PHOTOGRAPHY

PLATE 1

Coating a gelatin dry plate by hand. (*p.* 34)

PHOTOGRAPHY

BY

C. E. KENNETH MEES

D.Sc., Hon. F.R.P.S.

DIRECTOR OF RESEARCH AND DEVELOPMENT
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PREFACE

PHOTOGRAPHY is both an art and a science; it is an invaluable tool to those working in the other arts and sciences, and there are few activities of civilised man in which it has no part.

There are many books on the art of photography, some of which are intended for beginners or for those to whom photography is only an amusement, while others deal in a comprehensive manner with photographic technique and its applications. This book, which had its origin in a course of lectures given last Christmas at the Royal Institution, is intended to provide a general review of the whole subject of photography written in a simple and popular style. The Christmas lectures have been given for more than a century and are intended especially for young people. By custom, the lectures consist largely of experiments and demonstrations, which have necessarily been replaced in the book by description and illustrations.

Photographic science is derived both from physics and from chemistry. The preparation of the photographic material and its treatment after exposure may be regarded as a branch of applied chemistry; the exposure and the relation of that exposure to the photographic image involves the principles of physical optics. But photography has become differentiated

from its parent sciences, and there has been developed a science of photography with a literature, a terminology, and an instrumental technique of its own. And from the laboratories which are engaged in the study of photographic science will come the future developments in the practical art of photography.

It has been my fortune to be associated rather closely with the historical development of the subject. In 1901, while a student at the university, my attention was directed to the work of Hurter and Driffield, the photographic amateurs whose investigations laid the foundation for all subsequent work on photographic sensitometry; and from that time, I have been engaged in the study of the science of photography. In 1906, I entered the field of photographic manufacture by joining the firm of Wratten & Wainwright, in which my partners were Mr. F. C. L. Wratten and his son, Mr. S. H. Wratten. F. C. L. Wratten was at first a photographic dealer; then he began to manufacture materials, especially collodion emulsion, and he was among the very first makers of gelatin dry plates. Much of the knowledge which I have of the history of that period I received directly from Mr. Wratten.

In 1912, Mr. Eastman invited me to join the Eastman Kodak Company in Rochester in charge of their research work, and there I have known and worked with the group of men who developed that great industry. So that, in spite of the fact that, if fortunate, I may yet expect to watch the development of

photography for another score of years, I have known well those who have been responsible for much of its growth in the last sixty. It was this which tempted me to include so much history in this book.

The story of photography prior to 1851 as presented is taken from the usual printed sources, but, after that date, it is an account of the development of photography as I have known it myself, or as it has been told to me by those who have taken an active part in it.

To those who are watching the contemporary scene, the development of any art or science sometimes seems to proceed at a very variable rate, halting in its progress from time to time, only to burst forth again with renewed energy. But this is probably only an impression produced in the mind of the observer. In retrospect, the progress will appear far more uniform than it seemed to be at the time. Actually, the development of photography has never come to a standstill, and every year has seen changes, large or small, which have carried the seeds of still greater changes. Thirty years ago, I found it hard to conceive that great improvements in the art of photography were possible; to-day, I am certain that still greater improvements are imminent.

Rochester, N.Y.
June 8, 1936

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CHAPTER I

HOW PHOTOGRAPHS CAME TO BE MADE

FOR centuries many people who had admired the work of artists must have felt the desire to create pictures themselves, and yet were unable to do so because they did not possess artistic talent or a knowledge of how to apply paint to a canvas in the right way. Strangely enough, however, it was not this desire for a simple way of making a picture that led to the discovery of a chemical means of letting light make its own pictures; this came very largely by accident.

The fact that silver compounds are sensitive to light, especially when in contact with organic material, must have been known to the alchemists who first prepared nitrate of silver, because, as anyone who has worked with silver nitrate knows, it is certain to get upon one's skin and to blacken rapidly when exposed to sunlight.

The first clear record we have, however, is that in 1727 a German physician named Schultze was experimenting on the treatment of chalk with nitric acid and used some nitric acid in which he had previously dissolved some silver. He noticed that when the sunlight fell on the white mixture it turned

black immediately, and following the matter up discovered that the effect was due to the silver. He filled a number of bottles with a white mixture of chalk and silver nitrate, around which he put stencils, under the open parts of which the suspension discoloured. As soon as the contents of the bottle were shaken, the impression would disappear, but Schultze was interested in the effect and recorded his experiments.

Some years later, a Swedish chemist, Scheele, exposed paper coated with a layer of silver chloride to the solar spectrum produced by a prism. He found that the part exposed to the violet end of the spectrum darkened most quickly. A very strong effect is produced by rays which are beyond the visible rays of the spectrum, but Scheele did not notice this, and it was not until twenty-four years later that the ultraviolet rays were discovered by their effect upon silver chloride paper.

Scheele's experiments were repeated by an Englishman, Dr. William Lewis, and on the death of Dr. Lewis his notebooks were bought by the famous English potter, Josiah Wedgwood, who had a delicate son, Thomas Wedgwood, who developed a liking for chemical experiments.

Josiah Wedgwood was a member of a small, private scientific society which had a number of famous members, and it is not unnatural that when he was only nineteen Thomas started to repeat Schultze's and Lewis's experiments. By 1802, Thomas Wedgwood

was making prints successfully, on paper coated with silver chloride, from paintings made upon glass. In that year he published a paper at the Royal Institution with Sir Humphry Davy, the famous chemist, who was then in charge of the laboratory of the Royal Institution and was busy with his experiments on the isolation of sodium and potassium. Wedgwood not only made prints but attempted to make photographs from nature in a camera obscura.[1] He did not succeed, but Davy was able to print upon paper the image projected by a solar microscope, provided, as he says, 'that the lens was very close to the paper,' so that the image was of small size and of maximum intensity.

The publication by Wedgwood and Davy was entitled *An Account of a Method of Copying Paintings on Glass, and Making Profiles, by the Agency of Light upon Nitrate of Silver*. This mention of profiles is a reference to one of the forms of portraiture which preceded photography. Before portrait photography was discovered, there were people who made what were called *silhouettes*, which were profile pictures cut out of black paper and stuck on to white paper. Some of these silhouettists were very clever indeed. Others who had not great ability arranged their sitters so that they got sharp shadows thrown by a lamp on to a white screen and this gave them the profile to copy.

Wedgwood and Davy's greatest problem was how to *fix* their pictures; that is, how to prevent their

[1] See p. 5.

being destroyed when exposed to light. To fix the pictures, it was necessary to find a chemical substance which would dissolve silver chloride and leave only the silver image. It is rather astonishing that Davy could not discover this, especially as common salt would have served the purpose, while ammonia would have given excellent results. The account of the experiments concludes: 'Nothing but a method of preventing the unshaded parts of the delineation from being coloured by exposure to the day is wanting, to render this process as useful as it is elegant.' This much needed method, however, remained wanting from 1802 until 1839, when Sir John Herschel pointed out to Fox Talbot that *hypo*, which the chemists call thiosulphate and which he himself had discovered in 1819, could dissolve away the unaltered chloride of silver and enable him to fix the pictures. Since that time to this, hypo has been the mainstay of the photographer, enