notches and superficial ornamentation. The right side of the shield has been broken away, exposing a natural mould from its visceral surface. This shows impressions of gill pouches, apparently with outlets into a chamber beneath the shield. ×3. Bloomsburg shale, Perry County, Pa.

FIG. 2. *Cyathaspis wardelli* Ruedemann. Photomicrograph of the middle and superficial layers of the shield. The inner lamellar layer has been broken away and does not appear in the illustration. The rows of flattened tubercules of vasodentine with their overhanging tops are well shown. Guymard Quartzite beds, near Otisville, N. Y.

[11] *Bulletin*, Buffalo Society of Natural Sciences, Volume XII. Catalog of Fossil Fishes in the Museum of Buffalo Society of Natural Sciences.

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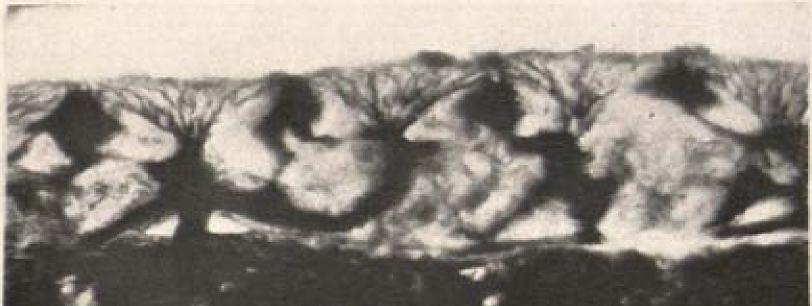

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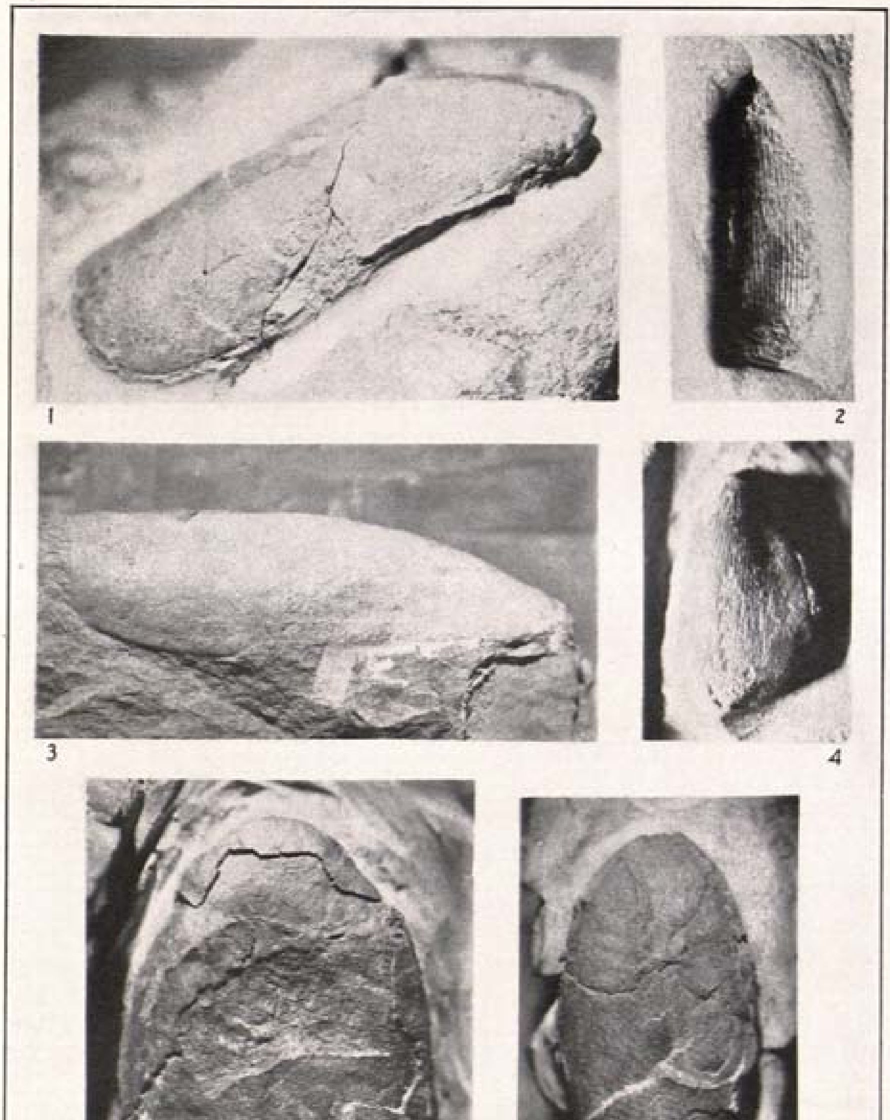
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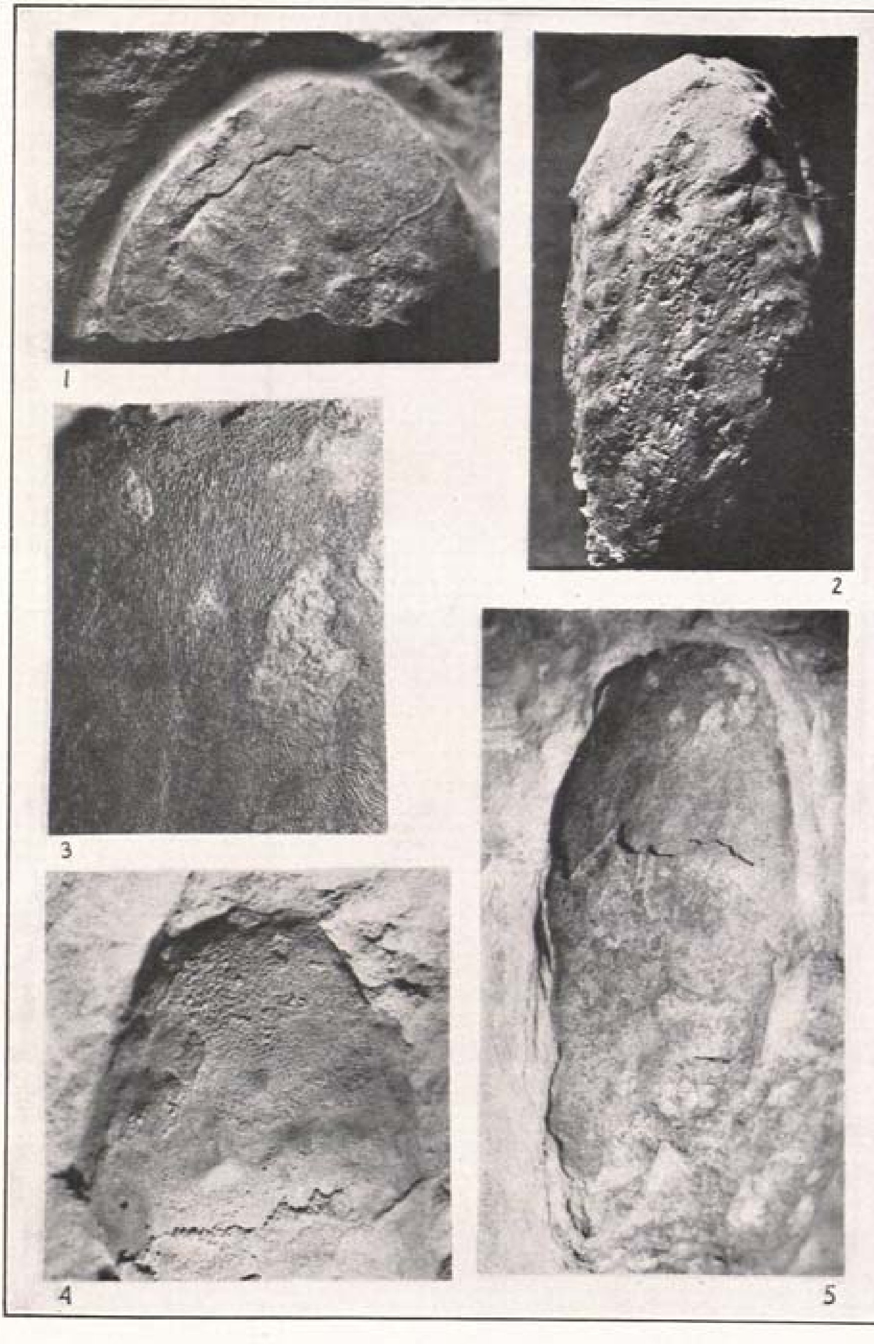
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EXPLANATION OF PLATE II.

FIG. 1. *Cyathaspis van ingeni*, spec. nov. Complete dorsal shield in side view and showing the right orbital notch. The ornamentation is mostly worn away. × 2½. Guymard Quartzite beds, near Otisville, N. Y.

FIGS. 2 AND 4. *Palæaspis, sp.* Detached spines. Perhaps from the mid-dorsal region behind the shield. × 3. Bloomsburg shale, Perry County, Pa.

FIG. 3. *Palæaspis bitruncata* Claypole. Complete dorsal shield preserved as a natural mould of the visceral surface. The orbital notches, pineal pit and impressions of semi-circular canal ridges are preserved in this specimen, although not well shown in side view. × 1. Bloomsburg shale, Perry County, Pa.

FIG. 5. *Cyathaspis wardelli* Ruedemann. Uncrushed specimen lacking the posterior end, and seen in dorsal aspect. Much of the shield has been destroyed. × 3. Guymard Quartzite beds, near Otisville, N. Y.

FIG. 6. *Cyathaspis wardelli* Ruedemann. Visceral mould from complete dorsal shield showing its uncrushed contours. × 2. Guymard Quartzite beds, near Otisville, N. Y.

EXPLANATION OF PLATE III.

FIG. 1. *Palæaspis americana* Claypole. Fore part of dorsal shield shown as a mould from the visceral surface. Arising from the pineal region are to be seen a pair of sensory canals running forwards and outwards. The impressions of gill pouches and other visceral organs are well shown. × 1½. Bloomsburg shale, Perry County, Pa.

FIG. 2. *Palæaspis bitruncata* Claypole. Mould from the visceral surface of nearly complete dorsal shield showing the impressions of the gill pouches. × 1¼. Bloomsburg shale, Perry County, Pa.

FIG. 3. *Palæaspis bitruncata* Claypole. Enlargement of a part of the ornamentation in the pineal region of the specimen illustrated in Fig. 5. Bloomsburg shale, Perry County, Pa.

FIG. 4. *Palæaspis bitruncata* Claypole. Mould from visceral surface of dorsal shield in the region of the snout, showing position of orbits, pineal body and semi-circular canals (?). × 2. Bloomsburg shale, Perry County, Pa.

FIG. 5. *Palæaspis bitruncata* Claypole. Nearly complete dorsal shield shown partly as a mould of the inner surface. × 1¼. Bloomsburg shale, Perry County, Pa.

EXPLANATION OF PLATE IV.

FIG. 1. *Cyathaspis wardelli* Ruedemann. Nearly complete dorsal shield showing the sutures of the rostral and right lateral plates to the central disc. × 3½. Guymard Quartzite beds, near Otisville, N. Y.

FIG. 2. *Cyathaspis van ingeni*, spec. nov. Fragmentary dorsal shield showing the anterior suture of the left lateral plate. × 2½. Guymard Quartzite beds, near Otisville, N. Y.

FIG. 3. *Palæaspis*, sp. Visceral view of fragmentary shield showing stains apparently leached through from sensory canals. × 2. Bloomsburg shale, Perry County, Pa.

CULTURE PROBLEMS IN NORTHEASTERN NORTH AMERICA.

By FRANK G. SPECK,

University of Pennsylvania.

(*Read April 23, 1926.*)

For some time there has been a growing need of a general survey, with an attempt at interpretation, of the cultural properties of the Indians of northeastern America. Thus far nothing to supply it has been produced because few ethnologists have been attracted sufficiently to the region as a field of research. The culture area of the northeast is an immense one. Simplicity is its striking quality, one which at the first glance creates a feeling of wonderment at its undeveloped primitiveness, or raises an alternative thought; that it may be simplicity arrived at through recession from a more complex phase of culture under which these tribes have previously lived.

The northeast, however, bears strongly upon one's consciousness, after more mature contemplation of these possibilities, as being one of the world's marginal cultural zones, an archaic one, where human groups have resided for a long time apart from culture changes and innovations which have arisen elsewhere on the continent. To account for this we need only consider the isolated position, the wide, cold and inhospitable country, thinly populated and removed from outside contact by reason of its continental terminal position and distance, bounded on the east by the Eskimo of the Atlantic coast, on the north and northwest by the Eskimo on the Arctic coast, and on the west and south by distant groups having more advanced institutions whose inclination was more to evade the barren north than to migrate into it. We can hardly think of these natives of the northeast otherwise than as populations who have followed the same mode of existence for a very lengthy period, tribes which, to do this, cling to the habitat of the caribou and moose, the beaver, the seal, and the bear, the canoe-birch and the long semiarctic winter. Let us say, then—fully realizing that for the present a paper like

mine can hardly be expected to solve any of the problems set down,—that the northeastern Algonkian represent a people who very long ago achieved their adjustment to the requirements of a far northern existence and kept to it no matter where they had to migrate to. and if they were residents of North America at the end of or just before the last period of glaciation, that they retreated northward, keeping to the barren territories of the north as these opened up with the release of the land from glacial after-conditions.

Let us turn, however, from anticipation, to the actual survey of the ethnology of the northeast and to the comparison of its features with those of other northern culture areas. On the whole we are confronted, as will become clear, with a display of traits in the northeast which mark this area to be most primitive in its culture character. Local developments are weak; the general economic characteristics occur also among the Athapascan and even some Siberian tribes. The isolation of the Labrador enclosure has caused it to become a vast preserve of elements which, upon being traced out in respect to distribution and then analyzed for their motives, show them to belong most fundamentally to the vast circumpolar culture belt. If we can imagine the requirements of a crude age domiciled in the barren interior of a semiarctic environment, we can readily understand what features would be most important in the maintenance of life for a people so located. The contrasts, it might be added, which stand forth against the Eskimo type of culture bordering on the coasts are very great, and yet some correspondences may be expected and are actually found.

Practically no developments taking place within this area have achieved a distribution outside its confines, another evidence of its isolation and primitiveness. There has been no apparently no opportunity or outlet for a backflow of either culture or people toward the west. All the drift has been eastward. The area had perhaps achieved its optimum of population; the balance may have been reached, belong which the natives did not increase against the rigors of an exacting and infertile environment. Yet another reason for the stability of population seems to stand forth, in that early native ingenuity was not sufficient to overcome the difficulties and unresponsiveness of barren nature by inventions which would have

enabled the people to exploit to a fuller degree the resources of the peninsula. Then, above all in importance, is the further consideration that the region was out of the path of culture diffusion. And so it remained untouched by the advancing frontiers of agriculture, the agricultural arts, and those of native political and social change which moved from certain centers in the southeastern, central and southwestern portions of the continent transforming unruled, unorganized hunting units into settled and socialized farming groups as we see them among the central and eastern central Algonkians. As a consequence of the geographical isolation of the northeast, especially of that portion lying north of the St. Lawrence, there seems to be scarcely a practice or an idea that can be attributed to migration from neighboring cultures. This statement might seem indeed to be dangerously positive, but at present it seems to be borne out by a survey of the ethnic content. The one exception to it may be the use of tobacco and stone smoking pipes.

Progressing to the task of enumerating the divisions and characteristics of the northeastern culture area as a whole, two well marked subdivisions stand forth. One lies north of the St. Lawrence, embracing the entire Labrador Peninsula, except where the Eskimo inhabit the coast, from a line connecting the mouth of the Saguenay river with the southern extremity of James Bay. This includes the bands hitherto known collectively as Montagnais and Naskapi. The other division lies south of the St. Lawrence in the maritime provinces of Canada and in Maine, roughly from the Merrimac river to Quebec and eastward, embracing seven or eight known tribes of the Wabanaki group.

The Montagnais–Naskapi Group, North of the St. Lawrence.

We may first devote attention to the northern, or Labradorean group, one inhabiting a vast region of about 625,000 square miles extent with probably less than 4,000 Indian inhabitants. The customs and speech of the bands throughout the Labrador Peninsula are in the wider sense essentially uniform. Differentiation is chiefly noticeable between the smaller bands located on the southern watershed toward the St. Lawrence, those on the northern or Ungava and

Atlantic watershed, and the thirdly those in that portion of the peninsula facing towards Hudson Bay. There has been in the past a tendency among ethnologists to classify these groupings as though they possessed tribal differentiation, by referring to them as Montagnais, Naskapi and Cree, respectively. There seems, however, to be little real cause for this terminology, since neither group-consciousness nor internal political relationship can be shown for the same areas, no fixed dialectic properties and no definite culture analogies appear to mark them out distinctly within the geographical boundaries mentioned for them. As for racial characteristics, similar types, in head form, face width, complexion and stature, seem, from available data, equally dispersed over the whole extent of the population. Dr. Hallowell's conclusions, from the physical measurements taken during our recent expeditions show a preponderance of the meso-brachycephalic type similar to the Athapascan. Recent measurements from the area are about the same as those previously published by Boas.

It would then be more appropriate, I believe, to refer to the Indians of the whole area as Montagnais-Naskapi, there being some authority in earlier literature for the retention of these two names. The designation of the bands on the eastern coast of James and Hudson Bay as Cree, by Skinner, proves upon further test to be for the present inadvisable, in view of the fact that the dialects here possess affinities with those of the Labrador interior as much as with the Cree proper. I must also give Michelson credit for having reported the same conclusion some years ago. And again a correction may be made in the prevailing opinion, one much promulgated by ethnological writers, that the Height of Land, forming the watershed between the St. Lawrence and the Arctic drainage area, is a boundary dividing the so-called Montagnais on the southern side from the so-called Naskapi of the north. It turns out, indeed, that the inhabitants of the southern coasts, from about Seven Islands eastward, are, in both speech and habit, almost identical with the interior groups recognized as true Naskapi, and hence deserve inclusion with them. The amount of our material, it may be confessed, both linguistic and ethnological, has heretofore been sufficiently meagre to excuse such inaccuracies in nomenclature of which we have all been more or less

guilty. It is only since some knowledge of the forms of speech and customs of the remaining bands of the central and eastern interior, and the eastern coast, has been acquired that we are permitted to offer the following survey, which will, in subsequent years, have to be still further corrected and improved. From a cultural and at the same time a dialectic viewpoint, the whole peninsula falls into three subdivisions, the most extensive and the most simplified one is that covering the whole northern, the central and eastern territory, that is, roughly outlined, from Lake Nichicun (Lat. 53, Long. 71), in the interior, north to Ungava Bay (Lat. 58), east to the Atlantic Labrador coast, where, of course, the Eskimo range cuts it short. The same grouping embraces the southeastern coast, coming up into the Gulf of St. Lawrence about as far as Seven Islands, (Lat. 50, Long. 66). This is the area to which the term Naskapi has been applied quite generally in the past, and we may still refer to the bands within it by the same name. Among the natives themselves the term Naskapi denotes a crude, uncivilized being (*nàskwopi*). From this point on, ascending the Gulf and river coast of the St. Lawrence to a little above Quebec (Lat. 47, Long. 72), and then sweeping northward to a point, above Lake St. John, about Lat. 51, Long. 72, and eastward following the Height of Land back to the longitude of Seven Islands, is the boundary of the traditional Montagnais cultural and dialectic type. The Indians realize marked differences between the bands occupying the interior and those near the coasts. The former are called "People of the Interior," (*Notcimiwilnùts*), the latter "People of the Sea" (*Winipegwilnùts*). The northwestern sector finally, from below Rupert House (Lat. 50, Long. 80) and Rupert river northward as far as the uninhabited region north of Lake Minto (Lat. 57), and east to about latitude 72, is characterized by a set of dialectic and culture factors entitling it to recognition at present as another separate subdivision. It remains as yet actually an unknown block. For this undergroup we may propose the name Mistassini-Cree, accepting the authority of those who have referred to the Mistassini Indians proper as exhibiting the typical culture traits of the bands residing immediately north and west of them. Since, however, the Mistassini have been occasionally called Naskapi, it might be unnecessary to give this

group a separate name were it not for the divergence of their speech, in respect to phonetics, from that of the accepted Naskapi type in the central and eastern interior. There is reason to think, also, that when more is known of the populations northwest of the Mistassini, those lying on the Hudson Bay Coast, other characteristics in social and religious matters will cause them to rank somewhat farther apart.

Within the Labradorean group may be included the former Beothuk of Newfoundland, whose identity confronts us as one of the world's ethnological puzzles. There are some undecided affinities between this group and the Eskimo, the Montagnais-Naskapi and the Wabanaki. The entire absence of satisfactory linguistic matter however, makes the Beothuk identity uncertain, though an Algonkian nearness has been noted. Other ethnic features, and the scant cranial material preserved in the museum at St. John's, examined and measured by Michelson, suggest derivation from the Labrador mainland. A general survey of extant culture remains in Newfoundland also suggests a Labrador rather than a Wabanaki relationship, unless one regard the so-called Red-Paint culture of Maine as constituting a true and independent type and its horizon to have extended far enough east to have anciently encompassed Newfoundland. A word or two might be added concerning the characteristics of Beothuk art, of which over a hundred specimens, in the form of carved bone ornaments, have been figured by Howley. The prevalence of carved zigzag and triangle pattern series, to the exclusion of almost any other motives, corresponds to the type of decoration so noticeable on the one hand in western Eskimo, and on the other in Micmac and Wabanaki carved ornamentation. The resemblance is striking enough to present an invitingly perplexing problem.

For the purpose of specification, we may recognize a certain integration of groups in the whole northeastern culture area which may be referred to in the use of the term "band." I choose this in the sense proposed by Goldenweiser, meaning a group inhabiting a fairly definite territory with a more or less stable number of families, possessing paternally inherited privileges of hunting within tracts comprised again within the boundaries of the territory, often having an elected chief, speaking with idioms and phonetic forms by which they and

outsiders distinguish themselves as composing a unit, often with minor emphasis on this or that social or religious development, often with somewhat distinctive styles of manufacture and art, and finally, travelling together as a horde and coming out to trade at a definite rendezvous on the coast. Intermarriage, in the majority of cases, is also within the families of the band, though it should not be imagined that anything but the most humanly expedient associations, economic, social and marital, may exist between neighboring bands and even sometimes between those whose central haunts may be some hundreds of miles apart.

The more or less separate bands of the Labrador peninsula number approximately, so far as we know at present, twenty four. Since I have only recently determined most of them, the names and locations given should be regarded as tentative in the case of the more remote northwestern groups, concerning whom we have merely information derived from indirect native sources and not through contact. The band names may accordingly be announced as follows: White Whale River, Ungava, Barren Ground, Big River, Kaniapuskau, Petisikapau, Michikamau, Northwest River, Nichikun, East Main, Rupert House, Mistassini, Lake St. John, Chicoutimi, Escoumains, Bersimis, Godbout, St. Marguerite, Shelter Bay, Moisie, Mingan, Natashquan, Musquaro, and St. Augustin. At present it will suffice to say that these bands are located in the drainage areas of the rivers and lakes whose names they bear.

Here in the Labrador area we observe the exclusive occupation of hunting, trapping and fishing, not even relieved by the excitement of warfare. The equipment of the chase included the simple bow and arrows with bone points. The arrow feathering and the so-called Mediterranean form of arrow release suggest Eskimo influence. (The map of distribution in Wissler's latest book is in error in respect to this region.) A lance with bone point, for spearing caribou and beaver, and the toggle harpoon for salmon and seals bear also the same complexion. The usual crooked-knife with an iron blade is in common use. Gill nets both of twine and "babiche," and bone pointed fish-hooks, which require to be swallowed by the fish, are employed. Snares and deadfalls are in constant service. In transportation the bark canoe, the man-drawn toboggan, and in

later times the sled drawn by dogs, and, above all in importance, a very broad rounded snowshoe are characteristic. The snowshoe stands forth so prominently in the whole area that Birket-Smith speaks of it as a snowshoe culture area. The bands in the southern part of the peninsula have adopted the French manner of dog harnessing with shafts and tandem traces; those in the north and east, that of the Eskimo, with the single dog-trace in span formation. Shelter is provided by the conical, many-poled birch-bark wigwam in the southern area, while in the north, where bark cannot be gotten, it is of caribou skin. The question of a three or four pole foundation, emphasized by Wissler, does not enter here since the poles are not taken down when camp is moved. The dome-shaped lodge of skin and canvas is also general among the northern and eastern bands. Heat and light come from wood fires. A noteworthy feature here is the hunter's temporary shelter, an open-topped head-high windbreak of canvas or skin thrown about the wigwam poles. Protection from cold depends solely upon immense fires built low within a trench in the snow. The Athapascan resort to a similar practice. Clothing is of woven hare-skin coats with hoods, and leggings, and wrist bands, neck bands, wraps, separate sleeves, socks, wraps and robes. Besides the woven hareskin winter clothing, caribou skin hooded and sleeved long-coats and leggings, with detached mocassins are usual forms of garments. The men mostly wear their hair bobbed at the neck, some wear it long and unconfined except for a rag or band to keep it out of the eyes, the women theirs wrapped on little wooden blocks hanging over each ear. In household furnishings there are the ubiquitous birch bark baskets and buckets and food vessels, for the most part ornamented with etched designs. Bags and pouches of many varied forms, are made of animal and bird skin with the pelage and plumage left on.

Tools and implements are largely of bone and antler; harpoons, arrowheads, fish-barbs, skinning-tools of bear tibia cut obliquely, hair-scrapers of caribou leg bone sharpened at one side, grease-scrapers of the same bone cut obliquely and notched at the end, snowshoe needles, awls, knives, meat-picks, perforators, needle-cases, bag-fasteners and pipe-cleaners. It is indicative of an early phase of industry that the bone tools are never hafted but used in the naked

hand. In woodwork there are shallow oval bowls, spoons with flat wide bowls, needles for weaving hare-skin garments and robes, net needles, canoe-mallets, knife- and awl-handles and net-floats. Among recent manufactures iron has come into use for the crooked-knife blade, semi-lunar scraper used on seal-skins, awl-point and European file and axe.

Stone implements are restricted to hand mauls for breaking caribou bones and pounding meat, net-sinkers and whetstones, and the beautifully conceived, thin-walled, slate tobacco-pipes with a keel base. On pre-European camp sites we find the curved edge stone gouge, a slightly grooved axe, slate points and large quartzite and quartz chipped blades evidently ancient knives and scrapers. The stone missiles are not generally barbed, though they have a stem, resembling these of the Eskimo.

Art decoration includes painting on leather, birch-bark etching, and in later times, beadwork and silk embroidery. Color symbolism, animal and plant realism, and conventional double-curve designs with tree and floral forms having prophylactic values are prominent. The geometrical zigzag and triangle are also patterns. Designs have spiritual control powers, are of dream derivation, act as fetishes, in short are symbolic factors. The wide, shallow, single-headed drum with snares or buzzer, is general, and a skin rattle, both serving in individual religious and shamanistic accompaniments and in assembly dances. Among amusements the pin and bone game of a somewhat Eskimoan form is prominent.

There is, in short, no religious organization nor are there group ceremonies; no organized government, seldom even chiefs, no regulated inheritance of chieftainship, no regulations tending toward social control, no mother-in-law taboo, no betrothal nor marriage ceremony other than the social dance.

The social organization of the whole group seems to be based solely upon the family unit, in the kinship sense, each having its own inherited, somewhat fixed, territorial limits. Personal names here generally have reference to some personal peculiarity; sobriquets.

Mythology and folklore correspond rather closely with those of the trans-Laurentian Wabanaki tribes, in the characteristics of supernatural beings, in the weakness of ceremonialism, and in the

general individuality of versions as told by different narrators. The attributes of the trickster-transformer hero appearing here under the name of Tsekàbec (Tsekabesh), for which at present no trustworthy meaning can be suggested, indicates that there is reason to think that the career cycle of the hero resembles both that of the Cree-Ojibwa and the Wabanaki.

The belief in supernatural owners of the game is widespread in Labrador, and is apparently exclusive to the Montagnais-Naskapi among northern Indians but it brings up again that perplexing question of eastern North American and Palæasiatic correspondences.

A feature of individual hunting ceremonialism in the whole northeastern area, north of the St. Lawrence, is the *nimabàn,* or "dance string." I have treated this object in a short paper, describing it as a pack- or carrying-strap for small game, decorated with symbols representing dream-helpers or in some cases game animals desired by the hunter. There is much individual variation in its features. This object is held in reverence by its owner as the source of dream revelations as to the whereabouts of game. We find its employment general among the Montagnais-Naskapi, and even weak vestiges of its former occurrence among the Wabanaki. As yet only inferences may be drawn as to its existence among the Athapascan, from one direct reference to it among the Loucheux. I believe, however, that it may yet be reported more generally from the northwestern interior. A similar situation seems to exist in respect to the general distribution of the hunter's dream revelation aside from association with the *nimabàn.* We have, of course, a continuous distribution, over the northeast, of dream instructions concerning the hunt. This subject I have dealt with in more detail in separate papers. While it has not been emphasized in the Athapascan region as a psycho-religious feature, its presence there may be interpreted from the myths already available collected by Petitot and Goddard. Another ceremonial feature diffused over the whole north is scapulimancy; divination by means of scorching an animal's shoulder blade and observing the cracks and burnt spots. Beginning with the northeast we find this practice of divination to be general and fundamental among the Montagnais-Naskapi. It does not, however, seem to have crossed to the southward of the St. Lawrence, judging from existing Wabanaki

sources. And to the westward we have a reference to it among the Athapascan, from only one mention so far as I know, recorded by Whitney among the Dog Ribs. While its American occurrence was overlooked by Kroeber in his recent volume—pardonably enough since it had not been recorded in print although known and observed some years ago—the same author has traced and emphasized its widespread occurrence throughout northeastern and Central Asia, and even westward into the ancient classical Mediterranean region and northern Europe, as an associate of sheep domestication. I might add that in this idea we encounter one of the most significant indications of circumpolar culture affinities that can be cited.

The foregoing remarks are intended to summarize the ethnology of the Labrador area. Localized developments in the northeast are few in comparison with those belonging to the older more fundamental culture layer covering both sides of the St. Lawrence. The lack of development in organized shamanism, government, social organization, religious ceremonies and economic processes is significant. Evidently culture contact with other Algonkian groups, who have benefited by contact in their turn with more southerly centers of diffusion, touched the surface of the Labrador region only very lightly, and even then only on its southern and southwestern margins. I may add that hardly a thing can be pointed out as indicative of diffusion from Iroquoian sources; a consideration having an important bearing upon the problems of the north, because we shall meet with strong Iroquoian influence south of the St. Lawrence as we now come to the survey of properties of Wabanaki ethnology.

The Wabanaki Group South of the St. Lawrence.

South of the St. Lawrence river, that great cleavage line of Algonkian culture and physique in the north, reside the members of the Wabanaki group, beginning with the Pigwacket of New Hampshire, extending eastward and embracing the Sakoki, Aroosaguntacook and Norridgewock, and the better known Wawenock, Penobscot, Passamaquody, Malecite and Micmac, with an approximate native population of some 6,000. Here a relatively uniform set of internal features, all the fundamentals, compare rather closely with the corresponding properties of the Labradoran group. But a number of

evidently more recent acquisitions seem to indicate a departure from the older common level. The Wabanaki group shows us again the preponderance of snow-shoe hunting and economic winter-activity, the important feature of well-defined family hunting territories and loosely organized society manifesting a tendency toward patriarchy. Here likewise the chiefs lacked pronounced power, though a confederacy developed later modeled after that of the Iroquois. Industrial life was characterized by the constant use of birch-bark for the covering of the conical, tipi-like wigwams, canoes, baskets and containers, even armor. The iron-bladed crooked-knife, and the iron double-handled draw-shave are here as they are all through the north. The area is characterized, too, by a particular phase of northern art in which floral patterns and curves lead in importance where the field is beadwork. The beadwork is probably a development from an earlier painting technique or moose-hair embroidery. In other fields of decoration, woodwork, and the porcupine quillwork of the Micmac, the triangle and zigzag are characteristic figures. The dog was present as a domestic creature aiding in the hunt, but never, in this area, for drawing the toboggan. The snowshoe is indispensible and has a medium width. Certain peculiar properties in archæology such as the limitation of types of utensils to the gouges, celts, slate bayonet-like spears, and so-called "plummet stone" stand out prominently, while small stone arrowheads, grooved axes and pottery (except on the coast) are scarce. Special mention needs to be made of the survival among these tribes of the moose-hide canoe which Birket-Smith assigns to an antiquity equal to that of the Eskimo kayak. This craft points to an early period of northern life even if the importance given it by him be challenged.

Despite the evidences of an ancient northern culture among the Wabanaki tribes we can perceive a radical influence in political, social and religious life and mythology, resulting from contact with highly organized more sedentary tribes on their southern and western margins. Since there is practically nothing to be said, so far as is now known, on this point when referring to the Montagnais-Naskapi, we discover here our main interest in respect to problems of diffusion. Due almost exclusively to education by contact with the Iroquois, the Wabanaki nomads, of an original culture and temper comparable with

that of the Labrador nomads, later in their development acquired maize, tobacco and bean cultivation. These brought in a mass of adhering customs and beliefs. Among such are included pottery (though we should not be too certain that a crude pottery industry had not developed earlier associated with a meat diet), splint basketry, the wooden corn-mortar and stone pestle, a number of recipes for preparing food, together with planting, and harvesting customs, and folklore. Besides we have reason to include most likely some influences in the form of garments, hair-dressing and the wooden baby-carrier. A simplified form of the Iroquois game of snowsnake is, for instance, another diffusion as far eastward as the Penobscot at least, something for amusement and gambling strangely unknown to the Montagnais-Naskapi.

Some of these influences reached only part way across the Maritime Provinces, having little effect upon the tribes east of the Androscoggin and Kennebec rivers. The arrested passage of a number of Iroquoian and central Algonkian material traits eastward may account for their presence, often thoroughly assimilated, among the Abenaki of St. Francis, and their corresponding weakness, poor assimilation, or complete absence among the Penobscot, Malecite and Micmac. Many of the dances and their songs are analogous to those of the Iroquois. In the field of religious ideas and mythology we notice many differences between the north and south St. Lawrence areas, most of which may also be attributed to Iroquoian diffusion working eastward south of the river. Yet it should be emphasized that there is a deep sub-stratum of resemblance, both negative and positive, in the mythology of both subdivisions. The culture-hero conception of Wabanaki cosmology has a peculiar analogous quality to that of the Montagnais-Naskapi, something still to be studied. As has been remarked of economic life, the assimilated Iroquois and central Algonkian features in mythology become less noticeable as we proceed toward the Micmac on the far eastern extreme. It is quite evident that this group is the most divergent of the Wabanaki division which, as Dixon has pointed out some years ago, may be attributed to an earlier wave of eastward migration. Referring to the probability of certain typical older Algonkian sub-strata of mythology, we note in the extreme east, the absence of certain things fun-

damental in the mythology of the central Algonkian and the Iroquois, notably the flood story and the earth-diver theme.

The social subdivisions of the Wabanaki were the family bands, with territorial locations paternally inherited. There is considerable social similarity with the Labrador tribes. The family groups bore animal names derived from the principal animals figuring in their territories. Personal names were generally derived from animals, often the family animal patronyms. They appeared as nicknames referring to some personal peculiarity. War names, titles or those referring to incidents were not of common occurrence.

Another social feature of this area was the segregation of young unmarried men in a lodge by themselves. Their mission during this period was to cultivate running power and endurance to pursue the moose, for communal provender. Formal marriage and betrothal rites are present also, the medium of proposal being wampum. These complexities by contrast, do not appear north of the St. Lawrence.

The social and political superiority of the Iroquois was waging a successful conquest over the Algonkian "starvelings," as one ethnologist has called them, of northern New England and the Maritime region, but Iroquoian contact could not educate them out of their individualism and into the community sphere. Nor could the same influence convert their religious life from its simple belief in personal guardians, dream-controls and forest demons, into the organized cults of the Central Algonkian region. Shamanism illustrates a similar aspect. The individual conjuror's practices of the whole northeast contrast with the assembly performances of the Iroquois shaman societies and the Central Algonkian *Midèwin* society.

Agriculture can hardly be regarded as having existed in the early culture complex of the north, where the Algonkians are most typically revealed, for the details of corn cultivation, myth, and ceremony, are correspondent with those of the Iroquois and do not extend eastward beyond the pale of Iroquois influence in general. Since corn can be cultivated farther north than it was in early historic times, we may reasonably assume that its cultivation would not have been abandoned in any native migration to a region where it could possibly be retained even with great effort. Abandonment under adverse physical conditions is not the fate of agriculture when once acquired

either in neolithic Europe, or, to cite a case in the New World, in the arid southwest.

That the Wabanaki peoples have been undergoing a culture metamorphosis from a simpler stage, originally adjusted to a northern environment, into a more developed one, through the influence of Iroquoian proximity just considered, seems fairly manifest. An intimate study of Penobscot ethnology shows forth, indeed, several time strata, the upper one being marked by the display of many more advanced social and economic properties. The change in culture brought about by the arrival of the Iroquois on their borders seems to have been curiously coincident with an alteration in climate and faunal distribution in the Laurentic region.

To make clearer the change in life which has affected the southern and southwestern margins of the northeastern Algonkian habitat zone, one may refer to the northward movement of faunal and floral life which has had its influence upon local culture properties. It is well known, for instance, that certain of the animals of the Transition zone are moving beyond their former limits into the Hudsonian. For instance, a northward drift of the moose has been observed, working toward the northwest and toward the northeast, and the same is true of the red deer in the northeast, which have only within the last two or three years been first met with and killed by hunters of the Lake St. John band of Montagnais. These cervine movements have been accompanied by what seems to be a retreat of the caribou toward the north. A related movement has been especially true of the caribou and deer in Maine. With the introduction of animals belonging to a warmer zone, a change has actually been recorded for some of the Algonkian tribes within the past two generations from a primarily nomadic hunting type of life, concerned with the caribou and moose, to one more settled in character, partly agricultural, and centering around the Virginia deer. These changes are usually contemporaneous with the introduction of splint basketry, the decline of the birch-bark basketry, and an introduction of ethnic features which seem comparable to those of the Iroquois. Pottery, in the north, may be possibly ascribed to such a culture diffusion. I refer to the Penobscot of Maine and to the Montagnais in northern Quebec as examples of this recent culture change. With a broader vision of human cul-

ture changes in mind it seems to suggest an analogous picture to what we believe happened in European prehistory.

The Archæological Problem.

Having now touched upon the fundamentals of culture among the two major divisions of the northeastern Algonkian north and south of the St. Lawrence, we may turn to the consideration of some general problems concerned with both as participants in the same original and probably ancient complex. The archæological question confronts us at once.

In view of the climatic and geographical conditions it seems safe to say that no other type of culture can have existed in the far north than that possessed both by the Eskimo along the coasts and the northern Indians who occupy the inland regions today. And if, as Steensby believed, the palæo-Eskimo were an inland people, then we might imagine the two, early Eskimo and Indian, to have carried on a similar life at an earlier period by force of economic circumstances. If Steensby's argument in favor of an interior origin for the pre-Eskimo be regarded favorably, or if it turn out to be demonstrable, then we may account for the resemblances in culture marking the Eskimo and the northern Indians in general, for the normal economic life of the Indian is strikingly like the Eskimo summer life. The latter phase Steensby accepts as the fundamental Eskimo culture setting; the winter phase a development. No matter just how the solution may develop, we are coming slowly to a conviction of Eskimo and palæo-Indian, possibly palæo-Algonkian, economic affinity. The annual cycle of the sub-arctic Indian embraces two phases of existence in a respect reminding one greatly of the seasonal changes of living among the Eskimo, which have been regarded by Boas, Mauss, and Steensby as a primary characteristic of their culture. The northern Algonkian, and, so far as we can ascertain from still incomplete records, the Athapascan as well, perform a seasonal migration from the interior steppes and forests where their winter hunting-grounds are located, to the coasts or to the great bodies of fresh water, to spend there the early summer, returning when the season of insect pests, forest fires and drought have ended, to their winter stations in the interior. That this migration is fundamental to north-

ern culture is shown by the accordance between the movement and the intention on the part of these nomads to allow the game in their family hunting-districts a period of quiet for the purposes of recuperation. Principles of game conservation which are general in the economic life of the northern Algonkian, as I have undertaken to show in a number of papers on the subject, are only possible under the conditions outlined above. During the summer season at their water locations, the northern populations subsist upon fish, water fowl, eggs, and in the instances where they come out from the interior to the sea, sealing becomes an important activity. I shall refer later to the significance of this dual culture pattern in an attempt to suggest an explanation for the differences in archæological material which characterize culture levels in Maine and in Labrador; material regarded by some as referrring to different chronological periods in human history, if not to different racial groups. Whereas if we look at it from this point of view it is not impossible that these same may be differing phases of life of a single people, comparable to those just mentioned, of contemporaneous occupation. While the direction in respect to seeking land and water in the summer migration is the opposite in the case of the Indian and the Eskimo, nevertheless the primary character of the movement has in both cases a similar and a related origin—a seeking for requirements which have developed into necessities of life in their own culture sphere. The almost universal Algonkian dependence upon hunting and fishing, as insisted upon by Wissler, the accompanying limited nomadism, the development in means of forest transportation, and hunting on snowshoes all illustrate the basic features of northern Indian culture. While the annual winter migration is from land to sea on the part of the Eskimo, especially those west of Hudson Bay, it appears as the reverse among the northern Indians. The northern Indian and Eskimo cultures, then, seem largely differentiated through the development of winter culture among the Eskimo. The two in summer would be living less in contrast with each other than the same Indians and their Algonkian relations on the Plains, for instance, or in the upper Mississippi region where they practiced agriculture and acquired its associations. We are in a position, to cite one case, to understand why the Eskimo will eat raw meat, while the Indian never

does. The former is often obliged to feast upon meat without being permitted by the nature of his situation to prepare it by means of fire, as for example, when game has been killed on the sea ice. The Indian is seldom under this stress, since his game inhabits the timber, be it ever so small, where fuel is obtainable.

A solution of the archæological problem will, nevertheless, be impossible until much later despite our most ardent hopes at the present. Things may even develop to remind us of the theory of racial migration eastward in the north, at least as far as it concerns the interior peoples and cultures, suggested some time ago by Sollas.

The presence of a type of culture in central Maine, somewhat specialized in respect to burials, accompanied by quantities of red ochre, abundance of grooved "gouges," so-called "plummets" and long slate spear-points, has provided ground for recognition of an assumedly very old culture by Moorehead under the name of Red Paint people. This introduces another aspect of the problem. The absence of skeletal material from this level, however, makes speculation regarding authorship as yet reliant entirely upon stone artifacts of limited class-types. On the Maine coast are shell-heaps containing the remains of long-headed people who employed much bone in implement making and who made pottery. The usual types of stone objects from the Red Paint graves seem not to be represented in the shell-heaps and vice versa. Hence there is a tendency to regard them as products of different ages of industry, the shell-heaps being supposedly later. While there is some plausibility in such an explanation, according to the usual methods of archæology, it should not be overlooked that the Algonkian of this as well as of the Labrador region rotated through two cycles of economic life, the one consisting of a short early summer season at the sea and lake shore engaged in fishing and, when at the sea coast, in gathering shellfish. The same seasonal variation marks the ethnic life of the existing Labrador tribes as well as those recently inhabiting Newfoundland, and a corresponding double phase of archæology seems, despite the lack of general survey knowledge, to be true of some parts of the southern Labrador region. This habit would seem to go back then to very early times. From the interior sites come the gouges, axes and chipped quartzite edged-tools, evidently implements of the chase,

several types of which seem to correspond with those of Maine both in form and in frequency of occurence. Then there are the shell-heaps on the southern Labrador as well as on the Maine coast, though the former are nowhere as deep as those in Maine. From the interior locations in both areas the implement types contrast with those of the coastwise shell-heaps. In both areas the annual summer migration to the coast and the fall migration away from it is noteworthy. Might this fact later prove an approach for the understanding of the apparent stone-age culture differences? Along this line consideration might be given to the question arising from the absence of certain implement types in the shell-heaps which occur in the interior, and the absence of pottery and bone implements in the Red Paint burials of the interior while they exist in some abundance in the shell-heap sites. We could, however, imagine that the specialized life of the coast sojourn in spring—in contrast with the winter life amid the snows of the interior—where a different diet would be consumed, where shell-fish, fish and seals would be taken, where the requirements for fire and shelter would be different, that the bow and arrow, lance, and wood-getting activities of the winter period, subsisting on moose and caribou, would bring into play implements for which there would be no need whatever on the coast during the warm season. Such a thought alone could account for the frequency of the large stone gouges in the red-paint burials of the interior and their lesser frequency on the coast, if we assume that these tools were employed in tree-felling. For the fuel problem would assume primary importance in the winter life of the northern natives before the acquisition of European axes, and we may plausibly expect that some of the primary tool types in stone must have served in fuel-getting. If the aboriginal peoples of the interior of Maine roasted much of their caribou and moose meat for their winter subsistence they would not be unlike the Montagnais-Naskapi of today, and they would not have missed their cooking vessels. Besides, when occasion arose, birch-bark vessels have been brought into use for boiling with stones. I am almost inclined to say that the ordinary earthenware vessels of the Algonkian type would not have endured the cold and exposure of the nomadic northern winter-period. We have a somewhat similar instance in the case of the meat-eating Plains culture area

whose nomadic populations got along without pottery vessels. As long as Moorehead's idea of two cultures in Maine still continues to hold its plausibility, and until skeletal remains from the interior are obtained, and until the archæology of the Labrador interior is known, this as well as other interpretations of conditions must remain only suggestions.

If some such device as Douglass's tree-ring method in the southwest, or Montelius's clay-laminæ studies in Swedish archæology could be found here, we might be in a more solvable situation. But the interformational mix-up in the archæology of eastern America leaves us in chaos at present, except for some indications perhaps of stratification both vertical and horizontal, of possibly several supposedly Algonkian strata beneath those of Iroquoian determination, brought forth by Skinner and Parker.

A feature of much importance to us as a tentation toward an understanding of early culture in the northeast is the prevalence of bone utensils of many forms in contrast with a paucity of stone material. Skinner, in particular, does not consider a proficiency in bone-working to have been an earmark of early Algonkian industry. It has generally been thought that where supposedly Algonkian sites, show an abundance of bone material that this has been due to a patterning after Iroquois industry. In Labrador, and to a certain extent in the Wabanaki area, the preference of bone material for the manufacture of arrow-points, harpoons, knives, skinning-tools, scrapers, awls, perforators, needles, punches, needle-cases, and fastenings for bags, is a striking note in native industry. Some of these bone articles among the Montagnais-Naskapi have undoubtedly been patterned even after Eskimo tools, some of them actually obtained directly from the Eskimo and imitated by Indian workmen. Stone tools are limited in scope in this region. We find hammers and mauls, grooved axes and a few flaked stone blades representative of the types of lithic industry. There seems good reason to regard bone-working, in the Labrador region especially, as an art of great antiquity, since in the shell heaps on the south coast of the peninsula these implements also occur. Whether or not we are to expect the discovery of an older and lower stratum of culture in this region showing a greater prevalence of stone material is a question still to be settled. The explora-

tion of sites in the interior is, accordingly, a matter most urgently demanded. I cannot resist the temptation, while mentioning the bone-working industry, to refer to the resemblance in form and function between the implements here in northeastern America and those found in the closing period of the Old Stone Age and in the Transitional (Epipalæolithic) in Europe. The specimens which have been illustrated by Obermaier as coming from the Azilian and Maglemosean levels in Europe suggest some forms which are familiar in the contemporaneous life of the Labrador Indian. Among them is a perforated bone-pointed implement described as "bone-polishers." It is difficult to conceive just what objects could have been polished by implements of this type but when we find bone pins and fasteners used among the northern tribes to fasten bags and pouches of skin, and when both American and European forms have a hole near one end evidently for the attachment of a thong, a more plausible explanation of use seems at once suggested. The legbone of a large animal bevelled to a cutting edge occurs both in the European age referred to (and possibly as far back as in the Mousterian) and in northeastern America—in Europe being regarded as an "ax," but in Labrador constantly observed in use as a skinning tool, brought into service after the beast's hide has been opened at the belly by an incision with a sharper knife. Again the sharp bone-pointed "fish-hook," as it has been called in Europe where occurring in latest Palæolithic levels, is likewise a fish-hook, almost identical in form among the Montagnais-Naskapi. But here the hook is fastened at an abrupt angle to a wooden or bone shank by means of a raw-hide lashing, which, when swallowed by the fish with the bait which has been wrapped around it, causes the fish to be impaled by its gullet, not by its gills.

Eskimo and Athapascan Correspondences with the Northeast.

We may now touch upon the question of contact and reciprocal influence between the Eskimo and the northeastern Algonkian divisions. It should be recalled that until the seventeenth century there had been a long period of conflict between the Montagnais-Naskapi and the Labrador Eskimo beginning on the Hudson Bay coast and terminating on the Atlantic coast. This leads us to entertain the inference

that considerable later borrowing might have taken place in both sectors of the Labrador area. We shall see shortly that the common possessions of the two races in this section are quite numerous, but the problem is somewhat different when we try to trace the origin of some peculiarities which confront us in the physical characteristics and culture properties of the Wabanaki below the St. Lawrence. If we had definite information to prove the earlier existence of Eskimoid populations in this zone, it might be easier to explain why the Wabanaki are longer-headed and why a few peculiarities of industry, costume, shamanism, and mythology seem to correspond with traits which mark the Eskimo. Two points of view may be taken on the matter. One, that there were Eskimo south of the St. Lawrence, and that during an early migration of Algonkian toward the east they were absorbed by the latter. The other would attribute the few Eskimoan cultural peculiarities to a period before the bifurcation of the Algonkian in their eastward drift, when the parental group was in contact with earlier Eskimo in some era of residence nearer to the Hudson Bay region. In any case I feel that the Eskimo correspondences in material culture, which we notice both north and south of the St. Lawrence, and which do not overlap in these regions, are an indication that the earlier home of the possible common ancestor of the Montagnais-Naskapi and Wabanaki divisions was in a region where Eskimo contact happened. This is a reason to keep the opinion of a northern, an earlier center of dispersion.

A review of the Eskimo and Labrador Indian correspondences shows a fairly large number of features. In material culture we have sled dog-driving in the northern sector, the skin canoe, conical tent, upper garments which are characterized by the pointed hood and sleeves, and the "puckered" mocassin. The latter is also sometimes attached to an upper portion forming a boot. We have the peculiar method of female hairdressing, the hair bound in a bunch over each ear, tatooing of females by vertical lines on the chin and cheeks, and incidentally a toilet article in the back scratcher. Fur bags are exceedingly common in both cultures, some taking the form of the "roll-up" compartment pouch, other being the bags made of the leg skins of deer or caribou sewed lengthwise side by side. We have certain correspondences in games, notably the cup and ball game.

and physical contests. In weapons and utensils we have the toggle-harpoon (without, however, the separate foreshaft), the pronged fish spears, slings, and nets; in knives the so-called semilunar scraper ulu), both in stone and iron, the crooked-bladed knife, the leg-bone scraper, the use of thongs of hide, the bone needle and needle case, and the stone, flat-based tobacco pipes. The arrow with a flattened nock and two feathers, and the primary, or first and second finger, arrow release may be added. Even the skin tent may possibly possess an architectural history which is worth noting in this regard. Among the Wabanaki, for instance, the bark covered, conical tent is flat on the front side or door section. This feature is distinctive, particularly for the Wabanaki area, and is also noticeable in tent construction occasionally north of the St. Lawrence. The peculiar way in which the Eskimo erect the skin tent, with the opening at the front at a tripod which supports the ridge pole, suggests by a little use of the imagination that among the tribes where the front of the tent is flat across, the construction may have developed from a similar principle.

To resume our list of correspondences, we find, both among the Eskimo and the northeastern Indians, the family to be the social unit. Some moral laxity is noticeable. Government is simple or absent, and we have, besides, the well-noted records of cannibalism, and the abandonment of orphans and the aged. If it is denied that the Indians have followed these latter practices, references to them are numerous enough in mythology. A few similar taboos of diet and the treatment of remains of game; the sharing of the first game killed may also be noted, together with the belief in the reincarnation of the souls of animals. Certain shamanistic features stand forth, such as shaman exploits, the use of the drum, which instrument itself is somewhat similar in form among both groups, shamanistic individualism and the non-differentiation of priests and shaman in the community. In mythology, while the correspondences are not profound, we have an underlying analogy in the frequency of human tales, the redundancy of the cannibal, the abandoned-boy, the abandoned-aged motives, and, north of the St. Lawrence especially, tales connected with the overlords of different types of game animals; for instance, the king of the caribou and the king of the fish. Again, the practice of carry-

ing on contests and ordeals to establish the championship of strangers, so commonly alluded to in Wabanaki mythology, is remindful of Eskimo procedure; the stranger's ordeal of the wrestling match, foot racing, high jumping, the heat test, and the freezing test.

String figures among the Montagnais-Naskapi are numerous, and many correspond to those of the Eskimo, comparing the findings of Jenness and Mrs. Hallowell. Among these Indians they are executed to influence the game animals and serve as magico-religious agents for success.

Something may also be noted concerning shamanism. By contrast with the western Eskimo idea of plurality of the spirit-familiars of the shamans, Turner and Hawkes both note that the Labrador shamans do not aspire to more than one guardian spirit. The collection of tales from the east coast of Labrador contains some narratives expressing the belief in the single spirit helper. One of these, especially, (The Place Where the Caribou Live) corresponds in its principles with the Montagnais-Naskapi tale of the master of the caribou. A similar version is given by Turner for the Ungava Eskimo so we may infer that there is some basis of accuracy in the provenience of the single guardian spirit belief in Labrador both among Eskimo and Indians.

A characteristic form of decoration on flat surfaces of bone among the Montagnais-Naskapi is that of incised dots which through use become filled and blackened with grease and dirt. They receive the designation of "bird tracks" among the Naskapi where we find this form of ornamentation to be more predominant. The dotted ornamentation has been shown by Boas to be also characteristic of the central Eskimo, and it has appeared since the time of his writing (1907) on specimens from Etah, North Greenland, and again to the westward of Hudson Bay. Boas has in one instance suggested an Indian origin for them. Now, in a recent paper having been able to report the same ornaments among the northern and eastern Labrador Indians, we can revive the idea with new force. I am inclined to regard these as a common old property of the sub-arctic peoples. And, it might be added, the incised zigzag and triangle decoration, which finds a setting far and wide among the Algonkian-speaking tribes from Newfoundland to Hudson Bay, is another art motif of

comparable antiquity for them. Birket-Smith, from his observations as a member of the Thule Arctic Expedition has recently reported among the Eskimo of the Mackenzie region eastward, decorative elements corresponding to those of the Indians, another evidence of culture approach of the two peoples.

The simple dot design, which might appear to be connected with the dot and circle ornament of Eskimo art, is to my mind a question to be considered by itself. The dot alone is very widespread. It appears in regions of North America, where its connection with northern culture, and, more narrowly considered, with Algonkian, is not too obvious unless we trace its diffusion from a base very remote in antiquity. By doing this, it would seem, we might even extend it back to something as old as an Aurignacean milieu from its occurrence there in specimens of ivory carving. The circle-dot design, however, is much more restricted in its occurrence, and, being essentially confined to the Eskimo, would appear as a development associated in origin with the intensive use of the drill and " compass " or dividers, in working on bone and ivory, which is not prominent beyond the horizon of Eskimo technology. The simple dot ornament, on the other hand, could arise from a technical process in which the simple awl or point-perforator is the common instrument. In such a case it is a motive with a very wide as well as a deep distribution in the north where the extensive employment of skin, bark and wood material, all of which involve constant use of the awl, is an outstanding characteristic of industrial life. This setting eminently accords with what we strike among the northern, and, at the same time, typical Algonkian populations.

This list is far from being complete in respect to details. And again there are some ideas included in it appearing in Athapascan culture and which undoubtedly will call for revision from the point of view of meaning. Nevertheless the scope of the correspondences, even in its present rough form, appears significant.

The earliest fundamental association with an outside culture and linguistic group by the earlier Algonkian peoples seems then to have been with those of an Eskimoan type. As yet we may feel, however, that the tendency to regard a few suggested linguistic affinities of the two groups as pointing to relationship, is insufficiently grounded.

We should not forget that modern Eskimo culture contains distinct properties contrasting with those of the adjacent Indians, who nowhere show possession of the composite bow, the spear-thrower, the foreshafted harpoon, the stone-lamp, and the snow-house, and competent winter raiment, while the Eskimo get along without snowshoes, bark-canoe, and overlook the utility of the dead-fall in killing animals, a device which is universal among the Indians. It is in having invented these very devices that Eskimo culture has taken its distinctive form enabling its producers to dwell on the Arctic coasts—a developed culture with no analogy anywhere in fact.

The Algonkian of the far northeast compared with other Algonkian groups portray an early phase of culture of their own stock at large much as do the Athapascan inhabiting the far northeast of their range towards Hudson Bay. Wissler has emphasized the need of information from the northeastern Athapascan in recognition of the likelihood of their possessing the unmodified culture properties of their group. For the Athapascan have undergone modifications on their northwestern, southwestern and southern boundaries by Eskimo, Northwest Coast, and Plains culture contact respectively. Morice recognizes the same. The marginal modifications seem analogous to the situation among the Algonkian who have been modified undoubtedly on the southwest and southern boundaries by contact with the peoples of the upper Mississippi valley and the middle Atlantic region, and probably in the far north by Eskimo attrition. By elimination, then, of some of the evidently more recent acquirements, the underlying Algonkian and Athapascan culture phases seem brought more closely into affinity, whatever this may mean in view of their radically different speech types.

While we have so little from the Athapascan to base a comparison upon, there are, however, some properties differentiating them from the equally northern Algonkian. The Athapascan are recorded as eating meat raw upon occasion. We have no records, either documentary or living, of this practice in the northeast. The technique of porcupine-quill embroidery and weaving is a general Athapascan property, and the design motives are geometrical, not curved. The techniques of weaving babiche bags and willow-rod baskets are also common there. In the northeast this is not done. In mythology the

earth-diver motive, and in social organization the mother-in-law taboo and puberty rites for girls are present in Athapascan tribes. All of these features are absent among the northeastern Algonkian. There are undoubtedly other features of comparison which deserve enumeration by one better acquainted with Athapascan ethnology. For instance, it has recently been shown by Speir that in respect to kinship terms the Montagnais of Labrador belong in the same category as the people of the Mackenzie basin—all cousins being addressed as siblings.

Some northeastern correspondences with the Athapascan are, however, worthy of serious consideration as possible derivations from the northwest. The type of shelter, even in some of its peculiar details, the moccasin and lower portion of legging attached, the abundance of birch-bark vessels and receptacles, and their etched decorations, the patterning of the sleeved fur coats, and a fairly large number of minor utensils, offer correspondences. Some few of these ethnic traits extend not only over the northeastern and Athapascan areas, but into Asia as well. Especially significant is the wide distribution of scapulimancy; that is, divination by scorching the shoulder-blade of an animal until, by the burnt spots and cracks appearing, a desired answer to a question, or an indication is given of the direction in which game may be found. The burnt shoulder-blade divination is complex enough in origin not to have arisen independently among unrelated groups of people, and therefore, I believe, may be pointed out as one of a number of probable trans-Pacific practices which came eastward with very early migrant peoples. It is connected with the practices recorded in antiquity from China, and many adjacent regions, through Siberia as well as in the west in ancient Greece.

The significance of the northeast as a fundamental, archaic, interior culture of the north appears, moreover, with some additional emphasis in view of the fact that it lies somewhat below and apart from the type of culture which characterizes the Athapascan of the northwest. And I would proceed for this reason to regard the Athapascan as probably representing a culture phase, likewise interior in its adjustments, which has intruded upon a margin in the north and

retained some peculiarities which point to a relatively more recent Asiatic influence, or perhaps migration.

Some General Aspects.

Reverting again to the consideration of some wide culture generalities, we observe the northeast to be a region of high individualism. There seem to be virtually no group conventions. This simple culture condition permits no military organization, no system of government, no social fraternities nor septs, in short nothing more along such lines than what is so characteristic of the central Eskimo, and so far as we know, of the unmodified Athapascan.

Here the individualism of the forest nomadic Algonkian of the older school asserts itself as strongly as it does in its leaning toward anarchy, toward a personal religion revealed through dreams, and conducted by more or less individual and personal rights of sacrifice, propitiation and conformance to self-imposed hunting regulation taboos and controls. The Algonkian of the entire northeast seems to have preserved his individualism on a grand scale, even in circumstances where his original simple order of life has become invaded by superior ideas and institutions. Contact with the more advanced tribes on the western borders seems, indeed, to have stimulated a faculty of interpretation and imagination in the Algonkian mind, but not to have fundamentally caused wholesale changes. The same is surprisingly true even in respect to recent European contact.

As I have remarked before, the isolated position, together with the culture simplicity in particular, of the groups north of the St. Lawrence, puts them in a light of extreme significance. Owing to geographic conditions they have remained intact from outside influence to a degree, it would seem, that can hardly be paralleled elsewhere on the continent, unless it be the Plateau area in the Rockies. There is but one source of contact borrowing open for consideration and that is with the Eskimo of Labrador and those of Hudson Bay. The Eskimo being fairly well known, an evaluation is here possible for someone who will give the matter detailed attention. It would seem that the culture properties of the Labradorean peoples may be extremely archaic and fairly representative of an Algonkian period which may be the most typical that can be associated with the picture

of the early culture form of this widely flung and much varied linguistic stock.

In considering the validity of the argument, we might make reference to a law in zoology which seems applicable to the distribution of man. The principle is observed that species which do not show a great divergence from the supposed parental types have either resisted disruption, or that they have not been subject to changing influence, or that they are near the center of distribution where their type has been developed, remaining about the same in characteristics within their unchanging habitat.

To test this condition in northeastern America we shall have to secure evidences of the time duration of the inhabited period in the Labrador peninsula, through archæological exploration along the coast and in the interior. This has only been superficially begun on the coast, so at present no evidence is at hand as a basis for even a guess at the result.

Simplicity and individualism both characterize the institution of shamanism among the tribes north and south of the St. Lawrence. Thus these extreme eastern regions, which are equally remote from contact with the Central Algonkian, whose shamanism amounts to an institution, we find to be noteworthy for the same lack of organization. There are two ways in which the contrast between the northeastern and the central phases of culture may be looked at. One is to trace the northeastern conditions backward, assuming a process of degeneration, in later time from a former more elaborate stage, comparable perhaps to that which flourished among the tribes of the central group. Skinner expressed himself in favor of this view. Let us briefly review this possibility. There is something to support such an assumption in the facts of history and geographical association, for we know, through local tradition, and statements made by the Jesuits, that the Montagnais-Naskapi may have been immigrants from the west to the northeast. And we have reason to credit a similar Wabanaki claim that their predecessors came from further west. Thus there appears to have been a two-fold, possibly a bifurcated drift, at one time down the St. Lawrence basin from the central regions, one stream penetrating the country to the north of its shore, the other covering the region to its south. So the culture gradations

among the Algonkian from the Atlantic coast on the east to the Great Lakes region may be explained, if one choose to do so, by assuming a process of deculturation progressing with the advance of migration from the central region eastward toward the north Atlantic coast. There is, however, another attitude toward the situation, one that I touched upon in an introductory paragraph, accepting the evidence of simplicity in culture as natural of a more elementary type remaining near the environment where it assumed its normal form. In this case we would interpret the conditions by inferring that the eastern tribes have retained a form of simple, primitive culture which the central tribes have outgrown. The likelihood of the eastern migration of the Algonkian does not pose as a strong objection in this case because such a migration at an early time could have served to remove part of the primary Algonkian group from the range of outside culture influence, leaving this division as the conservator of the original simple culture by reason of its self-isolation. Dixon has already treated this possibility in a paper on Algonkian migration. In this case we would expect to meet the culture gradations spoken of in going from east to west. Besides this, there would be a certain local, non-uniform individuality in customs due to the irregular nature of group development while progressing from a simple, nascent stage through the various periods of growth congenial to their circumstances. We seem to find these variations in many minor respects from tribe to tribe in the group, so much so in some ethnological topics that the differences would be natural to tribes which are widely separated instead of among neighbors as is the case in some respects among the Penobscot, Malecite and Micmac. For the Algonkian have been extensive imitators if not innovators. The local variations seem considerably less in the Montagnais-Naskapi group north of the St. Lawrence, the more marked uniformity here being plausibly an evidence of more recent dispersion from the earlier center. There is ample historical ground for this idea because within historic times the Montagnais have expelled the Eskimo from the St. Lawrence coast and have themselves been pressed upon by the Iroquois. The Wabanaki group on the other hand has been resident where we find it located for some time prior to the opening of the historic period, since we have no records at all of extensive tribal

movements. Hence these bodies must have had a longer period of settled residence in which to develop local minor differences. On the whole the second possibility appeals more strongly to my mind than the first as a possible explanation of conditions in the Algonkian northeast. In this case simplicity of social, religious and ceremonial organization, limited nomadism, hunting and fishing, no agriculture, and a crude technology, are together the ear-marks of a relatively unaffected older Algonkian type of culture. In the neighboring Eskimo region a somewhat similar situation prevails, as is shown by Boas in one of his comparative studies. The central Eskimo are more primitive, more isolated and simpler in culture than those of Alaska, whose advancement in social ceremonial and industrial complexity is presumably due to contact with the organized culture of the northwest coast tribes. The assumption, moreover, that progressive growth from the simple to the complex is more natural and normal than retrogression, making proper allowances, to be sure, for historical fluctuations in culture, logically requires less proof than the opposite.

Some general tendencies of development concerning the family band are made possible by the material so far accumulated, incomplete as it is. In the first place we note considerable variation in the size of the hunting tracts of different tribes. Their magnitude, it appears, bears some relation to the density of population. This is illustrated by a comparison of the Montagnais-Naskapi groups of the Labrador peninsula, whose districts are proportionately larger, whose families are fewer in number, the more we proceed toward the northern interior. We may still construct upon the data somewhat further. The more northerly people, of the Labrador area, have fewer economic resources. Agriculture is denied them, the game animals are fewer. The Virginia deer does not range into the Labrador peninsula, nor does the moose extend eastward beyond the Saguenay so far as existing conditions go. The raccoon is also wanting. Hence the caribou, who are wandering in habit, and the hares, who suffer diminution at times, afford uncertain supplies to the natives, viewing their life in periods of decades, while, during the winter, bears are unobtainable and beaver and muskrat are taken only through extreme effort. These creatures are their staples of life. Serious economic

handicaps are suffered! Such circumstances must be thoroughly valued by the ethnologist. Adherence to one of the recognized principles of method would lead us to infer that the tribal groups comprising fewer persons, forming groups who are hunting within more extensive bounds, would stand forth as representing pioneers, so to speak, on the expanding frontier of a migration. By a comparison of these circumstances among different neighboring groups proceeding in one direction or another, the direction of the population drift would seem to be away from the more habitable regions where the human population is denser, where economic facilities are better, and where the family or privately owned land hunting-areas would henceforth be smaller in extent. The application of such a hypothesis fits the circumstances of the European colonization of America quite generally, and it only remains for some equally reliable historical facts to be adduced in the case of the supposed Algonkian migration to render it as creditable as the other. Thanks to the Jesuits we have some few historical landmarks of an eastward Indian drift toward the northeast.

I have already briefly worked out this test from several other parts of the northeast and reported the method and inference in papers concerning the migration eastward of the Micmac of the maritime provinces and the Montagnais-Naskapi of the Labrador peninsula. Now, having determined the probable social-economic characteristics of migrational termini, we may be in a position to apply the criteria to other regions in tracing tribal movements on the continent.

Outlines and Conjectures.

Practically all the fundamental culture traits, those which turn out to be common to all or to most of the Algonkian-speaking groups, seem to be of a northern adaptation. Among them may be mentioned the sibless type of society, weak chieftaincy power, drum-shamanism, tailored clothing, floral ornamentation, the conical and the dome-shaped skin and bark lodge, the loose-headed plain harpoon, the composite canoe, limited hunting nomadism within the family territories, the fondness for residence near water, and then the many negative ceremonial and social characteristics. Even where their present en-

vironment is not of a northern type, there are indications, as among the eastern central Algonkian for instance, of surviving northern culture features ostensibly persisting despite changes brought about by migration or by the acquisition of ideas introduced through diffusion. From this one might infer a northern habitat for the palæo-Algonkian peoples, or, by a contrast, a more northern and colder climate to have surrounded the early groups when they evolved their fundamental culture; a climate that has changed into a warmer era since its occupation. We have seen indications of this culture change accompanied by faunal variation within a period embracing not much more than a century in Maine among the Penobscot, and here the influences beneath it are both environmental and contactual (from the Iroquois). Yet no matter what the factors may be shown to be, our Algonkian culture retrospects in most areas seem to be more and more northern as the stages are unrolled backward.

In short, we seem to be coming, by a process of elimination, to a certain inference, that in the northeastern Algonkian groups, both north and immediately south of the St. Lawrence, we have two phases of a culture type characteristic of a very old North American period —one which is fundamentally as northern in complexion as the Eskimo, but which contrasts in being adapted to an *interior winter* and a *coastal summer* habitat. Yet it should not be overlooked that the Algonkian farther south on the Atlantic seacoast show a decided preference for the proximity of water and hold to a low altitudinal habitat, as Wissler has previously pointed out, where fishing may be carried on. This does not necessarily disturb the assumption of an earlier more northern habitat for the great family, because it exhibits a continuation of the normal summer life of the northern peoples into a warmer zone where the coasts are not rendered untenable to man though the ferocity of winter storms and the piling up of ice and the emigration of the fish. I think this point of view will become clear upon contemplation.

A significant feature, which seems to deserve attention in a discussion of this character, is that in the far north the dual culture type is marked—a coast-wise one represented by the Eskimo and the littoral groups of northeastern Asia, and an interior one represented by the Athapascan and Algonkian peoples of America and

again by some tribes of the Siberian east coast. Everywhere, in surveying Indian culture in the far north, we encounter the adaptation to interior winter conditions, the dependence upon large game animals, the hunting on snowshoes, the game-drive, trapping for fur clothing, fishing with a spear, and possibly with nets, portable shelter beneath skin or bark, the necessity for complete body-clothing, the dependence upon wood fires for heat and cooking, the necessity for adequate means of transportation in summer and winter—the bark canoe (the skin-canoe in places), toboggan, snowshoe, and dog-transportation. The mobilities of a non-agricultural population! The simple family group, the absence of political cohesion, the fundamentality of the family hunting-district, the weakness of the power of chiefs, and the unfeasibility of large and prolonged religious festivities, together with the corresponding development of individualism, all seem to mark the peoples of northern Asia and America apart from other groups south of them with a clearness which entitles them justly to rank, I feel certain, as one of the typical world-marginal culture types emphasized recently by anthropologists.

The dual culture form has been signally emphasized by both Hatt and Birket-Smith for the northern peoples of the Old as well as the New World. It seems to weld another link in the chain of unity embracing the circumpolar peoples. The latter author applies this pattern to the Algonkian, calling the two phases the ice-hunting and the snowshoe stages. Hatt denotes his phases as the coast civilization and the inland civilization. I have previously mentioned the curious fact that the Indians of Labrador themselves—poor ignorant savages—have conceived the same interior and coast distinctions in their thought upon their own life; an old thought to them but a new one to us! Happily we all agree in its essentials!

The all-important question of the earliest assignable homes of the Algonkian nucleus is one which might naturally be thought of at this time. But much is yet to be done in identifying and analyzing the influences which have affected the supposed marginal areas of the family before we can hope to arrive at any estimate of the original base content. It will probably develop that the region below Hudson Bay will become the type locality. If not this, then the lower St. Lawrence region. Sapir, and also Lowie have already thought

of a home for the stock considerably west of its present geographical center, through allowance of the western location of the Arapaho and Blackfoot. An opinion favoring a region west of Hudson Bay as a center of early Algonkian distribution has been published by Birket-Smith, I find through the attention of Dr. Hallowell, in 1918. His excellent theoretical paper on this puzzling question was based upon a study of older documents only. Without, however, having deduced a satisfactory method of evaluating the present distribution of dialect and physical type and above all not having solved the riddle of archæology in the east, nor even explored the surface conditions in wide areas of the northern habitat of the stock, I would hardly venture to express a fixed opinion. There is much to make the St. Lawrence watershed worthy of serious consideration as a region of very early occupation in view of the awaited archæological disclosures, the simplicity and uniformity of the ethnic types there, and the conformity of the region with the environmental requirements of post-glacial culture. If the western location of the Arapaho and Blackfoot would draw the older center westward what can be thought of the archaic stone age properties of the eastern coast Beothuk, the Red Paint and the north Atlantic shell-heap cultures? If we assume a migration into the eastern area, as there is some reason to do, it must be pushed back to a very early period, one which would provide a subarctic, interior setting for the early cultural home of the family—one possibly adjacent to the Palæo-Eskimo wherever it happens to be fixed. A period antedating the acquisition in the north of any southern culture traits would seem to be demanded. Hence if there is ever any stronger reason than that which exists at present for assigning any North American culture type to an early neolithic or a transitional archæological (epipalæolithic) classification I am prepared to see it accomplished for this area.

The anthropological properties of the northeast have to be understood as consisting of three elements, race, language and culture. Inasmuch as there is relatively so little material available covering the physical characteristics of the whole region, we can do hardly more as yet than point out the resemblance in head form between the Labrador Algonkian and the Athapascan, and the differentiation here from the longer head-form south of the St. Lawrence. The central

divisions of the Algonkian-speaking population, meso-cephalic like those of the Hudson Bay and Labrador area, show that this cranial type is the more widespread, hence probably of more recent origin whether we approach the question of skull-form as a criterion, after the manner of Dixon or whether we consider mutability of form as possible within the group, following Boas. A change in head-form in the region is evident by comparison of the older with more recent material, the older population being longer-headed than the present inhabitants who speak Algonkian. It is in the Wabanaki territories that we encounter, both among the older and among the existing groups together, the longer head. The Wabanaki group is marginal to the stock and isolated in position. So, whatever we may say respecting the other points of language and culture, the Wabanaki division is entitled to serious consideration as a physical representative of some old era in the historical development of the stock. We need not as yet attempt to solve the ensuing problem, as to whether the broader-headed race acquired an Algonkian culture and language by the process of invasion or by that of internal physical change. There is little to show that the term Algonkian can be applied to race with any fixed value, for in the matter of head-form alone the variations are enough to show that the Algonkian averages extend over into other culture groups and linguistic stocks. Yet one might imagine for the present that the terminal and marginal long-headed Wabanaki, apparently the only Algonkian group showing this head form, have preserved more than the others an old combined racial and cultural type. So it would require, I believe, a certain lack of imagination to rely solely upon the thought that the advent of a single Algonkian tribe, speaking one tongue and of homogeneous culture, took place in eastern North America, as Skinner thought. Such a vision seems almost as crude as the older views of the so-called Aryan race and language group. I can see no urgent reason as yet for adhering to a dogma of unity of original speech, race and culture for populations so widely spread and diverse. An Algonkian culture can be found in Labrador, another one in the Wabanaki area, another one in the Great Lakes region, each having certain claims to consideration as an archaic one. The same is true of physique and when we come to include the evidence of language we do not find that the

most archaic type of speech adheres to any one of these classified types.

It is not easy to think through clearly to a conclusion in the face of so many serious gaps in our existing knowledge of physical and linguistic variations within the Algonkian group. Final treatment of the whole question, therefore, will have to be deferred despite the eagerness of some ethnologists to predict conclusions. Let it become clear that we cannot logically speak any more of the Algonkian as an integral unit, referring to language, race and culture. We are indeed getting farther away from the unity concept the more our knowledge expands. Within the Algonkian language group we know there are several physical types, and some variant culture types along its margins. We have to hesitate in our efforts to draw conclusions in the presence, for instance, of the apparent fact that Algonkian languages have invaded the plains without effecting culture modifications toward an Algonkian pattern, and similarly again in the southeast. Likewise, by contrast, other linguistic units have invaded Algonkian linguistic boundaries without changing their speech, and yet have come to harmonize their culture qualities with those of the region, for example the Siouan Winnebago, as shown by Morgan, Radin, Wissler, Lowie, Speir, and Skinner, and, may we not add, in physical and economic aspects, certain of the Iroquois (Mohawk). As radical as the assumption may seem just now, it is even possible to attribute certain Algonkian-Iroquoian similarities in head-form, stature, in bone work, even ceramics, in dress and decorative art motives, in the use of bark, even in some aspects of social life, to the absorption of an older stratum of northeastern culture, call it Algonkian if need be, on the part of invading Iroquoian-speaking populations. We have evidence, as I have again undertaken to show in a recent paper, of an acculteration of Algonkian principles in social organization among the Oka Iroquois, who invaded the Algonkian of the Ottawa valley in very recent times. In such an assumption we can at least conceive grounds for admitting the evidence produced, for instance, by Skinner of a centrifugal migration of the older Algonkian into the Great Lakes region of Wisconsin in fairly recent times, under the impact of Iroquoian invasion, and, I would add, for another similar eastward shift, into southern New England, of a partly "Iroquo-

ianized" Algonkian-speaking group. It would not be denied, I believe, that there has taken place in Iroquoian history, a modification along certain economic lines toward a northern type of life,—in this case an Algonkian one, since there is no other to fit.

Now, as we pause to consider where, then, the nearest approach to unity in the three basic requirements;—old physique (*i.e.*, cranial form), nomadic, cold-fauna, hunting culture and Algonkian language may be found, the way points itself out to the region south of the St. Lawrence from northern New England east to the Atlantic and Newfoundland. In this area we have a general modern as well as early dolichocephalic population, according to the compilations of Boas, and Dixon. We have, moreover, the indications of an unelaborate interior hunting culture brought to light through the investigations of Willoughby and Moorehead. We also have in the Newfoundland area another archaic culture level in the Beothuk type. In respect to the ethnology of the modern peoples, the Wabanaki, of this area, we have an old northern culture form. Linguistically the Wabanaki tribes form a unit in the broader sense, which has primitive characteristics, somewhat specialized in phonetics and morphology, but according to Michælson, not so pure in form, as in the regions occupied by the central Algonkian-speaking group. In short, if we lift off the top layer of Iroquoian culture influence (in agriculture, political organization, chieftaincy, social ceremonies, and certain influences in mythology) dating only back to the seventeenth century, from the Wabanaki area we get a stratum in which the requirements approach unity to a degree which would permit us to use the term palæo-Algonkian in referring to it. I have adopted this term in consideration of a similar usage for industrial levels in the Old World in general and through the sanction of usage by Steensby in reference to the Eskimo problem. North of the St. Lawrence a generally similar culture level is found with a somewhat more Arctic complexion, and specialized linguistic developments appear, which are not shared by the also specialized types south of the St. Lawrence. In these respects the Montagnais-Naskapi of the Labrador region may, I think, be included within the palæo-Algonkian horizon, but we are obliged to recognize the intrusion of another cranial form into this zone, the meso- and meso-brachycephalic type. To what extent these

phenomena appear, either clinging together or separated, as we proceed westward below and beyond the Hudson Bay region, it is impossible to say. And until investigation has covered these points it will be impossible to locate the termini any more definitely. We shall then know to what extent the archaic culture level may have been spread from the Atlantic to the Great Lakes and beyond, and into the semiarctic zone, and to determine where and to what degree its margins were indented by culture invasions on the south and on the northwest, and finally to form some idea of the culture character resulting from the absorption of the old level by penetrating streams from the more southern portions of the continent, illustrated, for instance, by my suggested explanation of the Iroquoian situation.

And finally we may undertake to construct a picture, duly realizing that of course at present nothing can be said difinitely that may not be modified and corrected. First, a not greatly differentiated northern, hunting population, long-headed by contrast with the later inhabitants,—ancestors of the Eskimo and Algonkian one could say—existed in the interior west of Hudson Bay in the steppes and thinly forested regions. An early pressure of invasion from Asia tends to push these groups eastward, one branch of them advancing to the Arctic coast and developing to form in time the Eskimo type, race and culture, the other adhering to the interior environment and moving eastward in the familiar setting working south of the St. Lawrence to become founders of an old culture there. These latter carried the lower cephalic index to the region of northern New England and the Maritime Provinces. Dixon has in several instances previously expressed his opinion of a scheme of migration bringing Algonkians in several waves to the east. The preference for the south St. Lawrence route might be answered for by the unfavorable hunting prospects of the Labrador region at the time of the migration, due to the recency of its clearance from glacial conditions. A greater antiquity for the human occupation of the Atlantic coast of Maine than for the gulf coast of Labrador is shown by the much greater depth of the layers of shell-deposits in Maine. And besides the archaic, so-called Red Paint, culture of the interior of Maine has to be considered in chronology. The botanical affinities of Newfoundland with the coastal fringe of the northern part of the continent

south to New England are impressing American observers more and more. Such a view affects our problem by strengthening the idea of early human occupation over the same south St. Lawrentian area as a more favorable early distributional zone, while the route of life-diffusion on the Labrador side was blocked by unfavorable after-conditions of the pleistocene. Next, the broader-headed Indian population all the way across the subarctic zone may be tentatively explained as an arrival in the whole expanse of country from the westward, filling, we may imagine, the either unpopulated or sparsely populated Labrador regions. This entered, we are still indulging in guesses, carrying a subarctic phase of life eastward, one somewhat parallel to that which entered much earlier and became domiciled south of the St. Lawrence as the longer-headed type. A word of caution must be said before we can speak too definitely of head-form among the Eskimo and Indians as showing distinct contrasts. The northern Indian at least appears to have been of a broader-headed type, by contrast with that south of the St. Lawrence, according to the published records of Boas, Dixon and Wissler and the recent measurements of Hallowell, and the same is true in reference to its contrast with the eastern Eskimo. Recent Eskimo lists published by Jenness, however, both on cranial material and on the living, show the living populations to have a higher index, thus lessening the contrast and creating a feeling that with a fuller series of measurements from both groups another attitude could be taken on the matter of Indian and Eskimo classification. At the present awaiting challenge, it stands, as stated by Dixon, that there has been a brachycephalization of the north, the brachycephals relentlessly supplanting the dolichocephals who were driven to the marginal area.

PROGRESS IN THE STUDY OF RACE MIXTURES WITH SPECIAL REFERENCE TO WORK CARRIED ON AT HARVARD UNIVERSITY.

By EARNEST A. HOOTON, B.A., M.A., Ph.D., B.Litt.

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The study of race mixtures is perhaps the most important field of research in Physical Anthropology to-day. The term "race" as applied to man has recently been defined by the writer as follows:[1]

> A race is a great division of mankind, the members of which, though individually varying, are characterized as a group by a certain combination of morphological and metrical features, principally non-adaptive, which have been derived from their common descent.
>
> A primary race is one which has been modified only by the operation of evolutionary factors, including the selection of its own intrinsic variations and of the modifications, adaptive or non-adaptive, possibly caused by environmental stimuli.
>
> A secondary or composite race is one in which a characteristic and stabilized combination of morphological and metrical features has been effected by a long-continued intermixture of two or more primary races within an area of relative isolation.

Obviously the present population of the world consists, for the most part, of secondary or derived races. Man is a migratory and promiscuous animal, and a primary race, as defined above, is well-nigh an anthropological abstraction. The existing races of man, however, may be grouped according to their mutual physical affinities in the following four classes: (*a*) Whites (often regrettably called "Caucasians"), (*b*) Negroids, (*c*) Mongoloids, (*d*) Intermediates. Each of these classes includes at least three races. The White group comprises the Alpine, Armenoid, Mediterranean and Nordic races, and possibly others. The Mongoloid class consists of the Mongoloids proper, the Indo-Malayans, the American Indians. The Negroids include the African Negroes, the Melanesian-Papuans, and the Negritoes. The residual Intermediate class is made up of

[1] Hooton, E. A., Methods of Racial Analysis, *Science*, January 22, 1926, lxiii, 76.

three more or less allied races—the Ainos, the Dravidians and the Australians, and of the Bushmen-Hottentots and Polynesians who are somewhat removed from the preceding subgroup and from each other. The principal characteristic of the Intermediate class is that its constituent races are in no case predominantly White, Negroid, or Mongoloid, but each exhibits distinct resemblances to two or more of the preceding classes in association with features, in some

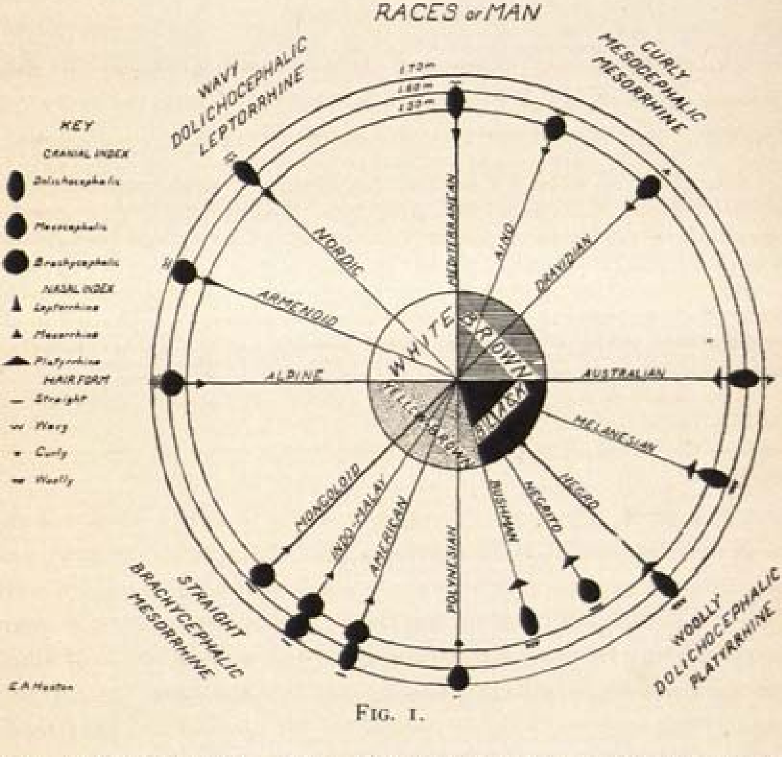

FIG. 1.

cases, peculiar to itself. Most of the races in this group are probably the stabilized result of radical hybridizations, but the Australians and the Aino may represent the surviving elements of ancient and in some respects generalized races. Fig. 1 is an attempt to show the approximate relationships of modern races classified on the basis of combinations of hair-form, cranial index, nasal index, pigmentation and stature. This diagram was drawn up for class-room use and does not represent a scientific contribution. The plotting of char-

acters is based upon modal or mean values which in some cases rest upon inference rather than upon observation. The figure is introduced here to illustrate the manner in which one racial complex of physical criteria shades into another, and particularly to show the positions of those racial groups which have been called "Intermediates."

It is apparent from the study of Fig. 1 or from the examination of any scheme of classification of modern races that racial mixtures are of two categories: (*a*) radical mixtures between races physically far removed from each other, and (*b*) mixtures between allied races. Mixtures within the White races or within the Negroid races, for example, involve matings of types physically more similar than in the case of crossings between Negroid and White races. Because of the absence of obvious dissimilarities in the physical traits of the intermingling stocks, race mixtures between allied races have occurred from prehistoric times down to the present day without inciting, for the most part, either social prejudice or anthropological investigation. The offspring of such matings do not form physical types sufficiently distinct to set them apart as a class. Such offspring tend to be absorbed into one or other of the parental stocks. The inheritance of physical characteristics in such crosses is nevertheless of great interest and it is probable that hybrid vigor may manifest itself physically, mentally and culturally in the more favored offspring of such matings. Unfortunately, however, the habit of miscegenation between allied races is of such long standing that it has resulted in obscuring the original physical combinations in the parent races by the establishment of countless mixed types representing various degrees of admixture of the parent stocks and manifesting a series of almost imperceptible gradations between one racial combination and another. The ultimate effect has been an obliteration of the distinguishing characteristics of allied races which makes it almost impossible to ascertain what the original combinations were. It is even more difficult to find considerable groups of people who are unmixed with allied races and conform to our definition of primary racial types. It is doubtful whether many such representatives of primary races exist at the present time. It therefore seems that it is no longer possible to study the effect of the

intermixtures of closely allied races with any hope of clear-cut scientific results.

On the other hand radical race mixtures involve the interbreeding of parental stocks with strikingly dissimilar physical features. The offspring often constitute types obviously different from either of the parental races, although sharing in some of the features of each. Such crosses attract attention and arouse social prejudice. They even raise the question as to the biological efficiency of the resulting hybrid types, which are sometimes said to be "disharmonic." Radically different races as a rule have produced dissimilar cultures and diverse social traditions. Many infer from the association of physical and cultural differences between races the existence of equally diverse racial mental qualities, although these have never been demonstrated in any scientific way. At any rate, the hybrid resulting from the intermixture of radically different racial stocks is likely to be regarded as a physical and social anomaly—a sort of anthropological bastard, except in the event of these crossings having taken place in an area of isolation and between such great numbers as eventually to establish a secondary or composite race.

Radical race mixtures have long been "viewed with alarm" by statesmen, sociologists and anthropologists. Many of those who have been disturbed at the social consequences of such crossings have consoled themselves with a pious hope that human hybrids would prove to be like mules, "ornery but sterile." That this hope is illusory has been amply demonstrated wherever radical crossings occur in sufficient numbers to receive even the inadequate attention of the census-taker. It is now becoming apparent to the public at large that the investigation of the consequences of radical race mixtures has more than a purely academic interest. It is obvious that data of scientific worth should be secured to enable us to answer the following questions:

1. How do radical hybrids compare with their respective parent stocks in fertility and vitality? What is the rate of increase in each case?

2. How do radical hybrids compare with their respective parent stocks in regard to mental characteristics?

3. What is the status of such hybrids with respect to social efficiency and economic and political stability?

4. Do such hybrids when produced in large numbers tend to form a buffer class or to be assimilated by one or other of the parent stocks, and in either case what are the sociological and biological consequences?

5. How are physical and mental characters inherited in such hybridizations?

These questions cannot be answered satisfactorily on the basis of any existing data. To awaken interest and to secure support for the necessary investigations has been a slow and difficult process. Some few still small scientific voices have been crying in the academic wilderness for many years; and latterly not a few journalists have been bellowing in the market-places. The former have effected the accomplishment of a number of small but valuable researches upon the results of race mixture, and the latter have made possible the public support which is essential for further and more conclusive investigations.

The principal object of this paper is to report progress upon a number of investigations of race-mixtures which have been carried on by or through the influence of the Division of Anthropology of Harvard University. Most of these researches have grown out of interest awakened in students or colleagues as a result of a course in race-mixture which was first offered by the writer in Harvard University in 1916. The data of most of these investigations have not been collected by the writer personally, who confesses himself to be one of that drab female type of anthropologist which remains at home and reproduces the species while the more brilliant male roves abroad in quest both of adventure and of food to be brought back for home consumption.

Investigations Completed.

Study of Hawaiians, Pure and Mixed. In the course of two visits to the Hawaiian Islands during the years 1916 and 1920, my colleague, Professor A. M. Tozzer, collected anthropometric and sociological data on 508 subjects, including pure-blood Hawaiians and various admixtures of the Hawaiians with Chinese, Japanese and a variety of European racial stocks. The anthropometric data have been analyzed by Dr. L. C. Dunn, who has already published

a preliminary report on a portion of the material [2] and will shortly publish his results in full. It is a matter of common knowledge that the native Polynesians in these islands are mixing with alien stocks so rapidly that full-blooded Hawaiians will soon cease to exist. The complexity of the racial crosses is already quite bewildering. Dr. Tozzer was able to secure measurements on a large number of F_1 hybrids and upon a considerable number of back-crosses, but upon a few F_2 offspring only, and these, for the most part, immature individuals. Dr. Dunn has emphasized in his study the respectable series of full-blooded Hawaiians and the considerable number of Hawaiian-Chinese mixtures. The pure Hawaiians are tall, heavy people with prevailingly wavy hair and pronounced brachycephaly. The Southern Chinese with whom they have mixed are considerably shorter, with straight hair and a tendency toward dolichocephaly. The resulting hybrids are intermediate in stature and there is a clear dominance of brachycephaly and straight hair. In the first generation hybrids resulting from crosses with Europeans, the darker pigmentation of the Polynesian stock appears to be dominant and there is no hybrid vigor displayed in stature. The corpulence of the pure Hawaiians disappears and the more finely-cut European features tend to assert themselves. The few F_2 individuals studied seem to indicate some tendencies toward segregation of characters, but there is not sufficient evidence available to settle this question. The present writer does not wish to forestall the important results of the investigation of Doctors Tozzer and Dunn. These results include some extremely interesting information upon the inheritance of bodily characters and upon the fertility and vitality and social status of the hybrids.

A much more extensive study of race mixture in Hawaiians was undertaken by the late Dr. Louis R. Sullivan of the American Museum of Natural History in collaboration with the Bishop Museum of Honolulu. This study includes observations upon several thousand individuals. Dr. Sullivan's premature death prevented the completion of his analysis of the data, but, fortunately,

[2] L. C. Dunn, "Some Results of Race Mixture in Hawaii," Eugenics in Race and State, Vol. II, Second International Congress of Eugenics, Baltimore, 1923, pp. 109–124.

this work is now being carried out to its conclusion by Dr. Clark Wissler.

The publication of these two studies of race mixture in Hawaii will make available to science a mass of material on miscegenation between Polynesians and White and Mongoloid racial stocks. Both of these investigations indicate a high fertility in the mixed marriages studied.

Pitcairn Islanders and Norfolk Islanders.—In 1789 the crew of the British warship Bounty mutinied, and soon afterwards a colony was established on Pitcairn Island in the South Pacific by the mutineers and by a number of Polynesians whom they had brought with them to the island. The romantic story of the mutiny and of the bloody events which transpired after the foundation of the colony is well known. From the intermixture of about six English sailors and approximately the same number of Tahitian women there arose a hybrid progeny which has inbred for about five generations. The larger number of these people now reside on Norfolk Island whither the colony was removed after Pitcairn became too small for its maintenance. There are about 400 persons in the colony on Norfolk Island and about 175 members of the group which returned from Norfolk to Pitcairn. These Polynesian-European hybrids constitute an almost ideal sample for the study of race mixture, since their European antecedents are fairly well known and they have been so isolated that little back-crossing has occurred. They represent the intensively inbred progeny of primary crossings.

In 1923 Harry L. Shapiro, one of the most able of the graduate students of Anthropology then at Harvard, set out to study this racially mixed group. This research was aided by a fellowship granted to Mr. Shapiro by the Bishop Museum of Honolulu, and the results of the investigation are now in process of publication by that institution. Mr. Shapiro's ship was prevented from calling at Pitcairn by bad weather, but he proceeded to Norfolk Island and remained there for about four months. During this time he secured anthropometric data on about 150 adult descendants of the mutineers, in addition to full genealogical information and some extremely important historical and sociological material. During his stay on Norfolk Island Mr. Shapiro gained the confidence and affec-

tion of these sensitive and reserved people to such an extent that upon his leaving they presented to him as a parting gift a Tahitian poi-pounder, the property originally of one of the Polynesian ancestresses of the group and said to be the only native artifact which has been preserved from the wreck of the Bounty.

The analysis of the data collected by Mr. Shapiro provides no support for the statements that have been made with respect to the alleged physical and mental deterioration of these inbred hybrids. On the contrary they manifest hybrid vigor in certain characters. They exceed both of the parent stocks in stature and their head diameters are among the largest means recorded for living peoples. Contrary to what seems to be the case in Hawaiian-European and Hawaiian-Chinese hybrids, the Norfolk Islanders show a tendency toward dolichocephaly. The features of these people are predominantly European, although a characteristically hybrid nose was often observed. The hair is usually very dark and the skin color is intermediate between that of brunet Europeans and that of the brown Polynesians. There is much individual variability and, curiously enough, more curly hair is found among these Norfolk Islanders than among either British or Tahitians.

Anthropologists may expect from the publication of Dr. Shapiro's studies of the Norfolk Islanders material not inferior in interest and importance to Professor Eugen Fischer's classic work on the Hottentot-Boer hybrids.

Studies of Skeletal Material.—For the past ten years the research efforts of the writer have been directed principally toward the solution of the problem of distinguishing racially pure and mixed types in the analysis of skeletal material of archæological origin. The absence of genealogical data and the paucity of historical data render this task very difficult. Two principal investigations have been undertaken. The first, an analysis of the racial elements among the extinct peoples of the Canary Islands, was based upon a study of some 450 crania. The results of this investigation have already been published.[3] They are of interest from a methodological standpoint and particularly from the light shed upon the

[3] E. A. Hooton, "The Ancient Inhabitants of the Canary Islands," Harvard African Studies, Cambridge, Mass., 1925, Vol. VII.

affinities of the so-called "Cro-Magnon race," which is supposed to have been represented in the Canarian archipelago.

The second investigation involves the study of the skeletal remains from more than 1,800 burials excavated at the ruined Indian pueblo of Pecos, New Mexico, by the Andover Pecos Expedition. Most of these skeletons are dated according to stratigraphic sequence. The problem in this case is to study the changes in the population which have taken place in the course of the two thousand or more years of the pueblo's occupation and to distinguish the various subtypes which are represented in this sample of the American race. It is perhaps an effort to single out the component types of a composite race, rather than a study of race-mixture. This work has been carried out with the assistance of a number of graduate students and is almost finished. The results will be published by Phillips Andover Academy.

Investigations now in Progress.

Study of Mulatto Families.—Our knowledge of the results of crosses between Negroes and Whites in the United States is deplorably small. Up to the present time no adequate anthropological study of the American Negro has been published. Dr. Melville K. Herskovits of Columbia University has recently carried out extensive anthropometric researches upon Negroes and mulattoes of Harlem, New York City, and upon the students of Howard University, Washington, D. C. Dr. Herskovits has already published some preliminary results of great value and his completed contribution to the knowledge of this subject is eagerly awaited by anthropologists conversant with the methods he is employing.

In 1917 Caroline Bond (now Mrs. Day), a student at Radcliffe College, began to collect for the present writer anthropometric, genealogical and photographic data pertaining to mulatto families. Mrs. Day is unusually qualified for this task since she herself has Negro and Indian blood and comes of a family which has long been associated with the higher education of the Negro. Consequently, she has a very extensive acquaintance among the educated and well-to-do colored people of the United States. The present writer considers the genealogical data already collected by Mrs. Day quite

unique and invaluable. They include in some instances photographs or copies of portraits of members belonging to five generations of a family, together with information as to the proportion of Negro, White, and Indian blood in each individual. Hair samples of living individuals and anthropometric measurements are also included. Unfortunately, after Mrs. Day left Radcliffe College the work had to be stopped, owing to lack of funds. At the beginning of the present year the Bureau of International Research of Harvard University and Radcliffe College, established by the Laura Spellman Rockefeller Memorial Fund, undertook to finance studies of the anthropological and sociological effects of race mixture under the direction of the writer and of his colleague, Professor A. M. Tozzer. This assistance has made it possible for Mrs. Day to devote full time to the gathering of data during the present year. The work is proceeding apace, but the analysis of material will not begin for a year or more.

It has long been the opinion of the writer that reliable data on Negro-White crosses in this country can best be secured by the utilization of competent colored investigators. He has obtained from Mrs. Bond and from other colored students much new information concerning the inheritance of physical characters in such mixtures, all of which, however, requires confirmation from mass studies before it can be presented as final.

Studies of Finns, Lapps, and of Crosses between Finns, Lapps and Swedes.—At the beginning of last summer Martin Luther, a graduate student in Anthropology at Harvard, began an investigation of the colony of Finns living at Lanesville and Rockport, Massachusetts. Mr. Luther was particularly interested in the occurrence and causation of a certain flattening of the posterior portions of the parietals, which is found in these peoples and also in Armenoids and in some other stocks. This we suspect to be an effect of race mixture. In addition to regular anthropometric data, Mr. Luther has secured an elaborate series of cranial contours, facial casts, blood samples and tests of manual dexterity from a series of 160 adults and more than 60 children and adolescents of these localities. Nor has he neglected sociological data which bear upon the problem of assimilating these immigrants. It seemed advantageous during the present summer

for Mr. Luther to extend his material, and for this purpose he was sent to Finland and Lappland under the auspices of the Bureau of International Research. In Finland Mr. Luther is receiving the heartiest coöperation on the part of anthropologists and government officials, and at present writing has secured anthropometric data and sociological information on 130 adult Finns and 104 adult Lapps. Before his return in the fall he will have gathered much more ample material. It is planned to continue the collection of observations pertaining to these peoples until the end of the present year and to begin the analysis of data at that time.

Study of Berbers, Arabs, and Mixed Types of Morocco.—Little is known of the anthropometric characters of the Berbers and Arabs of Morocco. Apparently no anthropologist has studied the physical features even of the sedentary town dwellers within the comparatively quiet zone of the Sultan's influence. The physical anthropology of the independent tribes is practically unknown. The Rif Berbers, who have put up such a magnificent struggle for independence against overwhelming odds, are known to include a very large blond element which is said to be indistinguishable in most respects from the racial type commonly called "Nordic." Blonds have existed in Northwest Africa from prehistoric times. It is in the area where this type occurs most frequently that the most democratic tribal and village organization is found. Here also the love of individual and group independence is associated with personal pugnacity and collective belligerency. Race mixtures here include crosses between most of the White races and also various Negroid types. The possible relation of such mixtures of peoples to the political turbulence which commonly prevails in this area is worthy of investigation.

Carleton S. Coon, a graduate student in Anthropology in Harvard University, has been sent to Morocco under the auspices of the Bureau of International Research to spend a year in investigating the anthropometric and sociological characters of the pure and mixed racial types. Mr. Coon is well qualified for this work, having made two previous trips to Morocco for archæological and anthropological purposes, and possessing a knowledge of Arabic. In the course of these earlier expeditions he was able to make some valuable

archæological reconnaissances and to establish relations with natives and with French officials which should facilitate his present work. Mr. Coon has been in Morocco less than two months at present writing, and has already succeeded in obtaining complete measurements and photographs of about 114 Rif Berbers. These data were gathered in Tangier. Latest information is to the effect that Mr. Coon has been obliged to relinquish his plans for work in the Spanish zone of Morocco, owing to the marked discourtesy and even violence shown him by the Spanish authorities in that area.

It is hoped that this year of field work in Morocco will result in the collection of representative series and tabulated sociological data pertaining to each of great Berber groups in Morocco; namely, the Rifi, the Shluh, the Breber, and the Arabs.

An independent but related research in Algeria and Tunisia is being carried on by Homer Kidder, a former student of Anthropology at Harvard and one of the founders of the American Folk-Lore Society. Mr. Kidder has obtained measurements on more than 300 Tunisian Jews and is now extending his studies to the Kabyles of Algeria.

Investigations in Prospect.

Study of Mixed and Pure Types in Mexico and Central America.—The plans for the study of race mixture under the auspices of the Bureau of International Research include an investigation of mixed and pure racial types in Mexico and Central America. In this area the crosses between Indians, Whites, and Negroes are of great interest in their relation to the cultural status of the various elements in the population and the notorious political unrest which prevails there. It is proposed to send Dr. George D. Williams, a graduate student of Physical Anthropology in Harvard University, to collect data pertaining to these peoples. Dr. Williams expects to begin work next February and to remain in the field for the better part of a year. He will pay particular attention to the pathology of races and mixed types in this area.

Study of Peoples in Egypt and the Sudan.—Another graduate student of Anthropology, Walter B. Cline, has just been sent to Egypt for a year of field work under the auspices of the Harvard African Studies and of the Peabody Museum. Mr. Cline's primary

object is to study the palæolithic deposits of the Nile Valley and of the adjacent desert areas, but he also hopes to gather anthropometric and ethnological data pertaining to some of the tribes of the Eastern and Libyan deserts, with particular reference to crossings with Arab strains.

Concluding Remarks.

This paper has been devoted principally to accounts of the studies of races and race mixtures carried on by students or members of the Division of Anthropology of Harvard University. But it also includes mention of a number of related investigations which are being carried on by other anthropologists. It does not aim to be exhaustive in this respect.

There are two very encouraging aspects of the situation in regard to racial studies. The first is the interest in such projects exhibited by great research foundations. From these foundations has come the financial support hitherto unobtainable. Until this year studies of race mixture at Harvard University have been carried on almost entirely at the expense of the investigators themselves, with the help of an occasional travelling fellowship. Now, with the aid of the Bureau of International Research, it has become possible to undertake more ambitious projects which should yield better results. But even this generous assistance has been insufficient for the paying of salaries to field workers. Those at present engaged in the gathering of data are receiving maintenance and travelling expenses only. This fact introduces the second encouraging aspect of the situation, which is the availability of trained and competent young investigators.

A few years ago there was an almost complete lack of able students who were willing and equipped to undertake the arduous and ill-paid work of the physical anthropologist. Now a fair number of very promising young men and women are intent upon entering this profession. Our present needs are: continued and larger support for research upon racial problems, an increase in the number of permanent posts available for physical anthropologists in research institutions, and more chairs for the teaching both of Physical Anthropology and of other branches of Anthropology in our

universities. If these needs are satisfied the present writer is willing to predict that we can produce in this country a body of physical anthropologists, archæologists and ethnologists who in a decade will make greater progress in the solution of problems pertaining to the natural history and cultural history of man than their few hampered predecessors have been able to accomplish in the last half-century.

HARVARD UNIVERSITY.

EQUIANGULAR SPIRAL POLYGONS AS PRESENTING THEMSELVES IN ELECTRICAL ENGINEERING.

BY A. E. KENNELLY.

(*Read April 23, 1926.*)

DEFINITION.

The ordinary polygon may be defined, for present purposes, as a geometrical plane figure whose successive sides make equal angles with each other and have equal lengths, or lengths in a constant ratio of unity. The equiangular spiral polygon, here to be considered, may then be defined as a geometrical plane figure whose successive sides make equal angles with each other, and have lengths in a constant ratio, in general different from unity.

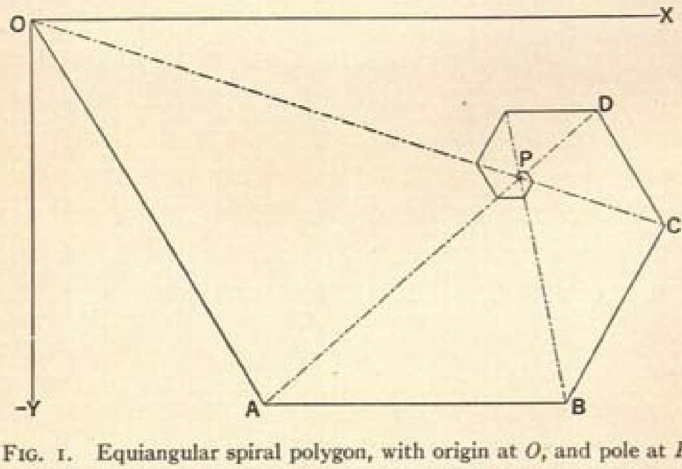

FIG. 1. Equiangular spiral polygon, with origin at O, and pole at P.

Thus in Fig. 1, starting from the origin of coördinates O, the successive sides OA, AB, BC, etc., are straight lines in the plane XOY. They make with each other equal angles OAB, ABC, BCD, etc.—in this case 120°—and the ratio of the lengths of successive pairs of sides

$$\frac{OA}{AB}=\frac{AB}{BC}=\frac{BC}{CD}=\cdots=a, \qquad \text{numeric (1)}$$

where a is a numerical constant, ordinarily greater than unity—in this case 1.493. The extension of this geometrical sequence terminates, after an infinite number of steps, in the final position or pole P of the equiangular spiral polygon.

There exist an infinite number of possible equiangular spiral polygons, both in regard to variations of contained constant angle, and to variations of constant ratio a.

It may be taken for granted that the essential geometrical properties of equiangular spiral polygons are known to mathematicians. Thus, the ratios of polar distances to the successive vertices of such a polygon, is also constant and equal to a. For in Fig. 1

$$\frac{PO}{PA}=\frac{PA}{PB}=\frac{PB}{PC}=\cdots=a. \qquad \text{numeric (2)}$$

Consequently, the successive plane triangles, OAP, ABP, BCP, CDP, etc., are all similar, and the ratio of such successive areas is

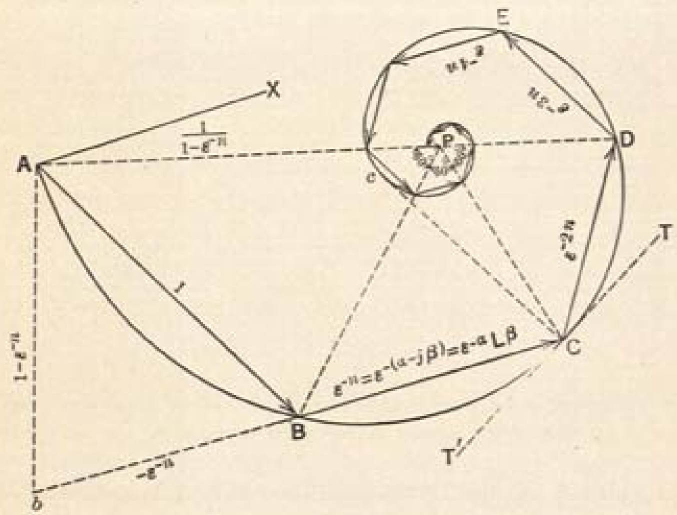

FIG. 2. Spiral polygon of vector ratio ϵ^{-n}, with origin at A, and reference axis AX, with geometrical method for determining the position of the pole P.

a^2. Moreover, the envelope of all the vertices of an equiangular spiral polygon is an equiangular spiral, as in Fig. 2, where the vertices $ABCDE$ of the polygon are enveloped by the contacting

external equiangular spiral. A similar internal equiangular spiral may also be drawn contacting with the sides *AB*, *BC*, *CD*, etc. These equiangular spirals possess the well known property, indicated in their name, that the angle between the polar radius vector at any point, such as *PC* in Fig. 2, makes a constant angle *PCT* or *PCT'* with the tangent *T'CT* at that point. Again, the angles at the pole subtended by the successive sides of the polygon, such as the angles *OPA*, *APB*, *BPC*, etc., (Fig. 1), are equal, in this case 60°.

Application to Electrical Engineering.

It is probable that such fundamental properties of equiangular spiral polygons have already been noted and reported by mathematicians; so that it is here proposed only to consider such polygons from the applied-science standpoint, and in particular to discuss their application to the theory of uniform alternating-current conducting lines, in the transient state of building up to a final steady voltage or current, after suddenly applying a sinusoidal electromotive force at the generating end.

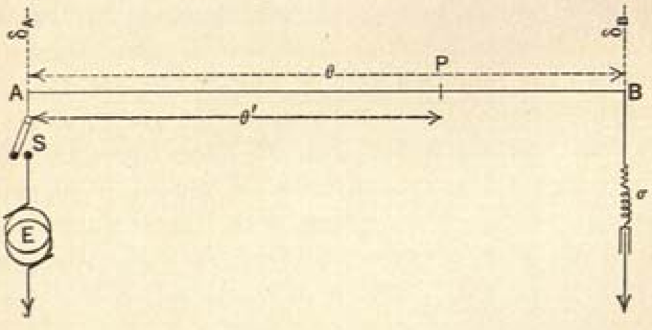

Fig. 3. Uniform line *AB*, energised at *A* through switch *S*, from an alternating current source of negligible impedance.

The subject of such regular initial alternating-current wave transients has already been discussed to some slight extent.[1] It is known that if the alternating e.m.f. is assumed to be impressed at the generating end of the line *AB*, Fig. 3, at a zero moment; *i.e.*, at a moment when the instantaneous value of the sinusoidal e.m.f. is passing through zero, so as to applied without electric "splash,"

[1] Bibliography 1, 3, and 5.

a succession of waves of alternating current and e.m.f. advance along the line at a speed commensurate with that of "light" in the dielectric used to insulate the line, that they are reflected from the receiving apparatus at B, and again from the generator apparatus at A, so that these waves, repeatedly reflected to and fro, merge towards the ultimate final state into the final steady value of voltage and current proper to each and every point along the line. It is also known that such successive steps of upbuilding towards the final state correspond to the successive sides of an equiangular-spiral polygon. It is here proposed to discuss, in somewhat greater detail than is believed to have yet been reported, the nature and properties of the polygons that pertain to particular cases.

Arrival of Successive Voltage Waves at a Point P on a Line.

In the transient state following the closure of the switch S, at A, Fig. 3, on some zero moment of e.m.f., the first voltage wave arriving at P, comes from A directed towards B. The second arrives from B, after reflection there, and is directed back to A. The third is a new reflection from A, directed towards B, and so on. Thus all the odd numbers of the series arrive at P from A; while all the even numbers arrive from B. The hyperbolic angular length of the line AB is taken as θ hyps $\angle$, and the angular distance of P from A, as θ' hyps $\angle$. If m_v is the vector transmission coefficient of voltage waves passed through the load σ when arriving at B,

$$m_v = \frac{2\sigma}{z_0 + \sigma}, \qquad \text{numeric } \angle \quad (3)$$

where σ is the vector impedance of the load, and z_0 is the surge impedance of the line at the impressed[2] frequency $\omega/2\pi$ cycs.

$$z_0 = \sqrt{\frac{r + jl\omega}{g + jc\omega}}. \qquad \text{ohms } \angle \quad (4)$$

The odd series of waves (1st, 3d, 5th, etc.) reaching P, if E is

[2] The term "cycs" is here used as an abbreviation of the phrase "cycles per second," connoting a frequency.

the rms. or effective value of the voltage applied at A, will be:

$$E\epsilon^{-\theta'}, E(1 - m_v)\epsilon^{-(2\theta+\theta')}, E(1 - m_v)^2\epsilon^{-(4\theta+\theta')}, \cdots, \quad \text{volts} \angle \quad (5)$$

while the even series will be:

$$E(m_v - 1)\epsilon^{-(2\theta-\theta')}, - E(m_v - 1)^2\epsilon^{-(4\theta-\theta')}, E(m_v - 1)^3\epsilon^{-(6\theta-\theta')}, \cdots, \quad \text{volts} \angle \quad (6)$$

The summation, term by term, of both series alternately, builds up to the final steady voltage at P.

It will be observed that in each of the series (5) and (6), the ratio of any one term to its predecessor is constant and equal to $(1 - m_v)\epsilon^{-2\theta} = \epsilon^{-2\delta_A}$, a planevector or complex number. This means that each series may be represented by a spiral polygon, and the polygons are similar, having the same vector ratio.

The vector sum of two similar spiral polygons, taken step by step, alternately from each, is itself another similar spiral polygon. The final voltage ultimately built up at P in the steady state is the vector voltage, drawn to the pole of the summation polygon.

We may describe the spiral polygon representing the series of voltage waves arriving at P from A, as the A-voltage polygon, and that representing the series from B, as the B-voltage polygon, while the combination or summation polygon of alternate waves from each end, may be termed the AB-voltage polygon.

Arrival of Successive Current Waves at a Point P on a Line.

During the initial transient state, the successive current waves arriving at P, from A towards B are:

$$I_0\epsilon^{-\theta'}, \; I_0(m_c - 1)\epsilon^{-(2\theta+\theta')}, \; I_0(m_c - 1)^2\epsilon^{-(4\theta+\theta')}, \; \cdots, \quad \text{amperes} \angle \quad (7)$$

where I_0 is the initial outgoing current at A, or E/z_0 amperes $\angle$, and m_c is the vector transmission coefficient of current waves arriving at B, and delivered through the load σ. The value of m_c is:

$$m_c = \frac{2z_0}{z_0 + \sigma}. \qquad \text{numeric} \angle \quad (8)$$

The coefficients m_v and m_c, in any given case, are so related that

$$m_v + m_c = 2, \qquad (9)$$

or

$$m_c - 1 = 1 - m_v. \tag{10}$$

Similarly, the successive current waves arriving at P from B, are:

$$I_0(m_c - 1)\epsilon^{-(2\theta-\theta')}, I_0(m_c - 1)^2\epsilon^{-(4\theta-\theta')}, I_0(m_c - 1)^3\epsilon^{-(6\theta-\theta')}, \cdots.$$

amperes $\angle$ (11)

In each of the series (7) and (11), the ratio of any one term to its predecessor is $(m_c - 1)\epsilon^{-2\theta} = \epsilon^{-2\delta_A}$. This is the same ratio as in series (5) and (6). Consequently series (7) and (11) are both spiral polygons, and they are similar. Moreover, they are similar to the voltage spiral polygons.

The actual process of building up of current waves at P is by alternate terms from the A and B series. This gives rise to an AB current polygon.

Time Interval Between Successive Waves Arriving at P.

If the angle subtended by a uniform conducting line L km. long, in the steady state, at a given impressed frequency f cycs, is:

$$\theta = \sqrt{ZY} = \sqrt{(R + jX)(G + jB)} = \theta_1 + j\theta_2 = L(\alpha_1 + j\alpha_2),$$

hyps $\angle$ (12)

where Z is the total impedance of the conductor in mhos $\angle$, and Y is the total admittance of its dielectric in mhos $\angle$; then the interval of time, T seconds, required for a wave of voltage or current at this frequency f cycs to traverse the line in either direction is:

$$T = \frac{\omega}{\theta_2}, \qquad \text{seconds (13)}$$

$\omega = 2\pi f$, being the impressed angular velocity in circular radians per second, and θ_2 being the imaginary component of θ, in circular radians. The apparent velocity, or group velocity, of the waves is also known to be:

$$v = \frac{\omega}{\alpha_2}. \qquad \text{km./sec. (14)}$$

If the point P is situated midway between the two ends of the line, the successive A and B waves of voltage or current will succeed each other at uniform and equal intervals of time. If however, the point P is placed near to one end, say near to B, the interval of time between an A wave and the B wave its next successor, will be relatively short; whereas the interval between a B wave and the A wave its next successor, will be relatively long. If, moreover, the point P is moved up to the end B, the A and B waves will coincide, or double up on each other. The AB polygon will then be the same as either the A or B polygon; but to a doubled scale of magnitude.

On Locating the Pole of a Spiral Polygon, Having Given Any Pair of Successive Sides.

In Fig. 2, let AB and BC be a pair of given successive sides of a spiral polygon. The length of AB may be taken provisionally as unity. The vector value of BC is given as

$$\epsilon^{-n} = \epsilon^{-(\alpha - j\beta)} = \epsilon^{-\alpha}\cdot\epsilon^{j\beta} = \epsilon^{-\alpha} \angle \beta \quad \text{numeric } \angle \quad (15)$$

where ϵ is the base of Napierian logarithms, $\epsilon^{-\alpha}$ is the length of BC in terms of AB as unity, while B is angle of BC with the direction of AB, in circular radians.

The next side CD will then be ϵ^{-2n}, DE being ϵ^{-3n}, and so on. The vector distance of C from A will evidently be $AC = 1 + \epsilon^{-n}$. AD will similarly be $1 + \epsilon^{-n} + \epsilon^{-2n}$. It follows that the vector distance AP, from the starting point to the pole of the polygon, will be:

$$1 + \epsilon^{-n} + \epsilon^{-2n} + \epsilon^{-3n} + \cdots = \frac{1}{1 - \epsilon^{-n}}. \quad (16)$$

To find this vector distance AP, we produce CB back to b, so that $bB = BC$. We thus have $Bb = -\epsilon^{-n}$, and $Ab = 1 - \epsilon^{-n}$. We then take the planevector reciprocal of Ab, and this is equal to AP in magnitude and phase, or in size and slope. The angles PAB and BAb are equal; while the length AP is the reciprocal of the length Ab, or

$$\frac{Ab}{AB} = \frac{AB}{AP}. \quad \text{numeric } \angle \quad (17)$$

The points A, B, C, D, $\cdots$, etc., forming the vertices of the equiangular polygon, lie upon the equiangular or logarithmetic spiral $ABCD$. The constant angle ϕ of this spiral, or the angle between the polar radius vector and the tangent at any point, is the angle PCT. This angle is defined by the relation

$$\tan \phi = \frac{\beta}{\alpha}, \qquad \text{numeric} \quad (18)$$

β being expressed in circular radians and α in hyperbolic radians.

In the case represented by Fig. 2

$$-n = -\alpha + j\beta = -0.2825 + j\frac{\pi}{3} = -0.2825 + j1.0472, \quad (19)$$

so that

$$\tan \phi = 1.0472/0.2825 = 3.7069$$

and

$$\phi = 74^\circ\, 54'. \quad (20)$$

This angle ϕ is therefore the negative slope of the vector n.

Another equiangular spiral of the same slope might also be drawn on the internal side of the polygon $ABCD$. It would contact with the successive sides of the same.

Voltage and Current Polygons for the Case of a Freed or Grounded Line.

It is evident that the vector ratio of successive terms in series (5) and (6) or (7) and (11),

$$(1 - m_v)\epsilon^{-2\theta} = (m_c - 1)\epsilon^{-2\theta} = \epsilon^{-2\delta_A} \quad (21)$$

is of the same type vectorially as ϵ^{-n} in Fig. 2. It is directly connected with the position angle δ_A of the generating end A, and it is evident that the values of α and β depend on the transmission coefficient m_v or m_c of the load, as well as on the angle θ of the line. Both θ and the coefficient must be known in any given case, before the corresponding spiral polygons can be assigned. If, however, we free the line at B, so that $\sigma = \infty$, we have $m_v = 2$, and $m_c = 0$; while $(1 - m_v) = (m_c - 1) = -1$; on the other hand, if we ground the line at B, $\sigma = 0$, we have $m_v = 0$, and $m_c = 2$; so

that $(1 - m_v) = (m_c - 1) = +1$. In the former case, the vector ratio of successive waves of either voltage or current becomes

$$\epsilon^{-n} = -\epsilon^{-2\theta} = -\epsilon^{-2\theta_1 - j2\theta_2} = \epsilon^{-2\theta_1} \angle \pi - 2\theta_2. \quad \text{numeric} \angle \quad (22)$$

Hence each wave (*A* or *B*) of voltage or current bears to its predecessor the size ratio $\epsilon^{-2\theta_1}$, and the slope or phase difference of $\pi - 2\theta_2$ radians.

Equiangular Voltage Polygon at *B* of an Eighth-wave-Length Line Freed at *B*.

We may consider the simple and interesting case of a line *AB*, Fig. 3, freed at *B*, or with $\sigma = \infty$, and energized at *A*, on a zero instant, the line being just one eighth of a wave-length for the impressed frequency, and the successive voltage waves being reckoned at the free end.

The angle of the line may be taken as

$$\begin{aligned} \theta &= 0.34658 + j0.7854 = \theta_1 + j\theta_2 \qquad \text{hyps} \angle \\ &= 0.34658 + j\pi/4 \\ &= 0.34658 + \underline{j0.5}. \end{aligned}$$

Here $\theta_2 = \pi/4$ circular radians, or 1/2 circular quadrant.[3] If the sinusoidal e.m.f. *E*, impressed at *A*, has a maximum cyclic amplitude of ± 1.414 volts, or an effective value of 1.0 volt and rms. (root mean square), assumed as of standard phase; then the first wave arriving at *B* will be $1.0\epsilon^{-\theta} = \epsilon^{-0.3466} \overline{\angle}\, 45° = 0.707 \overline{\angle}\, 45°$ volt. This is the first *A* wave. It is instantly followed by an equal *B* wave reflected from the open end. The result is a doubled or *AB* wave of $1.414 \overline{\angle}\, 45°$ volts, as shown by the side *OA*, Fig. 4. The ratio of successive waves being

$$-\epsilon^{-2\theta} = -\epsilon^{-(0.69315 + j1.5708)} = \epsilon^{-0.69315} \cdot \epsilon^{j1.5708} = 0.5 \angle 90°,$$

the next *AB* arrival is $0.707 \angle 45°$, or *AB*, Fig. 4. The internal angle of the polygon is 90°, and each side has half the length of its predecessor. The pole of the polygon is at *R*, and the vector *OR* (extended) intersects all of the corners *DFB*. This vector *OR* is the final steady-state voltage at *B*. It is also

$$E \operatorname{sech} \theta = 1.0 \angle 0° \operatorname{sech} (0.34658 + \underline{j0.5}) = 1.26 \overline{\angle}\, 18°.6 \text{ volts.}$$

[3] An underscored j component indicates quadrant measure.

This is the steady rms. or effective voltage produced at the open end B of this line, after 1.0 rms. volt has been applied at A for a sufficient length of time to enable the residue to be neglected.

Any line whose length is one eighth of a wave, freed at B and energized at A without splash, will build up its B end voltage according to a right-angle polygon, as in Fig. 4. Here the A and B waves are equal, and coalesce into an AB wave of double magnitude.

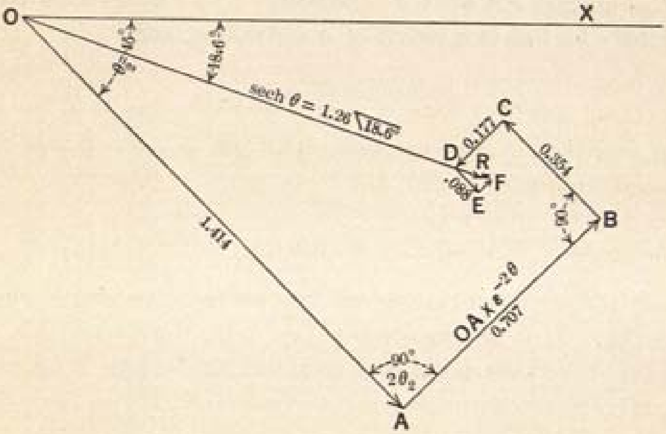

FIG. 4. Spiral polygon of voltage waves building up at the free end B of an eighth-wave line.

The current waves at the same free end consist of pairs of A and B waves precisely equal and opposite in phase; so that the A current polygon is that of Fig. 4 drawn to half scale, counting the first outgoing wave at the generator switch as unity, to standard phase. The B current polygon is drawn negatively in all parts, with respect to the A polygon in such a manner that the resultant current at B is always zero.

Current and Voltage Polygons for an Eighth-wave Line Grounded at the Distant End B.

With the line grounded at B, we have seen that the coefficients $(1 - m_v)$ and $(m_c - 1)$ are both $+1$, and the vector ratio of successive voltage or current waves is

$$\epsilon^{-n} = \epsilon^{-2\theta} = \epsilon^{-2\theta_1 - j2\theta_2} = \epsilon^{-2\theta_1} \angle 2\theta_2 \quad \text{numeric } \angle \qquad (23)$$

for both the A and B polygons. Thus, if we consider the building up of current at the grounded end B, and take the initial outgoing current at A, namely

$$I_0 = \frac{E}{z_0} \qquad \text{rms. amperes } \angle \quad (24)$$

as unity at standard phase; then the first arrival of current at B is $\epsilon^{-\theta}$. This instantly doubles, by reflection from B, making the first combination AB wave $2\epsilon^{-\theta}$ amperes $\angle$. For the case already considered of a line one eighth of a wave long, and

$$\theta = 0.34658 + \underline{j0.5},$$

we have, in Fig. 5, the first doubled or AB wave at the grounded end represented by

$$OA = 2\epsilon^{-0.34658} \overline{\vee}\ 0.5 = 2 \times 0.707 \overline{\vee}\ 45^\circ = 1.414 \overline{\vee}\ 45^\circ.$$

The next AB wave will have half this size, and a slope 90° lagging behind OA. It is represented in Fig. 5 by the vector AB. The successive AB waves are shown to approach the pole R; such that the final vector OR (produced) intersects all the vertices $BDEF$, etc. The vector

$$OR = \text{cosech}\ \theta = 1/\sinh (0.34658 + \underline{j0.5}) = 1.265 \overline{\vee}\ 71^\circ.6.$$

The voltage waves, in this case, mutually cancel at B, leaving zero resultant.

We may thus conclude that any eighth-wave line, either freed or grounded at the far end, develops AB combination waves of voltage or current at that end, which are either always zero, or contain right angles between successive sides.

Voltage Polygons at P for a Sixteenth-wave Line, Freed at the Distant End.

If the distant end of the line is freed, we have seen that the coefficient $(1 - m_v) = -1$; and that the vector ratio of each wave to its predecessor at any point P along the line is:

$$\epsilon^{-n} = -\epsilon^{-2\theta} = \epsilon^{-2\theta_1} \angle (\pi - 2\theta_2). \quad \text{numeric } \angle \quad (25)$$

Figure 6 represents the *A*, *B* and *AB* polygons, for a line having

$$\theta = 0.3466 + j\frac{\pi}{8} = 0.3466 + \underline{j0.25}.$$

The vector ratio is

$$\epsilon^{-0.6932} \angle 135^\circ = 0.5 \angle 135^\circ.$$

Each side has half the length of its predecessor, and makes with it an interior angle of 45°.

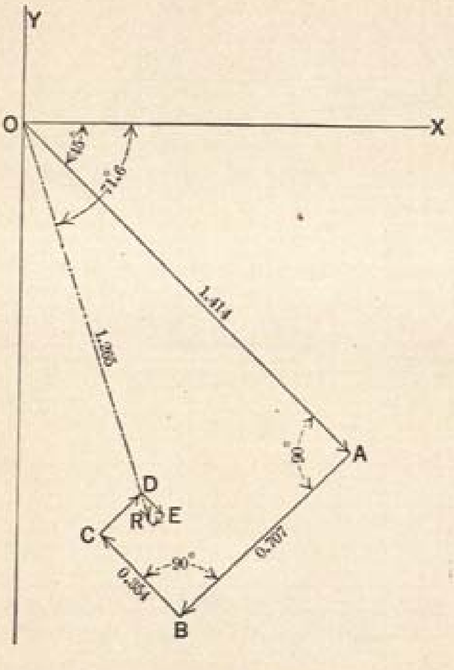

FIG. 5. Spiral polygon of vector current *A* waves building up at the grounded end *B* of an eighth-wave line.

If the e.m.f. impressed at *A* is 100 ∠ 0° volts, without splash, the first wave of voltage to arrive at *P*, half way along the line is

$$100 \times \epsilon^{-0.1733} \overline{\angle}\ \underline{0.125} = 84.1 \overline{\angle}\ 11^\circ.25.$$

This is the vector *OA*, Fig. 6. The first *B* wave is

$$100\epsilon^{-0.520} \overline{\angle}\ \underline{0.375} = 59.5 \overline{\angle}\ 33^\circ.75 \text{ volts.}$$

This is represented by the vector *Oa*. We now have, for the *A* series, the successive components *AB*, *BC*, *CD*, etc., each half of its predecessor in length, and making with the same an internal angle of $\underline{0.5}$, 45°, or half a quadrant. The resultant vector sum, or the vector to the pole of these *A* waves, is *OR*.

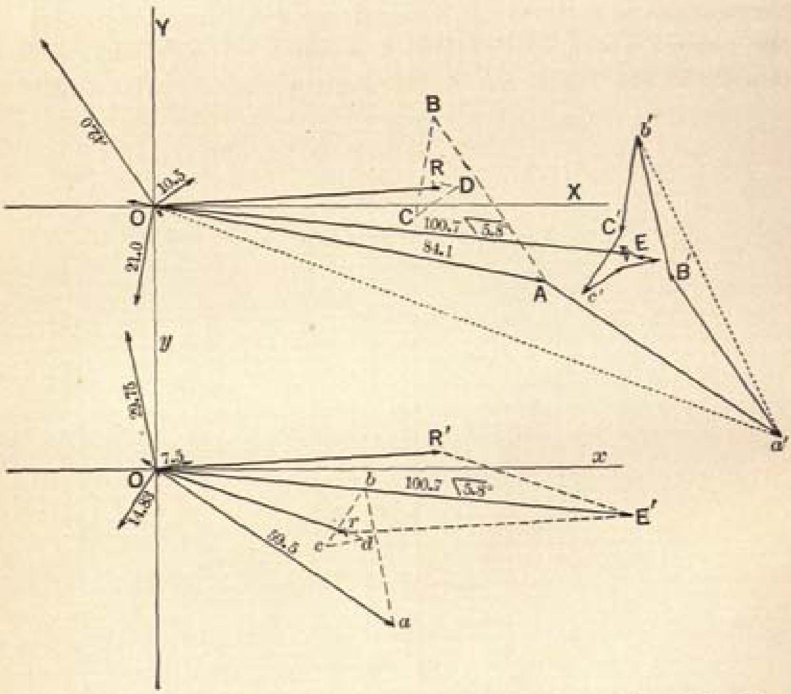

Fig. 6. *A* and *B* spiral polygons of voltage waves, also the combined *AB* polygon for a point *P* on a sixteenth-wave line freed at *B*.

The successive *B* waves arriving at *P* are *Oa*, *ab*, *bc*, *cd*, etc. Their final resultant is *Or*, the vector drawn from *O* to the pole of this equiangular polygon. The resultant voltage at *P*, in the steady state, is the vector sum of *OR*, and *Or*, or $OE' = 100.7 \;\overline{\diagdown}\; 5^\circ.8$ volts. We may, however, trace the successive sides of the *AB* polygon. They are *OA*, *Aa′*, *a′B′*, *Bb′*, *b′C′*, *C′c′*, etc. This might be represented as a spiral polygon having the sides *Oa′*, *a′b′*, *b′c′*, etc. The vector ratio of this *AB* polygon is likewise $0.5 \angle 135^\circ$, each side being half the length of its predecessor and making therewith

an interior angle of $2\theta_2$ circular radians, in this case 45°. The final or polar resultant voltage OE' is known to be given by the relation

$$\frac{E_P}{E_A}=\frac{\sinh \delta_P}{\sinh \delta_A}=\frac{\cosh\,(0.1733+j\underline{0.125})}{\cosh\,(0.3466+j\underline{0.25})}=1.007\ \overline{\smash{\angle}}\ 5^\circ.8. \quad (26)$$

Corresponding spiral A, B and AB polygons could be drawn for the current waves at P. The A polygon would be the same as that $OABCD$ in Fig. 6, but the B polygon would start with a different

FIG. 7. Vector voltage building up at distant free end of a quarter-wave line.

vector Oa; because the reflection of the current wave from the open end at B would have the opposite phase to the voltage wave so reflected. The AB polygon would thus differ greatly from that in Fig. 6; but it would still have a side ratio of 0.5 and have internal angles of 45°.

If the line, instead of being freed, were grounded at B through

a known vector impedance, the building up of voltage and current would still be in conformity with some spiral polygon, and the vector ratio would be obtainable from (21).

Case of Quarter-wave Lines, Freed or Grounded.

In the case of any quarter-wave line, its angle θ is

$$\theta = \theta_1 + j\frac{2\pi}{4} = \theta_1 + j\frac{\pi}{2} = \theta_1 + j\underline{1}. \quad \text{hyps} \angle \quad (27)$$

If such a line is freed or grounded, the vector ratio of the spiral polygon is $\epsilon^{-2\theta_1} \angle 0°$. The spiral polygon thus assumes the limiting case of a straight line.

Fig. 7 represents the case of a line $\theta = 0.6 + j\underline{1}$, freed at B, and having a voltage of $1.0 \angle 0°$, applied at A without splash. The waves of voltage are reckoned at the free end B. The first A wave is

$$1.0 \times \epsilon^{-0.6} \overline{\smallsetminus}\, 90° = 0.5488 \overline{\smallsetminus}\, 90°.$$

This is instantly doubled, by reflection, into an AB wave of OA $1.0976 \overline{\smallsetminus}\, 90°$. The vector voltage ratio is

$$\epsilon^{-1.2} \angle 0° = 0.30119 \angle 0°.$$

The successive AB waves are OA, AB, BC, etc., all in the same straight line, 90° in phase behind the impressed voltage at A. The resultant voltage is

$$OR = 1.5707 \overline{\smallsetminus}\, 90° = \text{sech}\,(0.6 + j\underline{1.0}).$$

We may say, therefore, that when such a quarter-wave line is freed at the far end, the spiral polygon of voltage at that end is a straight line, 90° behind the standard phase of impressed voltage at A.

Case of Voltage and Current at a Point P on a Quarter-wave Line, which is Either Freed or Grounded at B.

If the point P is intermediate between A and B, there will be an A polygon, a B polygon, and an AB polygon of voltage and of

current. Each and all of these polygons will be straight lines, having, however, different slopes.

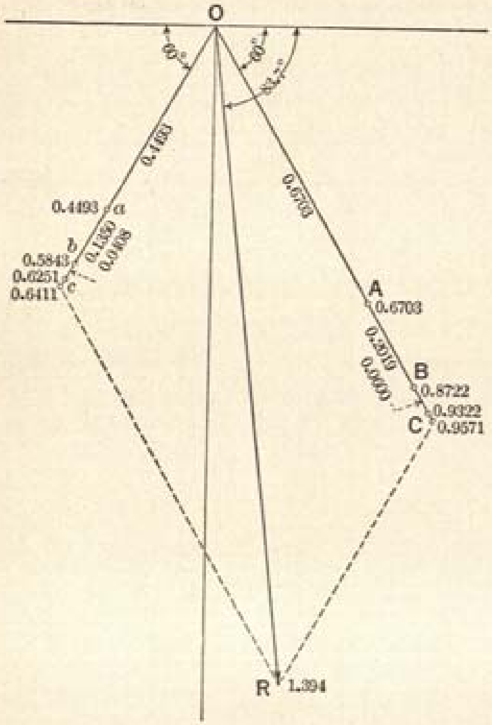

FIG. 8. *A* and *B* voltage polygons at an intermediate point *P* on a quarter-wave line freed at *B*.

Figs. 8 and 9 indicate the conditions for the building up of voltage on the line above considered, at a point two thirds distant from *A*, and one third distant from *B*. The angular distance of this point from *A* would thus be $0.4 + j\underline{0.667}$, and from *B*, $0.2 + j\underline{0.333}$ hyps. The first voltage wave to arrive at *P*, after applying $\overline{1.0}$ $\angle 0°$ rms. volt at *A*, without splash, would be

$$\epsilon^{-(0.4+j\underline{0.667})} = \epsilon^{-0.4} \urcorner\!\!\!\!\!\!\smallsetminus 60° = 0.6703 \urcorner\!\!\!\!\!\!\smallsetminus 60°,$$

represented by the planevector *OA*, Fig. 8. The vector ratio of the *A* polygon being $0.30119 \angle 0°$ the next voltage wave arriving from *A* will be $0.2019 \urcorner\!\!\!\!\!\!\smallsetminus 60°$, or *AB*. The final resulting *A* voltage thus built up is $0.9571 \urcorner\!\!\!\!\!\!\smallsetminus 60°$.

Similarly, the first voltage wave reflected from B and arriving at P, is

$$\epsilon^{-(0.8+j\underline{1.333})} = \epsilon^{-0.8} \angle\, 120^\circ = 0.4493 \angle\, 120^\circ,$$

and is represented in Fig. 8 by the planevector Oa. The succeeding B waves are indicated by the prolongations of this line ab, bc, etc. The finally built up B series of waves is $0.6411 \angle\, 120^\circ$. The final

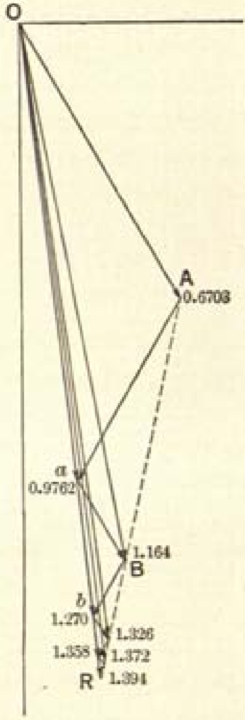

FIG. 9. *AB* polygon attaining the same resultant voltage.

total voltage at P, is the vector sum of the A and B waves, or $OR = 1.394 \angle\, 83^\circ.7$. This is also expressed by the ratio

$$\frac{\cosh\,(0.2 + j\underline{0.333})}{\cosh\,(0.6 + j\underline{1.0})} = 1.394 \angle\, 83^\circ.7 \qquad (28)$$

according to the well known theory of such lines in the steady state.

The successive A and B waves are indicated in Fig. 9, for the same case. These successive arrivals at P give rise to the vector

zigzag path *OAaBb*, etc. The *AB* waves are however *Oa*, *ab*, etc., all in same straight line *OR*.

At any point *P* on this quarter wave line, there is, when the *B* end is freed, one particular straight line for the *A* waves, another for the *B* waves, and a third for the *AB* waves. The straight line of *AB* waves coincides with the resultant *OR* of the final sums of the *A* and of the *B* waves. If the point *P* is brought to coincide with *A*, the generator end of the line, the vector *OR* coincides with $1.0 \angle 0°$, the impressed voltage throughout all time, including both transient and subsequent steady states. As *P* is shifted from *A* towards *B*, the size of the straight line polygon *OR* increases, and its slope increases negatively. At the free end *B*, the size is a maximum and the slope is just 90°.

Current Waves at Point *P* on Quarter-wave Line Freed at *B*.

With the point *P* one third remote from *A*, as in the last example, the current wave polygons are indicated in Figs. 10 and 11. The first *A* polygon becomes the straight line *OC*, Fig. 10, assuming that the initial outgoing current at the generating end is $1.0 \angle 0°$, or that it is taken as unity at standard phase. It will be noticed that the *A* current-wave vector *OC*, terminating ultimately at $0.9571 \angle 60°$, is the same as the *A* voltage-wave vector *OC* of Fig. 8. The *B* current-wave vector *Oc*, in Fig. 10, has the same size as *Oc* in Fig. 8; namely 0.6411; but it has the opposite direction. The resultant current wave *OR* in Fig. 10 is thus $0.8446 \overline{\angle}\ 18°.50'$; whereas the resultant voltage wave *OR* in Fig. 8 was $1.394 \overline{\angle}\ 83°.7$. The resultant current wave is also known to comply with the relation

$$\frac{\sinh\,(0.2 + j\underline{0.333})}{\cosh\,(0.6 + j\underline{1.0})} = 0.8446 \overline{\angle}\ 18°\ 50'. \qquad (29)$$

The *AB* development is similarly presented in Fig. 11. Here the vector zigzag path pursued is *O*, *A*, *a*, *B*, *b*, etc., culminating finally in *OR*. The summation of vectors by pairs is, however, *Oa*, *ab*, etc., to *OR*. All these are on the same straight line $0.8446 \overline{\angle}\ 18°\ 50'$.

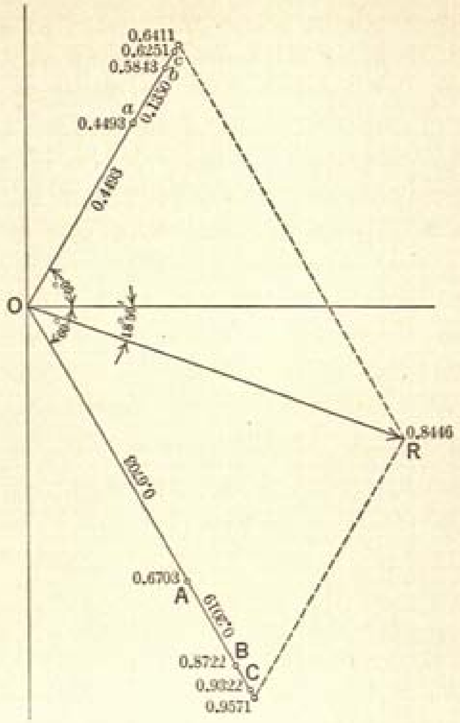

FIG. 10. Vector current waves building up at intermediate point P of a quarter-wave line A polygon, B polygon and resultant.

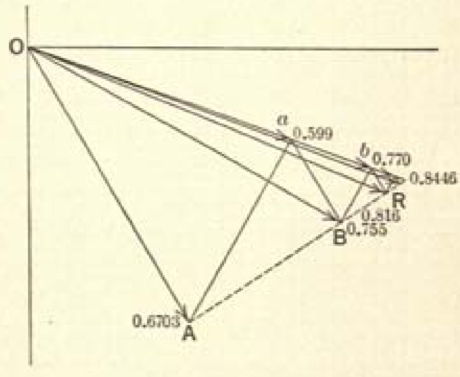

FIG. 11. Vector AB polygon current waves building up at intermediate point P on a quarter-wave line.

We may thus conclude that on any quarter-wave line, freed at the far end, the A, B and AB series of current waves are straight-line polygons, at each and every point P. When the point P is near to A, the A and B straight lines are nearly horizontal and determine a nearly horizontal resultant. When P is near to B, the A and B straight lines are nearly vertical, and their resultant is nearly zero.

A line which is more than a quarter wave-length ($\theta_2 > \underline{1}$), the relations between internal and external angles of the polygon become inverted, and the external angle becomes $2\theta_2$. The original condition becomes restored at line lengths exceeding one wave-length.

Growth Factor of Waves.

It has been shown elsewhere [4] that according to theory, satisfactorily checked by observation, waves of voltage or current at any point P on such a simple circuit as that of Fig. 3, build up during the transient state, according to the expression:

$$S(1 - \epsilon^{-2k\delta_A}), \quad \text{volts} \angle \text{ or amperes} \angle \qquad (30)$$

where S is the vector value of the final voltage or current at the selected point P, in the steady state, δ_A is the position angle of the generating end of the line in the steady state, and k is the number of complete AB waves that have reached the point P at the moment considered. The vector value of the coefficient $(1 - \epsilon^{-2k\delta_A})$ is called the growth factor of the voltage or current, at that moment. Thus if $k = 0$, no AB waves have arrived at P, and the growth factor is zero. If $k = \infty$, the factor is unity. The successive stages of growth are 0, $1 - \epsilon^{-2\delta_A}$, $1 - \epsilon^{-4\delta_A}$, $1 - \epsilon^{-6\delta_A}$, and so on. These points determine vectorially the equiangular spiral polygon already described, AP Fig. 2, being taken as unity, and the vectors BP, CP, etc., being $\epsilon^{-2\delta_A}$, $\epsilon^{-4\delta_A}$, etc. The growth factors of voltage and current at the same point of the same circuit are the same, while the corresponding polygons are similar.

Conclusions.

(1) Equiangular spiral polygons present themselves in the discussion of the initial transient states of voltage and current over

[4] Bibliography 3.

uniform lines, loaded at the B end, and energized without splash at the A end, by the sudden application of a steady sinusoidal e.m.f. of uniform frequency.

(2) The spiral polygon of voltage or of current, at a given point on the line, depends upon the angle θ subtended by the line, and angle δ_B subtended by the load at B, as well as on the position of the point P on the line where the growth towards the steady state is observed.

(3) The vector ratio of successive sides of the polygon is the same for all points on the line, and depends only on the hyp. position angle of the generator end, $\delta_A = \theta + \delta_B$; where δ_B is the hyp. angle subtended by the load at B. If the line is either freed or grounded at B, so as to eliminate the load, the vector ratio of the growth polygon will depend only upon θ, the hyp. angle of the line. In the last named case, the ratio of the length of each side in the polygon to its predecessor, will be $\epsilon^{-2\theta_1}$, and the internal angle contained between successive sides will be $2\theta_2$ cir. radians, where $\theta_1 + j\theta_2 = \theta$.

(4) The series of A waves, or waves arriving from A, form one spiral polygon. The series of B waves form another, and their alternate summation by pairs, or the AB series, form a third. All have the same vector ratio of successive sides.

(5) On any single line with fixed load at B, the growth factor of the AB voltage waves, and of the AB current waves is the same, and so is the vector ratio of their respective polygons, depending only upon the position angle δ_A. The voltage and current polygons are similar.

(6) On a quarter-wave line, freed or grounded at B, the angle between successive sides becomes 180°, or the polygon becomes a straight line as a limiting case. Each point P on the line develops rectilinear A, B, and AB polygons. The same relation holds for three quarter, five quarter, and odd-quarter-wave lines.

(7) On an eighth-wave line, freed or grounded at B, the angle between successive sides becomes 90°. The A, B and AB polygons become quadrantal.

List of Symbols Employed.

a scalar ratio of successive sides of polygon (numeric).

α exponent of scalar ratio of successive sides (numeric).

α_1, α_2 real and imaginary components of the linear hyp. angle of a uniform line (hyps. per km.).

B susceptance of an alternating-current line (mhos).

β angle between successive sides of a polygon (cir. radians).

c linear capacitance of a uniform line (farads/km.).

δ_A, δ_B position angles of the terminals A and B of a line in the steady state (hyps $\angle$).

E electromotive force impressed on a line at A (rms. volts $\angle$).

E_A, E_P voltages at points A and P of line in steady state (rms. volts).

$\epsilon = 2.71828...$

f frequency impressed on the line (cycles/sec. or cycs.).

G dielectric conductance of uniform line (mhos).

g linear dielectric conductance of uniform line (mhos/km.).

$\theta = \theta_1 + j\theta_2$ angle subtended by a uniform line in steady state (hyps $\angle$).

θ' angular distance on a line between points A and P (hyps $\angle$).

I_0 initial outgoing current at A (amperes rms. $\angle$).

$j = \sqrt{-1}$.

k the number of complete AB waves that have visited a point P toward building steady state (numeric).

L length of line (km.).

l linear inductance of line conductor (henrys/km.).

m_c transmission coefficient for current of load at B (numeric $\angle$).

m_v transmission coefficient for voltage of load at B (numeric $\angle$).

n exponent of vector ratio between successive sides of a polygon (numeric $\angle$).

$\pi = 3.14159..$

R resistance of a line conductor (ohms).
r linear resistance of line conductor (ohms/km.).
S steady-state value of voltage or current at a point P of a line (volts $\angle$ or amperes $\angle$).
σ impedance of a load inserted at B end of line (ohms $\angle$).
T time of single wave passage over the line in one direction (sec.).
v group velocity of waves over a line (km./sec.).
ϕ angle of an equiangular spiral, between tangent and polar radius vector at any point (radians or degrees).
X inductive reactance of a line (ohms).
Y dielectric admittance of a line (mhos $\angle$).
Z conductor impedance of a line (ohms $\angle$).
z_0 surge impedance of a line (ohms $\angle$).
ω impressed angular velocity (cir. radians/sec.).

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WITHOUT PRETENSIONS AS TO COMPLETENESS.

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THE HISTORY OF *ŒNOTHERA BIENNIS* LINNÆUS, *ŒNOTHERA GRANDIFLORA* SOLANDER, AND *ŒNOTHERA LAMARCKIANA* OF DE VRIES IN ENGLAND.[1]

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(*Read April 22, 1926.*)

Introduction.

The summer of 1925 gave to me a long awaited and much desired opportunity to examine herbaria of England for data on the time of appearance and distribution in England of *Œnothera biennis* Linnæus, *O. grandiflora* Solander, and *O. Lamarckiana* of de Vries. These are species of particular interest to geneticists working with œnotheras who hold widely different opinions on the part that each has played in the development of certain conspicuous Œnothera floras of England. The most important problem is that of the time of appearance of *Œnothera Lamarckiana*. Was it present as early as 1806, when Smith described in the " English Botany " a remarkable display of œnotheras on the sand hills of Lancashire? Or did it appear in England much later, perhaps not much before the date 1860, when Carter and Company of London offered it to the trade as a cultivated plant, and after this become established frequently as a garden escape in various localities?

De Vries (1914, pp. 358, 359) and Gates (1915, pp. 17, 73, 84) in their desire to establish the presence of *Lamarckiana* in England close to the time when Lamarck's plants were grown in the gardens of the Museum d'Histoire Naturelle at Paris about 1796 have unequivocally expressed the opinion that the œnothera flora of 1806 over the sand hills of Lancashire contained *Lamarckiana* and that Smith's account and Sowerby's figures of *Œnothera biennis* in the

[1] Genetical Studies on Œnothera—XIV. Papers from the Department of Botany, University of Michigan, No. 251.

English Botany, vol. 22, p. 1534, 1806, refer to *Lamarckiana* and not to *biennis* as stated.

I have never accepted these views (Davis, 1913, 1915), although open-minded with respect to evidence, and I am now prepared to take a positive position against them, holding that the œnothera flora of Lancashire in 1806 was *biennis* and also that the herbarium of the Museum d'Histoire Naturelle in Paris contains no material that establishes the existence of *Lamarckiana* as early as 1796, that the plants grown by Lamarck (*Œnothera Lamarckiana* Seringe) were forms of *Œnothera grandiflora* Solander (Davis 1912*b*), and that other material of this period, including a specimen of Michaux's, believed by de Vries to be *Lamarckiana* cannot be so identified. I shall reserve a discussion of the herbarium material at Paris for another paper and at this time only consider evidence in British herbaria bearing on the part that *biennis, grandiflora* and *Lamarckiana*, together with some other large-flowered species, have played in the development of conspicuous Œnothera associations of England.

I found no one in the herbaria that I visited inclined to accept the views of de Vries and Gates. There was general agreement that Smith was correct in identifying the Œnothera of Lancashire in 1806 as *Œnothera biennis* Linnæus. To B. D. Jackson of the Linnean Society, A. J. Wilmott at South Kensington, W. B. Turrill at Kew, H. Gilbert Carter and A. W. Gray at Cambridge, H. Baker at Oxford, and F. E. Weiss at Manchester I am greatly indebted for the time and attention given to me in my examination of herbarium material. I should have made poor progress without their patience and courtesy in matters of establishing dates and localities, identifying hand writing, and otherwise tracing the history of sheets through the information that well organized herbaria have to give and about which the visitor generally knows so little.

It would seem hardly possible that there is no other herbarium material bearing on the early history of Œnothera floras in England than that which I found at the chief centers and the few additional references which Gates (1915) gives. If this paper stimulates further search for evidence on the problems here presented it will have served a purpose.

Œnothera biennis Linnæus

By *Œnothera biennis* I refer to the species as limited in that careful analysis by Bartlett (1913) of the Linnean species which was abundant on the sand hills of Holland when Linnæus published the Hortus Cliffortianus in 1737 and which has become familiar to Œnothera geneticists through the studies of de Vries and through cultures derived from his lines. It is a species which a few years ago was not known to grow wild in North America, but Bartlett[2] through garden cultures has identified with the Dutch plant material collected from Montreal and from Newcomb and Lowville in New York State.

I shall begin the discussion of *Œnothera biennis* with the consideration of the specific problem of the determination of that species of Œnothera conspicuous and abundant on the sand hills of Lancashire in 1806. Sir James Edward Smith (1806), founder of the Linnean Society, under the name *Œnothera biennis* in the first edition of the "English Botany," wrote as follows:

> Not without the most mature deliberation have we been induced to admit this into a work on British plants. Its being naturalized on dunghills and waste ground either here or in Germany, as mentioned in Roth's excellent Flora, when known to have been introduced to our gardens from America about two hundred years ago, would not have satisfied us. Our specimen was gathered on the extensive and dreary sand-banks on the coast a few miles north of Liverpool, where millions of the same species have been observed by Dr. Bostock, and Mr. John Shepherd, perfectly wild, and covering a large tract between the first and second range of sand-hills. Some natural cause has no doubt established it there, though possibly from the opposite shores of the Atlantic.
>
> It is a biennial, and flowers from July to September. The stem is 2 or 3 feet high, often branched, leafy, angular, rough with minute tubercles, and hairy. Leaves alternate, ovate or lanceolate, toothed, downy; the lowest on stalks, longer and somewhat waved. Flowers sessile in the bosoms of the upper leaves, so as to form a large spike. They expand in the evening, and are delicately fragrant, of a fine pale yellow. Calyx reflexed. Petals wedge-shaped, waved. Stamina equal and erect. Pods short, rough, full of seeds which differ from those of the Epilobium in having no down or wing.

There is nothing in the description of Smith which is not true of both *biennis* and *Lamarckiana*. Characters that distinguish the two species, likely to be shown in herbarium material, are:

[2] Bartlett, H. H. A preliminary review of the allies of *Œnothera biennis* in New York State (in manuscript).

Œnothera biennis.	*Œnothera Lamarckiana.*
Mature buds. 5.5–6 cm. long.	Mature buds. 8–9 cm. long.
Sepal tips. 3–4 mm. long.	Sepal tips. 6–8 mm. long.
Petals. 2–2.5 cm. long.	Petals. 4–4.5 cm. long.
Stigma. About 3 mm. below the tips of the anthers.	Stigma. 5–7 mm. above the tips of the anthers.
Stems. Green above, the papillæ never red.[3]	Stems. With large red papillæ over the green portions of the stem.

Smith's account is accompanied by a plate drawn by James Sowerby with the date December 1, 1805, which is here reproduced (Plate I.) since from it de Vries and Gates have largely reached their conclusion that the plant illustrated was *Lamarckiana* and not *biennis.* The measurements of the buds and flowers are intermediate between *biennis* and *Lamarckiana* and the stigma is not placed below the level of the anthers as in *biennis* although neither is it drawn well above the anthers as it should be for *Lamarckiana.* I have never been satisfied with this criticism of Smith's identification with *biennis* both on general grounds of probability and because it has seemed to me most unlikely that, if the plant were *Lamarckiana,* Smith and Sowerby would have failed to bring out in the description and figure such conspicuous peculiarities of *Lamarckiana* as the red papillæ over the green stem, the long sepal tips, and the great length of the style.

Fortunately this controversy is settled by a sheet in Smith's Herbarium of the Linnean Society in London (Plate II., Fig. 1). This sheet bears the label "Œnothera biennis, Engl. Bot." The two specimens on the right are numbered 1 which refers to the statement "Sand hills on the coast a few miles north of Liverpool, September 1805. Mr. J. Shepherd." The other specimen on the left of the sheet is numbered 2, and with this is the record "From near Woodbridge, Suffk., where it covers acres of ground. Mr. D. Turner." All of this matter is in the handwriting of Smith.

[3] There is a *biennis*-like plant with red papillæ over the stem which I found in cultivation in the Cambridge Botanical Garden and on three sheets in the collections of Charles Bailey at the University of Manchester. These sheets were: (1) St. Brelades Bay, Jersey, July 31, 1871, Coll. by Charles Bailey; (2) Sandhills Burnham N. Somerset, Sept. 1883, Coll. W. B. Waterfall; (3) Burnham, North Somerset, August 1886, Coll. Jas. W. White. The genetical constitution of this plant should be studied.

Œnothera biennis. Plate from the "English Botany," Vol. 22, p. 1534, 1806. Drawn by James Sowerby from material "sent to Sowerby by Smith from Liverpool." Specimens of the material, preserved in Smith's Herbarium of the Linnean Society, are shown in Plate II., Fig. 1.

FIG. 1.

FIG. 2.

FIG. 1. *Œnothera biennis* in Smith's Herbarium of the Linnean Society. The two specimens on the right were from "Sand hills on the coast a few miles north of Liverpool, Sept. 1805." Sowerby's figures in the "English Botany" (reproduced in Plate I., of this paper) were dated Dec. 1, 1805 and drawn from this or similar material.

FIG. 2. Specimen of *Œnothera biennis* in the Herbarium of Linnæus, collections of the Linnean Society. Believed to be of a date earlier than the 1753 edition of the "Species Plantarum."

The three specimens have flowers of the size of *biennis* and some of the stigmas are clearly shown below the tips of the anthers as in this species. The bud tips are those of *biennis* as is the puberulent and pilose pubescence of the sepals and stem. The papillæ on the stem are not dark red and only have that light reddish brown tint that is so common on old herbarium material; it is therefore probable that younger parts of the stems were clear green. The capsules measure about 29 mm. which is very close to the length of greatest frequency, 27 mm., reported by de Vries (1901, p. 312) in a study of 356 capsules of *biennis* which ranged in length from 18 to 38 mm. It is impossible that the plants could have been *Lamarckiana*, in all points the specimens agree with *biennis*.

Our concern is chiefly with the specimens numbered 1 from "Sand hills on the coast a few miles north of Liverpool, September 1805. Mr. J. Shepherd." They were collected by the John Shepherd and from the same locality mentioned in the "English Botany." Also, the date, September 1805, is of the year when Sowerby drew his figures which are dated December 1, 1805. The original colored drawings of Sowerby in the collections of the Linnean Society bear the following note "Sent to Sowerby by Smith—from Liverpool." In these drawings the sepals are a clear green and no red is shown in the papillæ over the stem although the long hairs are drawn carefully and red is shown on the side of the stem and lower leaf. There can be no doubt that Sowerby worked from these very specimens or from similar ones, but he failed to present correctly the stigma-anther relations and he drew the plants somewhat too large. It was the habit of Smith to preserve specimens of the material on which illustrations for the "English Botany" were based.

The specimen numbered 2 with its record shows that *biennis* at this time grew in profusion also in Suffolk. D. Turner refers to Dawson Turner (1775–1858), banker of Yarmouth.

To make clear the identification of Smith's plants of the "English Botany" 1806 with *Œnothera biennis* Linnæus compare the specimens of Fig. 1, Plate II., with that of Fig. 2 which is a specimen of *biennis* from the Herbarium of Linnæus in the collections of the Linnean Society. This sheet bears the name *biennis* in the handwriting of Linnæus and the shoot shows flowers, buds, stem characters and

stem foliage remarkably well preserved; the locality is not given, the date must have been earlier than the 1753 edition of the "Species Plantarum." There is also complete agreement of these specimens of Smith's and Linnæus's with that important sheet in the Hortus Cliffortianus 1737 labeled *Onagra latifolia* and, except for the suggested difference in flower color, with the sheet labeled *Onagra latifolia flore sulphureo.* The latter is believed to hold a specimen of the *sulphurea* variety of *biennis* although the flowers are now too stained and faded to show their original color.

Other publications of a few years later give little or no further information concerning *Œnothera biennis.* Thus Smith (1813) in Rees' Cyclopedia simply restates matter from his account in the "English Botany" with, however, this sentence of significance: "This (*Œnothera biennis*) is the only British species of Œnothera, nor was it till very lately admitted as such." By this Smith probably meant that *biennis* was the only species growing wild in conspicuous associations. Don (1832) adds nothing of importance to Smith's account in the "English Botany. Baxter (1839) gives a description and plate of *Œnothera biennis* which, however, are not very satisfactory. Gates (1915, p. 16) holds that Baxter refers to *Lamarckiana* but I can see no evidence for this view. The plate shows flowers drawn the size of *biennis* and folded stigma-lobes projecting only slightly beyond the tips of the anthers; the lower portions of the lobes are below which is not true for *Lamarckiana.* The stem is described as of "pale green color, rough with minute tubercles"; there is no mention of the tubercles as being red, a characteristic of *Lamarckiana* which could hardly have failed to receive notice. Baxter gives a long list of localities from some of which specimens of *biennis* had been preserved, particularly plants from Crosby and Southport in Lancashire and Woodbridge in Suffolk in herbaria of Smith, Borrer and Babington. It seems highly probable that Baxter saw some of this material in herbaria which must have been notable collections at that time. Lindley (1833) describes an "*Œnothera biennis* var. *grandiflora*" which certainly was not *O. biennis* and will be considered later in this paper with a group of narrow-leaved, large-flowered œnotheras having pubescence similar in character to that of *Lamarckiana,* and with red papillæ.

The treatment of *Œnothera biennis* in later editions of the "English Botany" did not improve on the first edition and some curious errors developed. Thus the figures of *Œnothera biennis* in the third edition of the "English Botany" are copies and rearrangements of some parts of the original plate of James Sowerby with the addition of a lower leaf and a capsule. The coloring and drafting is not so good. The description is by Boswell-Syme (1865) and gives the general information of the first edition but with the following statements of size, "Calyx tube about 2 inches long, the free portions twice as long as the part adhering to the ovary; Petals 1¼ to 1½ inches or more across; . . . Pod 1–1½ inch long." These measurements are too large for *biennis*, but they approximate the size of the figures on the plate and perhaps these were judged to be accurate representations of size. We know from the preserved specimens of Smith that James Sowerby drew his figures of *biennis* too large.

What do the British herbaria tell us of the history of *biennis* in England and especially on the sand hills of Lancashire? There is given in Table 1 records of sheets of *biennis* known to me from the herbaria of the British Museum at South Kensington, the Royal Botanic Gardens at Kew, the Linnean Society, and the herbaria of the universities at Cambridge, Oxford and Manchester. They present a clear history of rather frequent collections from Lancashire following the interest established by Smith through the "English Botany" in 1806, and there are numerous scattered reports from other localities. Thus before 1840 William Borrer gathered material from Crosby Warren, W. A. Leighton from Crosby Sands, B. H. Allen and Miss Potts from Southport, all in the region of Smith's original report. More recent sheets give records of specimens collected in 1872, 1877, 1878, 1883, 1885, 1907 and 1913. Some of these specimens were gathered by Charles Bailey and by J. A. Wheldon who knew *Œnothera Lamarckiana* as well as *Œnothera biennis* and clearly separated the two species. Bailey (1907, p. 7) records some other collections of *biennis* at Crosby, and Wheldon (1913) gives a good description and plate of the plant with an interesting account of its distribution and associates on the sand hills of Lancashire. These excellent botanists, familiar with the region, knew their plant thoroughly and there was no doubt in their minds of its identification

with *Œnothera biennis* Linnæus. It is clear that *biennis* since 1806 has been continually on the sand hills of Lancashire established as a wild species. For *Lamarckiana*, as we shall presently see, there is no evidence of presence in England until about 1860 when Carter and Company of London presented *Lamarckiana* to the trade.

The older records of *Œnothera biennis* show that it had been in English gardens for more than a century previous to 1800. There is the excellent specimen in the Morisonian Herbarium of Oxford University which bears the label "*Lysimachia lutea corniculata non papposa Virginiana major.* Moris. Hist. Oxon. I., 271, No. 7." This plant was grown in the Oxford Physic Garden about 1680 by Morison or possibly later by J. Brobart his assistant; 1680 is the date of the Morison's "Plantarum Historia Universalis Oxoniensis." Miller (1760) figures on Plate 189 (published in 1757) two plants differing in flower size both of which, however, show clearly stigmas placed below the anthers in the position characteristic of *biennis.* The larger flowered plant designated "*foliis ovato-lanceolatis planis Vir. Cliff. 33*" seems most certainly to have been *biennis;* it could not have been *Lamarckiana* as suggested by MacDougal (1907). Miller states that the plant "is more commonly seen in the gardens than any of the other species." Gates (1915) gives references to *biennis* in a number of collections of Linnean and pre-Linnean dates and the evidence is clear that the plant in these early years was a subject of particular interest as an attractive American introduction.

TABLE I.

SPECIMENS OF ŒNOTHERA BIENNIS LINNÆUS FROM BRITISH LOCALITIES OF DATES LATER THAN 1800.

1780. *Œnothera biennis*, Cottage Garden, 1780. (Smith's Herbarium, Linnean Society.) Handwriting of Smith.

1805. First specimen—Sand hills on the coast a few miles north of Liverpool, Sept., 1805. Mr. J. Shepherd. Second specimen—From near Woodbridge, Suffolk, where it covers acres of ground, Mr. D. Turner. (Smith's Herbarium, Linnean Society.) Handwriting of Smith.

1806. Mrs. I. Turner, 1806. (General Herbarium, Royal Botanic Gardens.) Probably the wife of Dawson Turner.

1811. Suffolk coast, Rev. G. R. Leathes, 1811. (General Herbarium, Royal Botanic Gardens.)

1810–1820. First specimen—Sussex, Wm. Borrer, Esq. Second specimen—Crosby Warren, W. Borrer. (Herbarium, British Museum.) These

specimens have no dates, but Borrer (1781–1862) probably collected them between 1810 and 1820. Crosby Warren is Smith's locality in Lancashire.

1825–1843. Crosby Sands, Lancashire, Mr. W. A. Leighton. (General Herbarium, Royal Botanic Gardens.) Rev. W. A. Leighton (1805–1889).

1829. Woodbridge, Suff., July, 1829, Dr. Jermys. Herb. C. C. Babington. (British Herbarium, Cambridge University.)

1832. Near Headford, Aug., 1832, Herb. R. J. Shuttleworth. (Herbarium, British Museum.)

1835. Southport, Lancashire, Oct., 1835, B. H. Allen. Ex. Herb. Churchill Babington. (British Herbarium, Cambridge University.)

1837. Crosby Warren near Liverpool, July, 1837, W. Borrer. Herb. C. C. Babington. (British Herbarium, Cambridge University.)

1837. Crosby Warren, below Liverpool, July 31, 1837. (Borrer Herbarium, Royal Botanic Gardens.) Probably collected by Borrer.

About 1839. Southport (Lancashire). Ex. Herb. Miss Potts, Chester. (British Herbarium, Cambridge University.)

1843. Woods about Bexley, Kent, 1843. Ex. Mr. E. Edwards. (Herbarium of Charles Bailey, University of Manchester.)

1843. By railway between Walton and Weybridge, Surrey, Sept., 1843. (Watson Herbarium, Royal Botanic Gardens.) Collected by H. C. Watson (1804–1881).

1844. W. Swansia, Glanmorgan (S. Wales), July, 1844. Com. by M. Moggridge. (Watson Herbarium, Royal Botanic Gardens.) Matthew Moggridge (1803–1882).

1845. North Cray Woods, Kent, 1845. (Herbarium of Charles Bailey, University of Manchester.)

1846. Plymouth, Devon, Sept., 1846, H. Goulding. (Herbarium of Charles Bailey, University of Manchester.)

1848. Hebburn Ballast Hills, Banks of the Tyne, Durham, 1848. Coll. and communicated by John Storey. (Watson Herbarium, Royal Botanic Gardens.)

1852. Brookgate, Halstead (Kent), July, 1852. Mrs. Atkins' herbarium. (British Museum.)

About 1854. Exmouth sands (Devonshire). Ex. herb. Rev. W. N. Crotch, Taunton. (British Herbarium, Cambridge University.)

1861. Burnham (Buckingham), July, 1861. Herb. John Sadler Gale. (British Herbarium, Oxford University.)

1862. Lea, gravel walk from Lea Hull to the church, Aug. 11, 1862. Herb. R. T. Lowe. (Herbarium, British Museum.)

1864. Canal in clover field, Thames Ditton, Surrey, July, 1864. From Hewett C. Watson. (Herbarium, British Museum.)

1867. Barmouth (North Wales), 28, VIII., 1867. E. Capron. (British Herbarium, Oxford University.) There are two specimens from Barmouth and above a small specimen of uncertain identity from Albury Park.

1872. Sandy field W. of Mersey View, Waterloo, Lancashire, 8, VIII., 1872. Coll. J. H. L. (Herbarium of Charles Bailey, University of Manchester.)

1872. Waste ground about London, 1872. (Herbarium of Charles Bailey, University of Manchester.)

1875. Bristol by river, Aug. 28, 1875. (Herbarium of Charles Bailey, University of Manchester.)

1875. Railway Banks, Glosterside of Avon, Sept., 1875. (Herbarium of Charles Bailey, University of Manchester.)

1877. Sandy ground, Crosby, S.W. Lancashire, 17, IX., 1877. Ex coll. J. Harbord Lewis, Liverpool. (British Herbarium, Oxford University.)

1878. Railway Bank, Aberdovy, N. Wales, VIII., 1878. Coll. H. E. Fox. (Herbarium of Charles Bailey, University of Manchester.)

1878. Sandy Fields, Crosby, Lanc., August, 1878, J. Comber. (Herbarium of Charles Bailey, University of Manchester.)

1883. Ainsdale, Southport, Southwest Lancashire, Sept. 21, 1883. Coll. Charles Bailey. (Herbarium of Charles Bailey, University of Manchester.)

1885. Southport, Southwest Lancashire, Oct. 12, 1885. Coll. Charles Bailey. (Herbarium of Charles Bailey, University of Manchester.)

1907. Sandhills, Hightown, S. Lanc., Aug. 30, 1907. Leg. J. H. Wheldon. (Herbarium of Charles Bailey, University of Manchester.)

1907. Birkdale near Southport, West Lancashire, Aug. 24, 1907. Coll. Charles Bailey. (Herbarium of Charles Bailey, University of Manchester.)

1907. Sandhills, Hightown, S. Lanc., Aug., 1907. Leg. J. A. Wheldon. (Marshall Herbarium, Cambridge University.)

1913. Sand dunes, Hightown, S. Lanc., 4, IX., 1913. Leg. J. A. Wheldon. Cult. for fifteen years at Walton. (Marshall Herbarium, Cambridge University.)

1913. A duplicate of the above in the Herbarium of Charles Bailey, University of Manchester.

Œnothera grandiflora Solander.

In sharp contrast to the numerous herbarium sheets in England of *Œnothera biennis* is the marked scarcity of material that may be identified as *Œnothera grandiflora* Solander. This large-flowered, long-styled species could never be confused with *biennis* and *Lamarckiana* by anyone familiar with its characters, but because the species is almost unknown to the present generation of British botanists the characters that will distinguish herbarium material are given below.

Œnothera grandiflora.

Stems. Sparsely pubescent, green above, reddish below, papillæ never red over green portions of the stem.

Leaves. Smaller, lanceolate, distinctly petioled, plane, with less pubescence.

Fowering shoots. Clustered, approximate branching.

Inflorescence. More open, narrower bracts.

Buds. Long slender hypanthium and slender cone.

Sepals. Glabrous or almost glabrous.

Sepal tips. 8–10 mm. long, attenuate and with relatively little pubescence.

Ovary. Glabrous.

Capsules. 2.5–3 cm. long, glabrous.

Œnothera Lamarckiana.

Stems. With heavy pilose and puberulent pubescence, numerous red papillæ over green portions of the stem.

Leaves. Larger, broader, short petioled or almost sessile, the larger crinkled, more evident pubescence.

Flowering shoots. Frequently single long branches.

Inflorescence. Dense spike, crowded, flat topped, broader bracts.

Buds. Stronger hypanthium and much wider cone.

Sepals. With heavy pilose and puberulent pubescence.

Sepal tips. 6–8 mm. long, thicker and with heavy pilose pubescence.

Ovary. Strongly pilose and puberulent.

Capsules. 2–2.5 cm. long, strongly pilose and puberulent.

It will be noted that the most striking difference between *grandiflora* and *Lamarckiana*, likely to be shown by herbarium material, is that of pubescence on sepals, ovaries and capsules; *Lamarckiana* is heavily pilose and puberulent over these parts, *grandiflora* is almost glabrous. In these respects *grandiflora* also differs from *biennis* which in addition is distinguished by its smaller flowers and stigma below the anther tips.

Œnothera grandiflora is very well known to such geneticists as have in recent years grown material from its habitat at Dixie Landing, Alabama, and no species of Œnothera has so clear a history of introduction into Europe (MacDougal 1905, p. 7). The plant was discovered by William Bartram in 1776 near Tensaw, Alabama, on an expedition undertaken at the request of John Fothergill, M.D. Solander's original description in Aiton's Hortus Kewensis, 1789, from material grown at Kew, states that *O. grandiflora* was introduced by John Fothergill in 1778. The type specimen in the herbarium of the British Museum at South Kensington with "Hort.

Fothergill 1778" makes it evident that Bartram must have sent seed to Fothergill. This specimen has suffered from the attacks of insects but the material shows clearly the bud form and attenuate sepal tips of *grandiflora* and the scant pubescence over the sepals and other parts characteristic of the species.

The British herbaria that I visited apparently have almost nothing to show from English sources that is clearly *Œnothera grandiflora*. Gates (1915, p. 13) records specimens from Cobham Lodge 1829 and 1831, which I have not seen, and there is a specimen at Cambridge University labeled "Herb. J. D. Gray. Waste ground near St. Botolph's station, Colchester, Coll. J. D. Gray, Aug. 1881." There were some sheets, incorrectly identified, belonging to plants that in some respects resembled *Lamarckiana* but were neither this species nor *grandiflora*. These are considered at the end of this paper with other sheets under the heading "Narrow-leaved, large-flowered œnotheras from British localities with pubescence similar in character to that of *Lamarckiana,* and with red papillæ."

I was greatly surprised at this paucity of information concerning *grandiflora* in England, and later was much interested to find this comment of Wheldon (1913, p. 207): "The old garden *Œnothera* appears to have been *O. biennis,* as *O. grandiflora* (which I presume would include *O. Lamarckiana*) for a long time, judging from cultural directions in old gardening books, was regarded as a somewhat tender plant, fit only for growing under glass." Also, Sims (1819) writing of a "Pubescent Great-Flowered Œnothera" which he calls "*Œnothera grandiflora* B" and regards as a pubescent variety of *Œnothera grandiflora* remarks "scarcely to be considered hardy, though so marked in the catalogues." Sims's plant was not *grandiflora* but possibly some associated form since we know from garden cultures that with *grandiflora* in southern United States are other large-flowered œnotheras that may be isolated.

The only records of *grandiflora*-like plants growing wild in England of recent date seem to be those of Gates (1913, 1914) who grew cultures from seeds of a large-flowered Œnothera colony at Birkenhead near Liverpool. Gates's cultures from this source contained some lines of *grandiflora*-like forms together with dwarfs, and also types resembling *Lamarckiana* and some of its derivatives. He did

not see the original colony at Birkenhead but concludes (Gates 1914, p. 386) that "it evidently contains a great profusion of forms belonging to both *O. Lamarckiana* and *O. grandiflora*." This Birkenhead colony is cited as exceptional among the numerous stands of Œnothera in Lancashire which Gates, in agreement with the observations of Bailey and Wheldon, found to be *biennis* or *Lamarckiana*, one or both.

I have strongly the impression that *grandiflora* in England does not establish itself as a garden escape, in sharp contrast to *biennis* and *Lamarckiana* which are frequently found in suitable situations. It may be expected to appear sporadically, as it has done in a number of localities in the United States, but with us, also, it does not hold its own except in its special southern habitats. *Œnothera grandiflora* to reach full development requires the conditions of long, warm or even hot summers. The lines that I have carried for the past seventeen years did very well in the long humid summers of Philadelphia, but in New England and at Ann Arbor they have flowered so late that to obtain seed it has always been necessary to pollinate early and to protect the developing capsules from frost. There is of course always the possibility of *grandiflora* crossing with other forms that may be near it and such a colony as that at Birkenhead may have been a mixture of types, including hybrids.

Œnothera Lamarckiana of de Vries.

It must be stated at the outset of this discussion that by *Lamarckiana* we mean the plant made familiar to botanists by the material which Prof. de Vries has so freely distributed to all interested in Œnothera genetics. We know the characters of this plant very well through all stages of its development. We know that there is a number of races within the species but that these are distinguished by minor peculiarities which do not affect the fact that *Lamarckiana* is a very clearly defined species with marked peculiarities of leaf form, habit of growth, pubescence, inflorescence, bud form, flower size and structure, capsule size, etc., together with a very high degree of seed sterility and about 50 per cent. bad pollen. There is abundant evidence both from its breeding behavior and peculiarities of its chromosome distribution that the plant is heterozygous and a striking

illustration of an impure species (Davis 1922), maintaining itself by the virility of the type of heterozygotes that constitute almost all of its product of viable seeds.

I was much surprised to find how common *Lamarckiana* has become in south and central England. It is one of the frequent plants of private gardens, against walls and in borders where it readily sows itself. It frequently escapes from cultivation and may be seen along railroad tracks in the suburbs of cities. As would be expected the showy *Lamarckiana* is now much more commonly in cultivation than the smaller flowered *biennis* which earlier was a popular plant in cottage gardens.

As a wild plant *Lamarckiana* is best known through colonies in Lancashire where they were first reported by Charles Bailey (1907), who made careful observations on extensive growths of the plant at St. Anne's-on-the-Sea. Bailey states that he gathered the same plant at Southport, Ainsdale and Birkdale on the opposite shore of the estuary of the Ribble in 1881 and in subsequent years. Wheldon (1913) also studied the plant noting that *Œnothera biennis* is much more plentiful and more widely spread on the dunes of South Lancashire and *Lamarckiana* more abundant north of the River Ribble; also that *Lamarckiana* was mostly on "made ground near towns." Gates (1914) visited the region and found the colonies of *biennis* and *Lamarckiana*, the latter plants exhibiting various racial peculiarities as shown by their inheritance through cultures. He states that exact duplicates of De Vries's race of *Lamarckiana* are infrequent but that they may differ in only one character as in bud color. Cultures from seeds of the Lancashire plants by MacDougal (1907, p. 8) and Gates (1914) gave variants some of which were comparable to those from the *Lamarckiana* of de Vries.

I visited St. Anne's in the summer of 1925 and found *Lamarckiana* still present on the outskirts of what has become a rapidly growing summer resort. Collecting seeds from different plants of this St. Anne's material the following interesting cultures were grown at Ann Arbor in the summer of 1926. (1) Culture 26.45, a germination of 29.8 per cent., gave 260 *Lamarckiana*, 2 *lata*, 2 *nanella*, 1 *hero*, 2 small-leaved plants with red bud cones, 2 *scintillans*-like rosettes. (2) Culture 26.46, germination 31.9 per cent., gave 207 *Lamarckiana*,

1 *lata,* 2 *nanella,* 2 *scintillans*-like rosettes. (3) Culture 26.48, germination 34 per cent., gave 76 *Lamarckiana,* 2 *lata,* 2 *hero,* 1 *scintillans*-like rosette. The *scintillans*-like rosettes failed to develop shoots. The hero plants, with only 30 per cent. good pollen and many of the grains 4-lobed, were probably triploids. The percentages of germination were close to those determined for lines of *Lamarckiana* from de Vries, and examinations of pollen showed the characteristic proportion of 50 per cent. bad grains. This behavior of St. Anne's material is what would have been expected of *Lamarckiana.*

Some excellent material of *Lamarckiana* from St. Anne's was distributed by Bailey and may be found in the herbaria of the British Museum, Royal Botanic Gardens, Oxford University, and elsewhere, and a large number of sheets is at the University of Manchester. In this material are specimens of at least three forms which are not *Lamarckiana.* The first is smaller flowered, with shorter styles and short sepal tips as in *biennis,* and may be a cross between *Lamarckiana* and this species. The second form with the stigma near the base of the petals closely resembles *brevistylis.* The third plant designated by Bailey a "narrow-leaved form" is distinguished from *Lamarckiana* by its narrow, eliptical leaves with longer petioles, slender bud cones, and shorter sepal tips. The form suggests certain large-flowered American species of the West, having that appearance of weediness so generally characteristic of œnotheras, an appearance in sharp contrast to the luxuriance of *Lamarckiana.* This plant together with certain specimens from Lancashire to be noted in the next section of this paper indicates that other species besides *biennis* and *Lamarckiana* have been on these sand hills.

An interesting situation is opened when we try to trace the history of *Lamarckiana* in England. There is very little herbarium material with distinctive characters of this plant clearly shown. I have listed all of the sheets that I know in Table 2, arranged so that they run from specimens of recent date back to what I believe to be the earliest specimen of Lamarckiana. To these may be added references of Gates (1915, p. 15); "Herb. Hort. Kew 1883," "Uxbridge, England 1907," and "Garden at Reigate, Boulanger 1907." Returning to the list in Table 2, from St. Anne's there is a number of sheets of Charles Bailey collected in 1907 and somewhat earlier. From Bidston Junc-

tion, near Birkenhead, there is a sheet of C. T. Greene dated 1905. A particularly good specimen of a cultivated plant from the garden of Edward Leeds bears the date 1876. In 1871 and 1872 Churchill Babington collected specimens on waste land (probably escapes) at Banbury (Oxford) and at Cornfield, Suffolk. The most important specimen is of a plant grown in 1862 by Dr. Asa Gray at Cambridge, Massachusetts, from seed received from William Thompson of Ipswich, England.

In an earlier paper (Davis, 1913) I brought this sheet to the attention of British botanists emphasizing its probable close relations to the material of Carter and Company, seedsmen of London, who about 1860 placed *Œnothera Lamarckiana* on the market. I hoped that its importance to an understanding of the cultures of Carter and Company might lead to the discovery of other specimens bearing on the problem of the origin of *Lamarckiana*. I offer this sheet as the oldest specimens of *Lamarckiana* known, holding that de Vries and Gates have failed to present satisfactory evidence for the existence of *Lamarckiana* previous to 1860.

The sheet (Plate III.) bears notes in the handwriting of Dr. Asa Gray to the following effect—in ink "Œ. Lamarckiana," "Hort. Cantab. 1862," and "from seed of Thompson, Ipswich"; in pencil and probably of a different date "said by English horticulturists to come from Texas." It was the habit of Dr. Gray at that time to use herbarium labels marked Hort. Cantab. and this fact together with the absence of other writing on the sheet indicates that the plant was grown in the botanical garden at Cambridge, Massachusetts. The note "from seed of Thompson" refers to William Thompson of Ipswich, England, who died in 1903. William Thompson was a seedsman and a most enthusiastic cultivator with correspondents in all temperate countries and the introducer of numerous herbaceous plants more particularly annuals and biennials.

It is highly probable that William Thompson with his interest in novelties, obtained from Carter and Company their new Œnothera and that the seed sent to Dr. Gray was either directly from this source or from plants cultivated by Thompson. It will be remembered that Carter and Company stated that they received their seed from Texas, which accords with Dr. Gray's note "said by English

Specimens in the Gray Herbarium of Harvard University from a plant of *Œnothera Lamarckiana* grown by Dr. Asa Gray at Cambridge, Massachusetts, in 1862 from seed sent by William Thompson of Ipswich, England. This sheet is offered as holding the oldest specimens of *Lamarckiana* known, possibly not more than one or two generations removed from the cultures of Carter and Company.

FIG. 1.

FIG. 2.

FIG. 1. An Œnothera figured by Lindley in Edwards's "Botanical Register," Vol. 19, p. 1604, 1833. Probably associated with early introductions into England of certain narrow-leaved, large-flowered œnotheras with pubescence similar in character to that of *Lamarckiana* (see Table 3 of this paper), which were in cultivation as early as 1830.

FIG. 2. Specimens in the herbarium of Cambridge University claimed by Gates (1915, p. 15) to be *Œnothera Lamarckiana*, "the exact counterpart of de Vries's race." Label, "Mus. Henslow, *Œnothera grandiflora*, Switzerland, J. Dalton." No date, but must be of the early nineteenth century. The pubescence is of soft hairs scattered on sepals and stems. There are no red papillæ bearing stiff hairs on the stems, neither is there characteristic puberulence, and therefore the pubescence is not that of *Lamarckiana*. Also, the leaves and bracts are rather narrow for *Lamarckiana* and the sepal tips are not so attenuate. The material is not *Lamarckiana*.

horticulturists to come from Texas." If this interpretation of the sheet in the Gray Herbarium is correct the plant was very close indeed to the cultures of Carter and Company, possibly not more than one or two generations removed. This sheet then gives evidence on the composition of the cultures of Carter and Company immensely more valuable than the very unsatisfactory accounts in *The Floral Magazine*, Vol. II., Plate 78, 1862, and in "L'Illustration Horticole," Vol. IX., Plate 318, 1862, both accompanied by the same figure of an impossible Œnothera.

The importance of this sheet in the Gray Herbarium (Plate III.) has led me to re-examine the specimens with the advantage of a wider acquaintance with *Lamarckiana* and *grandiflora* than when I wrote the first description (Davis 1912*a*, 1913).

Stem. Strongly pilose and puberulent, the long hairs arising from red papillæ, wholly as in *Lamarckiana*.

Leaves. *Lamarckiana*-like in form and puberulent pubescence. The large leaf, about 18.5 cm. long, suggests by its form the basal leaves of *Lamarckiana*.

Inflorescence. Rather more open than that of *Lamarckiana* but no evidence of approximate branching as in *grandiflora*.

Bracts. Broad at base and puberulent as in *Lamarckiana*.

Buds. More slender hypanthium and bud cone than that of *Lamarckiana;* in these respects *grandiflora*-like.

Sepals. Strongly pilose and puberulent as in *Lamarckiana*.

Sepal Tips. About 9 mm. long, attenuate as in *grandiflora*, but heavily pilose as in *Lamarckiana*.

Petals. About 4.5 cm. long.

Stigma Lobes. 4, about 5 mm. above the tips of the anthers.

Ovary. Heavily pilose and puberulent and with red papillæ as in *Lamarckiana*.

Capsules. 3 cm. long. Heavily pilose and puberulent as in *Lamarckiana*. The capsules are longer than in most races of *Lamarckiana* (2–2.5 cm.) and not so stout, but they do not taper as in *grandiflora*.

It will be noted that the plant is typical of *Lamarckiana* in all important respects except the more slender buds, attenuate sepal tips, and longer capsules. In these respects the plant is similar to *grandiflora*, but the heavy pubescence on the structures is that of *Lamarckiana;* the sepals and capsules of *grandiflora* are glabrous or almost glabrous. Pubescence is a most important character in judging relationships among the œnotheras and the pubescence of the stem, leaves, sepals, ovaries and capsules of these specimens is

wholly that of *Lamarckiana*. The large broad leaves are also characteristic of *Lamarckiana* and remove this plant from narrow-leaved species with which it might be confused. The capsules are longer than in most races of *Lamarckiana*, but they fall within the range of measurements recorded by de Vries (1901, p. 312) in a study of 568 capsules of *Lamarckiana*.

Thus in pubescence, leaf form, inflorescence, flower structure and capsule form the specimens show clearly the characters of *Lamarckiana*. In bud form and attenuate sepal tips only do we find suggestions of another species. In early papers I was inclined to emphasize this resemblance to *grandiflora* but the strong pubescence of stems, buds and capsules makes it unlikely that *grandiflora* contributed to the blood of this plant. These characters, if typical of the plant, seem more likely to have genetic relation to some other species than *grandiflora*.

I have hinted that there may have been other large-flowered œnotheras in England besides *biennis*, *grandiflora* and *Lamarckiana* to complicate the problem of tracing the history of the latter species. In my examination of herbarium sheets last summer I found evidence of such material in specimens differing from *Lamarckiana* most conspicuously through the presence of narrower leaves and these specimens will now be considered. I hold that these specimens are not of *Lamarckiana* and that there is no herbarium evidence of the presence of *Lamarckiana* in England or elsewhere before the time, about 1860, when Carter and Company presented the plant to the trade.

TABLE 2.

SPECIMENS OF ŒNOTHERA LAMARCKIANA OF DE VRIES FROM BRITISH LOCALITIES.

1907 and earlier. Various sheets of Charles Bailey of specimens from St. Anne's-on-the-Sea, Lancashire. (Herbaria, University of Manchester, British Museum, Royal Botanic Gardens, Oxford University.)

1905. Sandy waste ground about the railway at Bidston Junction, 3 miles N. of Birkenhead, Cheshire. C. T. Greene, Date July 7, 1905. (Herbarium, British Museum.)

1876. Cultivated specimen from the garden of Mr. Edward Leeds (General herbarium, Royal Botanic Gardens). A particularly good specimen of *Lamarckiana*.

1872, 1871. First specimen—Waste places, near North Western Railway, Banbury (Oxford), Aug. 25, 1872. Coll. A. French. Second specimen—In corn field on waste land, not truly wild, Corkfield, Suffolk. Churchill Babington, Sept. 9, 1871. (Herbarium, British Museum.)

1862. Hort. Cantab. 1862, from seed of Thompson, Ipswich. (Gray Herbarium of Harvard University.) A plant grown by Dr. Asa Gray at Cambridge, Massachusetts from seed sent by William Thompson, a seedsman of Ipswich, England. It seems probable that Thompson obtained his material from Carter and Company of London who placed *Œnothera Lamarckiana* on the market as a novelty at about 1860.

Narrow-Leaved, Large-Flowered Œnotheras from British Localities with Pubescence Similar in Character to that of Lamarckiana and with Red Papillæ.

My interest in narrow-leaved, large-flowered œnotheras with pilose and puberulent pubescence similar in character to that of *Lamarckiana* was stimulated last summer by the examination of that specimen of Michaux's in the herbarium of Museum d'Histoire Naturelle at Paris which de Vries (1914) has brought forward as a plant of *Lamarckiana*, a conclusion that Gates (1915) has accepted. I shall discuss the specimens on this sheet in detail in another paper. At this time it is only necessary to note that however similar Michaux's plant may have been to *Lamarckiana* in bud and flower structure and in pubescence its foliage removes it entirely from this species.

There are many leaves shown on the two specimens on the sheet of Michaux's, one the upper part of a shoot and the other a lower section where the stem was thick. All leaves and bracts are elliptical-lanceolate, tapering to long petioles which measure as much as 2 cm. in the larger leaves. One of the larger leaves is 15 cm. long and 2.8 cm. at its greatest width a ratio of width to length less than 1 : 5. This narrow leaf form *Lamarckiana* definitely does not have. Indeed, *Lamarckiana* and *biennis* are exceptional in having broad short-petioled leaves which give to the plants an aspect of luxuriance in sharp contrast to the weediness of most œnotheras. We may never be able to identify Michaux's plant, but I venture to believe that it was a tall plant, very leafy but without great range of leaf size. The buds were at least 9 cm. long, the hypanthium long and slender, and the flowers exceptionally large. It was a coarse plant with much heavier pubescence than that of *Lamarckiana* although of the same nature. There are types of œnotheras in south and west

North America and probably elsewhere which have these characteristics in various degrees, but they have not as yet been given careful study through garden cultures.

It was then a matter of much interest to find in English herbaria a number of sheets suggesting in various particulars this plant of Michaux's, that is to say, they were narrow-leaved, large-flowered and had the type of pubescence found in *Lamarckiana* including red papillæ over the stem. I have listed these specimens in Table 3 but detailed descriptions will not be given since I shall not attempt to identify them holding only that they are not *Lamarckiana*. They are clearly not one species and none of the specimens can be safely matched with the sheet of Michaux's. Some of the specimens have important associations with dates and with localities and these will now be considered.

In the Lindley Herbarium of Cambridge University are two sheets of the years 1827 and 1828 with references to Douglas. This was David Douglas (1798–1834) who in 1823 was sent by the Horticultural Society to collect in America. He was in Rio in 1824, British Columbia in 1825–27, California 1830–32, and on the Fraser River 1832–33 (Britton and Boulger 1893). The sheets bear the initials H. H. J. the significance of which is not clear but a letter to me from R. H. Compton of 1911 states that they seem to refer to the garden of the Horticultural Society. The correspondence of dates indicates that these plants were some of the Douglas introductions and the note on the sheet of 1827 "N.W. America" bears out this interpretation. Another specimen in the Lindley Herbarium labeled "Œ. grandiflora H. H. J. 1828," with no locality given, from the heavy pubescence and red papillæ is clearly not *grandiflora;* it has the appearance of a cultivated plant. The letter of 1911 from R. H. Compton tells of a specimen in the Lindley Herbarium with data "grown in garden from seed sent by Tate from Mexico 1824"; Compton states that the specimen "agrees pretty well with *Lamarckiana* in size, hairiness, etc., bracts very large, however, up to 9 cm."; this extraordinary length of bracts is far beyond that of *Lamarckiana*. Search for this sheet in the herbarium of Cambridge University has not been successful.

These plants are particularly interesting in connection with

Lindley's plate of "*Œnothera biennis* var. *grandiflora*" in Edwards's Botanical Register, Vol. 19, p. 1604, 1833. Lindley's description gives little information of importance which together with the synonymy (*biennis* Linn., *grandiflora* Ait., *suaveolens* Desf., *muricata* Linn.) shows that he did not recognize the specific differences among the œnotheras that he mentions. The illustration (Plate IV., Fig. 1) shows a plant obviously of the large-flowered group with a very narrow lower leaf measuring in the figure about 22.5 cm. long and only 3 cm. at its greatest width. Here then was a large-flowered, narrow-leaved œnothera probably hairy, since it was placed as a variety of *biennis* rather than associated with *grandiflora* which Lindley states has "scarcely any hairyness." It is interesting that Lindley should write "The plant now figured is not uncommon in gardens; it is one of the handsomest of all biennials and as easily managed as the common *Œnothera biennis* itself." This remark gives further evidence that the plant was not *grandiflora* which is not easily grown and apparently never became in England a common garden plant. Since the plants associated with the name of Douglas and possibly grown in the gardens of the Horticultural Society in 1827 and 1828 are in the herbarium of Lindley it appears probable that they were part of Lindley's conception of an "*Œnothera biennis* var. *grandiflora*." It is clear that some large-flowered, narrow-leaved œnotheras were in cultivation before 1830 and that these were neither *biennis*, *grandiflora*, nor *Lamarckiana*. They were probably, at least in part, introductions from southern or western North America and possibly from South America.

Next on the list is a specimen of 1867 from Tenby, South Wales, apparently collected on waste lands of rabbit burrows. This specimen is interesting for its particularly long narrow leaves, thick stem indicating a tall plant, and rough pubescence. It suggests very strongly some of the large coarse species of America and since Tenby is a seaport may readily have been an introduction; it does not have the appearance of a cultivated plant.

In more recent years we have a clear record of narrow-leaved, large-flowered œnotheras on the sand hills of Lancashire. There are two specimens of 1905 from the herbarium C. Theodore Green collected at the nearby stations of Formby and Fairfields between

Liverpool and the River Ribble. These specimens are similar and have long narrow leaves thick stems and a heavy rough pubescence. They were probably tall coarse plants more likely to be introductions than garden escapes since they did not have the foliage and trimness that makes *Lamarckiana* attractive for cultivation.

Finally, there was in 1907 another Œnothera on the coast of Lancashire collected by Bailey at St. Anne's-on-the-Sea and distributed by him as a "narrow-leaved form" of *Œnothera Lamarckiana*. I saw a number of sheets of this plant in the herbaria visited and they are likely to be found in any collection of the Bailey Œnothera material from St. Anne's. It was a narrow-leaved plant with buds more slender than those of *Lamarckiana*, and flowers not so large. The sepals were red, the sepal tips shorter than in *Lamarckiana*, but the pubescence was similar. I cannot identify this plant with any American species known to me, but there are suggestions in it of western American œnotheras. It would be interesting to know whether the plant is a species independent of *biennis* and *Lamarckiana* on the sand hills of Lancashire. There is, of course, the possibility of its being of some hybrid derivation.

The evidence is clear that large-flowered œnotheras other than *biennis, grandiflora,* and *Lamarckiana* have entered England at various times and that some of them were cultivated before 1830. Also, some of the early introductions, previous to 1830, were at least in part from southern or western North America and possibly from South America. These are matters of interest in connection with the problem of the origin of *Œnothera Lamarckiana,* which will now be briefly considered.

TABLE 3.

SPECIMENS OF NARROW-LEAVED, LARGE-FLOWERED ŒNOTHERAS FROM BRITISH LOCALITIES, WITH PUBESCENCE SIMILAR IN CHARACTER TO THAT OF LAMARCKIANA AND WITH RED PAPILLÆ.

1824. *Œnothera grandiflora* Lam. Grown in garden from seed sent by Tate from Mexico 1824. (A letter from R. H. Compton of 1911 states that this specimen is in the Lindley Herbarium of Cambridge University, but recent search for it has not been successful.)

1827. N.W. America. Douglas 126. H. H. J. 1827. (Lindley Herbarium, Cambridge University.)

1828. *Œ. grandiflora.* H. H. J. 1828. (Lindley Herbarium, Cambridge University.) Handwriting of Lindley.

1828. *Œ. suaveolens* Desf. H. H. J. Douglas 1828. (Lindley Herbarium, Cambridge University.)

1867. Herb. Trimes, 1873. Tenby (South Wales), Burrows, April 9, 1867. (Herbarium, British Museum.)

1905. Ex herbario, C. Theodore Green. Freshfield, July 8, 1905. (Herbarium, British Museum.) Freshfield is in Lancashire.

1905. Ex herbario, C. Theodore Green. Sandhills alongside of L. and V. R. about Formby, Lancashire. C. T. Green. Date August 7, 1905. (Herbarium, British Museum.)

1907. *Œnothera Lamarckiana*, narrow-leaved form. St. Anne's-on-the-Sea, West Lancashire. Charles Bailey, 1907. (In the collections of Charles Bailey at the University of Manchester, and distributed to other herbaria.)

The Problem of the Origin of Œnothera Lamarckiana.

Our interest in the problem of the origin of *Œnothera Lamarckiana* has shifted with the passing years. It is no longer a matter of deep concern to the geneticist when or where *Lamarckiana* arose. The genetical analyses to which this plant has been subjected and which are still in progress show clearly that *Lamarckiana* is heterozygous, an impure species complicated by the presence of lethals that prevent the full expression of certain segregates except when occasional shifts of the lethals permit their appearance as is the case when *nanella* is thrown. There are also numerical irregularities of chromosome distribution at meiosis which account for several of the sports from *Lamarckiana* as in the case of non-disjunction responsible for *lata* and several other 15 chromosome variants and derivatives of higher chromosome numbers; also, there is the chromosome behavior that determines the triploid and tetraploid types.

As an impure species *Lamarckiana* must be regarded as behaving like a hybrid whether its heterozygous nature be in part the result of gene mutations of long standing or came about wholly or in part as the result of some immediate crossings. I have shown (Davis 1916, 1924) that from suitable parent stock (*Œnothera biennis* and *O. franciscana*) it is not difficult to obtain a hybrid, *neo-Lamarckiana*, so similar to *Lamarckiana* that it is not easily distinguished from this species, in the collective sense, by common taxonomic practice, and further that such a hybrid may behave in selfed lines after a manner similar to that of *Lamarckiana*.

To the student of œnotheras, however, it will always be a matter

of interest to trace as far as possible the history of this remarkable plant and of other species with which he works. Some may still hold to the hope that *Lamarckiana* will be found as a wild species, local to some part of North or South America. This cannot be ruled out as impossible and would not change its status as an impure or heterozygous species, but I do not think it likely for the reason that *Lamarckiana* does not have the appearance of a wild *Œnothera*. The breadth and large size of its leaves, the trimness and luxuriance of its growth are far from the habit of wild œnotheras which with their narrow and smaller leaves are characteristically weedy in appearance. Only one Œnothera, that I know, approaches *Lamarckiana* in these respects and that is *biennis*, which one naturally suspects as a possible contributor to its parentage on the hypothesis that *Lamarckiana* arose as a hybrid in England.

The history of the attempts of Gates (1910) to establish an early presence of *Lamarckiana* in Europe has been one of steady retreat and a critical examination of material at Paris has forced me to the conclusion that Lamarck did not grow the plant in Paris and did not know it. The Paris material will be considered in another paper where certain conclusions of de Vries, which I cannot accept, will be discussed.

A sheet (Plate IV., Fig. 2) in the herbarium at Cambridge University should, however, be noted although the specimens are not of British origin. It bears the writing "Œnothera grandiflora, Switzerland, J. Dalton"; there is no date but the sheet is regarded as of the early nineteenth century. Gates (1915, p. 15) claims the material to be *Œnothera Lamarckiana*, "the exact counterpart of de Vries's race." With this identification I cannot agree for the pubescence is of soft hairs scattered on sepals and stems. There are no red papillæ on the stem bearing stiff hairs, neither is there the puberulence characteristic of *Lamarckiana*. In this material, as on many herbarium sheets of Œnothera, pubescence presents the best evidence of relationships and the pubescence of these specimens is not that of *Lamarckiana*. The leaves and bracts are rather narrow for *Lamarckiana* and the sepal tips are not so attenuate. Unfortunately mature capsules are not present. This material certainly cannot be referred to *Lamarckiana*.

In my opinion the only date known for the appearance of *Lamarckiana* is that of its introduction to the trade by Carter and Company, about 1860, supported by the excellent specimen of the plant (Plate III.) grown by Dr. Asa Gray in 1862 from seeds sent from England. Before 1860 is a blank since I do not believe that any specimen or description of earlier date can be identified with *Lamarckiana*.

It is, however, a matter of great interest that narrow-leaved, large-flowered œnotheras with pubescence similar in character to that of *Lamarckiana* were introduced into England and in cultivation as early as 1830. The evidence for this has been given in connection with the discussion of the earlier herbarium sheets listed in Table 3. Thus Tate in 1824 apparently sent seeds from Mexico and certainly Douglas in 1827, and perhaps later, from North America. Lindley's (1833) conception and figure of an "*Œnothera biennis* var. *grandiflora*" (Plate IV., Fig. 1) is probably connected with some of this material since the specimens were in his herbarium. Lindley expressly states that "the plant now figured is not uncommon in the gardens." We have then excellent evidence that large-flowered œnotheras were in cultivation in England from about 1830 on, and that this material was not *Œnothera grandiflora* Solander. They were probably a mixture of forms from different sources and of different introductions and the scanty herbarium material left to us is not likely to make close identification possible.

It seems to me probable that Carter and Company obtained their material of *Lamarckiana* in England and from large-flowered œnotheras which were evidently favorite plants of the English gardens. I do not think that their statement (*Floral Magazine*, Vol. 2, 1862) that the original seed of *Lamarckiana* came from Texas can be taken seriously in which view de Vries and Gates have expressed agreement. That Lindley should have pronounced the plants of Carter and Company to be *Œnothera Lamarckiana* signifies nothing in view of his obviously uncritical knowledge of Œnothera species as shown in his account of "*Œnothera biennis* var. *grandiflora*" (Lindley 1833), with its confused synonymy, and because the specimens of Lamarck's plant grown at Paris, about 1796, have proved to be *Œnothera grandiflora* Solander (Davis 1912*b*). I think it probable

that Carter and Company, struck with the beauty and luxuriance of some English garden plant or garden escape, decided to develop it as a commercial venture and that their product became invested with the myth of a Texan origin.

Whether Carter and Company obtained their plant directly from an English garden or as a garden escape is not material, but there is no evidence that it could have come from the sand hills of Lancashire. Granting that Bailey (1907, p. 5) was correct in reporting collections of *Lamarckiana* in Lancashire as early as 1881, there is, nevertheless, a considerable stretch of intervening years following the time when Carter and Company isolated their line somewhat previous to 1860. The records of *biennis* from Lancashire (Table 1) show collections of 1810–20 (W. Borrer), 1825–43 (W. A. Leighton), 1835 (B. H. Allen), 1837 (W. Borrer), 1839 (Miss Potts), 1872 (J. H. L.), 1877 (J. Harbord Lewis), 1878 (J. Comber), 1883 and 1885 (Charles Bailey), and there must have been many other visits of botanists for the region has been one of particular interest from the time when Smith (1806) wrote so enthusiastically of its peculiarities in the "English Botany." It is hardly conceivable that so conspicuous a plant as *Œnothera Lamarckiana* would pass unrecorded if it were present in Lancashire much before 1880. Consequently we seem forced to the conclusion that *Lamarckiana* came to Lancashire as an introduction, an opinion held by Wheldale (1913). The readiness with which *Lamarckiana* establishes itself in England as a garden escape indicates the probable manner of its introduction into Lancashire.

If Carter and Company obtained their material from among cultivated plants of English gardens, or from garden escapes, there are permitted abundant possibilities of its being of hybrid origin, and its parentage might readily have involved *Œnothera biennis* and some narrow-leaved, large-flowered Œnothera with pubescence similar to *Lamarckiana*, that is, some species of Œnothera among the introductions which we know to have been grown in English gardens about 1830 and later. The degree of success which I attained in the synthesis of my plant *neo-Lamarckiana* (Davis 1916, 1924) from *franciscana* × *biennis* suggests such a possible origin since *franciscana* is one of those western American species narrow-leaved and

large-flowered and with pubescence similar in character to that of *Lamarckiana.*

Finally it must not be forgotten that in keeping the name *Lamarckiana* for the plants of de Vries we do not refer to *Œnothera Lamarckiana* Seringe, 1828, which is a synonym of *Œnothera grandiflora* Solander, 1789, (*Œnothera grandiflora* "Aiton"). The incorrect identification by Lindley of the material of Carter and Company has invested a commercial product with a name that has passed into the synonymy of *Œnothera grandiflora* Solander (Davis 1912*b*). The association of the name *Lamarckiana* with the plant of Professor de Vries's life-long research has firmly established the name in extensive literature, but we should always think of the species as *Œnothera Lamarckiana* of de Vries, a species of permanent heterozygous constitution.

Summary.

The evening primrose upon the sand hills of Lancashire in 1806 was *Œnothera biennis* Linnæus and not *Œnothera Lamarckiana,* as claimed by de Vries and Gates. This is established by specimens in Smith's herbarium of the Linnean Society of London (Plate II., Fig. 1). From these specimens or similar ones Sowerby drew the figures (Plate I.) which accompany Smith's description of *Œnothera biennis* in the "English Botany," 1806.

Material in British herbaria (Table 1) gives a clear history of rather frequent collections of *biennis* from Lancashire, following the interest aroused by Smith's (1806) account in the "English Botany." The plant known to Don (1832) and to Baxter (1839) was also *biennis.* Not until recent years, after 1880, have we any records of *Lamarckiana* in Lancashire as discussed by Bailey (1907) and Wheldon (1913). Evidence is clear that *biennis* was grown in English gardens for more than a century previous to 1800.

Œnothera grandiflora Solander has never established itself in England, probably because the summers are not sufficiently warm. British herbaria have almost nothing that may safely be identified as *grandiflora.* Certain sheets, incorrectly named, refer to narrow-leaved, large-flowered œnotheras with pubescence similar to that of *Lamarckiana* (Table 3). Sims's "*Œnothera grandiflora* B. Pu-

bescent Great-flowered Œnothera" (1819) was not *grandiflora*, which is almost glabrous, but possibly some associated form such as are known to grow in the southern United States.

Œnothera Lamarckiana is now widely cultivated in England, having taken the place of *biennis* in popular favor. It may frequently be seen as a garden escape. The most extensive wild stands are on the sand hills of Lancashire. From observations of Bailey (1907) it seems probable that *Lamarckiana* has been in Lancashire since 1880, but there is no herbarium evidence of its presence in this region before Bailey's collections after 1900. The frequent collections of Œnothera material from Lancashire (Table 1) from 1806 to the time of Bailey's studies present no *Lamarckiana*, only *biennis*.

As shown in Table 2, there is very little herbarium material in England that may safely be identified with *Œnothera Lamarckiana*, and none of this is of earlier dates than 1860, at about which time Carter and Company placed *Lamarckiana* on the market. Of especial interest is the sheet in the Gray Herbarium of Harvard University (Plate III) with material grown by Dr. Asa Gray at Cambridge, Massachusetts, in 1862 from seed sent by Thompson of Ipswich, England. This sheet is offered as holding the oldest specimens of *Lamarckiana* known, possibly not more than one or two generations removed from the cultures of Carter and Company.

It is my belief that de Vries and Gates have failed to present satisfactory evidence for the existence of *Lamarckiana* previous to its presentation by Carter and Company about 1860. In another paper I shall present the results of an examination of material in Paris and give further evidence for my conclusions that Lamarck's plant was a form of *Œnothera grandiflora* Solander, and that other material of this period including a specimen of Michaux's, believed by de Vries to be *Lamarckiana*, cannot be so identified. The plant on a sheet in the herbarium of Cambridge University (Plate IV, Fig. 2) of the early nineteenth century with the writing "*Œnothera grandiflora*, Switzerland, J. Dalton," claimed by Gates (1915, p. 15) to be *Lamarckiana*, cannot be this species because of its pubescence of soft hairs together with other characters.

There is clear evidence in British herbaria (Table 3) of the introduction into England as early as 1830 and at later dates of cer-

tain narrow-leaved, large-flowered œnotheras with pubescence similar in character to that of *Lamarckiana* and with red papillæ. Of particular interest are introductions from America by Douglas, established by sheets in the Lindley Herbarium of Cambridge University. These plants probably were connected with Lindley's conception of an "*Œnothera biennis* var. *grandiflora*" (1833), the figure of which is reproduced in Plate IV., Fig. 1. Other plants of this general type have appeared in later years (Table 3), but it is a matter of great interest that large-flowered œnotheras, other than *biennis, grandiflora* and *Lamarckiana,* were cultivated in England before 1830, and that some of these introductions were from southern or western North America, one or both, and possibly from South America.

With respect to the origin of *Œnothera Lamarckiana* it seems to me probable that Carter and Company about 1860 obtained their material from some garden of England or from some garden escape. It is hardly possible that it could have come from the sand hills of Lancashire since the evidence is strong that *Lamarckiana* reached Lancashire much later as a garden escape. If *Lamarckiana* arose in England there are permitted many possibilities of its being of hybrid origin and its parentage might readily have involved *Œnothera biennis* and some narrow-leaved, large-flowered œnothera with pubescence similar to that of *Lamarckiana,* that is, some species of Œnothera among the introductions known to have been grown in English gardens about 1830 and later. The degree of success attained in the synthesis of *Œnothera neo-Lamarckiana* (Davis 1916, 1924) from *franciscana* × *biennis* is suggestive of such a possible origin, since *franciscana* is one of those western American species, narrow-leaved, large-flowered, and with pubescence similar in character to that of *Lamarckiana.*

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PREDICTION OF THE SPECTRUM OF THE COSMIC RAYS.

By MONROE B. SNYDER.

(*Read November 5, 1926.*)

One of the most important results of Millikan's discovery of the reality and absorptive character of the cosmic rays is his additional discovery "that these highest frequency rays are not homogeneous, but have a measurable spectral distribution."[1] It is this fact of a cosmic ray spectrum, with definite "lines." that has suggested the use of my theory of the nature of these rays for the prediction of the "lines" or "peaks" of absorption that should be observable in the band of these highest frequency rays. By use of the principle that these limiting X-rays of the K-series vary in absorption with the inverse fifth power of the atomic number, I have already shown[2] that the ultimate element of atomic number 143 produces by its explosive transmutation a highest radiation whose mass absorption coefficient per meter of water is .1791, and closely approximates to the Millikan observation of .18 per meter of water for this most penetrative cosmic radiation. I also found that Millikan's observation of the softest cosmic rays of an absorption of 0.3 per meter of water was produced by the exploding element number 129, whose theoretical radiation has an absorption of .2997 per meter of water. The close agreement of these theoretical values with Dr. Millikan's observation suggests that it would be worth while observationally to locate the other 13 "lines" due to atoms between numbers 143 and 129, as shown in the accompanying table. Here are presented all the mass absorption coefficients of cosmic rays produced by atoms from number 143 to number 106. Columns I and III of the table state the atomic numbers of the radiating elements. Columns II and IV state the corresponding line radiations in terms of their mass absorption coefficients per meter of water.

[1] Millikan, *Science*, November 20, 1925, p. 446.

[2] "Universal Atomic Volcanism and the Ultimate Atom," *Proc. Amer. Phil. Soc.*, 1926, 65, 170–182.

TABLE OF COSMIC RAY "LINES."

I	II	III	IV
143	.1791	124	.3652
142	.1854	123	.3803
141	.1921	122	.3962
140	.1991	121	.4128
139	.2063	120	.4303
138	.2139	119	.4487
137	.2218	118	.4680
136	.2301	117	.4884
135	.2388	116	.5098
134	.2478	115	.5323
133	.2573	114	.5561
132	.2672	113	.5811
131	.2775	112	.6075
130	.2884	111	.6355
129	.2997	110	.6648
128	.3116	109	.6959
127	.3241	108	.7287
126	.3371	107	.7634
125	.3508	106	.8001

In the new work proposed by Dr. Millikan [3] of tracing out the cosmic ray band on the highest mountains of Bolivia, it does not seem likely that he can improve his already remarkably accurate value for the absorption of the cosmic rays of highest penetration. But since softer cosmic rays may be verified on the higher mountains of Bolivia than those observed on Mount Whitney it seems likely that the observations may be extended in this direction. The table shows softer "lines" of absorption than it seems, from present knowledge, possible to observe anywhere on the earth's surface. The highest absorption coefficients predicted in the table are electroscopically observable, but thus far these lines are beyond the reach of any spectrographic record. As a series of line radiations of highest frequency and penetrative energy generated in the stars this uppermost cosmic ray spectrum of Dr. Millikan assumes boundless importance.

[3] *Science*, July 16, 1926, Supplement, p. viii.

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THE HEALTH WORK OF THE LEAGUE OF NATIONS.[1]

By VICTOR G. HEISER.

(*Read February 4, 1927.*)

One of the great achievements of modern civilization has been to prevent the transmission from country to country of communicable diseases. With increasing knowledge this has become more effective, until now, through the health work of the League of Nations, it has reached a high point of development. This branch of activity of the League of Nations is in reality a continuance and enlargement of the objectives of international sanitary conventions that have been in existence for many years.

Nations have sought to safeguard themselves largely through regulating maritime commerce. It is a very general belief that the health of Europe and America has been seriously menaced by the great unwashed hordes of the Orient. Apparently little thought has been given to the fact that at times the diseases of Europe have caused serious consequences for the people of the Far East. For instance, when Captain Cook and other intrepid explorers made their voyages to the South Seas, they took with them tuberculosis, smallpox, syphilis, gonorrhea, measles, and other diseases which were entirely unknown among the islanders of the South Pacific. The havoc wrought by the importation of these diseases stands among the great disasters of history. The unfortunate island people have suffered terribly through their contact with western civilization. They have been almost wiped out by the diseases which were introduced among them. An obligation therefore appears to rest upon our civilization to help control a situation that threatens a complete extermination of such a race as the Polynesians, for example.

In the days before transmission of disease was understood, it became empirically known that communicable diseases could be largely avoided by detaining infected persons in isolation for sufficiently long periods of time; forty days was regarded as a safe period, and from

that the word "quarantine" derives its origin. In the beginning, sanitary conventions were usually made effective between two countries. Gradually it became apparent that a group of countries could act to better advantage. For instance, when the Suez Canal was completed, it was obvious that all traffic from the East would have to pass through this very narrow neck of water. A veritable funnel was created into which a large part of the earth's population might pour its disease. By taking precautions at the entrances to the Canal, Europe could largely be safeguarded. An international quarantine service was established at Suez. The United States was loosely affiliated with this organization. In order to handle the traffic, stations were opened at Port Said and Suez. For ships that required detention of passengers, a gigantic quarantine station was installed at El Tor, with a capacity for quartering several thousand persons at a time.

Another development to control the international movement of disease came when sanitary safeguards were thrown around huge religious pilgrimages. It is an established fact that movements of large numbers of people, particularly fanatical religious groups, have been an important factor in spreading disease throughout the world. Prior to the World War, in order to save Europe from diseases of the Near East, an international sanitary committee was established at Constantinople, which prescribed certain precautions, particularly in connection with ships. As knowledge in the prevention of disease increased, it became obvious that sanitary conventions would require more frequent revision. But it was difficult to have adequate international representation at sanitary conferences, because the delegates usually had to be chosen from among the active administrative health officers, and they could not spend the many weeks away from home that were required to revise a convention.

With the advent of the Health Section of the League of Nations, workable machinery was provided which made it possible, through the health representatives of the various nations stationed at Geneva, to exchange opinions and work out solutions which could be presented at an international sanitary convention. In view of the varying needs of the countries and the constantly increasing scientific knowledge, it was difficult, even with the improved machinery of the League

of Nations, to formulate a convention which could have the adherence of all the countries of the world. It is obvious that under the old method employed before the existence of the League, it would have been almost impossible to work out a convention that could have had general approval. As soon as the Health Section of the League of Nations was established, it concerned itself with this matter. And it was largely the data collected under auspices of that body which enabled the International Convention held in Paris last May to arrive at an agreement within a month.

But the Health Section of the League performs many other important functions. Soon after it came into existence in 1919, Europe was confronted with the serious menace of typhus fever spreading from Russia westward. In the disorganized Europe that existed after the armistice, no one country was in position to establish the sanitary safeguards which were necessary in order to control an epidemic of such huge proportions. As the League could act for all of the countries directly concerned, an organization under its auspices was quickly perfected, which established disinfestation stations along the Russian border; and Europe was saved from a serious invasion of typhus, no doubt largely because of the excellent work done. The United States unquestionably benefited very greatly. Had Europe become seriously infected, we should have been compelled to undertake precautions on a very large scale. It may not be out of place to mention in passing that all of the countries belonging to the League of Nations, including Japan, China, and even little Siam, and other countries not menaced, paid their share to control an epidemic, that Europe might be saved from invasion; and we—a great rich, powerful nation—enjoyed the benefits of this work and made no contribution.

Soon afterward, as a result of the war between Greece and Turkey, thousands of Greeks were expelled from Turkey. It was not long before a severe smallpox outbreak occurred among the refugees. It was obvious that if Greece should become thoroughly infected with smallpox, the infection would in all probability spread to Europe. Again the United States would have been seriously threatened. Here was another task that obviously no one country could undertake for itself. It was perfectly apparent that the surest way to safe-

guard Europe would be to vaccinate the population of Greece. Again no nation could make such a proposal to a sovereign country. The League of Nations stepped in and offered its services, which were accepted. And owing to the extensive vaccinating done in Greece under League auspices, the epidemic was quickly brought under control and Europe and America were again saved.

The enormous extent of the traffic on the Danube is well known. Many countries border on this great artery of trade. The multitude of conflicting quarantine regulations of the different countries proved most embarrassing to commerce. Through the intervention of the League of Nations a set of uniform rules and regulations was adopted by the interested countries, which protects them as well as may be against invasion of disease, and places the minimum restriction upon commerce and international passenger travel.

Upon the request of the countries of the Far East, the League of Nations made a study of the possibilities of disease control through better international action. This finally resulted in the establishment by the interested nations of headquarters at Singapore, of which the primary object is the collection and dissemination of data relating to the dangerous communicable diseases. Such free interchange of information has made it possible greatly to improve the quarantine administration and to give timely notice of impending dangers. The office is conducted as a branch of the League of Nations in Geneva. Telegraphic reports are received at Singapore from thirty-nine countries, which are freely reporting their dangerous communicable diseases. To a very large extent suspicion and retribution have been replaced by confidence and common-sense action.

One of the modern means of dealing with disease is through the use of vaccines and serums commonly known as "the biologicals." As each country has been working more or less independently, a set of diverse standards has resulted. This has caused great confusion. For instance, a diphtheria antitoxin unit valued at 1 in Germany would be valued at 67 in the United States and at 2,500 in France; and still other standards are used by other nations. It is obvious that a doctor studying the reports of a foreign physician must be a mathematician; and if, as is frequently the case, he is in ignorance of what particular country's vaccine or serum is used, he is greatly

handicapped in his study of disease. A uniform standard seemed desirable—but how was it to be obtained? Here again the Health Section of the League of Nations showed its value by appointing an international committee, which made thorough research into the matter; and it is hoped that in a short time a uniform standard will be adopted, thus eliminating the confusion which has existed in the past.

If disease is to be dealt with intelligently, accurate bookkeeping of its incidence is necessary; it is obvious that vital statistics are essential in making comparative studies. Until recently, almost every country had a different system for recording such data, so that comparisons were more or less impracticable. The League of Nations called a meeting of representatives of the various interested countries, who sent their statisticians. After a study of the matter, a system was devised which will make uniform international adoption possible. The importance of using the same classification can scarcely be estimated. For instance, it was found that certain forms of cancer are apparently twice as prevalent in Great Britain as in Holland. The mere fact that attention has been brought to this matter will stimulate research, for there must be some good reason for this difference. Many other important data are in the process of being revealed through this uniform system of reporting.

Another outcome of the statistical meeting has been the establishment in Geneva of an office of epidemiological intelligence, which collects data with regard to communicable diseases from the entire world and issues weekly bulletins. Member nations that are in the direct path of an oncoming disease are promptly notified by telegraph and thus are able to take timely precautions. In the past there has been all too much effort on the part of many countries to suppress news with regard to outbreaks of quarantinable disease, thus unnecessarily menacing other countries. The free interchange of knowledge which is now on a fair way toward accomplishment will no doubt do much to improve the control of these diseases.

Another activity has been the establishment of an interchange of sanitary personnel among the different countries. By this is meant that the League of Nations invites one or more health officers from various nations, organizes them into a group, and sends them to other

countries to study the health measures employed. This has had a most stimulating effect. Countries that have good health departments have been glad to show their work; those that have not been so fortunate have been stimulated to do something better. The free interchange of opinions which has occurred among the various health officers frequently results in improved measures. The travels of these international groups have also brought about much newspaper publicity, which in itself has been for the advancement of public health. Many of the countries feel that their prestige has been enhanced by having foreign officers visit their work and report upon their activities.

The League has also made a study of the sanitary organization of many countries in the world and has published the results. This has made it possible to compare the health administration of the different countries, and those that were found backward have been making renewed efforts to improve their health measures. The maps which have been published, showing the extent of disease incidence, have had a most salutary effect.

The United States has always taken a prominent part in an effort to bring about suppression of the use of habit-forming drugs, notably opium and cocaine. Those especially interested, however, soon found that the League of Nations was the logical means to employ, if they wanted detailed information, or an international conference, or international action. And already two opium conferences have taken place under League auspices.

A large part of the Central African continent cannot be developed successfully on account of the prevalence of sleeping sickness, and this is a vital problem to numerous nations. Need for international action is again obvious. A combination of effort promises the greatest hope of finding satisfactory measures for control, and the League of Nations has been asked to nominate an international committee to deal with this matter.

Encouraged by the success which has followed international action in the control of yellow fever, the League of Nations has directed its attention to the possibility of performing a similar international service in the control of cholera. For some years now experts have been giving this disease serious consideration, and a number of researches

have already been made. In view of the very large number of countries in which cholera prevails, international action will be required if a uniform plan is to be agreed upon. Special studies are being made on certain phases of cholera. The results of these, combined with findings made in other places, may make it possible to devise a hopeful plan for controlling the disease. There is much reason to believe that from time to time cholera recedes to a few endemic centers, and when enough knowledge is available with regard to the disease, it is hoped to extinguish those centers and clear the world of a menace which has caused the loss of so many lives.

One of the great advantages of having an international office at Geneva is that it provides a storehouse where the world's knowledge with regard to the control of disease can be assembled and where investigators can find data and facilities for study. No one country, without the expenditure of huge sums of money—and even then the outcome would be very doubtful—can have such a library of information as is gradually coming into existence at Geneva. Comparing data such as have been accumulated there has already brought forth some very significant observations. For example, in the United States we are rather prone to pride ourselves on the high state of our achievements in the field of disease prevention, yet comparison of records shows that the United States ranks with the most backward countries of the world in maternal death rate. It is three times as dangerous to be a mother in the United States, for instance, as in Denmark. The mere fact that it is possible to make such statistical comparisons will no doubt result in renewed efforts in the United States to bring down the death rate from maternal mortality, the causes for which are largely preventable. Again, a study of the records has shown that hookworm disease is largely exported by one country, from which perhaps a million or more laborers emigrate yearly. Instead of trying to mop up the disease after it has been spilled all over the world, it would be a simple matter to control it at its source. In other words, if emigrants leaving an infested country were treated with an effective hookworm remedy, the export of the disease would be largely stopped; but what is everybody's business is nobody's business, and consequently the dissemination goes on.

The League is obviously in position to draw attention to a matter of this kind and no doubt coöperation could be had.

Probably malaria ranks among the most important preventable diseases in its ultimate effects and in the economic loss it entails. In India, for instance, over a million people die annually of this malady. And even here in the United States the number of deaths for which it is responsible, and the time lost by illness, with the resulting economic losses, are stupendous. Every year our Southern States suffer frightfully, and it so happens that malaria reaches its peak in September, which is precisely the month during which the cotton crop has to be picked, and the period during which the lumber activity reaches its greatest height. We have, therefore, through this disease, the minimum labor at the time when the maximum work is to be done, with the resultant unnecessarily increased cost of production. Malaria is receiving attention in many countries of the world, but through lack of coöperation and knowledge of what is being done in these countries, many unnecessary experiments are being made. In order to assemble the world's knowledge in this matter, the League has appointed a malaria commission, which is making studies of the disease in Europe, the Near East, the Orient, and the United States. It is reasonable to expect that when the data are assembled, more effective measures will result and much unnecessary experimenting can be avoided.

Inquiry developed the fact that all remedies proposed for malaria, with the exception of quinine, had little or no effect in the cure of the disease. It was further shown that one country had gradually acquired a monopoly in the production of quinine, that the cost had accordingly risen over 200 per cent, and that in the absence of competition the chances for a reduction in price were not promising. Literally thousands of lives could be saved, if the cost of the drug could be reduced. The League focused attention upon this matter. Steps are being taken by Italy to grow its own quinine in Africa and Java. The British renewed their efforts to produce quinine in India. Research laboratories began work to discover, if possible, a synthetic drug to accomplish what quinine does. Within the past few months one of Germany's laboratories has announced the discovery of a drug that gives promise of being better in many respects than quinine itself.

It appears to be more effective than quinine in benign tertian malaria, and to kill the gametes in the blood. The latter is most important and may have great bearing in controlling the spread of the disease. When patients treated with quinine are not completely cured, they often serve as reservoirs of malaria from which Anopheles mosquitoes receive their infection and spread the disease. If the new German preparation, plasmochin, kills the gametes in the human blood, a great source of potential infection will have been eliminated.

The foregoing are only some of the activities in which the Health Section of the League of Nations has been engaged. There are many more that time does not permit me to describe in detail. Studies are being made on infant mortality, tuberculosis, cancer, social medicine, means to improve health administration in many countries, the minimum requirements for the education of health officers, and many other matters that concern the welfare of mankind. But important as are all of these efforts, there are by-products of the Health Section's work, the aggregate value of which bids fair to promote the peace and happiness of the entire world. The interchange of health officers among some forty countries has set up an international commerce in ideas that no customs barrier can interrupt. The mutual friendship and understandings that have resulted from these visits have already been important factors in interpreting the better qualities of one people to another. The exchange of scientific knowledge may eventually lead to the same method of analysis being applied to settle the ordinary differences among nations, and when that happy day comes, reason will replace hate and prejudice, and the well-being of the people throughout the earth will be greatly promoted.

BEHAVIOR OF ORGANIC BASES TOWARD SOLUBLE TUNGSTATES.[1]

By EDGAR F. SMITH.

(*Read December 4, 1926.*)

In 1861 Scheibler,[2] in his classic paper on tungstates, alluded briefly to the precipitation of tungstic acid from solutions of the 5 : 12-sodium salt (sodium paratungstate) by means of a slightly acidulated solution of quinine sulphate. The results showed that the procedure was quantitative in character but Scheibler withheld his recommendation of the method because the resulting ignited tungsten trioxide was never *yellow* in color, but had a greenish hue.

This was the first attempt to introduce an organic base as a precipitant of tungstic acid. Some years later Allen Rogers, working in this laboratory, found that benzidine precipitated tungstic acid completely from solutions of normal sodium tungstate Na_2WO_4·-$2H_2O$). And, thereafter, v. Knorre published an interesting communication on the use of benzidine chloride, in the determination of the tungstic acid content of sodium paratungstate.[3] It would seem that v. Knorre also used *tolidine* with success and expressed the hope that by these precipitants the separation of tungstic and phosphoric acids might be realized. However, a silence, not explained, fell upon these recommendations.

In the meanwhile, Tschilikin[4] recommended the precipitation of the tungstic acid in sodium tungstate ($Na_2O \cdot WO_3 \cdot 2H_2O$) with alpha-naphthylamine, asserting it to be a reagent as valuable and efficacious as the bases employed by v. Knorre. Further, he analyzed

[1] Contribution from the John Harrison Laboratory of Chemistry, University of Pennsylvania, Philadelphia, Pa.

[2] *Jr. prakt. Ch.*, 83 (1861), p. 288.

[3] The 5 : 12-sodium salt,—$5Na_2O \cdot 12WO_3 + 28H_2O$, as described in the *Z. für analyt. Chemie*, 47, 37; *Ber.*, 38 (1905), 783.

[4] *Ber.*, 42, 1302 (1909).

the alpha-naphthylamine tungstate obtained by him, and from the results deduced the formula

$$2(C_{10}H_9N_2)\cdot 5WO_3 + 3H_2O,$$

which doubled would be:

$$4(C_{10}H_9N_2)\cdot 10WO_3 + 6H_2O,$$

analogous to Wolcott Gibb's 4:10-sodium salt, and for reasons known only to himself Tschilikin also analyzed v. Knorre's benzidine tungstate, getting beautiful results confirmatory of the ratio two of base to five of tungstic acid, or the ratio 4:10, confirmatory also of the ratio of the salt

$$4K_2O\cdot 10WO_3 + Aq.,$$

as deduced by Wolcott Gibbs. These were most gratifying observations in view of the doubt cast upon the ratio 4:10 as existing between sodium oxide (Na_2O) and tungsten trioxide (WO_3), although proof of the existence of the same ratio had been given by others.[5]

The thought suggested itself that it might be well to apply various organic bases to solutions of different soluble tungstates. In the work described in the preceding lines it was mainly with common insoluble tungstic acid, as found in normal sodium tungstate and para-sodium tungstate with which the analyst dealt, although in the para-salt it is now known that the common insoluble acid is associated with soluble or meta-tungstic acid.[6] Hence, solutions of normal (1:1), para- (5:12) and meta- (1:4) sodium tungstates, as well as ammonium meta-tungstate, were made up with the purpose of exposing all of them to the same precipitants. It was accordingly observed that benzidine hydrochloride precipitated the preceding salt solutions completely in the form of voluminous masses, readily washed by decantation, and when filtered, dried and ignited, gave tungsten trioxide perfectly yellow in color. The carbon burned away completely and with ease, leaving no trace of green in the residue.

[5] See *Jr. Am. Ch. Soc.*, **44** (1922), 2028.
[6] *Chemical News*, CXXIX. (1924), p. 198 et seq.

Two determinations with sodium para-tungstate ($5Na_2O \cdot 12WO_3 + 28H_2O$) resulted as follows:

(*a*) 1.0348 gram salt gave 77.35 per cent WO_3,
(*b*) 0.8699 gram salt gave 77.47 per cent WO_3,

while the calculated percentage of tungsten trioxide in the salt is 77.37 per cent WO_3. The precipitant employed was *benzidine acetate*. It was added to the cold tungstate solution, equaling 250 cc. in volume. The flocculent benzidine tungstate subsided promptly after the addition of a slight excess of the precipitant, and was collected upon a filter and then washed with dilute acetic acid. The dry precipitate and filter were ignited together. The ignition was easy; the residue was lemon yellow in color.

Parenthetically it may be stated that molybdic acid was also quantitatively precipitated by benzidine acetate.

A solution of pure ammonium meta-tungstate was prepared, every 5 cc. of which contained 0.4110 gram of tungsten trioxide. On precipitating two similar portions (5 cc. each, diluted to 250 cc.) with benzidine acetate, filtering out and washing the benzidine meta-tungstate with acetic acid, igniting to WO_3 and weighing, there were obtained:

(1) 0.4118 gram WO_3,
(2) 0.4105 gram WO_3.

In these precipitations the benzidine acetate was introduced from a burette, drop by drop, under vigorous stirring. The benzidine meta-tungstate subsided quickly. The reaction was so sharp that its end could readily be noticed. Thus, for each of the 5 cc. portions of meta-tungstate solution, 6.2 cc. of the benzidine acetate were required. This interesting deportment may yet be developed into a volumetric procedure. In an additional case another portion of ammonium meta-tungstate solution, 5 cc. in volume, was diluted strongly with water and heated. The volume of benzidine acetate required for the complete precipitation was 6.6 cc. The precipitate was permitted to stand over night; removed by filtration, washed and ignited. The residue weighed 0.4096 gram WO_3, slightly lower than the theoretical.

These examples show conclusively that meta-tungstic acid is fully

precipitated from solutions of its soluble salts by benzidine. Of course, this was supposed to occur, as the total tungstic acid in the sodium para-salt had been obtained on using this reagent.

It was further noticed that *aniline hydrochloride* did not precipitate solutions of normal sodium tungstate and ammonium meta-tungstate, but in a 5 : 12 solution it produced a white, curdy mass which seemed to be quantitative. However, the following singular deportment must be mentioned, viz.: if the 5 : 12 solution had been boiled and the *aniline hydrochloride* then added, there was no precipitation. The fact that aniline hydrochloride had precipitated the 5 : 12-salt solution in the cold, and *not* after it had been boiled, surely indicates an hydrölysis of the salt 5 : 12 into 1 : 1 and 1 : 4, neither of which when alone had been precipitated by the aniline hydrochloride.[7]

A second attempt was made with a cold 5 : 12 solution, but the precipitation was *not* complete, as the filtrate was blued by contact with Zn and HCl.

It developed that *o-Toluidine Hydrochloride* precipitated normal sodium tungstate, ammonium meta-tungstate and the 5 : 12-salt incompletely; at least, all the filtrates were turned blue on exposure to the action of metallic zinc and hydrochloric acid.

On adding *pyridine* hydrochloride to a solution of normal sodium tungstate (1 : 1) immediate precipitation did not occur; but after twenty hours a compound had separated, in the filtrate of which a deep blue color appeared on the addition of metallic zinc and hydrochloric acid. Incomplete precipitation was also noticed in the solution of the 5 : 12-salt, while in those of the meta-salt (1 : 4) precipitation was immediate and thought to be complete, so that two portions of an ammonium meta-solution, each containing in 5 cc. 0.2019 gram tungsten trioxide gave

a. 0.1955 gram WO_3 and 0.1840 gram WO_3.

The filtrates from these precipitates remained colorless, when acted upon with zinc and hydrochloric acid.

Three additional portions (5 cc. each) of the ammonium meta-salt solution were treated as before, every care being taken in the handling of the pyridine precipitates, which gave,

[7] *Chemical News*, CXXIX. (1924), p. 198.

(*a*) 0.1927 gram WO_3,
(*b*) 0.1964 gram WO_3,
(*c*) 0.1948 gram WO_3.

What caused these variations from the theoretical requirements? As before, the filtrate showed no color reaction. It had also been learned that an excess of pyridine hydrochloride exercised no solvent or deleterious effect on the pyridine meta-tungstate, and that 20 parts of water dissolved 1 part of pyridine meta-tungstate, although this solubility was very materially reduced by the presence of an excess of pyridine hydrochloride.

Was the color test (with metallic zinc and hydrochloric acid) reliable or very delicate? To learn more on this point, 0.2019 gram of tungstic acid in the form of ammonium meta-tungstate was dissolved in 5 cc. of water. One cubic centimeter of this solution, equivalent to 0.0404 gram of tungstic acid, was diluted to 50 cc. and acted upon with the reducing agents. After an hour's standing, a slight purple coloration made its appearance. Again, 5 cc. of the solution in which there were 0.2019 gram of WO_3, had removed from it 1 cc.—.0404 gram WO_3, and this was diluted to 50 cc. and tested with like result, indicating that where not more than .04 gram WO_3 was present reliance could not be placed on this particular color reaction.

It seemed to be of interest to subject a portion of the pyridine meta-tungstate to a preliminary analysis; accordingly, 1.1758 gram of the salt was dried for a period of four and again of seven hours at 100° C., when it lost 0.0228 gram. The residue and crucible weighed 14.2825 gram. After ignition it left 0.9600 gram of WO_3 or 83.26 per cent. Assuming pyridine meta-tungstate to have the formula $(C_5H_5N)_2O \cdot 4WO_3$—the theoretical percentage of tungstic acid would be 84.21 per cent.

A second portion of pyridine meta-tungstate, treated as the first portion, gave however 84.21 per cent WO_3 in complete accord with the theoretical requirement, so that it may be proper to express the formula of this interesting body as

$$(C_5H_5N)_2O \cdot 4WO_3 + 2H_2O.$$

It seemed advisable to try out the action of quinine sulphate or chloride on sodium salts of insoluble and soluble tungstic acid.

Using a solution of sodium meta-tungstate (5 cc. of which contained 0.2026 gram WO_3)—there resulted:

(*a*) 0.2012 gram WO_3,
(*b*) 0.2029 gram WO_3,
(*c*) 0.2028 gram WO_3,
(*d*) 0.2022 gram WO_3,
(*e*) 0.2037 gram WO_3.

In these trials an excess of quinine sulphate was employed. The quinine meta-tungstates were almost snow white in color, whereas the precipitates formed in solutions of normal sodium tungstate and in sodium para-tungstate were tinged with a flesh-color. The meta-tungstate in every case left on ignition a beautiful lemon yellow colored trioxide—WO_3.

Two portions (5 cc. each) of the normal salt (1 : 1) solution were precipitated with an excess of quinine sulphate from solutions of 250 cc. volume. The filtration was made after standing two hours. The precipitates were washed with cold water containing quinine sulphate. The quantity of tungstic acid present in each instance was 0.1700 gram WO_3. There was found:

(*a*) 0.1704 gram WO_3,
(*b*) 0.1697 gram WO_3.

From two other portions, after letting the quinine tungstate stand an hour before filtration, there were obtained 0.1686 gram WO_3 and 0.1696 gram WO_3. The filtrates were not turned blue by action of zinc and hydrochloric acid.

In a third trial with the 1 : 1-salt solution, allowing the precipitate to stand four and a half hours before filtration, the quantity of tungstic acid obtained was 0.1700 gram, and upon still another, where the precipitate had stood twenty-four hours before filtration, there was found 0.1694 gram WO_3, so that the period during which the precipitate may stand before filtration occurs, may vary through a pretty wide range.

In none of these experiments were *blue* colorations by zinc and acid permitted finally to determine whether the precipitation had been complete; on the contrary, an aliquot portion of the filtrate was care-

fully evaporated to dryness and the residue examined for tungstic acid.

Turning to the 5:12-salt solution, it was found on precipitating it with an excess of quinine sulphate and allowing the same to stand for six days and six nights before filtration, that the resulting yellow colored WO_3 weighed 0.1903 gram instead of 0.1907 gram required. Also, that in portions which had stood over night the resulting tungsten trioxide weighed:

(*a*) 0.1907 gram,
(*b*) 0.1907 gram.

All these trials demonstrate that tungstic acid in its insoluble and soluble form may be estimated by the use of a quinine salt in excess. Care must be exercised carefully to wash out sodium sulphate. It tends to cling to the quinine salt.

It is established that quinine and cinchonine are similarly constructed; they contain one hydroxyl group, and quinine containing an additional methoxyl group is therefore methoxycinchonine, and cinchonidine is probably a stereo-isomeride of cinchonine. Because of this interesting relationship of the three basic bodies, cinchonine and cinchonidine were also studied analytically with normal, para- and meta-salts of the tungstic acid, and omitting the recital of individual experiments, it may be added that they all precipitated the acid quantitatively. It was to be expected, yet care must in all instances be observed to remove excessive sodium salts from the precipitates, otherwise the results will be high; this was particularly the case with cinchonine and cinchonidine, hence these reagents are not likely to be widely used in analysis.

Other observations noted in the course of this study were that quinine and cinchonidine precipitate solutions of sodium molybdate, while *nitron* precipitates the latter, as well as solutions of ammonium meta-tungstate. Chromatropic acid did not affect solutions of normal or meta-sodium tungstate. It is also true that *salicin* is without effect upon solutions of normal sodium tungstate, sodium para-tungstate or sodium meta-tungstate.

The several salts studied in this work were exposed to various solvents with the hope that results might follow which would have

value in determining constitution. Thus, it was observed that *nitrobenzene* had no solvent effect upon anhydrous normal sodium tungstate, sodium para-tungstate, ammonium meta-tungstate or pyridine meta-tungstate, nor was the latter soluble in *acetone*.

In *aniline*, normal sodium tungstate, sodium para-tungstate, sodium meta-tungstate and ammonium meta-tungstate were insoluble. They behaved similarly with *pyridine*. Anhydrous normal sodium tungstate was insoluble in *carbon disulphide*.

SUMMARY.

1. That the organic bases to which reference has been made are good precipitants for the quantitative estimation of the tungstic acid content of soluble salts.

2. That both forms of tungstic acid—the ordinary insoluble acid, and soluble or meta acid—in their soluble salts, are removed by the specified bases.

3. That the blue color reaction occasioned by metallic zinc and hydrochloric acid in solutions of tungstates is not reliable when small amounts of the tungstic acid are present; that all filtrates from precipitates should be evaporated to dryness and the residues tested for tungsten by some more dependable reagent.

4. Strong evidences are at hand that benzidine as chloride or acetate may yield a rapid and accurate means of determining tungstic acid volumetrically.

5. Certain organic solvents were applied to the various soluble tungstates and found to be valueless on the score of solubility.

AN INTERESTING BEHAVIOR OF SOLUBLE META-TUNGSTATES.[1]

By EDGAR F. SMITH.

(Read December 4, 1926.)

Very strong proofs [2] have been presented that such compounds as sodium para-tungstate or the 5 : 12-sodium tungstate—$5Na_2O\cdot 12WO_3 + 28H_2O$; the 4 : 10-sodium tungstate—$4Na_2O\cdot 10WO_3 + 23H_2O$, and the 3 : 7-sodium tungstate—$3Na_2O\cdot 7WO_3 + 16H_2O$,—are combinations of normal sodium tungstate (1 : 1-$Na_2O\cdot WO_3$) with sodium meta-tungstate or 1 : 4-sodium tungstate ($Na_2O\cdot 4WO_3 + 10H_2O$). The 5 : 12-salt, the 4 : 10-salt, and the 3 : 7-salt were not only resolved into normal sodium tungstate (1 : 1) and sodium meta-tungstate (1 : 4), but were synthesized by the union of definite amounts of the normal sodium and the sodium meta-salts. Every chemist is familiar with the strong basic character of aqueous solutions of normal sodium tungstate and the diametrically opposite, acid nature of sodium meta-tungstate solutions. In the antiquated formulations of chemistry such bodies as 5 : 12-, 4 : 10- and 3 : 7-sodium tungstates arose from the union of a very basic body like $Na_2O\cdot WO_3$ with the intensely acid substance—$Na_2O\cdot 4WO_3$. What would occur on bringing in contact aqueous solutions of sodium chromate ($Na_2O\cdot CrO_3$) and sodium molybdate ($Na_2O\cdot MoO_3$) with sodium meta-tungstate? To answer this interrogatory there were mixed

First, definite amounts of normal sodium chromate in solution, and sodium meta-tungstate. The mixture was gently boiled for five minutes. Soon the liquid became turbid and assumed an intense red color, due to the production of sodium bichromate. The liquid was filtered. The insoluble portion was white tungstic acid. The deep red colored filtrate stood over night, and by morning there had sepa-

[1] Contribution from the John Harrison Laboratory of Chemistry, University of Pennsylvania, Philadelphia, Pa.

[2] *Chemical News*, **129** (1924), p. 198.

rated a copious mass of crystals. One recrystallization gave them in colorless forms, strongly suggestive of crystals of the 4: 10-sodium tungstate. These were recrystallized and analyzed, when they yielded water, tungstic acid and alkali in accord with the requirements of the formula

$$4Na_2O \cdot 10WO_3 + 23H_2O.$$
$$8.33\% \quad 77.79\% \quad 13.86\%$$

On adding a cold solution of ammonium meta-tungstate to a solution of normal sodium chromate (Na_2CrO_4) the yellow color of the latter slowly assumed a red color. The change, however, was very rapid on the application of a gentle heat. Just as in the previous example, ordinary white tungstic acid separated, and from its filtrate, crystallized colorless forms which, on analysis, gave 13.35 per cent and 13.65 per cent of water, and 77.52 per cent of tungstic acid, again indicating the production of the 4: 10-sodium salt.

Would normal sodium molybdate ($Na_2MoO_4 + 2H_2O$) combine with sodium meta-tungstate to yield complexes, as did sodium tungstate ($Na_2WO_4 + 2H_2O$) and sodium meta-tungstate? To determine this point, definite quantities of sodium molybdate and sodium meta-tungstate were brought together and their aqueous solution warmed, when gelatinous tungstic acid separated, and in its filtrate beautiful twinned crystals appeared. These were purified. A portion on analysis gave 13.24 per cent H_2O, 77.52 per cent WO_3 and 9.24 per cent Na_2O (by difference), which would confirm the production again of the 4: 10-sodium salt.

A second portion of the same salt was exposed at 250° C. to the action of dry hydrogen chloride to expel any molybdic acid, if it existed in the crystalline body. It was not found. These behaviors are noteworthy. There was almost a conviction that sodium molybdate, at least, would yield a combination analogous to

$$x\,Na_2O \cdot WO_3\ y\,Na_2O \cdot 4WO_3;\ \text{thus, } x\,Na_2O \cdot MoO_3.\ y\,Na_2O \cdot 4WO_3,$$

but the experiments showed the opposite to be the case.

MARTINICHTHYS—A NEW GENUS OF CRETACEOUS FISH FROM KANSAS, WITH DESCRIPTIONS OF SIX NEW SPECIES.

By C. E. McCLUNG.

This is one of several nearly related genera belonging to no well determined family (Albulidæ, Elopidæ, Osteoglossidæ according to Woodward; Plethodidæ—Hay; Elopidæ, Plethodidæ, Albulidæ—Loomis). It has been confounded with the genus *Protosphyræna* by Cope and Hay because of the presence of a rostrum, but is, in fact, far removed from it. Up to the present time, only fragments of the skull have been known, and while the rostral portion indicated relations to the genus *Protosphyræna,* studies made from the occipital and parasphenoid region of certain other skulls led Loomis to found new genera which Hay regards as synonymous with *Anogmius.* It is not possible to determine with certainty whether the material before me belongs to Loomis' genus *Syntegmodus,* and I am, therefore, proposing the name *Martinichthys*[1] to designate the genus. I am led to do this partly because of the indefinite character of the type specimen of Loomis and partly because he figures parasphenoids of *Martinichthys* which he describes as belonging to a different genus from *Syntegmodus.* The descriptions of parts of two crania, with numerous vertebræ and rostra of seven different kinds, indicating as many species, will be given.

Definition of the Genus Martinichthys.—Skull high, rostrum short, more or less blunt, sometimes apparently worn on cephalic end, varying from slender to heavy in different species. Parasphenoid flattened on ventral surface and bearing pits or denticles, joined dorsally to alisphenoid and orbitosphenoid. Interorbital septum present. Mandible long in comparison with skull. Hyomandibular forming articulation with skull by a depression in the pterotic. Glossohyal long, flat and apposed to parasphenoid to form buccal mill.

[1] In honor of Mr. H. T. Martin of the Palaeontological Museum, University of Kansas, who has long been interested in the rostra of this form.

Dentition weak, confined to small denticles distributed over various bones of the mouth. Vertebræ completely ossified, small, delicately sculptured, pitted dorsally and ventrally. Fins and tail unknown.

MARTINICHTHYS BREVIS—new species, Specimen No. 497.
Genotype.

Cranium.—The cranium of the type specimen measures 140 mm. from the end of the rostrum to the occipital condyle and 47 mm. from the ventral edge of the condyle to the supraoccipital crest. It is crushed laterally, and the two hyomandibulars lie against the median series of cranial elements. The greatest width in the parietal region, restored, is 50 mm. The rostrum, on the ventral surface, is 43 mm. long and its greatest width is 30 mm. Its median cephalic surface is cleft for about 2 mm; the ventral surface is flat and covered with denticles, or pits for their reception; the dorsal surface is arched and covered with pits or grooves. The caudal edge is irregular in outline and, laterally, covers a deep groove for the reception of the prefrontals. On the mid ventral surface of the cranium, extending from the basisphenoid to the vomer, is the parasphenoid, 80 mm. long and 24 mm. in greatest width near its caudal end. The ventral surface is approximately flat and pitted, like the rostrum, for holding denticles. The articular surface of the occipital condyle measures dorsoventrally 12 mm. Interorbital septum well developed, as in *Syntegmodus* and *Anogmius.* There is a large orbitosphenoid and a smaller alisphenoid, both articulating ventrally with the parasphenoid. So far as can be determined from the specimens at hand, there is a continuous median partition between the two halves of the skull which, dorsally, diverges on each side, forming a partly enclosed brain case. I do not find evidences of a presphenoid such as is described by Hay for *Anogonius altus.* The appearances in *Martinichthys* are more nearly like what is represented by Loomis for *Syntegmodus.*

Mandible.—The mandibles are represented only by the imperfect right mandible showing the articular, connected with the quadrate, and the symphysial end. Between these extremities only a fragment, representing the more ventral part of the jaw, remains. The articular shows a strong dorsally projecting process that passes externally to the quadrate. In the region of the symphysis the dorsal edge is preserved and this shows a broadened margin covered by small denticles. The extreme length is 93 mm.

Palatine.—A flat, triangular bone, 30 x 65 mm., lies beside the parasphenoid and assists in forming the roof of the mouth. It is pitted on the ventral surface like the parasphenoid. The extreme width of the parasphenoid and of the two palatines in position would be 80 mm.

Hyoids.—In this specimen there are preserved the ceratohyals, basihyals, hypohyals and glossohyal, all in position but crushed laterally. The extreme length of the series in this specimen is 80 mm., of which the ceratohyals measure 43 mm. The glossohyal is large, deeply pitted dorsally and strongly supported by the hypohyal ventrally. When apposed to the parasphenoid, of equal length, it formed an efficient grinding apparatus. There are no evidences of urohyal or of branchiostegals.

Denticles.—A number of the bones in the mouth are pitted and have been described by Loomis as having a covering of a peculiar substance, which he calls "osteodentine." Hay fails to discover any peculiar material of this nature, but describes canals extending into the bone and also small sand-like teeth on the ridges. It would appear from my observations that there are a number of the mouth bones, which are very similar in construction of their external surfaces. In the specimen of *Martinichthys brevis* the parasphenoid, palatines, rostrum and glossohyal are thus pitted, and where they do not come into contact with other similar bones are covered with small, hollow, pointed denticles. Where these are broken off, it can be seen that their central cavity extends down into the bone upon which they rested. Upon the triturating surfaces these denticles give way to a ridged and pitted surface which, in life, was probably covered by a corneous and thickened skin. Such denticles appear in a number of genera.

Martinichthys ziphioides (Cope).

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1890, *Protosphyræna ziphiodes,* J. Felix, Zeit., Deutsch Geol. Gesellsch., XLII., p. 297.

1895, *Protosphyræna ziphioides,* A. S. Woodward, Cat. Fos. Fishes, Brit. Museum, III., p. 413.

1900, *Protosphyræna ziphioides,* F. B. Loomis, Palaeont., XLVI., p. 222.

1903, *Protosphyræna ziphioides,* O. P. Hay, Bibliog. and Cat. Fos. Vert. N. A., p. 379.

1903, *Protosphyræna ziphioides,* O. P. Hay, Bull. Am. Mus. Nat. Hist., XIX., Art. 1, p. 22.

Type specimen No. 2131 is in the American Museum of Natural History.

In 1877 (p. 822) Cope described from the chalk of Kansas a specimen of fish which he placed in his genus *Erisichthe* and to which he gave the specific name *ziphioides.* This specimen, now in the American Museum of Natural History, No. 2131, was described by Hay ('03 p. 22), who confirms Cope's identification. Felix ('90, p. 297), quotes Cope's description and dismisses the species with little more consideration. So far as I can discover, there has been no further notice of this interesting fish. Two good specimens in the museum of the University of Kansas enable me to correct several errors in previous descriptions, and to remove definitely the species from the genus *Protosphyræna* into the new genus *Martinichthys.*

The most complete specimen so far obtained (No. 498), was collected by Mr. H. T. Martin during the summer of 1909 in Trego County, Kansas. It consists of the axial complex of cranial bones and a series of 25 vertebræ. As may be seen from an inspection of accompanying figures, this is a very different fish from *Protosphyræna.* The conspicuous dentition of the latter animal is entirely lacking, and in its place appears the pitted bones so characteristic of *Anogmius.* This and the presence of well ossified vertebræ is sufficient to remove the form from *Protosphyræna,* to which it was attached purely on account of the presence of a rostrum.

From the descriptions of Cope and Hay, it will be observed that the rostrum is materially different from that of *Protosphyræna,* the difference indeed being so extensive as to lead both of these authors to describe the dorsal surface as the ventral. Two pits on the dorsal surface, similar to the alveoli of the vomerine fangs of *Protosphyræna,* led to the belief that these were identical structures. Be-

cause of the absence of functional teeth here, and also on account of the short, blunt rostrum, Cope surmised that the specimen studied was the remains of an old individual with an abraded and worn snout. Hay did not regard this explanation of Cope's as plausible, but agreed with him in conceiving the rostral depressions as alveoli of the vomerine teeth.

The material before me forms the picture of an animal very different from Protosphyræna. The extreme length of the skull from tip of rostrum to occipital condyle is 200 mm., of which the complete rostrum occupies a little more than 50 mm., so that in the matter of size there is considerable difference. The entire structure of the skull so far revealed in the new genus is lighter and more delicate than that of *Protosphyræna*. This difference is shown very strikingly in a comparison of the parasphenoids, for in *Martinichthys*, instead of being a strong massive element, it is slender and delicate in construction. Most striking, however, is the entirely opposite types of dentition in the two genera. *Protosphyræna* presents a type of the highest development in dental armature, with its strong, sharp, and firmly socketed teeth on the maxillaries, premaxillaries and vomers, while in the new genus there is an apparent absence of teeth except weak denticles disposed over the roof and floor of the mouth.

Since the rostrum is the most prominent and striking element of the skull, as well as its most common representative among fossils, it would seem desirable to describe it in some detail. In general, the description of Hay, l.c., is accurate, except for the confusion of the dorsal and ventral aspects, but additional features appear in the new specimens. Two of these specimens (Nos. 506, 507) are very similar in size and extent to that of Cope and Hay. They are figured on Pl. I., Figs. 8 and 9. Very striking, indeed, is the triangular roughened surface on the ventral aspect, which is sharply outlined by a shallow groove terminating on each side at the cephalic end by a deeper depression, the two being separated by a short tongue of bone extending caudally for a short distance in the median line. The area thus enclosed, for a distance of 50 mm. caudally from the cephalic apex is much roughened, suggesting the presence, in life, of a hardened, closely applied cartilaginous covering, probably having denticles. This terminates somewhat abruptly, leaving exposed the smooth

surface of the vomers, interpreted as the frontal by Hay. On each side of this is a deep pit, which is homologous with similar ones in *Protosphyræna,* for the reception of the premaxillaries. The tip of the truncate rostrum is smooth and in this specimen marked by two sharply defined rounded pits on its inclined cephalic extremity. Upon the side of the rostrum and forming the outer boundary of the groove enclosing the triangular roughened area, previously mentioned, is a narrow triangular bone, its apex directed cephalad, and its caudal portion just beside the pit for the reception of the premaxillaries. This is the bone which, in *Protosphyræna,* Felix calls the "ethmoidale laterale." Upon the dorsal surface appears another triangular bone, again the apex being cephalad, which represents either the frontal or prefrontal.

The entire surface of the rostrum is roughened, not as in *Protosphyræna* by a regular pattern of raised lines, but irregularly—an exception to this being the inclined tip of the rostrum, which is smooth.

ROSTRA OF FIVE NEW SPECIES.

Following are brief descriptions of six rostra, clearly belonging to five different species. Owing to their incomplete condition, no full account can be given. So far only two rostra have been found in connection with their skull, those of *M. ziphioides* and of *M. brevis,* but the close resemblance between the three specimens of *M. ziphioides* before me leads me to believe that we may expect some degree of specific constancy in the structure of the rostrum. This seems the more probable also in view of the considerable diversity manifestly appearing in the ones ascribed to other species and because of the resemblance between the two included in the species *acutus.* The figures from 1 to 10 of plate I., give clear views of these different rostra and supplement the brief descriptions.

MARTINICHTHYS ACUTUS—new species, No. 502.

Rostrum 17 x 27 mm. Short, pointed, with cephalic surface slightly inclined. In cross section, circular, smooth, without pits, except four on cephalic surface. (Fig. 6.)

Another specimen (No. 503), 17 x 29 mm. Similar, except it is somewhat flattened dorso-ventrally, and has two pits in cephalic end. (Fig. 5.)

MARTINICHTHYS GRACILIS—new species, No. 504.

An incomplete rostrum, now 21 x 55 mm. When complete it was probably 70 mm. long. (The longest rostrum as yet discovered.) Tapers gently toward the cephalic end. In cross section a flattened oval; surface smooth and only slightly pitted. Ventral surface flat. (Fig. 3.)

MARTINICHTHYS ALTERNATUS—new species, No. 500.

Rostrum 42 mm. long, 15 mm. wide. Dorsal surface straight, ventral surface inclined, forming an angle of about 20 degrees with dorsal. In this specimen the cephalic one third of the ventral surface forms an angle of about 45 degrees with the dorsal. (Fig. 2.)

MARTINICHTHYS LATUS—new species, No. 499.

Rostrum 40 x 73 mm., truncate, cephalic surface inclined, extending forward further on left than on right side, roughly pitted. Ventral surface crushed, but rough and finely pitted. In cross section, oval. This is the largest and heaviest rostrum so far discovered. (Fig. 4.)

MARTINICHTHYS INTERMEDIUS—new species, No. 501.

Rostrum 25 x 52 mm. Free portion short, cephalic-ventral surface rounded and forming an angle of about 45 degrees with the dorsal. (Fig. 1.)

DESCRIPTIONS OF FIGURES.

Specimens discussed in this paper are in the Palaeontological Museum of the University of Kansas. Most of them were secured in a direct effort to determine the character of the fish from which the rostra of *M. ziphioides* had come. In this way the very complete skull of specimen No. 497 was found by the author.

(This paper was originally prepared for the proposed S. W. Williston memorial volume.)

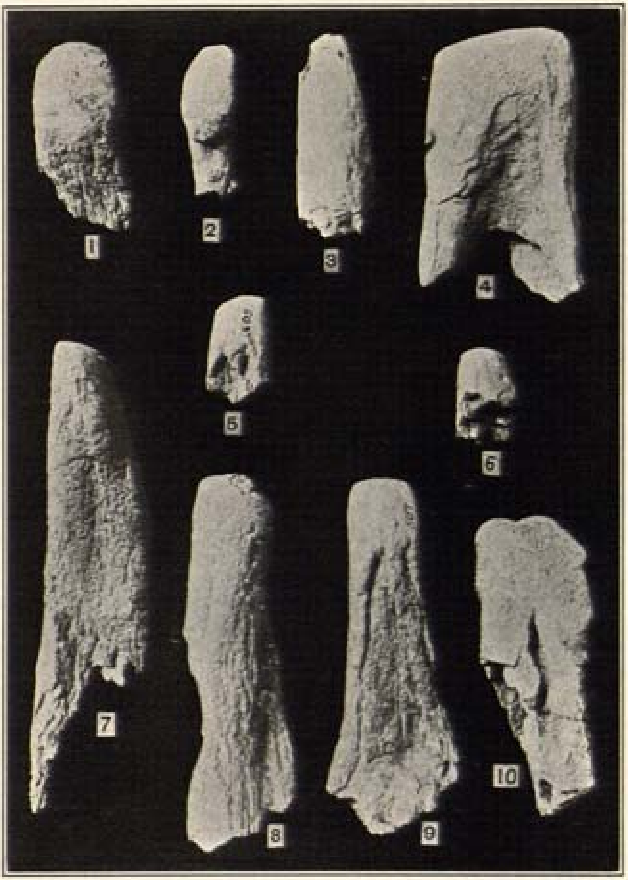


FIG. 1. Rostrum of *M. intermedius.*
FIG. 2. Rostrum of *M. alternatus.*
FIG. 3. Rostrum of *M. gracilis.*
FIG. 4. Rostrum of *M. latus.*
FIG. 5. Rostrum of *M. acutus.*
FIG. 6. Rostrum of *M. acutus.*
FIG. 7. Rostrum of *M. ziphioides.*
FIG. 8. Rostrum of *M. ziphioides.*
FIG. 9. Rostrum of *M. ziphioides.*
FIG. 10. Rostrum of *M. brevis.*

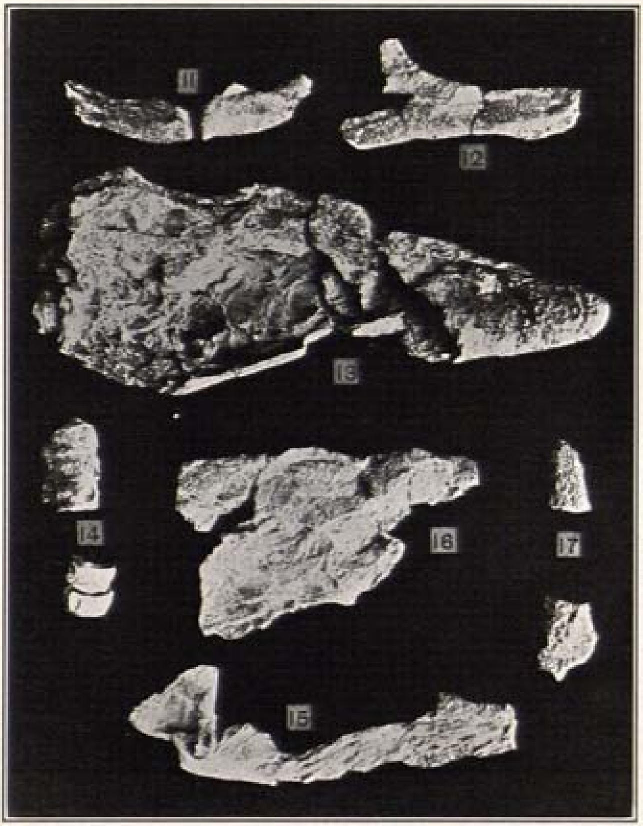


PLATE II.

FIGS. 11–17. Bones of the skull of *M. brevis* with five vertebræ.
FIG. 13. Lateral view of axial series of cranial bones.
FIG. 15. Lateral view of mandible and quadrate.

THE FLORA OF THE SERRA DA BOCAINA.[1]

By BERTHA LUTZ.

Introduction.

During his numerous expeditions to various parts of Brazil, Dr. Adolphe Lutz did not limit himself exclusively to the collecting of zoologic material or to work along his own special lines of research. Following the bend of the naturalist, interested in every aspect of nature and wishing to have a real knowledge of the regions visited, he made additional botanical studies and collected the more characteristic plants. As a result, he has acquired in the course of some years quite a large sized herbarium, which contains a great many interesting phanerogams.

He has now intrusted me with the revision and the cataloguing of his collections and I cannot help thinking that it is of a certain interest to publish the results. At the present state of knowledge concerning the Brazilian flora it seems obvious that much may be gained by studies concerning the regional aspects of the vegetation of this country and the distribution of species both in altitude and extension.

Dr. Lutz's herbarium includes plants from many parts of Brazil, chiefly from the hydrographic basin of the river S. Francisco, the northeastern states, the Paraná river, the Federal District and surrounding country, and the states of Rio de Janeiro, São Paulo, Sta Catharina and Minas Geraes.

I might have begun with any of these but finally decided to start the cataloguing with the plants from the mountain range of the Bocaina, which is a part of the maritime chain known as the "Serra do Mar."

This region has been visited by Dr. Lutz many times, at different

[1] A lesser-known region of Brazil's maritime range.

[2] Owing to her early departure for Brazil, Miss Lutz did not see the proofs of this article. Dr. Harshberger kindly gave them a careful examination.

seasons and much of the material for his original systematic work in entomology and other branches of zoölogy was collected here.

The flora of the Bocaina mountains is interesting in many ways. To begin with, it is hardly known to botanists, except for two excursions made by Glazious in 1864 and 1876, and a few modern ones, if I am not mistaken. For another thing, this range is lower than the Itatiaya, the part of the Mantiqueira chain which is only about 50 km. from it and running almost parallel to it. It is also nearer to the sea and offers consequently somewhat different conditions, especially as to rainfall. Finally, the flora of the mountains is always interesting and especially so in Brazil, where it offers a rich and varied field, principally owing to the *campos* formations with herbaceous species of many families and curious adaptations to more or less xerophytic environments.

There is evidently much similarity between the flora of the Bocaina and that of other coastal ranges and it has many points of contact with the nearby Itatiaya. As is to be expected under the more favorable conditions above mentioned, many of the mountain species are found at lower ranges. As a curiosity we shall give a few of the species found in both ranges, together with some indications as to their comparative altitudes.

Species.	Altitude.		
	Itatiaya.	Bocaina.	Difference.
Syphocampylus longipedunculatus	1,850	1,150	700
Lobelia camporum	1,900–2,400	1,350–1,580	550– 820
Coccocypselum condalia	1,900	1,300	600
Utricularia globulariaefolia	2,300–2,500	1,150	1,150–1,350
Nicotiana langsdorffii	2,200	1,150–1,250	1,050– 900
Leucothoë intermedia	2,300–2,500	1,300	1,000–1,200
Hypericum brasiliense	1,900–2,200	1,150	750–1,050
Rubus erythroclados	1,850	1,250	600
Prunus sphaerocarpa	1,850	1,150	700
Escallonia montevidensis	1,900–2,200	1,150	750–1,050
Berberis laurina	2,000–2,300	1,580–1,600	420– 700
Sophronitis grandiflora	2,300	1,600	700
Burmannia bicolor	2,000	1,500	500
Araucaria brasiliana	2,100–2,300	1,150	950–1,150

The altitudes given for the Itatiaya are those indicated by Dusen in his article on the flora of the Itatiaya, published in *Archives do*

Museu Nacional, Vol. XIII (1905), pp. 1 ff. Those of the Bocaina are at the points where Dr. Lutz and I found them, the altitudes being given in accordance with the measurements taken by Dr. Mario Roxo, a distinguished engineer, who has gone over the Bocaina and taken measurements many times.

This is of interest principally with regard to the plants considered as belonging to alpine or andine families, such as the Ericaceae and Ranunculaceae on one side; the Escalloniaceae and Berberidaceae on the other.

Some of the species considered by Dusen as belonging to the lower flora of the Itatiaya are also found at still lower altitudes on the Bocaina, as for instance:

Species.	Altitudes.		
	Itatiaya.	Bocaina.	Difference.
Mutisia coccinea	1,400	1,150	150
Salvia guaranitica	1,800	1,350	450
Hydrocotyle quinqueloba	1,800	1,150–1,300	650–700

It is only fair, however, to point out that these indications may be by no means absolute. There are also some exceptions to the general rule. *Anemone sellowiana*, for instance, was found by Ule in the Itatiaya already at an altitude of 1500 meters, although not in flower. Dr. Lutz, on the other hand, found the same species only at from 1,580 to 1,600 meters.

Phytogeographic Aspect.

According to the information given us by Dr. Mario Roxo, the larger part of the zone we travelled over was originally tropical rain forest, not only where it is still wooded, but also in much of the actual open country. The "*native campos*" only appear at the higher points to which we penetrated, such as the Ponte Alta and the Morros da Boa Vista, over 1,600 m.

In the old times, before the Central Railway of Brazil came into being, a trail used to lead up to the Bocaina mountains from the sea, passing through luxuriant forest, in which ferns were very plentiful.

We did not have the opportunity to use this trail, but approached

from inland over the hamlet of Formoso. Collecting was consequently not begun until a certain height was reached and the railway journey continued on horseback. Our plants are from above 1,000 meters altitude, with the exception of a small specimen of Fridericia speciosa, which was gathered at about 500 m.

Owing to difficulties of transportation, the radius of the excursions mentioned in this paper was not very great, going from the settlement at Formoso to the region called Bonito and from the Fazenda of that name to Ponte Alta and the bar of the river Mambucaba.

Consequently, we shall merely describe the localities as we found them and not as they were before the changes brought about by man in the original phytogeographic aspect.

Interesting Families and Species Found.

Among the more interesting plants occurring in the Bocaina we may cite: *Equisetum Martii,* a tall species found by Dr. Lutz in the month of January; *Bomarea spectabilis,* blooming in September and October, 1913, and *Amaryllis* (*Hippeastrum*) *psittacina,* which generally grows on humus-covered rock, but is epiphytic in trees at the Bocaina.

Only in the one excursion which I accompanied in January, 1925, we saw well over twenty species of Orchids, among them quite a number of *Oncidium,* several of them growing on stones like a species of *Epidendrum,* probably *elongatum* and some terrestrial representatives of this family. *Sophronitis grandiflora* was found in two places above 1,500 m. flowering in February. We looked for it in January, 1925, but did not find it. It was probably too early in the season, for it has been seen since.

On a damp spot in the woods by the banks of the river Bonito a balanophoraceous plant, *Helosis guyanensis,* was found in January, both in 1915 and in 1925, though much less developed the second time.

Berberis laurina and *Anemone sellowiana,* both very interesting mountain species, are found but are rather rare and only appear at higher elevations.

On the Boa Vista hills there grows an extremely ornamental apocynaceous climber, a species of *Mandevilea* (*Amblyanthera*) with

large beautiful rose-colored blossoms with yellow inner side of the corolla tube. They are fully 8 cm. long. It does not entirely fit any of the descriptions found in the scant literature at our disposal.[2] We were unable to consult the description of 45 species as indicated by K. Schumann, in Engler u. Prantl's "Die nat. Pflanzenfamilien." Comparison with Gardner's herbarium of the South Kensington Museum, made in 1914 by Dr. Lutz, did not lead to its determination, though it seemed nearest to *M. seleowii*. We shall give a short description of it at the end of this paper.

There are several Gentianaceae, considered as one of the more interesting families found in the mountain campos of Brazil. A scarlet *Lysianthus* grows on one or more of the hills, but is unfortunately retreating from the invasion of its territory by a bracken fern. Another one, which is blue, is rarer; there is also a small lemon-colored one. A *Dejanira* also grows in the Bocaina. It is similar to *embescens*, but has white blossoms. We shall describe it also, since it differs from those known to us. Besides these we have *Voysia uniflora* and *Zygostigma australe*.

The Gesneraceae are represented by quite a number of species, some of them common, like *Gesnera alagophylla*, known in Brazil as *potato of the fields*, on account of its round tubers found on the surface of stones and fallen tree trunks, and to a lesser degree *Hypocyrta hirsuta*. *Gesnera cooperi* is very handsome on the rocks that litter the course of mountain streams, and its brilliant blossoms are enhanced by the rays of sunlight filtering through the woods. *Gesnera maculata*, *Gesnera magnifica*, and *Codonophora prasinata*, the last two extremely handsome, are also among the plants gathered on this range.

The Melastomaceae and the Compositae include, as always in Brazil, the most plentiful species. In the Bocaina the Melastomaceous and Compositous plants are very variable in habit, from minute xerophytic species to great arborescent or climbing ones.

Distribution.

Forest.—Though much of this region must originally have been wooded, nowadays the forest is interrupted by large tracts of open

[2] "Flora Brasiliensis," etc.

country and finally becomes reduced to the depressions in the slopes of the mountains from which the rolling native campos begin to rise. There are some very tall species in the woods. Of those in flower we must mention huge specimens of *Clethra Brasiliensis*, the flowers of which are very difficult to obtain. *Vochysia* is represented in the woods by two different species. At the falls of the Cavalhada, near the Fazenda of the Bonito, there grows a very nice specimen of *Prunus sphaerocarpa*. There are some *Leguminosae*, of course, arborescent *Melastomaceae* and a very frequent species of *Croton*, with long pointed drip-leaves, that turn yellow and scarlet. In the garden of the Fazenda are two imported olive trees that have fruited once. There are some specimens with buds in the herbarium.

Among the climbers in the woods there are a few Melastomaceae and the composites *Bidens rubifolius*, *Wedelia subvelutina* and *Mutisia coccinea*, several Bignoniaceae, among them two *Opithecoctenium*, a red passion flower, and *Fuchsia integrifolia*, which grows everywhere in the mountains of S. Paulo and Minas.

Brunfelsia ramosissima and *hydrangaeformis*, both bushes, occur in these woods, mostly with very poor foliage, a condition probably due to insects.

In the upper woods we came across two Loranthaceae, a *Phoradendron* and a *Strutanthus*, I believe.

The lesser vegetation includes some *Polygalas*, a few earth orchids and a *Burmannia*, found in one place only but very abundant there. The creeping ground vegetation includes these species of *Hydrocotyle: Centella asiatica Bacopa* (*Herpestes*) *chamaedryoides*, *Viola cerasifolia*, *Drymaria cordata*, etc.

One copse, found near Bonito de Cima, with much drier soil than the woods, seems entirely made up of *Belangera tomentosa Styrax leprosum* (?) and a *Solanum* that was not determined.

River Banks.—The banks of the river, especially the Bonito, which in this region flows in a long and relatively narrow valley, are occupied in some spots by three Escalloniae. In January they are decked with white blossoms, like an orchard in spring, but I believe they flower for a longer period. Several small mountain streams come down from the higher mountains. In one of these, a tributary of the Bonito, going under the picturesque name of the Secret River

(Segredo), we once came upon the floating blossoms of a Papilionacea, considered a "*Timbó*" (a name given to the plants considered poisonous for fishes). It was a *Camptosema pinnatum*.

Valley of the Bonito River. In this valley are found small "pinheitaes," *i.e.*, groves of *Araucaria brasiliana*, which become very extensive in the south of Brazil, where the Serra do Mar gradually subsides, but where the latitude produces lower temperatures than would be afforded at similar altitudes in more northern zones. The higher elevations like the Bocaina, however, seem to compensate this, for the pines thrive just as well as further south. There are no other trees found together with the Araucariae. On these grow a small Orchid, probably a *Pleurothallis* and a *bromelia, Aechmea sp.* in which the Dynastor Napoleon moth has been observed to breed, and from which we raised caterpillars some years ago. Underfoot grows *Hydrocotyle* in the damp places and in the more common dry ground thrive two *Verbenas, V. hirta* and *V. rigida*, and *Cuphea mesostemon*. In the open places of the valley are found *Phytolacca thyrsiflora*, and *Nicotiana langsdorffii*, supposed to appear where clearings have been made. *Verbascum blattarioides* also rears its tapers.

It is interesting to note that some of the pasture grounds of the Bonito Fazenda are overgrown with *Achillea millefolium*, which must have been imported unwittingly. On the edges of the paths and roadsides in this valley and elsewhere a *Gomphrena* and a *Baccharis* are constant. There is some damp ground in this valley, and when this occurs, two *Haynaldia* and several species of *Habenaria*, among them the aptly named *sartor*, appear. Here *Cestrum corymbosum*, a more ornamental representative of this modest genus, appears.

Swamps.—In the swamps found in the Bonito valley and sometimes in the forest clearings the vegetation is made up of *Utricularia globulariaefolia*, three kinds of *Xyris*, some Eriocaulonaceae (others grow in the dry campos) and a *Begonia* with bright pink blossoms and red undersides of leaves. The latter makes brilliant splashes of colors in the bogs.

Campos.—The flora of the *Campos* is very interesting indeed. Some of the species found are very plentiful and overrun whole hills. Others, on the contrary, seem rare and localized. Among the com-

mon ones I should like to mention *Diclieuxia polygaloides*, with bluish stems and *Vernonia tomentella*, a hairy and resinous composite. *Tibouchina* minor is plentiful and pretty with its large well-formed flowers and gradually diminishing leaves, the lowest of which are tiny and pressed to the ground.

Lobelia camporum is found nearly everywhere. There is also a plentiful little *Polygala* with very narrow leaves.

In the higher campos *Microlicia isophylla* is the characteristic plant. It may begin to flower as early as January and is still found in bloom in June. Its vulgar name is " vassourinha," or little broom.

As is only to be expected, there are several Ericaceae in the Bocaina, chief among them *Gaultheria ferruginea* and *elliptica*, *Gaylussacia villosa*, and a *Leucothoe*, which does not entirely agree with the diagnosis in the " Flora Brasiliensis," but comes nearest to *intermedia*. I distinctly have the impression that this genus is in need of revision; some of the descriptions overlap considerably and possibly there are fewer species, and these more variable than one supposed at first.

Some of the campos plants are localized in a very few places. This is true of the handsome Apocynaceae mentioned, of some of the *Lysianthus* and *Alophia*. *Eryngium* of two species are found in isolated spots.

The plants growing above 1,200 meters show more or less xerophytic characters. Some display a covering of hairs, as *Gaultheria* and *Gaylussacia*, others have leathery leaves pressed against the stems. Some contain strong resins and many are small with showy flowers and reduced external vegetative organs. The vegetative apparatus is reduced to the minimum in *Chevreulia acuminata*, which might easily be taken for a moss. There are also *xerophytic* species of other Compositae and some very small Oxalidaceae in Glaziou's collections represented in the Herbarium of the Brazilian National Museum. Some have more than one xerophytic character. *Vernonia tomentella* may serve as an instance of this.

I should like to have an opportunity to make a more extensive comparison of the vegetation of the Bocaina with other ranges, both of the Maritime range and with other serras, but for the moment must confine myself to this initial contribution, which I consider far from complete.

Follows a list of the species found, with the dates at which they were in bloom. The collections were made in the years 1912, 1913, 1914, 1915 and 1925. In this last excursion, made at a very rainy season, I took part. The months of the year were January, February, April, June, September, October, and December, all of them represented in the collection, but most of all the first months of the year. The specimens referred to in the catalogue are to be found in the Instituto Oswaldo Cruz, with duplicates at the National Museum. Some of the Orchids were given to the botanical garden of this institution for cultivation, with very indifferent results.

The plants were determined almost entirely by Dr. Lutz and myself, under great difficulties, owing to the very scant literature. Glaziou's collections helped somewhat. *Oxypetalum sublanatum* was determined by A. Hoehne from S. Paulo, and Professor Sampaio of the National Museum gave some indications as to the Orchids. We thank them both, as also Dr. W. Roberto Lutz, his daughter and son-in-law, at whose fazenda we stayed during these excursions. I also wish to tender my gratitude to Dr. Mario Roxo for the indications as to altitude and other interesting data of this region, which he gave me very readily indeed.

Equisetaceae.

Equisetum Martii Milde. Leg. A. Lutz, 16 a 31, Dec. 1915.

Taxaceae.

Podocarpus Lambertii Klotzsch. Leg. B. Lutz (Ponte Alta), Jan. 1925.

Araucariaceae.

Araucaria brasiliana (A. Rich) Lamb.

Xyridaceae.

Xyris sp., Jan. 1925.
Xyris sp., Jan. 1925.
Xyris sp., Jan. 1925.

Eriocaulonaceae.

Actinocephalus pohlianus, Jan. 1925.
Paepalanthus itatiayae, Jan. 1925.
Syngonanthus caulescens Rub., Jan. 1925.

Juncaceae.

Juncus sp., Jan. 1925.

Liliaceae.

Smilax montana? Grieseb., Jan. 1925.

Commelinaceae.

3 undetermined species.

Amaryllidaceae.

Alstroemeria inodora Herb., Feb. 1915, Jan. 1925.
Amaryllis (*Hippeastrum*) *psittacina*.
Bomarea spectabilis Schenck., Dec. 1915.

Dioscoreaceae.

Dioscorea sinuata Vell., Jan. 1913, Jan. 1925.
Dioscorea piperifolia Willd., Jan. 1913, Jan. 1925.

Iridaceae.

Calydora (*Roterbe*) *campestris* Klatt, Jan. 1913.
Alophia geniculata? Klatt., Jan. 1913, Jan. 1925.
Sisyrhinchium incurvatum, Jan. 1913, 1925.
Sisyrhinchium incurvatum, March 1917.

Burmanniaceae.

Burmannia bicolor Mart., Feb. 1915.
Apteria lilacina (*cultivada*) Miers, Jan. 1915.

Orchidaceae.

Epidendrum elongatum Griesb., April 1913.
Sophronites grandiflora Lindl., April 1913, Feb. 1915.
Masdevallia infracta Lindl.?, Dec. 1915.
Govenia gardneri Hook., Jan. 1913, Jan. 1925.
Pogonia Rodriguesii Cogn., Feb. 1915.
Epidendrum fragranas Sw., April 1913.
Maxillaria sp., Jan. 1913.
Habenaria sartor Lindl., Jan. 1915, Jan. 1925.
Habenaria Reichenbachiana B. Rodr., Feb. 1925.
Habenaria sp., Jan. 1925.

Oncidium (5 undetermined species), Jan. 1925.
Zygopetalum sp., Feb. 1915.
Zygopetalum mackayi Hook., Jan. 1913.
Cyrtopodium sp., Feb. 1915.
Pleurothallis sp., Jan. 1925.

PIPERACEAE.

Peperomia marmorata? Sept.-Oct. 1913, Jan. 1925.
Others undetermined.

LORANTHACEAE.

Strutanthus sp., Dec. 1915.
Phoradendron sp., Jan. 1913, Feb. 1915.

BALANOPHORACEAE.

Helosis guyanensis Rich., Jan. 1915, Jan. 1925.

POLYGONACEAE.

Polygonum acre H. B. K., Feb. 1915.
Polygonum sp., Jan. 1925.
Triplaris sp., Feb. 1915.

PHYTOLACCACEAE.

Phytolacca thyrsiflora Fenzl., Jan. 1925.

CARYOPHYLLACEAE.

Drymara cordata W., Jan. 1925.

RANUNCULACEAE.

Anemone sellowii Pritz., Sept. 1913.

BERBERIDACEAE.

Berberis laurina Billb., Sept.-Oct. 1913.

LAURACEAE.

Ocotea (*Oreodaphne*) sp., Jan. 1915.
Ocotea (*Oreodaphne*) sp., Sept. 1913.

SAXIFRAGACEAE (ESCALLONIAE).

Escallonia mentividensis Cham. et Schl., Feb. 1915.
Escallonia vaccinoides St. Hil., May 1915, Jan. 1925.

Escallonia organensis Gardn., Jan. 1913, June 1915.

Cunionaceae.

Belangera tomentosa Camb., Jan. 1915.
Belangera cunionata Cambess., (Jan.?) 1913.

Rosaceae.

Prunus sphaerocarpa Sw., Jan. 1915, Jan. 1925.
Rubus erythrocaldos Mart., Jan. 1925.

Leguminosae.

Camptosema (*Dalstedtia*) *pinnata* Malme., Jan. 1913, Jan. 1925.
Mucuna altissima D. C., March 1914.
Crotalaria striata D. C., Jan. 1925.
Collaea speciosa L., Oct. 1913.
Desmodium sp.
Cassia sp.
Mimosa sp.

Oxalidaceae.

Oxalis sp., Jan. 1913, e 1925.
(Umbellasma ext. sup.)

Simarubaceae.

Picramnia warmingiana Engl., Jan. 1925.

Vocchysiaceae.

Vocchysia tucanorum Mart., Jan. 1913, March 1915, Jan. 1925.
Vocchysia oppugnata, Jan. 1925, June 1915.

Polygalaceae.

Polygala laurifolia B., Jan. 1915, Jan. 1925.
Polygala stricta? subulosa?, Jan. 1913, June 1915, Jan. 1925.

Euphorbiaceae.

Croton sp., Jan. 1913.
Croton sp.
Croton sp., Jan. 1925.
Manihot sp., Dec. 1915.
Acalypha sp., Jan. 1913, e 1925, Dec. 1915.

Sapindaceae.

Serjania sp., Jan. 1925.

Malvaceae.

Pavonia speciosa H. B. K., Jan. 1913, Glaziou 1864.
(Subpolymorpha.)
Hibiscus sp., March 1915.

Dilleniaceae.

Davillea rugosoa, Dec. 1915.

Hypericaceae.

Hypericum brasiliense Choisy. (Lambein Glaziou.)

Ilicinaceae.

Ilex affinis var. *angustifolia* Garden., Feb. 1915, Jan. 1925.

Violaceae.

Viola cerasifolia St. Hil., Dec. 1915, Jan. 1913, Jan. 1915, Jan. 1925.

Flacourtiaceae.

Casearia cambessedessii Eichl., Jan. 1915.

Passifloraceae.

Passiflora rubra L., Feb.-Dec. 1915, Jan. 1925.

Begoniaceae.

Numerosas especies que deixamos de determinar.

Lythrariaceae.

Cuphea mesostemon Koehne., Jan. 1925.

Melastomaceae.

Tibouchina herbacea Cogn., Jan. 1925.
Tibouchina minor Cogn., Jan. 1915, e 1925.
Tibouchina minutiflora Cogn., L. 1913, Jan. 1925.
Tibouchina arborea Cong.
Tibouchina clinopodiflora Cong. (or *gracilis*), Glaziou 1876, Feb. 1913.
Trembleya parviflora Cogn., June 1915.
Leandra nutans Cogn., Dec. 1915.

Leandra sp.
Lavoisiera australe Cogn., Jan. 1913.
Microlicia isophylla D. C., Jan. 1913, June 1915, Jan. 1925.
Miconia theesans?, Jan. 1913.
5 Tibouchinas e 6 other not determined species.

MALPHIGHIACEAE.

Tetrapteris ou Heterapteris, March 1924.

ONAGRACEAE.

Fuchsia integrifolia Camb., Jan. 1913, Jan. 1925.

UMBELLIFERAE.

Hydrocotyle barbarossa Cham. Dec. 1915.
Hydrocotyle hirsuta, Jan. 1925.
Hydrocotyle quinqueloba, Ruiz et Pav., Feb. 1915, Jan. 1925.
Centella asiatica Urb., Jan. 1925.
Eryngium paniculatum D. C., Jan. 1913.
Eryngium glazioviamnum Urb., Jan. 1915.

CLETHRACEAE.

Clethra brasiliensis Cham., Jan. 1925.

ERICACEAE.

Leucothoë intermedia Meissn., Jan. 1913, Jan. 1925.
Gaultheria ferruginea Cham. et Sehl., March 1915, Jan. 1925.
Gaultheria elliptica Cham., June 1913, Sept.-Oct. 1915, Dec. 1915, Dec. 1917.
Gaylussacia villosa, Oct. 1913, Dec. 1915.

STYRACACEAE.

Styrax leprosum? Hook. et Arn., Dec. 1915, Jan. 1925.

OLEACEAE.

Olea europea L., end of Sept. 1913.

GENTIANACEAE.

Dejanira sp., March 1914.
Lysianthus elegans, Jan. 1913, e 1925.
Lysianthus alpestris Mart., Jan. 1925, March 1914.

Lysianthus sp., Jan. 1913.
Voyria uniflora Lam., June 1915.
Zygostigma australe Gries., Jan. 1913, Feb. 1915.

Apocynaceae.

Amblyanthera sp., Jan. 1913, Jan. 1925.
Mesechites soalita Vell., Dec. 1915.

Asclepiadaceae.

Oxypetalum sublanatum Malme, Dec. 1915.

Borraginaceae.

Tournefortia sp., Jan. 1925.

Verbenaceae.

Verbena rigida Spreng., Jan. 1925.
Verbena hirta Spreng., Sept. 1913, Jan. 1925.

Convolvulaceae.

Jacquemontia martii Choisy, Jan. 1925.

Labiatae.

Salvia sellowinna Benth., March 1914.
Salvia guaranitica St. Hil., Jan. 1913, Jan. 1925.
Salvia coerulea Benth., June 1915.

Solanaceae.

Nicotiana langsdorffii Weinm., Jan. 1915, Jan. 1925, e outras occasio.
Cestrum corymbosum Schlecht., Sept.-Oct. 1915, Jan. 1925.
Brunfelsia hydrangaeformis Benth., Jan. 1913, Feb. 1915, Jan. 1925.
Brunfelsia ramosissima, Jan. 1913, Jan. 1925.

Scrophulariaceae.

Herpestes chamaedryoides H. B. K., Jan. 1925.
Verbascum blattarioides Lam., Jan. 1913 Jan. 1925.

Bignoniaceae.

Pithecoctenium dolichoides K. Sch., Nov. 19.
Fridericia speciosa.

Gesneriaceae.

Codonophora prasinata Lindl., Feb. 1915.
Gesnera magnifica Otto et Dietr., April 1912 (also found by Glaziou).
Gesnera maculata Herb., Dec. 1915.
Gesnera cooperi Paxt., Jan. 1913.
Gesnera alagophylla Mart., Jan. 1913, 1925.
Hypocyrta hirsuta Mart., Jan. 1925.

Lentibulariaceae.

Utricularia globulariaefolia Maet., Jan. 1913, 1925, Feb. 1915.

Acanthaceae.

Mendozia velloziana Mart., Jan. 1925.

Rubiaceae.

Coccocypselum condalia Person., Jan. 1925.
Declieuxia polygaloides, Jan. 1913, 1925.
Psychotria rudgeiodes?, Jan. 1925.

Cucurbitaceae.

Cayaponoa cabocla?, Dec. 1915, Jan. 1925.

Campanulaceae.

Lobelia camporum Pohl., Jan. 1913, Jan. 1925.
Haynaldia hilairiana, Jan. 1925.
Syphocampylus longipedunculatus Pohl., Jan. 1913, Jan. 1925.

Compositae.

Oligandra lycopoides Less.
Bidens rubifolius H. B. K., April 1915, Jan. 1925.
Wedelia subvelutina D. C., Jan. 1913, Sept.-Oct. 1915, Jan. 1925.
Mutisia coccinea Sr. Hil., Jan. 1913, 1925.
Chevreulia acuminta Less., Jan. 1913, Oct. 1915, 1925.
Gnaphalium sp., Jan. 1913, 1925.
Achillea millefolium L., Jan. 1913, 1925.
Baccharis camporum, Jan. 1913.
Eupatorium sp. (*Symphopappus*), Oct. 1913.
Mikania sessilifolia D. C., April 1915.
Xanthium spinosum Less???, Oct. 1913.

Mikania laevis D. C.
Vernonia tomentella Mart., Jan. 1913, 1925.
Tagetes minuta L., April 1913.
Ambrosia artemisifoliae L., Sept. 1913.
Adenostema sp., Feb. 1915.
Stevia veronicae D. C., Jan. 1913, Feb. 1915.
Erechtites hieracifolia D. C., April 1913.
Achyrocline alata D. C., April 1913.
Eupatorium serratum Soreng., April 1913.
Eupatorium laevigatum Lam., June 1913.
Erigeron maximum Link et Otto, Sept.-Oct. 1913, Jan. 1925.
Hypocheeris Gardneri Baker, Jan. 1913.
Trixis lessingii D. C., Aug. 1913.
Lucilia glomerata, Lucilia lundii, Lucilia acutifolia, Lucilia squarrosa, Lucilia marifolia, Glaziou, 1876.

THE FLUOGERMANATES OF THE UNIVALENT METALS.[1]

By JOHN HUGHES MÜLLER.

(*Read December 4, 1926.*)

Review of the literature of germanium shows that salts of the hypothetical fluogermanic acid, H_2GeF_6, are unknown, with the single exception of the potassium salt which was described by Winkler and used by him in the purification of germanium compounds.[2]

A few years ago the writer had occasion to prepare a considerable quantity of the potassium salt,[3] and at the time noticed that the properties of this compound differed from those behaviors shown in common with other complex salts of fluo-acids of the same type formula, especially those derived from silicon, titanium and thorium. This observation led naturally to the preparation of a complete series of fluogermanates as a means of establishing the relationship which exists between the fluogermanates themselves, and other fluo-salts of the more commonly known elements of the fourth periodic group. In addition to the proposed study of these compounds, much interest and purpose has been added by the kind coöperation of Dr. R. W. G. Wyckoff of the Geophysical Laboratory of Washington, who has undertaken the X-ray spectral analysis of these new crystalline salts. The structures of the potassium and cæsium salts have already been determined and show an interesting dissimilarity existing between them, the former possessing a hexagonal structure and the latter displaying an octahedral habit similar to that of analogous platinum, tin and silicon compounds.

The following communication concerns the preparation and analysis of all of the alkali fluogermanates, including the thallous and

[1] Contribution from the John Harrison Laboratory of Chemistry of the University of Pennsylvania.

[2] Winkler, *J. prakt. Chem. Soc.*, 36, 177, 1887.

[3] Müller, *J. Amer. Chem. Soc.*, 43, 5, 1085, 1921.

silver salts of the same acid and also deals with their respective densities, melting points and solubilities.

REAGENTS AND APPARATUS.

Lithium Fluoride.—The best obtainable grade of lithium chloride was dissolved in water and poured into an ammoniacal solution of ammonium carbonate. The middle fractions of the precipitated carbonate were selected and were converted to fluoride by action of pure hydrofluoric acid. The precipitated fluoride was thoroughly washed and centrifugally drained.

Sodium Carbonate.—"Baker's Analyzed C. P." sodium carbonate was recrystallized once from water, dried and dehydrated in vessels of platinum.

Rubidium Carbonate.—Commercial rubidium chloride was converted to the alum and the latter double salt fractionated from water solution, until the middle fractions were practically free from cæsium and potassium. The salt was then reconverted to chloride and the solution of the latter fractionally precipitated by addition of chlorplatinic acid. This operation was repeated many times, purposely rejecting first and last fractions, until the flame spectrum indicated the complete absence of cæsium and only traces of the common alkali metals. The chlorplatinate was then decomposed by ignition and the extracted rubidium chloride was changed to sulphate, and finally to carbonate, by the baryta method.

Cæsium Carbonate.—This salt was prepared from a quantity of cæsium alum originally nearly free from rubidium. The alum was several times recrystallized from hot water. The first crops of crystals were converted to sulphate and the latter salt was transposed to hydroxide by baryta and converted to carbonate by carbon dioxide. The carbonate was dehydrated and fused in platinum.

Potassium Carbonate.—Starting with a nearly pure potassium nitrate, the acid tartrate was precipitated and, after thoroughly washing and centrifugally draining, the acid salt was ignited in platinum to the pure carbonate.

Thallium.—Fairly pure metallic thallium was cut into fine turnings and exposed to the action of water and air, until the major portion of the metal had been converted to the hydroxide. The solution

of the latter was converted to carbonate after filtering out the residua of undissolved metallic particles. Qualitative analysis of the product failed to show any heavy metal impurity.

Silver.—Pure cupel silver was used. The metal was converted to nitrate, precipitated as carbonate, and the washed carbonate was converted to fluoride by dissolving in a slight excess of hydrofluoric acid.

Germanium Fluoride.—Pure germanium dioxide was prepared by the hydrolysis of the redistilled tetrachloride. With the pure ignited dioxide as a starting product, the required amount of fluoride was obtained in each case by weighing out the dioxide equivalent and dissolving in a slight excess of hydrofluoric acid.

Hydrofluoric Acid.—The best grade of concentrated "C. P." acid was redistilled from platinum retort and condenser. The redistilled acid was not stored in bulk but was redistilled in small amounts as required, conducting the distillate into known amounts of the alkali carbonate or germanic oxide and thereby producing the fluorides in known concentration.

Water.—The ordinary distilled water of the laboratory was redistilled in presence of a little permanganate and sulphuric acid, rejecting the first portions of distillate.

All preparations of the various fluorides and their complex salts were carried out in platinum vessels. In filtration and draining operations, funnels and perforated cones of platinum were used.

The purified salts, after dehydration in platinum vessels, were preserved in the dry state in vessels lined with either paraffin or Canada balsam.

Preparation and Analysis of Salts.

All of the described fluogermanates were made by adding the theoretical amount of germanium fluoride in hot aqueous solution to the hot solution of the univalent metal fluoride contained in a large platinum dish. The solutions were made sufficiently dilute to prevent precipitation of the complex salt, for the most part, until the mixtures were cooled. The solutions of the simple fluorides, all slightly acid with excess of hydrofluoric acid, were combined with rapid stirring and the resulting solutions were evaporated until much

of the complex salt crystallized out on cooling. The salts of sodium, potassium, rubidium and cæsium are all far more soluble in hot than in cold water and were comparatively easy to prepare in this way. Yields of these were increased by chilling the solutions to 0° C., filtering off the crystalline masses with centrifugal draining, and then further reducing the volume of the filtrate and re-chilling for second and third yields.

In the case of these four salts the alkali metals were weighed as carbonates, (anhydrous), and subsequently dissolved to the fluoride in slight excess of hydrofluoric acid. The germanium fluoride was prepared in equivalent quantity by weighing out germanium as dioxide and dissolving the latter in slight excess of warm hydrofluoric acid. The crystalline sodium, potassium, rubidium and cæsium salts were twice recrystallized from hot water, faintly acid with hydrofluoric acid, and again centifuged on platinum cones and dried in air ovens at 130°–140° C. The following yields of purest materials were obtained:

Na_2GeF_6 — 35 g. K_2GeF_6 — 45 g. Rb_2GeF_6 — 30 g.
Cs_2GeF_6 — 50 g.

The fluogermanates of lithium, thallous thallium, and silver are all very soluble salts and much more difficult to prepare in a pure and crystalline condition; hence their preparations are considered under separate headings.

Lithium Fluogermanate.—Lithium fluoride was weighed as such and suspended in cold water. The calculated amount of germanium fluoride, in presence of a slight excess of hydrofluoric acid, was then added and the mixture digested on the water bath until the lithium fluoride had practically all dissolved. After filtration the solution was evaporated to small volume and then chilled to 0° C. As the saturated solution of lithium fluogermanate holds 53.9 g. of the salt per 100 g. of solution at 25° C., it will be seen that this salt is about twenty-seven times as soluble as the corresponding sodium compound at ordinary temperature. The crystalline mass obtained by chilling the concentrated solution was recrystallized from water containing an excess of hydrofluoric acid. It was soon found that this salt could not be heated much above 100° C. without partial decomposi-

tion, with evolution of hydrofluoric acid and some germanium fluoride, as the heated salt failed to completely dissolve in water, leaving a residue of insoluble fluoride. Dried at 80–90° however, the salt appeared to remain unchanged but required some eight to ten hours to arrive at contant weight. When dried, lithium fluogermanate volatilizes rapidly without melting at 400° C., in which respect it differs from all of the other alkali salts of the same acid. The crystalline form of the salt does not appear to be the same as that of any of the other alkali fluogermanates and the crystals first separating seem to be hydrated. Both of these observances are uncertain at present but merit further consideration.

Thallous Fluogermanate.—The thallous salt resembles the lithium compound so far as its solubility is concerned; that is to say, it is too soluble in water to admit of easy crystallization. It was made by combining the calculated quantities of the simple fluorides in hot solution, in the presence of a slight excess of hydrofluoric acid.

The stock of thallous fluoride was dissolved to known volume and the concentration of an aliquot portion was determined by the chlorplatinate precipitation method, while the germanium fluoride required to form the complex fluoride was prepared as in the above described preparations. Care was exercised to mix the fluorides in very exact proportions, so that the mother liquor from the first crop of crystals obtained must have contained little else than the nearly pure salt and the excess of hydrofluoric acid. The crystals which separated on evaporating the solution were large and colorless and exhibited a beautiful pearly luster. Supersaturated solutions were easily obtained, from which masses of the crystalline salt appeared on inoculation with a minute fragment of the solid phase. The first yields of crystals were combined and twice recrystallized from pure water. Thallous fluogermanate is quite heavy (specific gravity 5.906) and melts at 465° C. The yield of pure salt was about 30 g.

Silver Fluogermanate.—The aqueous solutions of the simple fluorides were prepared from weighed amounts of metallic silver and germanic oxide respectively, and the fluorides in aqueous solution were mixed in the calculated ratio to produce the complex salt. The mixed solutions, upon concentration to small volume on the water bath in presence of a little free hydrofluoric acid, gave an oily liquid,

which upon cooling suddenly solidified to a colorless crystalline mass. The solid when heated to 80° C. or slightly above, remelted to a colorless liquid, which, when cooled slowly, remained in the supercooled liquid state for some time. This whole mass became almost instantly solid when stirred or when touched with the solid phase. After removal of all or nearly all of the free acid at 80–90° C., the salt remained completely soluble in very little cold water, but the neutral solution, on standing for some hours, deposited a small black precipitate which contained practically nothing but metallic silver. A solution in water containing a little free hydrofluoric acid, however, appears to remain unchanged on long standing.

Recrystallization of this silver salt requires a large amount of the initial material, as a solution weighing 100 g. carries as much as 88.03 g. of dissolved salt at 25° C. The crystals finally obtained by evaporating the concentrated solution in vacuo over sulphuric acid were large, colorless prisms, and when dry could be heated above the melting point of 80° C. without decomposition. Above 100° the molten compound slowly darkens and on subsequent treatment with water leaves a residue of nearly black metallic silver.

Analysis of Fluogermanates.

As is well known, the usual method for the decomposition and analysis of complex fluorides of the type Me_2RF_6 consists in the treatment of the salt with an excess of concentrated sulphuric acid, whereby hydrofluoric acid is expelled and the nonvolatile residue contains the univalent metal sulphate and the oxide of the acid-forming element. This general method is, however, not at all applicable to any of the fluogermanates above described. Such treatment of these compounds results in loss of fluogermanic acid itself or of germanium fluoride, which escapes with the acid vapors at the fuming point of sulphuric acid. Proof of this peculiarity on the part of the alkali fluogermanates consisted in treating them with sulphuric acid and passing the volatile products obtained by heating to fuming through a platinum condenser tube. All of these salts gave white sublimates even below 300° C., which upon treatment with water and excess hydrochloric acid gave solutions from which germanium sulphide was obtained by action of hydrogen sulphide. The presence of

fluorine was also proved by the glass etching test, which the hydrochloric acid solution of the same deposits gave when such solutions were sealed in glass tubes and allowed to remain in contact with the same at 100° C. for some hours.

After numerous unsuccessful attempts to obtain complete analyses of the alkali fluogermanates, the following method was found fairly accurate. The weighed salts were treated with a little concentrated sulphuric acid and were then carefully heated with the addition of several cc. of fuming nitric acid. The oxides of nitrogen and oxygen escaping from the decomposing nitric acid very slowly, but completely, remove the hydrofluoric acid at a temperature below the point of volatilization of germanium fluoride or fluogermanic acid, and the residue then contained on final heating to fuming—germanic acid and the alkali sulphate. The residues were then taken up in water and the solutions, after rendering about six normal with hydrochloric acid, were treated with hydrogen sulphide to saturation under pressure. The germanium sulphide so precipitated was in each instance converted to dioxide in the usual way and was weighed as such. The strongly acid filtrates, containing much hydrochloric acid and the original small excess of sulphuric acid, were simply evaporated to dryness and the alkali metal sulphate so recovered was weighed in the anhydrous condition.

Another scheme for partial analysis of any of the alkali fluo salts consisted in heating the weighed salt in a platinum crucible in a stream of hydrochloric acid gas. This method, while it gave only the alkali chloride, with loss of both germanium and fluorine, had the advantage of simplicity and high accuracy for the alkali metal content of the salts in question.

Analysis of the thallous and silver salts. The thallous salt was decomposed in the same manner as the above, by frequent treatment and evaporation with a mixture of fuming nitric and sulphuric acids, and the germanium was separated from thallium by precipitation of germanium as sulphide from a solution strongly acid with sulphuric acid. The sulphide of germanium at first thrown down was impure and discolored, due to co-precipitation of some thallium. This yellowish sulphide was treated with ammonia, and hydrogen sulphide was passed in until a small residue of black thallium sulphide re-

mained and all of the germanium sulphide had formed the soluble thiogermanate. The germanium was recovered from the filtrate by strongly acidifying with sulphuric acid and precipitation as before, from six normal acid solutions, as sulphide. The small residue of thallium sulphide was added to the main bulk of thallium sulphate and the solution was evaporated to expel nearly all of the sulphuric acid. The metal was recovered as sulphide, which was in turn converted to chloride and the thallium finally estimated as chlorplatinate.

The silver salt was also decomposed by sulphuric and nitric acids. The residue, which was completely soluble in strong ammonia water, was treated with hydrogen sulphide until the alkaline liquid was nearly saturated with the gas. The silver sulphide which separated was filtered off and, after retreatment with more ammonium sulphide, was converted to chloride in the usual way. The thiogermanate filtrate was treated as before described and the germanium finally weighed as dioxide.

Results of analyses appear in the table which follows.

TABLE I.

ANALYSES OF UNIVALENT METAL FLUOGERMANATES.

Li_2GeF_6.

Analysis.	Per Cent Lithium.	Per Cent Germanium.	Per Cent Fluorine.
1.	6.99	35.08	57.93
2.	7.12	35.94	56.94
Theoretical	6.92	36.18	56.90

Na_2GeF_6.

Analysis.	Per Cent Sodium.	Per Cent Germanium.	Per Cent Fluorine (by Difference).
1.	20.01	30.91	49.08
2.	19.98	30.89	49.13
3.	——	30.88	——
4.	——	30.95	——
Theoretical	19.78	31.10	49.12

K_2GeF_6.

Analysis.	Per Cent Potassium.	Per Cent Germanium.	Per Cent Fluorine (by Difference).
1.	30.01	27.95	42.04
2.	29.95	27.32	42.73
3.	29.98	27.49	42.53
Theoretical.	29.54	27.39	42.07

Rb_2GeF_6.

Analysis.	Per Cent Rubidium.	Per Cent Germanium.	Per Cent Fluorine (by Difference).
1.	48.01	20.51	31.48
2.	48.00	20.96	31.04
Theoretical.	47.81	20.29	31.90

Cs_2GeF_6.

Analysis.	Per Cent Cæsium.	Per Cent Germanium.	Per Cent Fluorine (by Difference).
1.	58.78	16.24	24.98
2.	58.72	16.19	25.09
Theoretical.	58.75	16.03	25.22

Ag_2GeF_6.

Analysis.	Per Cent Silver.	Per Cent Germanium.	Per Cent Fluorine (by Difference).
1.	49.89	19.00	31.11
2.	52.99	18.52	28.49
Theoretical.	53.65	18.02	28.33

Tl_2GeF_6.

Analysis.	Per Cent Thallium.	Per Cent Germanium.	Per Cent Fluorine (by Difference).
1.	——	11.94	——
2.	——	12.41	——
3.	67.76	——	——
4.	67.80	——	——
5.	68.20	12.02	19.78
Theoretical.	68.63	12.19	19.18

From the above analytical data it will be evident that the fluogermanates which were analyzed all conform to the expected type formula—R_2GeF_6, although in a number of cases the deviation from the theoretical percentage values is larger than that which is to be desired. It is altogether probable that the salts themselves were far purer than their respective analyses would indicate, owing to the method of preparation, and that the errors introduced are largely owing to imperfection in the analytical method. It should be stated, however, that the determination of germanium and an alkali metal in presence of fluorine is a quite difficult problem and that the procedure outlined is the first reported attempt to make this separation and is simply preliminary to a closer study of the problem involved.

In evidence of the purity of the potassium salt, for example, it was observed that the simple decomposition of the salt by ignition in a stream of hydrochloric acid gas gave values for the potassium content of the compound which were very close to the calculated amount of the alkali metal. Three analyses made in this way gave the following percentages for potassium: 29.48; 29.60; and 29.61 (theoretical = 29.54 if Ge = 72.5). This method is certainly much better for the alkali metal content, but was objectionable on account of the resulting loss of germanium and fluorine in an unrecoverable mixture with the excess of hydrochloric acid gas.

Specific Gravities and Melting Points.

Determinations of the densities of the fluogermanates were made through the use of pure toluene, which had been redistilled at constant boiling point (110–111°) and dehydrated by redistillation over metallic sodium. A 25 cc. pyknometer was used and comparatively large samples of the various salts were taken for each determination (10–15 g.). Results were obtained at 25° C. and refer to water at the same temperature.

Melting Points.—Melting points were obtained by the cooling curve method, using 5 to 10 g. of the salt, which was melted in a platinum crucible and allowed to cool slowly in a jacket of non-conducting material. A platinum-platinum-rhodium thermo couple was used, which had been previously calibrated by the cooling curves of bismuth, lead, zinc, antimony and silver. The probable error in temperature reading was ± 2° C. See Table 2.

TABLE 2.

SPECIFIC GRAVITIES AND MELTING POINTS OF FLUOGERMANATES.

Salt Formula.	Specific Gravity. D^{25}_{25}.	Melting Point. C°.	Remarks.
Li_2GeF_6	3.412	——	Rapidly volatilises without melting at 400°.
Na_2GeF_6	3.055	623°	Quite volatile at 750–800°.
K_2GeF_6	3.198	735°	Boils at about 835°.
Rb_2GeF_6	3.891	760°	Quite volatile at 800°.
Cs_2GeF_6	3.899	727°	Slowly volatile at 850°.
Ag_2GeF_6	3.920	80°	Slowly decomposes above melting point, darkens.
Tl_2GeF_6	5.906	465°	Slowly decomposes above melting point.

From the above table it will be seen that the densities of the alkali fluogermanates are not very widely varient and that the lithium salt is unexpectedly of greater density than either the sodium or potassium analogue. This appears to be connected with other points of dissimilarity between the lithium salt and the salts of the common alkali metals.

The cæsium salt shows a melting point which places it between sodium and potassium fluogermanates, instead of the expected position, in which it would follow the rubidium compound. This anomalous behavior is in remarkable agreement with the abnormal solubility of the cæsium salt, in which it falls between sodium and potassium instead of following rubidium as would naturally be expected. (See Table 3.)

SOLUBILITY OF THE FLUOGERMANATES.

Solubility determinations were made according to the method recommended by Findlay ("Practical Physical Chemistry"). In general, the various salts were dissolved in hot water and allowed to cool to near the required temperature, with consequent deposition of the large excess of dissolved salt. This was carried out in platinum dishes and the supernatent liquid, together with some of the suspended solid phase, was then poured off into the suitable container for preservation in the thermostat. The solutions were vigorously stirred for periods of thirty-six hours or more—at a constant temperature of

± 0.05°—before samples were taken for analysis. Samples were weighed in a platinum bottle (stoppered), and afterwards evaporated to dryness and gently ignited and weighed in a platinum dish.

The lithium salt, however, could not be treated in this way, as it could not be rapidly dehydrated without some decomposition. This salt appears to carry down some water, and heating even to 100° caused some loss of hydrofluoric acid. In consequence, it was slowly dried to constant weight at 80–90° in a water jacketed oven.

The very soluble silver salt was difficult to deal with, as it melts at 80° C. and at that temperature is soluble in water in all proportions. Dehydration of this salt was very slow, requiring many hours at 60–70° in the absence of light, followed by exposure in vacuo over sulphuric acid for several days before constant weight could be obtained.

The following table shows the results obtained for all of these salts and is accompanied by the solubility curves of the four alkali fluo salts of lesser solubility.

TABLE 3.

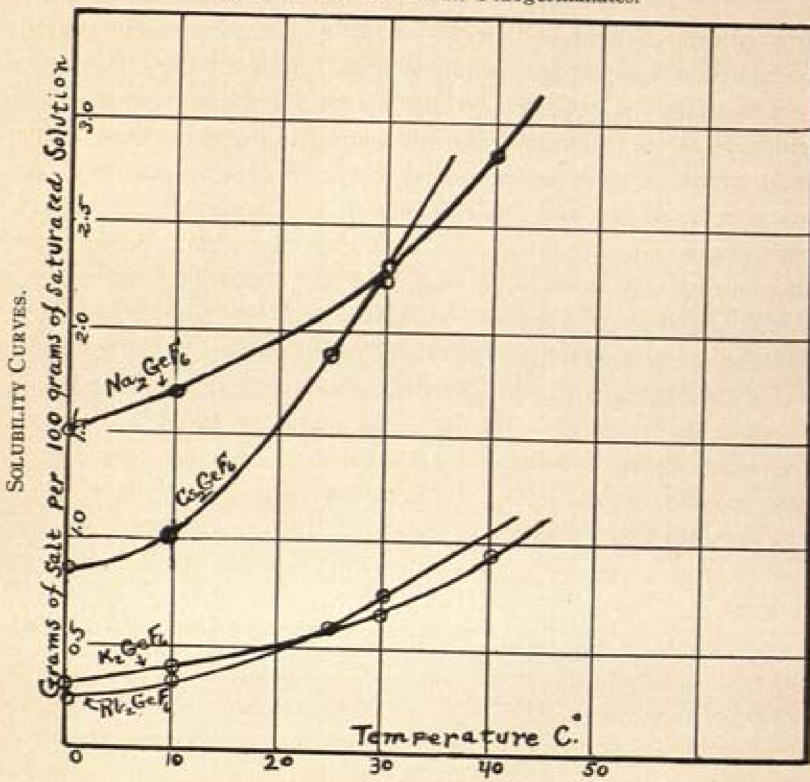
Solubilities of the Univalent Metal Fluogermanates Expressed in Grams of Salt per 100 cc. of Saturated Aqueous Solution.

Formula of Salt.	Temperature C°.					
	0°	10°	25°	30°	40°	80°
Li_2GeF_6	—	—	53.92	—	—	—
Na_2GeF_6	1.52	1.68	—	2.25	2.83	3.36
K_2GeF_6	0.25	0.363	0.59	0.65	0.95	—
Rb_2GeF_6	0.23	0.302	—	0.74	—	—
Cs_2GeF_6	0.84	0.98	1.89	2.28	—	—
Tl_2GeF_6	14.13	—	—	34.58	—	—
Ag_2GeF_6	—	—	—	88.03	—	Sol. in all proportions.

The solubility determinations of the alkali fluogermanates show that the cæsium salt possesses an unexpected solubility, which places this compound intermediate between the sodium and potassium analogues. This anomalous behavior is probably connected with the fact that Cs_2GeF_6 is not isomorphous with K_2GeF_6 as revealed by the X-ray spectra of these salts. The potassium salt shows hexagonal symmetry,[4] while the cæsium compound displays an octahedral habit

[4] P. Groth, *Chem. Krist.*, I., p. 486 (Leipzig, 1906).

Solubilities of the Alkali Fluogermanates.



similar to the analogous platinum, tin, and silicon compounds, as shown by the kindness and coöperation of Dr. R. W. G. Wyckoff of the Geophysical Laboratory at Washington. The results of this investigation will appear in a separate publication, under the title "Crystal Structure of Cæsium Fluogermanate" (Wyckoff and Müller, *Amer. J. Sci.*, April, 1927).

As before indicated, the abnormally low melting point of Cs_2GeF_6 (727° C.), also places cæsium between sodium and potassium in the same series of salts (see Table 2).

The fluogermanates of lithium, silver, and thallous thallium are all very soluble in water. They all three tend to form highly concentrated supersaturated solutions and differ considerably from the sodium, potassium, rubidium and cæsium compounds (see Tables 2 and 3).

The alkali metal fluogermanates in aqueous solution fail to give any precipitation of germanium sulphide, when such solutions are saturated with hydrogen sulphide either in neutral solution or in presence of free hydrofluoric acid. This stability toward hydrogen sulphide, which indicates the firmly bound nature of the fluogermanic acid radical, has already been made the basis of a separation of germanium from arsenic; for hydrofluoric acid solutions of arsenious oxide may be quantitatively precipitated by hydrogen sulphide, leaving all of the germanium in the filtrate as fluogermanic acid.[5]

Summary and Conclusion.

1. The fluogermanates of lithium, sodium, potassium, rubidium, cæsium, thallous thallium and silver have been prepared. These salts represent a new group of compounds, as the potassium salt is the only member of the series previously reported.

2. Methods of analysis of these salts are included, together, with determinations of their specific gravities, melting points and solubilities.

3. The somewhat anomalous position of the cæsium salt in reference to the other members of the series, as shown by its melting point, solubility and crystalline form, is of particular interest; for these properties place this salt in a position intermediate between the corresponding sodium and potassium compounds instead of at the end of the series, following the rubidium salt, as would naturally be expected.

4. The preparation of these salts in a pure condition is preliminary to a further study of their crystallographic structures which is made possible by the kindness of Dr. R. W. G. Wyckoff, who has undertaken their X-ray spectral examination.

[5] Müller, *J. Amer. Chem. Soc.*, **43**, 2549, 1921.

AN ECOLOGICAL-ANATOMICAL STUDY OF BEACH VEGETATION IN THE PHILIPPINES.

By RAYMOND KIENHOLZ.

(*Read April 22, 1926.*)

CONTENTS.

INTRODUCTION.

The shore line of the Philippine Islands, extending for thousands of miles, includes a variety of habitats affected by a variety of environmental factors. Extensive areas covered by mangrove species occupy the intertidal region in parts of the Islands, while equally extensive areas are occupied by brackish swamps in which the nipa palm is the predominant species. At other places many miles of level sandy beach occur, or great stretches of rocky cliffs come down to the water's edge. Many small islands are composed wholly of sand and rise only a few feet above sea level, almost free of vegetation or covered with a heavy growth of shrubs and trees forming the " beach jungle " characteristic of the Indo-Malayan region. Usually, however, the shore line of any given area is composed of all of these vegetational types and physiographic areas combined, no one of them being great in extent and yet each showing most of the features found on the more extensive areas.

With such a diversified shore line of muddy flats, sandy beaches, and rocky headlands, in protected bays or exposed to the diverse winds, currents, and wave action of the Pacific Ocean, the China Sea, the Sulu Sea, the Celebes Sea and other smaller seas, gulfs, and channels, subject to a varied rainfall and backed by the varied vegetation of the island's interior, the vegetation typical of these beaches proves to be composed of a large number of species of unusual interest from an ecological and an anatomical viewpoint. Merrill (22) in his "Enumeration of Philippine Flowering Plants" lists 258 species (exclusive of the orchids) as occurring usually along the seashore or along tidal streams, and of this number 33 per cent are endemic to the Philippines. This is an unusually high percentage of endemism when one considers the very wide, often pantropic, distribution of most of the beach species. Merrill (21) states that the percentage of endemism for all the plants found in the Philippines is 40 per cent, of which the species found in the virgin forests have an endemism of 60 per cent or more, while the plants of the thickly populated regions have an endemism of only 18 per cent. The total number of plants found on the beach would be materially increased, if those species are included which occasionally occur along the seashore, and if we included the ferns and the orchids.

In spite of this interesting diversity, little has been done in the Philippines to investigate the vegetation of the beach. An exception to this is to be found in the case of the mangrove and nipa swamps, which have always aroused the interest of the botanist, and in the Philippines have been studied largely because of their economic value. Whitford (32) in a study of the "Vegetation of the Lamao Forest Reserve" discusses the beach vegetation on that part of the Reserve bordering on the sea, where he finds a "dilute expression" of the vegetational types characteristic of the beaches of the Philippines. Based on the physiographic forces at work forming these habitats he recognizes: (1) Sandy beaches lying above high tide, populated by the *Ipomoea pes-caprae* formation and the *Barringtonia-Pandanus* formation; (2) Strand lying below high tide, populated by the Mangrove and *Nipa* formations.

Copeland's (9) ecological study of the San Ramon *Polypodiaceae* includes a few species found along the strand. These he compares

anatomically with the ferns of other habitats and in relation to the severe xerophytic conditions under which they live. Brown (5) in "Minor Products of Philippine Forests" discusses the mangrove swamps of the Philippines, their distribution and the species that characterize them. This work together with the work of Areschoug (1), Karsten (20) and others, makes it unnecessary to discuss this interesting feature of Philippine shore lines. Likewise the nipa swamps which are discussed by Brown and others are omitted from this study.

The classical work of Schimper (27) on the beach vegetation of the Indo-Malayan region will always serve as the basis for any work done in this region. Schimper, however, does not discuss the ecological anatomy of the sandy beach species nor pay particular attention to the vegetation of rocky cliffs fronting on the sea.

Area Covered.

The area to which particular reference is made in this paper is that near the town of Puerto Galera, located on the northern coast of the island of Mindoro. This island, the seventh largest in the Philippines, with an area of nearly 4,000 square miles, is comparatively little known. It is very mountainous, practically the whole interior being a chain of mountains extending from one end of the Island to the other. These mountains extend in spurs and ridges down to the coast, where they terminate in rocky headlands or promontories, alternating with low valleys which form sandy or muddy beaches depending on the amount of sediment brought down by the rivers and on the strength of the wave action and the currents in carrying this material away. The town itself is located at the narrow neck of land where a long, narrow, hilly, indented cape joins the mainland. This cape extends several miles out into the Verde Island Passage and is open on its eastern side to the currents, the wave action and the winds which sweep up this channel from the east. Its western side is protected by a number of small islands, separated by narrow channels, thus forming a comparatively shallow protected bay between them and the main cape. This protected bay with its many identations provide a series of sandy beaches, muddy flats, and rocky cliffs, within a small area, all of which are protected from direct contact

with wave and current action, while the eastern side of the cape affords a similar series open to the stronger action of the elements of the Passage, though not exposed to the open sea. Here we find all of the types of beach vegetation characteristic of the Islands except the nipa swamp. They are all on a small scale, but characteristic nevertheless, as regards species and environmental factors. All of the vegetation on the hills of the cape and some of it directly back of the beach has been altered by man, but very little of the beach vegetation itself has been removed or changed. The exceptions to this are the removal of some of the mangrove trees for tan bark or for firewood, and in a few cases the planting of coconut groves close to the beach and the consequent clearing away of all of the native vegetation.

Back of the town the land gradually rises to the coastal range of mountains about 2,500 feet in height. Many streams, all of them small, drain from these coastal mountains into the sea. Those streams draining directly onto the open coast where the currents and the wave action are strong form level sandy beaches, the stream sometimes being temporarily dammed at its mouth by a sand bar raised by wave action. Those draining into the sea at protected places, particularly into the protected bay to the west of the cape, form low, level sand, or mud flats, on which the mangrove species grow abundantly. The ridges from the coastal mountains end abruptly in rocky headlands of varying heights as they reach the sea. These ridges alternate quite regularly with the sandy beaches or with the muddy flats. Some of these rocky cliffs are composed of a sandstone rock which easily disintegrates into a fine sand, while others are composed of a much harder rock of volcanic origin. Frequently their seaward sides are not so steep but that they are partially or entirely covered with soil. At the foot of these rocky headlands there is frequently a narrow sandy beach, or a sandy beach thickly strewn with boulders, depending on whether the rocks of the cliffs are of sedimentary or of volcanic origin.

Because of the very wide and uniform distribution of most beach plants and because of the uniform environmental factors obtaining on the beach, the types of beach vegetation of this Puerto Galera area are fairly representative of beaches throughout the Islands. Dependent to some extent on the current rainfall, the vegetation of the rocky

cliffs and to a lesser extent that of the sandy beaches has a seasonal periodicity of vegetative activity coincident with the periodicity of the rainfall. As the seasonal distribution of the rainfall varies from a uniform rainfall the year round on the eastern coast of some of the islands, to a decided alternation of dry and wet season on the west coast of most of the islands, the seasonal appearance of the beach vegetation varies somewhat in different localities. However, this variation in rainfall probably does not affect the type of vegetation, nor the floristic composition of the vegetation found on the sandy beach in different parts of the Islands.

Work Done.

During the summer of 1923, the author made a trip through the southern islands of the Archipelago, stopping at many places to make observations and collections of the beach flora. The summer of 1924 was spent at Puerto Galera, where intensive collecting of material and the measuring of environmental factors were carried on as teaching duties permitted. Herbarium material was gathered, particularly of beach species; anatomical material, chiefly leaves, was collected and preserved and readings were taken on evaporation in various habitats, on wind movement, on temperature and on other factors. Observations were made on the distribution of various beach species and a considerable study made of the leaf structure of the beach plants, from fresh material cut with the sliding microtome and cleared with chloral hydrate or stained with various reagents, particularly chlorzinc iodide. This study of the fresh material was especially useful in making stomatal counts and in distinguishing chlorophyll-bearing cells from water storage tissue. The preserved anatomical material has since been sectioned and examined and the data obtained incorporated with that obtained from the fresh material.

The herbarium material has been determined by Dean Elmer D. Merrill of the University of California, to whom my sincerest thanks are due. The plant names used throughout this paper are those recognized by Merrill in his "Enumeration of Philippine Flowering Plants," hence no authorities nor synonyms are given.

Environmental Factors of the Area.[1]

Temperature on the sandy beach during the period of April to June as measured by Standard Weather Bureau thermometers averaged: maximum 88.6° F., and minimum 75.8° F.

Relative humidity on the beach was found to be very high even during the hottest days of the summer season, often being above 80 per cent at such times.

Evaporation was measured by standardized Livingston white spherical atmometers on a rocky headland, on the sandy beach and under the mangrove; the amount of water evaporated at these stations being in the ratio of 100, 58, 33. The constant wind on the rocky headland greatly increased the amount of evaporation.

Sunshine was not recorded beyond general notations on the clearness or cloudiness of the sky. The number of bright clear days was high and this together with the temperatures and almost constant wind movement produced a severe condition for plant life, particularly with regard to water loss from the plant.

Rainfall is fairly uniform throughout the entire year, with the driest months being February and March (about 2 inches per month). Increased precipitation in April, May and June reaches 6 or 7 inches per month, the total annual rainfall being over 53 inches.

Vegetation of the Beach.

The vegetation found along the shoreline of the Philippines may be divided into two distinct types based on the physiographic features of their habitat, namely: (1) that above high tide level and (2) that below high tide level. The area along the seashore which is above high tide level may consist of sandy beaches, rock strewn beaches or rocky cliffs extending up from the water's edge. The area below high tide level is made up of coral reefs, sandy flats or muddy flats submerged at high tide and characterized by the presence of mangrove and nipa swamps, those great "forests of the sea" which have received so much attention from botanists who have visited the tropics. These have received classic treatment at the hands of Schimper

[1] A fuller discussion of the environmental factors of this area and of the beaches of the Philippine Islands in general will be published later in the *Philippine Journal of Science.*

(27), Karsten (20) and others. In deeper water we find the marine vegetation, made up of algae and marine phanerogams.

Marine Vegetation.

The marine vegetation of Puerto Galera and of the Philippine Islands generally consists of two types: (1) the algae and (2) the marine phanerogams. The larger algae are few in individuals and few in species, as is characteristic of most tropical seas when compared to the abundant wrack and kelp beds of our north temperate sea coasts. A few species of *Halimeda*, a calcareous alga, may be found on the firmer sandy floors in shallow water or more likely on coral reefs covered with sand. *Laurencia* and *Caulerpa* are also found to a limited extent. Along muddier shores characterized by a sandy or rocky bottom covered by a layer of mud silt brought down by the rivers we find a considerable growth of *Sargassum* and *Padina*. Along clean sandy shores with a somewhat pebbly bottom we find much of the sea lettuce, *Ulva*.

The marine phanerogams are present in much greater abundance than are the algae and at low tide we find extensive flats of a sandy, slightly muddy or rocky character which, when not exposed to strong wave action, are covered with a growth of various marine phanerogams. The most conspicuous and extensive of these beds are composed of an almost pure growth of *Thalassia hemprichii*. In deeper water we find small beds or clumps of the very rank, coarse-growing *Enhalus acoroides*, which seems to prefer a slightly muddy bottom to a clean sandy bottom. *Diplanthera uninervis* is confined almost exclusively to a clean coral sand bottom, where it unites with *Halophila ovalis* to form dense beds which bind the sand so firmly that at their shallow edges, where wave action has broken up this "sod" of plants, one steps down off the bed eight to ten inches onto the sand which is being carried away by the waves and currents. *Cymodocea rotundata* forms extensive beds, seeming to prefer clean sandy bottoms, though sometimes being found on muddy sand bottoms. *Cymodocea serrulata* and *Halophila spinulosa* are much more rarely found and seldom form dense beds. These facts hold also for the shores of the coral sand islets of the Sulu Sea, where I have collected marine phanerograms at a number of stations.

SANDY BEACH.

The lower sandy beach is usually entirely free of vegetation except as seeds contained in the beach drift may attempt to gain a foothold, only to be submerged or washed away. *Barringtonia asiatica* often attempts to establish itself in this way. In many places even where there is considerable wave action there is a growth of mangrove species in the pure sand bottom often with a strip of water and of sandy shore between the clump of mangrove and the higher shore line. The species found in such places are not the species of *Rhizophora* or *Bruguiera* typical of the mangrove swamps but rather those members which are capable of growing and often do grow on sandy or rocky shores within reach of salt water and which form a transition between the true mangrove swamp and the sandy beach. The species usually found there are: *Avicennia marina* and *Sonneratia caseolaris* forming a considerable growth on the sandy, frequently submerged, beach, and *Agiceras floridum, Lumnitzera racemosa, Scyphiphora hydrophyllacea* and *Excoecaria agallocha* forming bushy growths on the sandy beach infrequently submerged by tides.

Usually, however, the lower sandy beach, where wave action is at all evident, is bare of vegetation except as creepers of *Ipomoea, Wedelia* or *Vigna* may grow down from the upper beach. The middle beach is characterized by a number of very typical creepers such as the pantropic *Ipomoea pes-caprae, Canavalia rosea* and *Vigna marina*. Creeping over and parasitizing the vegetation indiscriminately are tangles of the pantropic strand parasitic member of the *Lauraceae, Cassytha filiformis.* Clumps of *Euphorbia atoto,* widely distributed in the Indo-Malayan region, are found scattered on the middle beach and have their counterpart in the *Euphorbia polygonifolia* of our own coasts. Here, too, we find beds of *Sesuvium portulacastrum* and to a lesser extent *Allmania albida* and *Trianthema portulacastrum*. Many grasses and sedges characterize this part of the sandy beach, the most widely distributed and abundant being *Spinifex littoreus* and *Remirea maritima.*

The upper sandy beach is an almost impenetrable tangle of herbs, shrubs and trees, the creeping forms of which send runners down over the middle and lower beach. The woody-herbaceous plant, *Wedelia*

biflora; the scandent shrub, *Quisqualis indica;* the shiny, fleshy-leaved shrub, *Scaevola frutescens;* the hairy-leaved *Sophora tomentosa;* and the larger, delicate-appearing, amyrillidaceous plant, *Crinum asiaticum* form, with *Pandanus tectorius,* a thicket of the lower growing species. Under this thicket wherever possible the herbaceous plants characteristic of the middle beach are found. This whole mass of vegetation is bound together and to the tree growth characteristic of the upper beach by herbaceous vines such as *Calonictyon album* but more still by woody lianas and scramblers, some of which are very characteristic, such as *Dalbergia candenatensis* and *Caesalpinia nuga.* Other scramblers are *Strychnos luzonensis, Jasmium bifarium* and *J. aculeatum,* and *Finlaysonia obovata,* the last found near brackish water. Some lianas typical of the lowland forest also thrive along the seashore.

The most conspicuous element of the upper beach vegetation is the trees, one of the chief of which is *Barringtonia speciosa* from which Schimper (27) named his *Barringtonia*-formation, though he, in an earlier paper, had named it after *Terminalia catappa,* another common beach tree. Whitford (32) has combined the tree forms with the undergrowth forms, calling the vegetation of the upper beach the *Barringtonia-Pandanus*-formation. The trees mentioned are little if any more abundant, however, than *Thespesia populnea, Sideroxylon ferrugineum* or *Hernandia ovigera. Hibiscus tiliaceus* is very common also, though not at Puerto Galera. Most of these species with their shiny, leathery leaves form what is sometimes called the "beach jungle" or the "beach forest" when extensive in area as it often is on small sandy islands.

Smaller trees common to the upper beach are the hairy-leaved, gnarled, very common *Tournefortia argentea,* the small varnished-leaved *Dodonea viscosa, Opilia amentacea, Tristera triptera, Ximenia americana, Pemphis acidula, Suriana maritima, Pongamia pinnata, Guettarda speciosa* and *Morinda citrifolia.* Occasionally dense thickets of the introduced shrubs, *Prosopis vidaliana* or *Acacia farnesiana* are found on the sandy beach. *Vitex trifolia* forms thickets on the sand of the upper beach and its low growing variety *ovata* forms a dense cover in similar situations.

Heritiera littoralis with its peculiar boat-shaped buoyant fruits,

often found at the back of mangrove swamps, is also present on the sandy beach. *Xylocarpus moluccensis* and the shiny, leathery-leaved *Calophyllum inophyllum* often grow so close to the water's edge as to reach out over the water and receive reflected light from below.

On beaches strewn with rocks one often finds the leathery-leaved *Diospyros maritima* associated with *Avicennia marina* and others.

ROCKY HEADLAND.

The vegetation of this physiographic area is largely derived from the sandy beach or from the inland forests and consists of many species of a diverse nature. There are, however, certain plants which are almost always found on the steep cliffs overhanging the sea or on the large rocks and boulders forming the shore. Of these, the most characteristic are epiphytes belonging to the ferns; *Cyclophorus adnascens* on rocks and trees, *Polypodium scolopendium* and the humus collecting *Drynaria quercifolia*. These are able to withstand the dry season and to spring into luxuriance when the rains begin. Certain grasses and sedges also grow on the steep slope of the rocky cliffs, such as *Monerma repens, Panicum carnatum* and *Scleria lithosperma*.

Trees and shrubs likewise are found clinging to the sides of these rocky cliffs wherever a foothold can be obtained. The most common of these are: *Plectronia gynochthedes, Ardisia pyramidalis, Lunasa amara, Gardenia morindaefolia* and *G. merrillii* and *Vitex parviflora*. On certain rather open sloping cliffs *Cycas rumphii* and species of *Pandanus* are found abundantly. The liana *Derris mindorensis* is also found back of rocky shore lines. Herbs and epiphytes form an undergrowth on the steep slopes of cliffs. Two very characteristic and commonly found plants of the rocky cliffs are the leafless vine *Sarcostemma brunonianum* and the milky-juiced *Hoya cummingiana* with its 4-ranked leaves.

At the base of these cliffs may be a sandy or a rocky beach of small extent on which the common sandy beach species are found. On very exposed volcanic rock cliffs low down to the water I have found *Pemphis acidula* growing as a gnarled thick-leaved shrub; *Evolvulus alsinoides* and the grass *Monerma repens*.

FORM AND STRUCTURE OF BEACH PLANTS IN RELATION TO ECOLOGICAL FACTORS.

The vegetation of the sandy beach and the rocky headland is exposed to severe environmental conditions. These environmental factors may bring about a modification in the form or the habit of the plant or they may modify the structure of the plant parts, particularly the leaves. The form of the plant may be modified in response to the shifting character of the sand upon which some of the beach species grow. In the Puerto Galera region the shifting of the sand by wind is slight because much of the sand is coarse, the damp air and the frequent rains lessen the movement and the rocky headlands protect the sandy beaches from very strong winds. To what extent the plants of the sandy beach are affected by a shifting substratum or by wind blown sand it is difficult to say. I have noted on small windswept coral sand islets in the Sulu Sea, *Wedelia biflora* and other similar plants creeping over the sand, nowhere forming the bushy tangle normally so characteristic of *Wedelia*. Whether this creeping habit was an adaptation to excessive wind movement or whether it was due to the intense heat, light, and high transpiration rate, cannot be decided. The fact remains, however, that much of the herbaceous and some of the woody vegetation found on the beach is of a low growing habit.

Ipomoea pes-caprae, Canavalia rosea, C. microcarpa and *Vigna marina* are all herbaceous creeping forms sending runners out over the sand, which sometimes take root. *Wedelia biflora* and *Quisqualis indica* are often low growing forms particularly on the open sandy beach though they also form shrubby growths. Few of the grasses on the beach grow to a great height, while some forms such as *Spinifex littoreus* send out runners which take root to form new plants.

Allmania albida, Trianthema portulacastrum and *Sesuvium portulacastrum* are low growing, succulent, rosette plants, while *Euphorbia atoto* forms small low clumps. *Crinum asiaticum*, on the other hand, is an exception in that it grows to a height of four to five feet but is usually protected by the shrubby growth of *Scaevola frutescens* and *Wedelia biflora*.

Some of the shrubs and trees on the upper beach show signs of the high winds prevalent on the beach by their small gnarled form (*Tournefortia argentea*), and their umbrella-like shape (*Terminalia catappa, Barringtonia asiatica*). When *Scaevola frutescens* grows on small sandy islets it is often low, sprawling and gnarled. The tree growth on the rocky headlands is often dwarfed as a result of wind action. What little mechanical tissue is found in the leaves probably has little effect in protecting the plants against wind-blown sand.

Environmental factors which limit the supply of available water in the soil and make for a rapid loss of that already in the plant, are much more severe and much more potent than are the factors of shifting substratum and wind-blown sand, if we may judge from the large number of structural features which conserve the water supply of the plants found on the beach.

Many of the plants of the sandy beach are deeply enough rooted to have an abundant supply of soil moisture. In the case of mangrove and nipa swamp species and some of the beach trees growing on rocky beaches or at the base of cliffs where their roots are subject to salt water at high tide, the difficulty of water absorption causes a physiological drought which makes it imperative for the plant to conserve its water supply. Some beach plants and especially those of the rocky headlands growing on the exposed faces of the cliffs are dependent on the moisture in a quick draining or in a shallow soil. In spite of an abundance of water in the soil and a high relative humidity of the air the plants must conserve their moisture because of the high rate of evaporation brought about by the conditions enumerated below:

1. One of the most severe conditions under which the sandy beach vegetation and particularly the rocky headland plants must exist is the almost constant and often strong winds. Wind greatly increases evaporation as was evidenced by measurements discussed elsewhere.

2. The comparatively high temperature the entire year makes for a high water loss from the plant particularly when we consider the great heat reflected from the sand on which many of the plants grow.

3. The light of the tropical sun is very intense and when to it is added the reflection from the white coral sand of the beaches and

from the water and the breakers near the shore its effect on the plant must be severe. It not only increases the transpiration but may actually injure the tissue of the leaf itself. Copeland (8) says transpiration in the coconut is increased four times by a change from a light haze to full illumination.

4. The sandy substratum of the beach allows water to drain away or to be lost through evaporation very readily and rapidly, the surface layers drying out quickly.

5. Salt spray is sometimes thrown inland for some distance and the leaves of the beach plants especially are often coated with it. That the presence of this spray has an effect on the vegetation is indicated by Whitford (32) who cites an example of salt spray thrown inland by a typhoon settling on *Terminalia catappa*, a typical strand tree, and on *Artocarpus incisa*, an inland species. The *Artocarpus* was killed by the salt spray while *Terminalia* was unharmed.

6. Some of this salt spray falls on the soil but the investigation of Kearney (19) has shown that sandy beach plants are not halophytes, as the sand is comparatively free of salt. Plants growing in the mangrove and nipa swamps, and those found near enough to sea to be affected by salt water at high tide are true halophytes, however, and in addition to a high rate of water loss they have difficulty in absorbing water.

The presence of these factors of light, heat, and wind which greatly increase the rate of transpiration have brought about many structural features in the plant which tend to decrease the water loss and conserve the water already in the plant. These structural adaptations are noticeable in many of the plant parts but have been examined chiefly in the principal transpiratory organ, the leaf.

The change in the position of leaves during the period of greatest heat and light probably protects against excessive water loss and likewise against injury due to intense light. *Ipomoea pes-caprae* folds its leaves along the midrib with the inner faces together; *Canavalia spp.* and *Vigna* fold their three leaflets together; while *Euphorbia atoto* and *Sophora tomentosa* also have a slight amount of leaf movement to place the former's leaves closer to the stem with the upper side inward or fold the latter's leaflets together.

The total suppression of the leaf as a photosynthetic organ has

occurred in *Cassytha filiformis*, where the leaves are scale-like and protect the bud, the entire photosynthetic function being taken over by the stem. In *Sarcostemma brunonianum*, a frequent inhabitant of the rocky cliffs, the stem has likewise taken over the photosynthetic function.

Reduction in the size of the leaves has occurred in only a few species such as *Pemphis acidula* and *Suriana maritima*.

Thin, slender leaves, standing erect and receiving light on both sides is characteristic of most of the grasses and sedges found on the beach, particularly *Spinifex littoreus* and *Remirea maritima*.

Hairy leaves are abundant but in many cases the hairs are not numerous enough nor sufficiently developed to be a protection. The leaves are arranged in the order in which their hairy coverings are probably effective in reducing transpiration. *Heritiera littoralis* (closely overlapping peltate hairs on lower surface); *Vitex trifolia* (very dense mass of two-celled hooked hairs on lower surface); *Sideroxylon ferrugineum* (large flat hairs forming layer on lower surface); *Tournefortia argentea* (loose tangle of hairs on both surfaces). Hairs are present also in *Sophora tomentosa*, and *Pemphis acidula* but probably have little effect on the transpiration rate.

Waxy bloom on the leaf is found only in the case of *Euphorbia atoto*.

Greatly thickened cuticle and outer epidermal walls are found as follows, arranged in the order of their thickness; *Crinum asiaticum, Sideroxylon ferrugineum, Calophyllum inophyllum, Sophora tomentosa, Vitex trifolia* (upper surface only), *Xylocarpus moluccensis, Glochidion littorale*, and the epidermis of *Cassytha filiformis*. Other species have thickened outer epidermal walls which are cutinized or overlaid with a cuticle but the cutinization is not excessive.

Varnished leaves are especially well developed in *Dodonaea viscosa* and *Scaevola frutescens* and may reflect the light rays, as Wiesner has suggested. Many of the beach trees and especially the mangrove species have shiny leaves and may be classed as varnished.

Sunken stomates are frequently encountered. The species having them are here arranged according to the degree of depression (the figure in parenthesis following each species is the number of microns from the outer surface of the epidermis to the point of closure of

the stomate).[2] *Crinum asiaticum* (30.7), *Glochidion littorale* (30), *Sophora tomentosa,* (28), *Cassytha filiformis* (25), *Sideroxylon ferrugineum* (22), *Pemphis acidula* (18) and *Spinifex littoreus* (18). *Sophora* is probably the most effective as the surrounding epidermal cells overarch slightly to make a rather narrow, deep depression. Three other species have slightly depressed stomates.

Of the 22 species examined 50 per cent have sunken stomates, 41 per cent have stomates level with the epidermis and 9 per cent have raised stomates, these last being *Heritiera littoralis* and *Vitex trifolia;* the very abundant hairs probably act efficiently to prevent the rapid diffusion of the blanket of air of a high humidity immediately surrounding the stomates, hence the raised stomates do not lose water readily.

A hypodermal tissue is present in a number of the species examined. It varies from one to several cells in thickness and may or may not be accompanied by water storage cells. If the sub-epidermal cells free of chloroplastids are thick-walled I have considered them as hypodermis; while thin-walled cells free of chloroplastids I have considered as water storage cells. The hypodermal cells probably function as a strengthening tissue, as a water storage layer and also to reduce the intensity of the impinging light. *Heritiera littoralis, Vitex trifolia* and *Glochidion littorale* have well developed hypodermal layers, while *Xylocarpus moluccensis* has a single thick-walled hypodermal layer, below which is a layer of thin-walled water storage cells.

The abundance of water storage tissue is a striking characteristic

[2] The method here used of indicating the amount of stomatal depression by the number of microns from the general level of the epidermis to the point of closure of the guard cells means that each stomate, even though its outer edge is level with the epidermis or slightly raised, will have its point of closure several microns below the level of the epidermis. This figure varies from 5 microns to 15 microns (average 8.6 microns) for the 10 species whose stomates are level with the epidermis; that is, the outer wall of whose guard cells is level with the general level of the outer edge of the epidermis.

Of even greater importance in retarding transpiration than mere depression of a stomate in a shallow pit, is the length, diameter and tortuousness of the stomatal pore and the kind of vestibular chambers it has. These points can best be noted from the illustrations in Plates II. to VI. Thus the stomates of *Calophyllum inophyllum* (Plate IV.; 15a) are probably more effective in restricting transpiration that those of *Allmania albida* (Plate II.; 3a).

of the species examined. As the leaves become older they increase in thickness and much of this increase is due to an increase in the amount of water storage tissue, as in *Sesuvium portulacastrum.* In some cases, as *Pemphis acidula,* the cells which were chlorophyll-bearing cells in the young leaf become enlarged, the chloroplastids become attenuated or disappear entirely and the cells become wholly water storing in function. Only a few of the beach species can be called succulent. These are: *Sesuvium portulacastrum, Trianthema portulacastrum,* and *Pemphis acidula. Allmania albida* should probably be included here also, as its large chlorophyll-bearing cells are very largely water storing. Several other species have an abundance of centrally located water tissue: *Crinum asiaticum, Ipomoea pes-caprae* (sun form), *Spinifex littoreus* and *Tournefortia argentea. Wedelia biflora* and *Xylocarpus moluccensis* have water tissue below the upper epidermis while *Euphorbia atoto* has an abundance just above the lower epidermis. Most of the species enumerated above also have colorless parenchyma cells, doubtless storage in nature, around the veins. Only five out of the 22 species examined do not have any water storage tissue.

The arrangement of the chlorenchyma is indicative of the severe environmental factors under which the beach vegetation exists. Whether formed in response to the stimulus of light or some other agency, a leaf mesophyll composed entirely or largely of palisade tissue will transpire less than one made up of sponge tissue, the degree of compactness of either tissue determining the amount of transpiration. The mesophyll of the leaves of *Prosopis vidaliana* and *Vitex trifolia* are composed wholly of palisade, while *Sesuvium portulacastrum, Pemphis acidula, Ipomoea pes-caprae* (sun form) and *Tournefortia argentea* have palisade layers on both sides of the leaf with a water storage layer between. *Sophora* has a palisade above and a very imperfectly developed one below with sponge between. Six other species have a palisade-like development of the cells of the lowest sponge layer. *Trianthema portulacastrum* has a festoon of palisade cells around each vein, so characteristic of succulents, while the chlorenchyma of *Spinifex littoreus* is like a very compact sponge.

Mucilage cells are found in the epidermis and mesophyll tissue

of *Pemphis acidula*, the cortical cells of *Cassytha filiformis*, the mesophyll cells of *Hernandia ovigera;* while in *Thespesia populnea* slime cells are found. *Latex tubes* are found in *Euphorbia atoto.*

Stone cells are infrequently encountered in the leaves studied. *Prosopis* has many spool-shaped stone cells while *Scaevola* has scattering branched stone cells in the mesophyll.

Stereome tissue is developed in a number of the leaves as a mass of cells just above and below the veins or extending in a narrow band from the veins to the upper and lower epidermis. Whatever the function of the stereome, it is a significant fact that the leaves that contain it in the most highly developed form are from the beach tree species which show the greatest xerophytism in their structure. *Prosopis vidaliana, Heritiera littoralis, Xylocarpus moluccensis, Calophyllum inophyllum* and *Sideroxylon ferrugineum* show well developed stereome and *Vitex trifolia, Sophora tomentosa, Thespesia populnea* and *Glochidion littorale* show it poorly developed. The other species show none.

Leaf Anatomy.

The leaves of many species typical of the beach vegetation were gathered at Puerto Galera in 1924 and 1925 during April, May and June, toward the close of the period of least rain. These leaves were gathered from vigorous plants fully exposed to the environmental factors of the beach and in all cases fully mature, but not old, leaves were gathered. These were killed in medium chrome-acetic acid and were imbedded in paraffin in the usual way. They were cut and stained with safranin and light green.

The study of these sections served as the basis for the figures illustrating the structural features of the leaf. Additional information was obtained from a study of many of the leaves from fresh material. The figures represent the typical structure of the leaves in cross-section and are drawn to a scale of 110 with the exception of *Sesuvium* (× 47), *Cassytha*, cross-section of stem (× 66), *Pemphis* (× 66) and *Vitex* (× 266). The stomates are all drawn to a scale of 335 and the structural details are usually drawn to a scale of 110. The species are arranged according to their taxonomic sequence.

The detailed anatomical features of each species examined are discussed below.

TABLE I. SUMMARY OF THE STRUCTURAL FEATURES OF THE LEAF
(+ indicates presence of a character; ± indicates its imperfect development)

Species	Leaf			Hairs			Upper epidermis			Palisade						Sponge				Water storage tissue					Stomates			Lower epidermis		Inclusions			
	Relatively thick above 350μ	Succulent	Leathery	Upper surface only	Lower surface only	Both surfaces	Outer wall plus cuticle thick	Thick	Hypodermis	All of leaf	Both surfaces	Upper surface only	None	Compact	Loose	Middle of leaf or lower surface only	None	Compact	Loose	Below upper epidermis	Middle of leaf	Around veins	Thru the leaf at veins	Above lower epidermis	Sunken	Level	Raised	Heavily cutinized	Thick	Crystals	Latex	Mucilage cells	Stone cells
1 Spinifex littoreus	+	−	−	−	−	−	+	−	−	+	−	−	−	+	−	−	+	−	−	+	−	−	−	−	+	−	−	+	−	−	−	−	−
2 Crinum asiaticum	+	−	−	−	−	−	+	+	−	−	−	+	−	+	+	+	−	−	+	−	+	+	−	−	+	−	−	+	+	−	−	−	−
3 Allmania albida	+	+	−	−	−	−	−	+	−	−	−	+	−	+	+	+	−	−	+	−	−	−	−	−	−	+	−	−	−	−	−	−	−
4 Trianthema portulacastrum	+	+	−	−	−	−	−	+	−	+	−	−	−	+	−	−	+	−	−	+	−	−	−	+	−	+	−	−	−	−	−	−	−
5 Sesuvium portulacastrum	+	+	−	−	−	−	+	−	−	−	+	−	−	+	−	−	+	−	−	−	+	+	−	−	−	+	−	−	−	+	−	−	−
6 Hernandia ovigera	−	−	+	−	−	−	+	+	−	−	±	+	−	+	+	+	−	−	+	−	−	−	−	−	+	−	−	−	−	−	−	+	−
7 Prosopis vidaliana	−	−	−	−	−	−	−	−	−	+	−	−	−	+	−	−	+	−	−	−	−	+	−	−	+	−	−	−	−	−	−	−	+
8 Sophora tomentosa	−	−	−	−	−	+	+	+	−	−	+	−	−	+	+	+	−	−	+	−	−	−	+	−	+	−	−	+	−	−	−	−	−
9 Xylocarpus moluccensis	−	−	+	−	−	−	+	−	+	−	−	+	−	+	−	+	−	+	−	+	−	−	−	−	−	+	−	+	−	−	−	−	−
10 Euphorbia atoto	−	−	−	−	−	−	−	−	−	+	−	−	−	+	−	−	+	−	−	−	−	−	−	+	+	−	−	−	−	−	+	−	−
11 Glochidion littorale	−	−	+	−	−	−	+	−	+	−	±	+	−	+	−	+	−	+	−	−	−	−	−	−	+	−	−	+	−	+	−	−	−
12 Thespesia populnea	−	−	+	−	−	−	+	+	−	−	±	+	−	+	+	+	−	−	+	−	−	−	−	−	+	−	−	−	−	+	−	+	−
13 Heritiera littorale	−	−	+	−	+	−	−	−	+	−	−	+	−	+	+	+	−	−	+	−	−	−	−	−	−	−	+	−	−	−	−	−	−
14 Calophyllum inophyllum	−	−	+	−	−	−	+	−	−	−	±	+	−	+	+	+	−	−	+	−	−	−	−	−	−	+	−	+	−	−	−	−	−
15 Pemphis acidula	+	+	−	−	−	+	−	+	−	−	+	−	−	+	−	−	+	−	−	−	+	+	−	−	+	−	−	−	−	+	−	+	−
16 Siderosylon ferrugineum	−	−	+	−	+	−	+	−	−	−	±	+	−	+	+	+	−	−	+	−	−	−	−	−	+	−	−	+	−	−	−	−	−
17 Ipomoea pes-caprae (sun)	+	−	−	−	−	−	−	−	−	−	+	−	−	+	−	−	+	−	−	−	+	+	−	−	−	+	−	−	−	−	−	−	−
17 Ipomoea pes-caprae (shade)	−	−	−	−	−	−	−	−	−	−	+	−	−	+	+	+	−	−	+	−	−	+	−	−	−	+	−	−	−	−	−	−	−
18 Tournefortia argentea	+	−	−	−	−	+	−	−	−	−	+	−	−	+	−	−	+	−	−	−	+	+	+	−	−	+	±	−	−	−	−	−	−
19 Vitex trifolia	−	−	−	−	+	−	+	−	+	+	−	−	−	+	−	−	+	−	−	−	−	+	+	−	−	−	+	−	−	−	−	−	−
20 Scaevola frutescens	+	+	−	−	−	−	+	+	−	−	−	+	−	+	−	+	−	+	−	−	−	+	−	−	−	+	−	+	−	−	−	−	+
21 Wedelia biflora	+	−	−	−	−	−	−	−	−	−	±	+	−	−	+	+	−	−	+	+	−	+	+	−	−	+	−	−	−	−	−	−	−
Total number	10	5	7	0	3	3	12	8	4	5	12	11	0	21	5	13	9	3	10	4	5	10	4	2	10	10	3	8	1	4	1	3	2
Per cent	45	22	31	0	13	13	54	36	18	22	54	50	0	96	22	100	40	13	76	18	22	76	18	9	45	45	13	36	45	18	4.5	13	9
22 Cassytha filiformis	−	−	−	−	−	−	+	−	−	All palisade						−	+	−	−	−	−	−	−	−	+	−	−	−	−	−	−	+	−

Table I summarizes the presence or the absence of those structural features which may be of importance as adaptations to the environment of the beach. One of the most outstanding features of the sandy beach plants is the great thickness of the leaves, averaging

TABLE 2. MEASUREMENTS OF THE LEAF TISSUES

(THICKNESS OF THE TISSUES EXPRESSED IN MICRONS OR IN PERCENTAGE OF TOTAL THICKNESS. MINUS DEPRESSION INDICATES STOMATES RAISED)

Species	Total thickness (microns)	Cuticle and outer epidermal wall: Upper (microns)	Cuticle and outer epidermal wall: Lower (microns)	Upper epidermis and cuticle (per cent)	Hypodermis (per cent)	Water storage cells below ep. (per cent)	Palisade (per cent)	Sponge (per cent)	Central water storage cells (per cent)	Lower sponge (per cent)	Lower palisade (per cent)	Lower water storage cells (per cent)	Lower epidermis and cuticle (per cent)	Hairs (per cent)	Stomatal depression (microns)
1. *Spinifex littoreus*	630	4.0	3.0	4.5	0	71.4	0	20.0	0	0	0	0	4.5	—	18.0
2. *Crinum asiaticum*	525	12.6	9.0	10.0	0	0	20.0	23.0	14.0	24.0	0	0	9.0	—	30.7
3. *Allmania albida*	520	3.6	3.6	14.0	0	0	20.0	56.0	0	0	0	0	10.0	—	0
4. *Trianthema portulacastrum*	400	2.0	2.0	12.5	0	18.0	34.0	0	0	0	0	22.0	13.5	—	0
5. *Sesuvium portulacastrum*	1980	5.4	3.5	1.5	0	0	15.0	0	0	0	10.0	0	1.5	—	0
6. *Hernandia ovigera*	297	5.0	5.6	10.0	0	0	44.0	32.0	0	0	6.0	0	8.0	—	12.0
7. *Prosopis vidaliana*	210	3.7	2.4	7.0	0	0	86.0	0	72.0	0	0	0	7.0	—	10.8
8. *Sophora tomentosa*	270	9.0	5.4	15.0	0	0	37.0	19.0	0	0	7.0	0	12.0	—	28.0
9. *Xylocarpus moluccensis*	335	5.5	5.0	5.5	9.0	21.5	31.0	20.0	0	0	0	0	6.0	—	0
10. *Euphorbia atoto*	320	3.5	4.0	5.5	0	0	61.0	0	0	0	0	26.0	7.5	—	12.0
11. *Glochidion littorale*	330	4.0	6.0	4.5	10.5	0	30.0	46.0	0	0	0	0	9.0	—	30.0
12. *Thespesia populnea*	285	3.8	5.4	10.5	0	0	37.0	35.0	0	0	28.0	0	4.5	—	0
13. *Heritiera littoralis*	275	3.5	3.0	7.3	12.7	0	16.4	48.0	0	0	0	0	3.6	12.0	-12.0
14. *Calophyllum inophyllum*	330	7.2	6.0	8.5	0	0	24.0	31.0	0	0	8.0	0	7.5	—	0
15. *Pemphis acidula*	1035	3.7	3.0	4.3	0	0	10.0	0	75.0	0	6.7	0	4.0	+	18.0
16. *Sideroxylon ferrugineum*	325	9.5	8.0	9.0	0	0	41.0	41.0	0	0	0	0	9.0	+	22.0
17. *Ipomoea pes-caprae* (sun)	785	3.6	3.6	3.0	0	0	19.0	0	36.8	0	38.0	0	3.2	—	0
17. *Ipomoea pes-caprae* (shade)	260	3.5	3.5	8.1	0	0	25.5	32.0	0	0	24.0	0	10.4	—	0
18. *Tournefortia argentea*	690	2.7	2.7	3.3	0	0	19.0	0	45.0	0	28.0	0	4.5	+	0
19. *Vitex trifolia*	200	7.5	2.0	8.0	13.0	0	72.5	0	0	0	0	0	6.5	+	-6.0
20. *Scaevola frutescens*	515	4.5	2.7	10.3	0	0	49.0	35.5	0	0	0	0	3.2	—	0
21. *Wedelia biflora*	383	2.3	1.8	5.3	0	14.0	44.5	31.0	0	0	0	0	5.0	—	0
Total number	22	22	22	22	4.0	4.0	21.0	14.0	5	1.0	9	2.0	22.0	—	10.0
Average	495	4.9	3.5	7.6	11.3	31.2	35.0	35.4	48.5	24.0	18.5	24.0	8.18	—	20.6
22. *Cassytha filiformis*	—	6.3		—	—	—	—	—	—	—	—	—	—	—	15.0

495 microns in the 21 species studied and running up to almost two millimeters in some species. Another feature is the large amount of water storage tissue. Eighty per cent of the beach species I have examined have some form of water storage tissue while Harshberger (15) lists but 20 per cent of his New Jersey sand-strand species as succulent and 50 per cent of his salt marsh species. Kearney (18) finds but 54 per cent of his sand-strand species from Ocracoke Island containing water tissue and 44 per cent of his salt marsh species. If

those species typical of the mangrove were included in my calculations the number containing water storage cells would amount to over 90 per cent.

TABLE 3. NUMBER OF STOMATES PER SQUARE M.M.

Species	Upper Surface	Lower Surface	Total
Heritiera littoralis	0	448	448
Hernandia ovigera	0	383	383
Scaevola frutescens	0	324	324
Vitex trifolia	0	260	260
Sideroxylon ferrugineum	0	225	225
Xylocarpus moluccensis	0	200	200
Thespesia populnea	0	188	188
Glochidion littorale	0	185	185
Calophyllum inophyllum	0	156	156
Sophora tomentosa	0	102	102
Spinifex littoreus	0	102	102
Wedelia biflora	9	332	341
Crinum asiaticum	14	69	83
Allmania albida	73	118	191
Ipomoea pes-caprae (sun)	127	123	250
Ipomoea pes-caprae (shade)	97	98	195
Pemphis acidula	48	46	94
Trianthema portulacastrum	99	83	182
Prosopis vidaliana	170	108	278
Tournefortia argentea	40	23	63
Sesuvium portulacastrum	60	35	95
Euphorbia atoto	223	45	268
Cassytha filiformis	---	---	81
MANGROVE SWAMP SPECIES			
Rhizophora candelaria	0	97	97
Scychyphora hydrophyllacea	0	102	102
Agiceras sp.	0	105	105
Rhizophora mucronata	0	123	123
Sonneratia caseolaris	87	62	149

Table 2 indicates the total thickness of the leaf expressed in microns and the thickness of the tissues of the leaf expressed in percentage of the total leaf thickness. Wherever the thickness of the outer epidermal wall is spoken of, the outer epidermal wall plus the

cuticle is referred to, unless only the cuticle is specifically mentioned. In referring to the degree of elevation or depression of the stomates I have measured from the point of closure of the guard cells to the general level of the outer surface of the epidermal cells. This seemed more logical than measuring only to the outside of the outer cuticular ridge, as this often closes very imperfectly or not at all.

Table 3 arranges the leaves in the order of the abundance of their stomates per square millimeter, a few typical mangrove species being included for comparison with sandy beach species.

Spinifex littoreus (Plate I., Fig. 1; Plate II., Figs. 1, *1a*, *1b*).

This very widely distributed grass is found on the sandy beach from near the water's edge to far back upon the beach. It prefers beaches of fine sand and in such habitats it sends its characteristic runners in all directions, taking root and producing masses of spear-like leaves. It forms dense masses wherever it is found, and it is usually associated with various beach sedges and grasses as well as with *Ipomoea* and *Canavalia*.

Its erect leaves are stiff and sharp, in cross-section forming a broad U- or sharp V-shape, very thick at the midrib and tapering toward both edges. The entire upper (ventral) part of the leaf is a mass of *water storage cells* protected by an *epidermis* of fairly large cells, the outer walls of which are cutinized but the lateral and inner walls of which are thin and of cellulose. The *chlorenchyma* tissue forms a band of uniform thickness just inside the *lower* (*dorsal*) *epidermis*, hence the water storage tissue is most abundant at the midrib and tapers to nothing at the edges. The *veins* (large and small alternating) are all arranged near the lower epidermis and are imbedded in the chlorenchyma. The *parenchyma sheath* surrounding the bundles is thicker walled than are the chlorenchyma cells but contains chloroplastids, chiefly on the side next to the chlorenchyma. The *mestome sheath* is imperfectly developed and its walls are only moderately thick. *Xylem* and *phloem* cells are well developed and additional *stereome* cells are found above and below the xylem and phloem. The *lower epidermal cells*, especially the outer wall but also the lateral and inner walls, are heavily cutinized. Opposite the larger bundles the epidermal cells are much smaller than elsewhere,

and abutting on these smaller cells is the *sub-epidermal stereome*, made up of varying number of thick walled cells which extend to the parenchyma sheath of the vein. The *stomates* are located almost entirely on the lower surface (102 per square millimeter), but a few are found on the upper surface near the edge of the leaf. They are sunken (18 microns) below the general level of the epidermis. They are of the characteristic grass type, the guard cells being very thick-walled, the lumen having almost disappeared. The subsidiary cells are entirely uncutinized. The edges of the leaf are also provided with stereome cells. On the upper surface near the edge are one or two masses of poorly developed *bulliform cells* though none are located near the midrib.

Crinum asiaticum (Plate II., Figs. 2, 2*a*).

This amyrillidaceous plant with its large leaves grows on the upper beach with *Scaevola*, *Wedelia*, and *Sophora*, and likewise it may be found within or at the edges of mangrove swamps, or along brackish streams. It frequents the more open type of mangrove swamp which borders brackish rivers rather than the dense mangrove swamp formed by the typical mangrove species. Its fruits are often cast up on the beach by waves. Its leaves are large, linear, and thickened to a heavy midrib full of large air chambers.

The leaf structure of specimens growing on the sandy beach shows an *upper epidermal layer* of large, even-sized cells overlaid with a heavy *cuticle* (4.5 microns) especially thickened where the lateral walls join the outer walls. A single layer of short broad *palisade* cells is followed by several layers of rather loose *sponge cells*. A varying amount of *water storage tissue* is found in the center of the leaf below which are several layers of very open *sponge cells*. The *lower epidermis* is also heavily cutinized, the cells being papillate with from one to several papillae. This gives the epidermis a very wrinkled appearance in surface view. The *stomates* are large and few in number being seventy per square millimeter on the lower surface, and fifteen per square millimeter on the upper surface. They are most abundant on either side of the veins and are few in number or almost absent from over the veins and from between the veins. (They are all placed with their long axis parallel to that of

the leaf.) The cuticle forms two very prominent horn-like projections on the outer edge of the guard cells and some cutinization is also evident in projections on the inner edges of the guard cells. The stomates are sunken (30.7 microns) below the surface. *The veins* are few in number and widely separated, the *xylem* elements being poorly developed. Each vein is surrounded by an abundance of water storge cells but there is an entire absence of *stereome* cells.

Allmania albida (Plate II., Figs. 3, 3*a*).

A prostrate plant with lanceolate, rather succulent leaves. Merrill reports it only from Mindoro in the Philippines though it is distributed along the sandy seashores of India, Ceylon to Java.

Its medium thick leaves show few xerophytic structures beyond a slight *cuticle* on the upper and the lower surfaces and a succulency which probably acts as a xerophytic adaptation. One layer of large *palisade cells* is followed by several layers of rather loosely laid *sponge*. The cells of the palisade and sponge tissues are all large with sparse chloroplastids and they probably act as *water storage cells* as well as photosynthetic cells. The lateral walls of the *upper epidermal cells* are straight while those of the *lower* epidermal cells are wavy. The *stomates* are quite large and are found both on the upper (73 per square millimeter) and the lower (118 per square millimeter) surfaces of the leaf. They are level with the epidermis. The *veins* are very small, few in number and are free of *stereome* cells.

Trianthema portulacastrum (Plate II., Figs. 4, 4*a*).

This plant grows on the upper sandy beach especially near human habitations.

It is a prostrate rosette type with small, rounded leaves.

Its leaf structure is that of a typical succulent. The *upper epidermal cells* are large, thin-walled, of angular shape and uncutinized. Below this lies one or two layers of thin-walled *water storage cells.* The *chlorenchyma* tissue is compact and palisade-like, grouped around the veins in characteristic fashion. The *veins* are very abundant, small and free of stereome elements. They are surrounded by a *parenchyma sheath* free of chloroplastids but packed with starch

grains. Below the chlorenchyma more *water storage tissue* is found extending to the *lower epidermis* which is also uncutinized. The *stomates* are found on both the upper (99 per square millimeter) and the lower (83 per square millimeter) surfaces. They are level with the epidermal cells except on the upper surface where they are very slightly sunken. Subsidiary cells, which are much smaller than the adjoining epidermal cells accompany the stomates.

Sesuvium portulacastrum (Plate II., Figs. 5, 5*a*).

This pantropic strand plant is widely distributed throughout the Philippines along sandy beaches, forming solid patches in the fine sand of the upper and the middle beach. It is usually associated with *Canavalia, Vigna,* or with some of the beach grasses. Its large oblanceolate succulent leaves are often very thick and are composed chiefly of large water storage cells.

The *upper* and *lower epidermal cells* are uncutinized, and are comparatively thin-walled (3.5 microns to 5.4 microns). The *palisade* tissue is found just within the upper and lower epidermal layers, in layers of two to three cells thick. The rest of the leaf is made up of large *water storage cells* with very small fibrovascular bundles, free of stereome cells, scattered irregularly through the water tissue. An occasional crystal is found in the water cells. The *stomates* are found on both the upper (60 per square millimeter) and the lower (35 per square millimeter) surfaces. They are large, level with the epidermis, and are characterized by small cutinized outer beaks.

Cassytha filiformis (Plate III., Figs. 6, 6*a*, 6*b*).

This interesting parasitic member of the *Lauraceae* resembles the coarser species of *Cuscuta* of the Temperate Zone. The genus is Australian, but this species is pantropic in its distribution. It is locally abundant throughout the Islands on sandy seashores, or occasionally extending inland. Growing on the middle and the upper sandy beach or along the base of the rocky headland, it forms tangled masses of yellowish or greenish stems growing over and parasitizing practically all weeds, grasses, shrubs, and trees with which it comes in contact. When growing on the exposed middle beach, where it

often fastens itself on *Wedelia*, it is yellowish in color. When growing in shaded places it takes on a green color. The leaves are small and scale-like, protecting the bud. The photosynthetic function must therefore be carried on by the stem.

In cross-section the stem structure shows a single *epidermal layer* of heavily cutinized (6.3 microns), rectangular cells. The *cortex* is composed of one or two layers of rather small, rounded cells slightly thickened at their angles, which are free of chloroplastids, inward from which are several layers of *chlorophyll-bearing cells* elongated at right angles to the epidermis, appearing much like the palisade of a leaf. The small air spaces between the chlorophyll-bearing cells communicate with the larger air spaces below the stomates. *Mucilage cells* are scattered through the cortical tissue. There is no definite *endodermis*. Groups of very heavy-walled, small-lumened *cells* occur just outside the phloem. The *phloem* cells are thin-walled and small. The *protophloem* becomes crushed and disintegrated leaving a hollow space between the phloem and the thick-walled cells. An indefinite layer of *cambium* separates the phloem from the continuous ring of *xylem* made up of large pitted vessels and of smaller elements. The *protoxylem* is visible as small strands of tissue extending into the *pith* which is often rich in stored food.

The *stomates* are peculiar in that they are arranged in definite rows with their long axis at right angles to the long axis of the stem. They are accompanied by narrow subsidiary cells. One to several rows of cells separate adjacent rows of stomates. In cross-section the stomate is deeply sunken (25 microns). A heavy cuticular ridge forms an outer vestibule in the already narrow stomatal pore. The cavity of the guard cells are rather small and a partial inner vestibule is formed by cutinized ridges on the inner edges of the guard cells. The stomates number 81 per square millimeter of the surface of the stem.

Hernandia ovigera (Plate III., Figs. 7, 7a).

This large tree forms a part of the beach forest growing on the sand of the upper beach associated with *Terminalia catappa* and *Barringtonia asiatica*. Its hard round fruits incased in a bladdery envelope are characteristic objects in the beach drift.

The regular-sized *upper epidermal cells* are moderately cutinized (5 microns) with straight lateral walls. Two layers of compact palisade cells are characterized by the presence of very abundant, large *mucilage cells* of the same length as the palisade cells. The *sponge tissue* is very open with large air spaces, the lower layer being more compact and somewhat palisade-like. The *lower epidermal cells* are papillate and slightly cutinized (3.6 microns) with straight lateral walls. The stomates are sunken 12 microns below the level of the epidermal papillae. They are confined to the lower surface numbering 383 per square millimeter. Small subsidiary cells parallel the pore which is guarded by small cuticular ridges on the outer edge. The veins are numerous and free of *stereome* cells.

Prosopis vidaliana (Plate III., Figs. 8, 8*a*).

A shrub forming dense thickets along the seashore at Puerto Galera. It is found on the upper beach and forms a part of the shrubby growth, characteristic of the area. It usually occurs in pure stands and may have grasses, or *Sesuvium*, growing under it or nearby. Its small elliptical leaflets are smooth above and below.

Both the *upper* and the *lower epidermal layers* are slightly cutinized. Practically the entire mesophyll is made up of *palisade* cells. A few cells in the middle of the leaf are shaped like sponge cells but they do not form a complete layer and are chiefly noticeable near a vein or between two closely situated veins. The entire palisade is compact. The numerous *veins* are each surrounded by a sheath of colorless parenchyma. All but the smallest veins have some *stereome* tissue usually located below the *phloem*. Spool-shaped *stone cells* are found inward from the upper and the lower epidermal layers and lying parallel with the palisade. The *stomates* are found both on the upper (170 per square millimeter) and on the lower surface (108 per square millimeter). The stomates are slightly sunken (10 microns) in a cavity formed by the uparching subsidiary cells. The guard cells and the subsidiary cells are not cutinized, though the adjoining epidermal cells are. The lateral walls of the epidermal cells are straight.

Sophora tomentosa (Plate IV., Figs. 9, 9*a*, 9*b*, 9*c*).

This widely distributed leguminous shrub is typical of the upper part of the sandy beach associated with *Scaevola, Tournefortia, Wedelia,* and others.

Its leaflets are covered with silvery *hairs* all pointing the same way. These hairs are single-celled, thick-walled, and are seated on two basal cells somewhat sunken in the upper or the lower epidermis. These hairs are most abundant on the lower surface (33 per square millimeter) but are also found on the upper surface (20 per square millimeter). The regularly shaped cells of the *upper epidermis* are heavily cutinized with straight lateral walls. The mesophyll consists of three layers of *palisade* cells, the upper layer being compact, the lower two layers being somewhat open. An open *sponge tissue* follows, while a distinct *palisade* layer occurs just inside the lower epidermis. The *lower epidermal cells* are papillate with dome-shaped projections of cutin and are heavily cutinized throughout. The *stomates* are deeply sunken (28 microns) and are further protected by the over arching dome-shaped cutinized projections of the surrounding epidermal cells. There are 102 stomates per square millimeter on the lower surface and none on the upper. The *water storage cells* are found in groups situated inward from the upper and lower epidermal layers opposite the veins and usually connecting with them. The *veins* which contain a limited amount of *stereome* tissue are surrounded by cells containing simple *crystals.*

In certain older thicker leaves examined the palisade was much thicker, the water storage tissue more abundant and reaching to the veins, while the lower epidermal cells were much more papillate in structure and the stomates more deeply sunken.

Xylocarpus moluccensis (Plate IV., Figs. 10, 10*a*).

This small tree is found scattered along the upper beach, or at the base of rocky headlands, growing in the sand or among the rocks, with its roots frequently being reached by the tides. In the Philippines it is distributed from Central Luzon to the Sulu Archipelago, and its general distribution is from India to Madagascar, throughout Malaya to Polynesia. Merrill gives its habitat as "along open beaches, not in the mangrove."

Its leathery leaves show a number of xerophytic structures. A small-celled heavily cutinized (5.5 microns) *upper epidermis* is underlaid with a large-celled thick-walled *hypodermal layer*. A single layer of large thin-walled *water storage cells* is found below the hypodermis. The mesophyll of the leaf consists of two layers of *palisade cells* and of a *sponge tissue* the upper part of which is quite compact while the lower part is loose. The *lower epidermis* is also heavily cutinized. The lateral walls of both upper and lower epidermal cells are straight and thick. The very small *stomates* are level with the epidermis and are confined to the lower surface where they number 200 per square millimeter. They do not have subsidiary cells. The veins are infrequent and all but the smallest are accompanied by *stereome* cells.

Euphorbia atoto (Plate IV., Figs. 11, 11*a*).

This spurge is a common inhabitant of the sandy beach. The widely spaced plants, growing about one foot high are not confined to any particular part of the beach. It is found growing with *Sesuvium*, *Spinifex*, *Ipomoea*, and *Canavalia*. It is widely distributed in the Philippines, and is a characteristic beach plant of the Indo-Malayan region. Its small oblong leaves are greenish-white in color due to a waxy bloom.

The *upper epidermis*, free of hairs, is made up of smaller, less heavily cutinized (3.5 microns) cells than the lower epidermis (4 microns). The *palisade* and compact *sponge tissue* are clustered around the small veins which are free of *stereome* cells. A circle of *chlorophyll free cells* surrounds each vein. These cells have large nuclei and are abundantly supplied with starch. Two or three layers of *water storage cells* are located just above the lower epidermis. This accounts for the peculiar distribution of the *stomates* on the upper surface of the leaf (225 per square millimeter) as compared to the lower surface (45 per square millimeter). The stomates are slightly (12 microns) sunken below the general level of the epidermis. Anywhere throughout the mesophyll of the leaf *latex vessels* may be found.

Glochidion littorale (Plate IV., Figs. 12, 12*a*).

This plant forms thickets on the sandy beach or more usually along the shelving banks of tidal streams which are flooded at high tide.

Its leaf structure exhibits modifications which tend to conserve the moisture supply of the plant. The *upper epidermis* is composed of small cells, usually one layer, moderately cutinized (4 microns thick) with straight, thick, lateral walls and prominent nuclei. Below this is a *hypodermal layer* of larger cells, with much thicker straight lateral walls. The *palisade* is compact and is usually composed of one layer of long narrow cells. The *sponge* makes up over half of the mesophyll of the leaf. Its upper layers are open but its lower layers, the lowermost of which is palisade-like, are very compact. *Rosette crystals* are found in the sponge cells.

The *veins* are few and small, and are accompanied by a few *stereome* cells. The *lower epidermis* is composed of small papillate cells with the top of the papillae heavily (6 microns thick) cutinized. The lateral walls are thick and straight. The *stomates* are confined to the lower surface, they number 185 per square millimeter, and the narrow pores are paralleled by small subsidiary cells. They are deeply sunken (30 microns) below the papillate epidermal cells. Neither the small guard cells nor the subsidiary cells are cutinized while the outer wall of the epidermal cell is heavily cutinized and the lateral and the inner walls are of cellulose impregnated with cutin as is shown by their staining reaction.

Thespesia populnea (Plate IV., Figs. 13, 13*a*, 13*b*).

This small tree is characteristic of the upper beach and of the forests and thickets which occur on the sandy beach.

Its firm leaves are entirely free of hairs. The *upper epidermal cells* are regular in size and the outer walls are moderately thick (3.8 microns) but heavily cutinized (2 microns). A single very compact layer of *palisade* occupies the upper part of the mesophyll below which is a much looser layer of palisade. The *sponge tissue* is fairly open with very irregularly-shaped cells the lowest layer of which is palisade-like. Large groups of *slime cells* occur sparingly in the sponge. Strands of *water storage tissue* extend from upper to lower

epidermis at the veins and surrounding them. Most of these water storage cells contain rosette *crystals*. The *veins* are numerous and small, only the larger having a few cells of *stereome* tissue. The *lower epidermis* is cutinized and is interrupted by the very slightly sunken stomates. The *stomates* are confined to the lower surface where they number 188 per square millimeter. Scattered on the lower surface are small multicellular *glands* sunken in depressions in the epidermis.

Heritiera littoralis (Plate IV., Figs. 14, 14*a*, 14*b*; Plate V., Fig. 14*c*).

This large tree, with its entire, leathery leaves, forms a very characteristic part of the vegetation at the back of the mangrove swamp or along the sandy, or rocky, beach where its roots are often bathed by sea water. It is distributed throughout the Philippines.

In cross-section the leaf has a most striking appearance. The *upper epidermis* is composed of small cells, with thick, straight lateral walls. They are moderately (3.5 microns) cutinized. Below this is an *hypodermal tissue* from one to three cells in thickness, the cells of which are thick-walled and larger than those of the epidermis. Occasionally cells of the hypodermis, just below the epidermis, may be enlarged and contain *crystals*. At the veins the *hypodermis* is wider than usual. The *palisade* tissue is one cell layer in thickness and of a compact nature. Over half of the leaf is composed of a very loose *sponge tissue* which forms an excellent system of collecting cells, one funnel-shaped cell often being attached to several palisade cells and it in turn being connected to other cells below, the whole forming a very open tissue. These cells have large nuclei and large chloroplastids. The lowest layer of sponge is somewhat more compact than the other layers and a layer of cells along the veins is also compact. The *veins* are frequent and are placed at regular intervals. Opposite each vein is a narrow band of *thick-walled cells* extending up to the hypodermis and if the vein is large, extending also to the lower epidermis. All of the veins with their abundant *stereome* tissue are very conspicuous, dividing the mesophyll of the leaf into very definite areas, the whole giving the cross-section of the leaf a strikingly characteristic appearance. The *lower epidermis* is small-celled, the cells being moderately cutinized. The *stomates* are confined to the lower

surface and are very numerous, numbering 448 per square millimeter. They are small and are raised 12 microns above the general level of the epidermis. They open close under the overlapping peltate *hairs* which form a complete cover over the under side of the leaf. These hairs are many-celled and are attached at their center by a many-celled stalk. They overlap in various ways, some being entirely below the others, some entirely above, and others partly below and partly above. A very few of these hairs may be found on the upper surface.

Calophyllum inophyllum (Plate IV., Figs. 15, 15a).

A large tree found on the upper beach, forming a part of the beach forest and of the narrow fringe of trees characteristic of the upper part of the sandy beach. It is widely distributed throughout the Philippines and is a characteristic strand tree of the Indo-Malayan region. Its elliptical leaves are shiny and of a leathery texture.

The cells of both the *upper* and the *lower epidermis* have very wavy lateral walls and some of the cells are divided by from one to three cross walls. These wavy lateral walls cause the irregular size and shape of the epidermal cells, as seen in the cross-section of the leaf. Both the upper and lower epidermal cells are heavily cutinized (7.2 and 6.0 microns). Two and sometimes three layers of *palisade* cells of a compact nature underlie the epidermis while the lower part of the leaf is made up of a very loose *sponge tissue* the lower layer of which is palisade-like. This tree often extends branches out over the water in which case the leaves receive considerable additional light reflected from below. There are no *stomates* on the upper surface and they number 156 per square millimeter on the lower surface. The stomates are large, level with the epidermis, and have characteristic large subsidiary cells paralleling the stomatal pore. The guard cells have very prominent cuticular ridges on the outer edge while the lumen of the guard cell itself is very small. The subsidiary cells extend below the guard cells and below the epidermal cells. They appear to be filled with a brown substance of a homogeneous nature. The *veins* are few in number and most of them are large. The smaller ones are free of *stereome cells* but the larger ones are accompanied by heavy walled cells extending in a band three to four

cells wide from the upper to the lower epidermis. The margins of the leaf are heavily reinforced with stereome tissue.

Pemphis acidula (Plate V., Figs. 16, 16*a*, 16*b*).

This gray-leaved shrub is found both on rocky cliffs fronting the sea, and more frequently on the sandy beach, associated with *Scaevola, Sophora, Tournefortia* and *Wedelia*. It is occasionally found on low cliffs and rocky beaches close to the water's edge, clinging to the rocky substratum and yet apparently able to thrive. Its small elliptical leaves are gray from a hairy covering.

In cross-section both the *upper* and the *lower epidermal layers* show some cells which have divided into two or even three cells by horizontal walls. Usually in such cases the inner cell contains *mucilage*. These inner cells often protrude into the palisade. The outer walls of the epidermal cells are only slightly cutinized (3.7 microns) while the lateral and the inner walls are straight, thin, and of cellulose. Below the upper epidermis is a layer of compact *palisade* tissue from one to three cells thick. A similar but somewhat narrower layer of palisade occurs just above the lower epidermis. These palisade cells stain very deeply while in unstained paraffin sections they are brown, due, according to Areshcoug (1), to the brown liquid contents. The middle of the leaf is taken up chiefly with large thin-walled *water storage cells*, the upper and lower layers of which are palisade-like, the middle layers sponge-like in shape, though much larger in size. I have examined young leaves and found these water storage cells to contain a limited number of small chloroplastids which disappear as the leaf becomes older and acts more and more as a water storage leaf. This agrees with the findings of Areschoug. Scattered through this water storage tissue are groups of cells which stain deeply and are probably *mucilage- or tannin-containing cells*. Other groups of very small cells contain rosette *crystals* of calcium oxalate. Scattered over the upper (30 per square millimeter) and lower (22 per square millimeter) surface are straight thick-walled one-celled *hairs* sunken in the epidermis and extending almost parallel with it. They all point in the same direction, giving the leaf a silky appearance. The *stomates* are scattered in about equal numbers on the upper (48 per square millimeter) and the lower (46 per square

millimeter) surfaces. They are equally sunken (18 microns) below the epidermis on both surfaces. In cross-section the thick-walled guard cells show prominent cuticular ridges on their outer edges and a very slight ridge on the inner edge. The *veins* are few and small, located in the middle of the water tissue and are free of *stereome cells.*

Sideroxylon ferrugineum (Plate V., Figs. 17, 17*a*, 17*b*).

This large tree is commonly found scattered on the upper sandy beach or as a part of the beach forest. It is distributed throughout the Philippines and its leathery, shiny, elliptical leaves, and evil-smelling flower make it easy of identification.

In cross-section its leaves are characterized by a very thick *cuticle* (7.5 microns) overlying the rectangular *epidermal cells.* A compact *palisade tissue* composed of three layers of cells makes up half the thickness of the mesophyll. The lower layers of the palisade are shorter and somewhat less compact than the upper layer. The rest of the mesophyll is made up of an open *sponge tissue,* the lowest layer of which is palisade-like. The *lower epidermal cells* are very irregular in size, those next to the stomates being small. The lower epidermis is also very heavily cutinized though not quite as heavily as the upper. The *stomates,* which are located only on the lower surface, are small, are sunken 18 microns below the general level of the epidermis and number 225 per square millimeter. Several subsidiary cells accompany each stomate. The lower surface is protected by a covering of single-celled *hairs* which are all oriented the same way, are at different levels and overlap to some extent, thus forming a fairly complete cover. These hairs are flat and scale-like, fastened at their center to a short stalk which is deeply seated in the epidermal layer. Viewed from above these hairs are elliptical, pointed at both ends and show clearly their point of attachment. A few hairs are found on the upper surface also. The *veins* vary widely in size, are fairly abundant and are very conspicuous because of the abundance of *stereome tissue* which accompanies even the smallest veins.

Ipomoea pes-caprae (Plate V., Figs. 18, 18*a*–18*h*).

This herbaceous creeper is a very widely distributed inhabitant of the upper and middle beaches, sometimes sending its runners for many feet over the sand until its tip reaches the salt water and is killed back. It forms dense mats of vegetation and is associated with *Spinifex, Euphorbia, Canavalia, Vigna, Wedelia* and *Scaevola* as a typical pantropic strand plant. Its round leaves, notched at the tip, vary in size and thickness with age and habitat. They fold together along the midrib with their upper faces inward when heat and light are intense at midday.

Sun Form.—The old leaves, especially those growing in the sun, are very thick and fleshy, being often more than 800 microns in thickness. The *upper epidermis* is composed of regular-shaped cells with straight lateral walls and with *cuticle* which is slightly ridged, forming fine lines on surface view. The *veins* are few in number and scattered irregularly through the mesophyll. They are free of *stereome* cells. The *upper palisade* is composed of from two to three compact layers of cells. The central part of the leaf is made up of an extensive area of large-celled *water storage tissue* which may show the remains of chloroplastids, depending on the age of the leaf and the habitat in which it lived. The *lower palisade* is made up of from two to three compact layers of cells. The lower epidermis is similar to the upper.

Shade Form.—The leaves growing in the shade, are much larger and thinner, often only ⅓ the thickness of the sun form. The *epidermal cells* are quite large with straight lateral walls about the same thickness as in the sun form but less heavily cutinized. The *palisade* is formed of from two to three layers of small cells below which is a *region of more rounded cells* with very sparse, small chloroplastids. This region probably acts as a *water storage layer* and will lose its chloroplastids as the leaf becomes older. Around the larger veins these cells are entirely free of chloroplastids. The lower part of the leaf is composed of a loose sponge-like tissue but with most of the cells elongated at right angles to the leaf surface hence in reality a *palisade layer*. The *veins* are similar to the sun form.

The *stomates* are scattered about equally on both surfaces of the leaf and are accompanied by two rather large subsidiary cells arranged parallel to the pore. The sun leaves have a greater number of stomates per square millimeter than do the shade leaves, probably because the size of the leaf is smaller in the sun leaves than in the shade leaves.

	Upper	Lower	Upper	Lower
Sun	138	124	119	122
Shade	103	104	92	92

The sun leaves were obtained on the sandy beach open to direct heat and sunlight and were comparatively small and leathery. The shade leaves were growing in the shade of trees in a mixture of sand and black loam and the leaves were large and thin. The stomates are level with the epidermis on both surfaces of the sun and shade forms. They have rather prominent outer cuticular ridges.

Stomatal Closure.—A very interesting structure is noticeable in connection with the *stomates* of the sun leaf, particularly those on the upper surface. One of the subsidiary cells begins to enlarge until a vescicular swelling results, which bulges into the air chamber below the stomate and finally becomes cut off from the parent cell by a cross wall. This cell continues to proliferate until a number of cells are formed often completely filling the air chamber and crowding against the palisade cells. The central and largest of these cells has its outer wall closely pressed against the under side of the guard cells completely occluding the stomatal pore. This wall finally becomes heavily lignified even forming a slight papilla which forces its way up into the stomatal pore, effectively closing it. The rest of the cell walls remain unaltered. Haberlandt (14) reports a species of *Tradescantia* occluding its stomates by this peculiar method when grown in a drier atmosphere than usual. No occlusion of the stomates was noted in the shade form.

Sunken in depressions in the epidermis are many-celled thin-walled structures rich in protoplasm with prominent nuclei which are undoubtedly *hydathodes.* The lowest stalk cell penetrated into the palisade somewhat while the upper part is made up of many cells arranged in a rosette. These hydathodes are found in the sun form

on both the lower (11 per square millimeter) and the upper (8 per square millimeter) surfaces and are more abundant in the shade form than in the sun form.

Tournefortia argentea (Plate VI., Figs. 19, 19*a*).

A small gnarled tree with gray hairy leaves bunched at the ends of the thick twigs. It is characteristic of the upper sandy beach, being found on the outer edge of the so-called beach forest, or standing alone among the typical herbaceous beach plants such as *Ipomoea, Canavalia* and *Wedelia*. It is widely distributed throughout the Philippines and is a very characteristic strand plant of the Indo-Malayan region. The obovate leaves are supplied with *hair* on both surfaces, which gives them a grayish silky appearance. Although growing under severe conditions of exposure, the *upper* and *lower epidermal cells* are not heavily cutinized, probably because of the protection given the leaf by the unicellular unbranched hairs which arise as outgrowths of the epidermal cells.

A compact *palisade* of one or two layers lies below the upper epidermis. It is interrupted at intervals by strands of *water storage cells* which connect, chiefly opposite the veins, with the very extensive mass (5 cells thick) of large water storage cells which occupies the middle of the leaf. Below the water storage tissue are from two to three layers of loosely laid *palisade cells*. There is no sponge tissue. The *epidermal cells* are irregular in size. The *stomates* are found on both surfaces, there being 40 per square millimeter on the upper surface and 23 per square millimeter on the lower surface. They are level with the epidermis or even slightly raised. The *veins* are few in number and small, being entirely free of *stereome* cells.

Vitex trifolia (Plate VI., Figs. 20, 20*a*, 20*b*).

This shrub is found in thickets on the upper beach, chiefly in areas disturbed by man. It is widely distributed both in the Philippines and in the Indo-Malayan region. Its leaf structure, when growing in such regions, shows distinctly xerophytic structures. Its five to seven palmately compound leaflets are densely white-hairy on the under surface.

The *upper epidermal cells* are heavily cutinized (7.5 microns)

while the one or two *hypodermal layers* immediately below are also thick-walled. The mesophyll of the leaf is made up entirely of a very compact *palisade,* the deeper lying layers being somewhat less compact than the upper layers. The *water storage tissue* penetrates through the leaf at and around the veins and divides the mesophyll of the leaf into areas. The abundant but small veins have a very few *stereome* cells. The *lower epidermal cells* are uncutinized, practically all of them opposite the veins giving rise to characteristic two-celled *hairs.* The *lower epidermis* is somewhat wavy, the depressed areas between the veins being abundantly supplied with *stomates,* which are effectively protected by the overarching hairs. The stomates on the lower surface of the leaf are slightly raised (6 microns) above the level of the surrounding epidermal cells. They are confined to the lower surface where they number 260 per square millimeter.

Scaevola frutescens (Plate VI., Figs. 21, 21*a*).

This shrub with large delicate-appearing shiny leaves is widely distributed throughout the Indo-Malayan region as well as in the Philippines. It is characteristic of the upper beach, forming thickets together with *Wedelia, Pandanus, Tournefortia,* and *Quisqualis.*

The leaves are sessile, obovate, having a varnished appearance though their *cuticle* is not especially thick (1.5 microns). The prominent *upper epidermal cells* are only moderately cutinized, their outer wall being 4.5 microns thick. The *palisade* of three or four layers makes up about one-half of the mesophyll and merges gradually into the fairly compact sponge. The palisade cells are compactly arranged with only small air spaces between, but they are large, thin-walled and sparingly provided with chloroplastids. Very probably this tissue, as well as the sponge and the cells around the veins, acts in part as a *water storage tissue.* The *stomates* are small, level with the epidermis, and are confined to the lower epidermis, numbering 324 per square millimeter. The *veins* are small and infrequent, with almost no *stereome tissue* and are surrounded by a layer of parenchyma cells free of chloroplastids or containing them only on their outer sides. Large, slightly branched, irregular *stone cells* are found abundantly in the palisade and in the sponge tissue.

Wedelia biflora (Plate VI., Figs. 22, 22*a*).

Growing on the upper beach in bushy thickets or sprawling over shrubs is this widely distributed *Composite*. Occasionally it trails over the sands of the middle beach, its heart-shaped leaves when growing in such a habitat being small, thick, and rough to the touch. It is frequently found associated with *Prosopis, Scaevola* as well as with the smaller, lower growing grasses and herbs of the sandy beach.

The *upper epidermis* is made up of small cells, slightly cutinized (2.3 microns) with straight, thin lateral walls. Immediately below is a single layer of large thin-walled *water storage cells*. This water storage tissue penetrates the leaf from upper surface to lower surface at each of the numerous small *veins*. The rather open *palisade tissue* is made up of three cell layers, below which is an open *sponge tissue,* the lowest cell layer of which is somewhat palisade-like. The *lower epidermis* is thin, very lightly cutinized, with thin, wavy lateral walls. The *stomates* are small, with a narrow pore, and without subsidiary cells. They are level with the epidermis and are much more numerous (330 per square millimeter) on the lower surface than they are on the upper surface (10 per square millimeter). There is no *stereome tissue* at the veins.

Scattered on the upper surface, chiefly opposite the veins and to a lesser degree on the lower surface of the leaf, are *hairs* made up of three cells. The bulbous basal cell is imbedded in the epidermis and is thin-walled while the two terminal cells forming the hair are very thick-walled. The basal cell as well as the surrounding cells of the epidermis, which are radiately arranged around the base of the hair, are full of laminated protoplasmic contents. These surrounding epidermal cells have their outer walls heavily cutinized. It would appear from the structure and the location of these hairs that they are water absorbing hairs.

Summary.

1. An intensive study was made of a beach area at Puerto Galera, Mindoro, Philippine Islands. The vegetation and the environmental factors of this area are in general similar to those of beach areas throughout the Islands.

2. The beach may be divided into several areas based on physio-

graphic features; each area having its characteristic flora. These areas are: (1) sandy beach, (2) rocky headland, and (3) muddy flats. The first two are considered here.

3. The sandy beach is characterized by creeping herbaceous forms, such as *Spinifex littoreus* and *Ipomoea pes-caprae*, with a shrub-tree zone on the upper beach composed chiefly of *Scaevola frutescens, Tournefortia argentea, Pandanus spp.* and various trees.

4. The rocky headland flora is derived in part from the sandy beach and in part from the interior forests. There are few species particularly distinctive of the rocky headland.

5. Measurements taken show a temperature on the beach which is fairly low and uniform, when compared with similar situations in the interior of the Islands, but very high when compared with that of Temperate Zone beaches.

6. Evaporation is high and occurs on the rocky headland, the sandy beach and under the mangrove trees in the ratio of 100; 58; 33.

7. Wind movement is strong and steady, particularly on the rocky headland and increases the evaporation greatly.

8. Intense sunlight, salt spray and rapid drying out of the sand together with the above mentioned factors produce a severe environment, particularly with regard to loss of water from the plant.

9. These severe environmental conditions have affected the habit, and particularly the leaf structure, of those plants typical of the beach.

10. The leaves of the twenty two beach plants examined exhibit many xerophytic structures, the most outstanding of which are: thick leaves (45 per cent are over 350 microns thick), water storage tissue (80 per cent), sunken stomates (45 per cent) and thick cuticle.

11. These features are fully described, summarized and illustrated.

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EXPLANATION OF THE PLATES.

PLATE I.

FIG. 1. *Spinifex littoreus* on sandy beach near Puerto Galera, Mindoro, Philippine Islands.

FIG. 2. *Ipomoea pes-caprae* on shelving bank on upper sandy beach, Manila Bay, Philippine Islands.

PLATE II.

FIG. 1–1*b*. *Spinifex littoreus.*

FIG. 1. Cross-section of leaf. × 110.

FIG. 1*a*. Diagrammatic cross-section of the entire leaf. × 27.

FIG. 1*b*. Stomate. × 335.

FIG. 2–2*a*. *Crinum asiaticum.*

FIG. 2. Cross-section of leaf. × 110.

FIG. 2*a*. Stomate. × 335.

FIG. 3–3*a*. *Allmania albida.*

FIG. 3. Cross-section of leaf. × 110.

FIG. 3*a*. Stomate. × 335.

FIG. 4–4*a*. *Trianthema portulacastrum.*

FIG. 4. Cross-section of leaf. × 110.

FIG. 4*a*. Stomate. × 335.

PLATE III.

FIG. 5–5*a*. *Sesuvium portulacastrum.*

FIG. 5. Cross-section of leaf. × 47.

FIG. 5*a*. Stomate. × 335.

FIG. 6–6*b*. *Cassytha filiformis.*

FIG. 6. Surface view of epidermal cells and stomates of stem. × 110.

FIG. 6*a*. Cross-section of stem from epidermis to within the wood cylinder. × 66.

FIG. 6*b*. Stomate. × 335.

FIG. 7–7*a*. *Hernandia ovigera.*

FIG. 7. Cross-section of leaf. × 110.

FIG. 7*a*. Stomate. × 335.
FIG. 8–8*a*. *Prosopis vidaliana.*
FIG. 8. Cross-section of leaf. × 110.
FIG. 8*a*. Stomata. × 335.

PLATE IV.

FIG. 9–9*c*. *Sophora tomentosa.*
FIG. 9. Cross-section of leaf. × 110.
FIG. 9*a*. Stomate. × 335.
FIG. 9*b*. Hair from upper surface. × 110.
FIG. 9*c*. Water storage cells opposite vein. × 110.
FIG. 10–10*a*. *Xylocarpus moluccensis.*
FIG. 10. Cross-section of leaf. × 110.
FIG. 10*a*. Stomate. × 335.
FIG. 11–11*a*. *Euphorbia atoto.*
FIG. 11. Cross-section of leaf. × 110.
FIG. 11*a*. Stomate from upper surface. × 335.
FIG. 12–12*a*. *Glochidion littorale.*
FIG. 12. Cross-section of leaf. × 110.
FIG. 12*a*. Stomate. × 335.
FIG. 13–13*b*. *Thespesia populnea.*
FIG. 13. Cross-section of leaf. × 110.
FIG. 13*a*. Stomate. × 335.
FIG. 13*b*. Gland from lower surface of leaf. × 110.
FIG. 14–14*b*. *Heritiera littoralis.*
FIG. 14. Cross-section of leaf. × 110.
FIG. 14*a*. Stomate showing relation to the hairy covering on the under side of the leaf. × 335.
FIG. 14*b*. Cross-section of hair from lower surface of leaf. × 110.
FIG. 15–15*a*. *Calophyllum inophyllum.*
FIG. 15. Cross-section of leaf. × 66.
FIG. 15*a*. Stomate. × 335.

PLATE V.

FIG. 14*c*. *Heritiera littoralis*—Peltate hairs from under side of leaf as seen in surface view. × 110.
FIG. 16–16*b*. *Pemphis acidula.*
FIG. 16. Cross-section of leaf. × 66.
FIG. 16*a*. Stomate. × 335.
FIG. 16*b*. Hair. × 110.
FIG. 17–17*b*. *Sideroxylon ferrugineum.*
FIG. 17. Cross-section of leaf. × 110.
FIG. 17*a*. Stomate. × 335.
FIG. 17*b*. Hair from under side of leaf in cross-section and in surface view. × 110.
FIG. 18–18*h*. *Ipomoea pes-caprae.*

FIG. 18. Cross-section of leaf (shade form). × 110.
FIG. 18*a*. Stomate. × 335.
FIG. 18*b*. Cross-section of leaf (sun form). × 110.
FIG. 18*c*. Hydathode. × 110.
FIG. 18*d*–18*h*. Stages in the occlusion of a stomate from the upper surface of leaf. × 110.

PLATE VI.

FIG. 19–19*a*. *Tournefortia argentea.*
FIG. 19. Cross-section of leaf. × 110.
FIG. 19*a*. Stomate. × 335.
FIG. 20–20*b*. *Vitex trifolia.*
FIG. 20. Cross-section of leaf. × 266.
FIG. 20*a*. Stomate. × 335.
FIG. 20*b*. Hair. × 335.
FIG. 21–21*a*. *Scaevola frutescens.*
FIG. 21. Cross-section of leaf. × 110.
FIG. 21*a*. Stomate. × 335.
FIG. 22–22*a*. *Wedelia biflora.*
FIG. 22. Cross-section of leaf. × 110.
FIG. 22*a*. Stomate. × 335.

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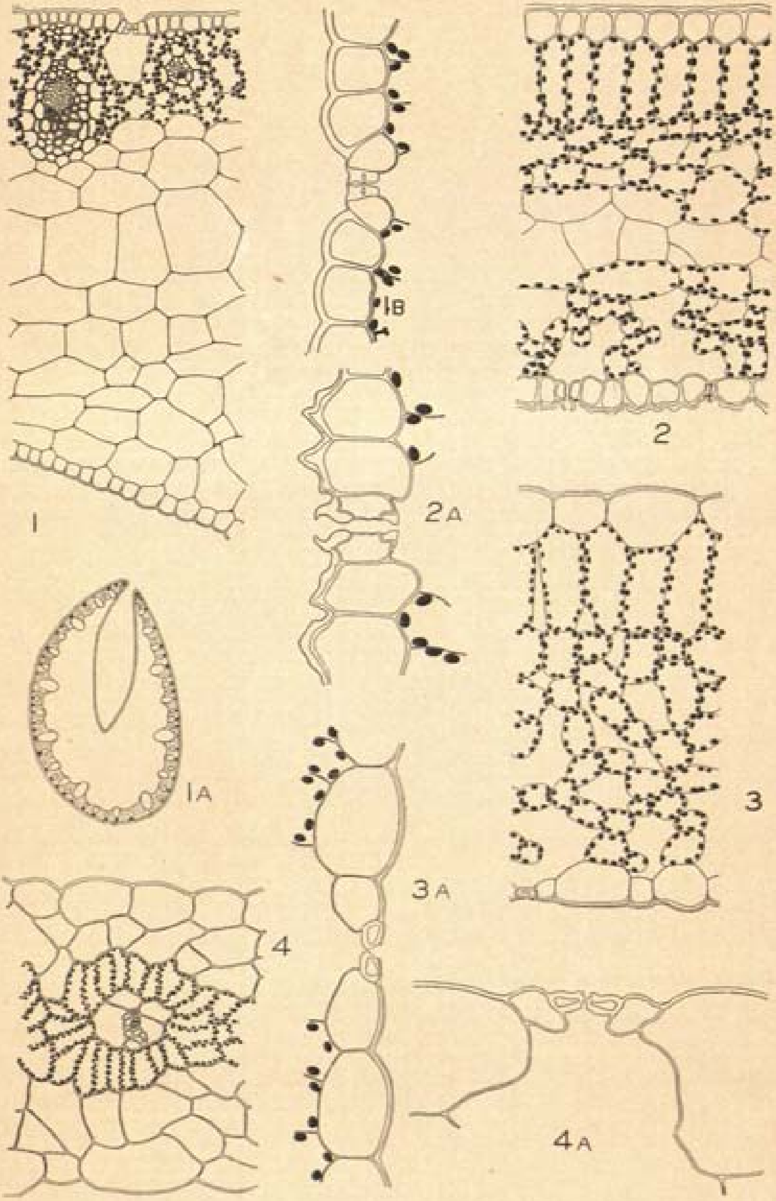
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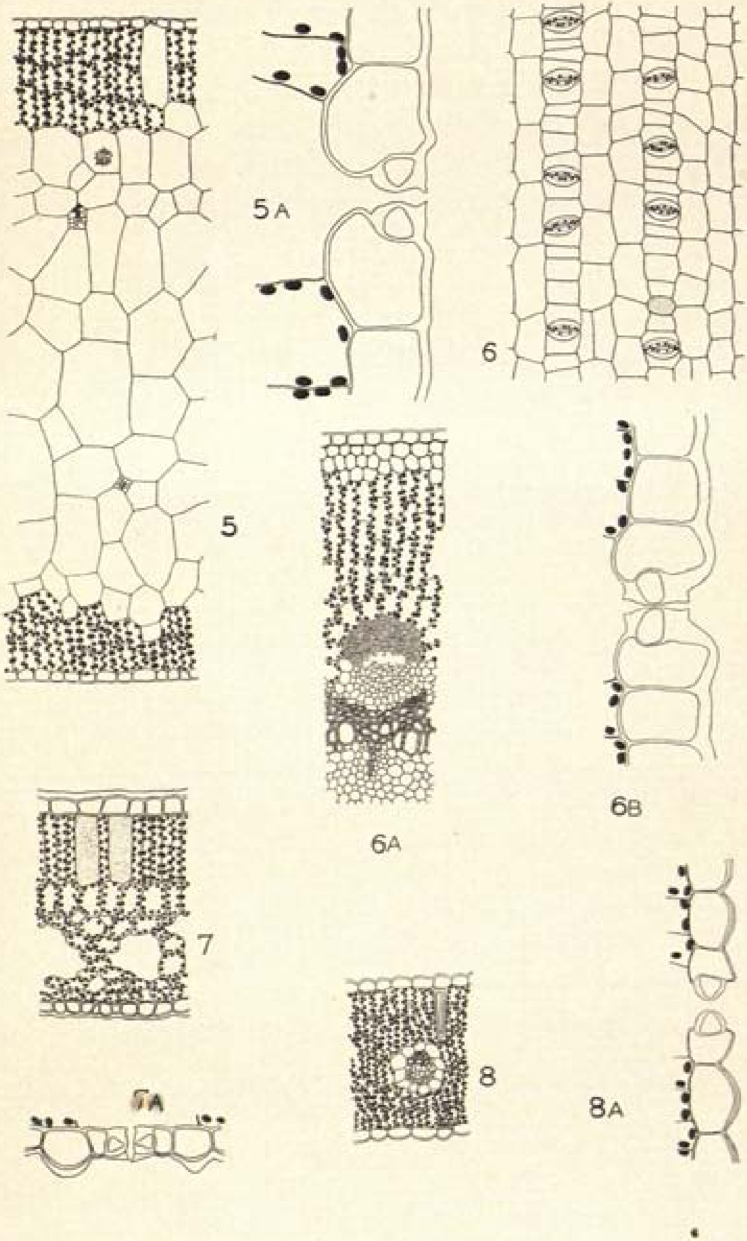
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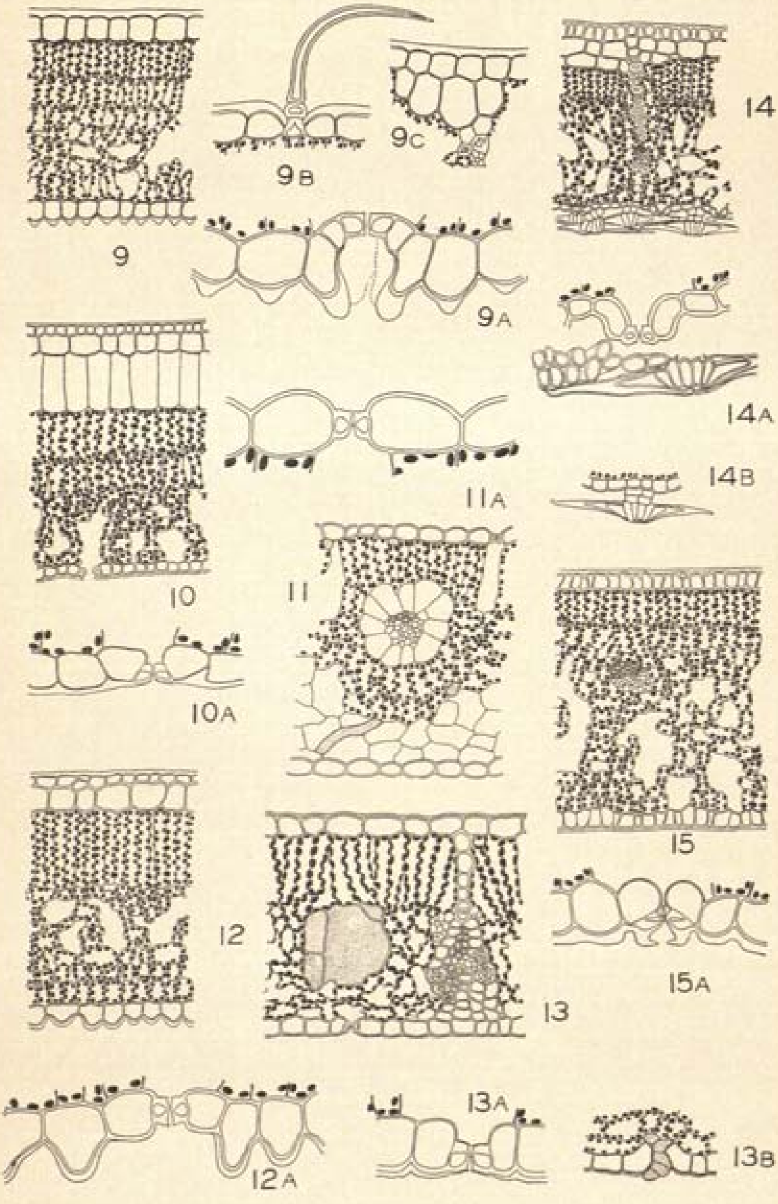
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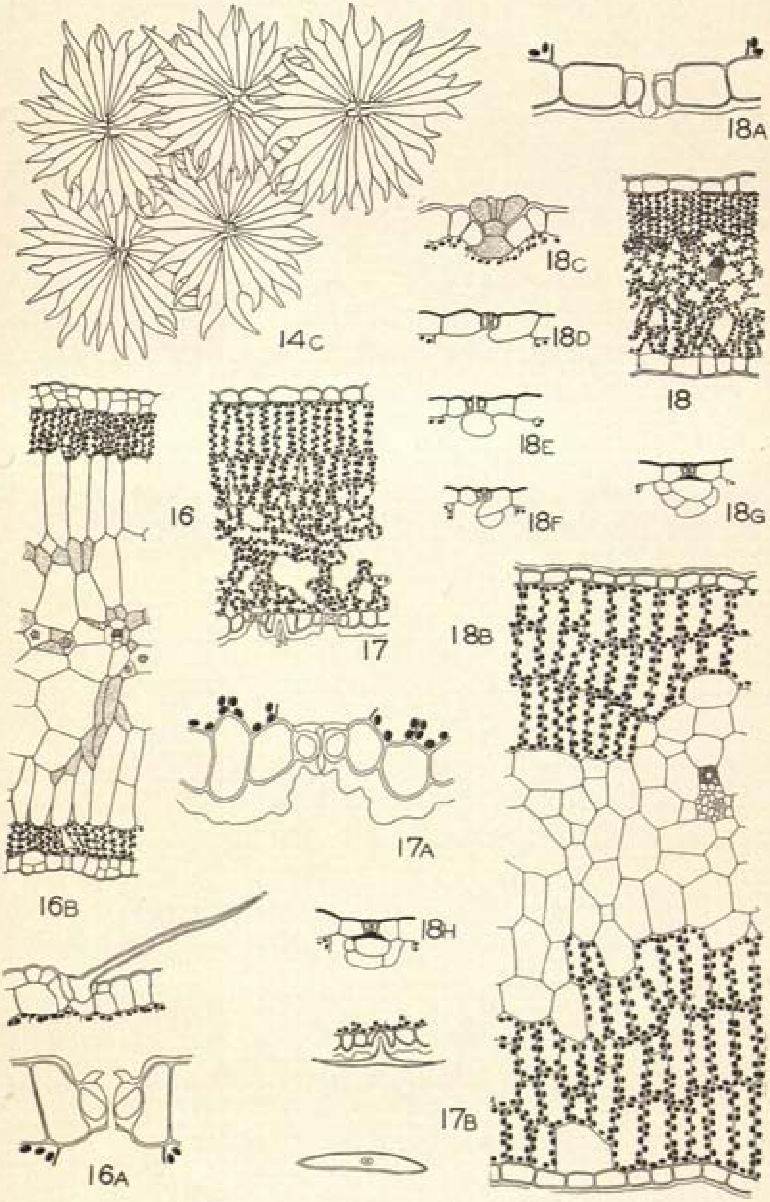
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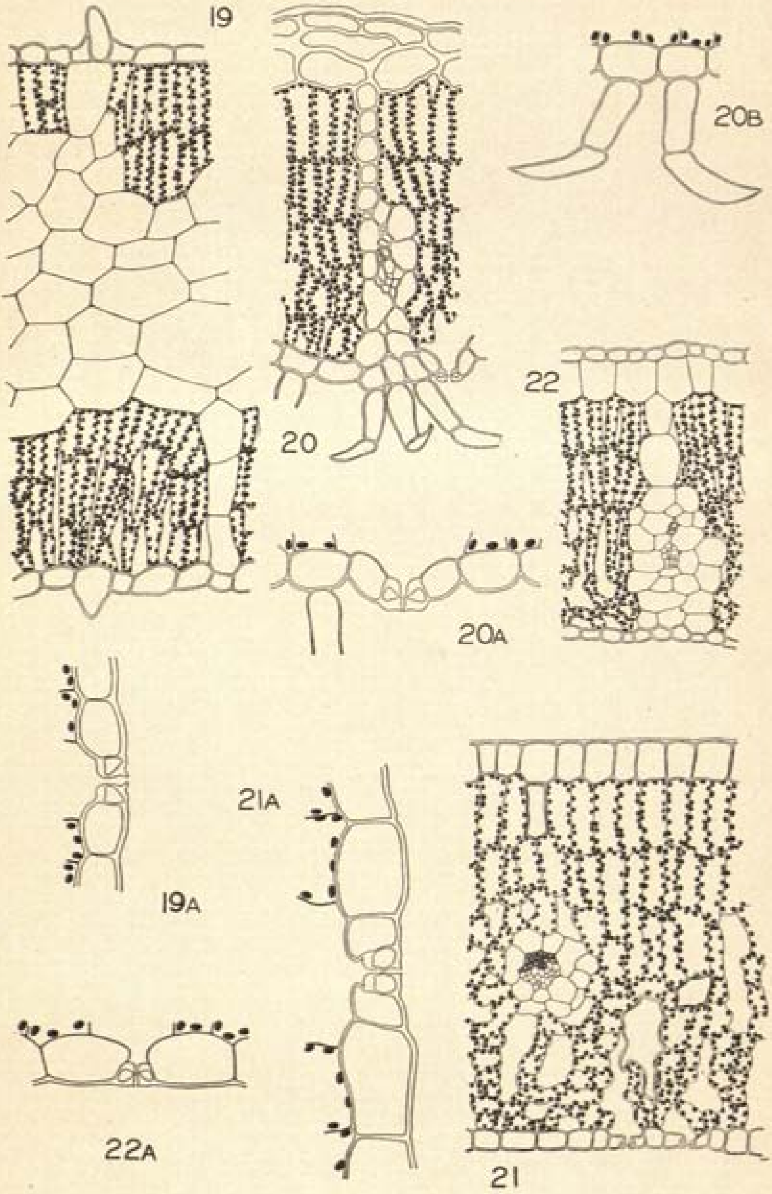
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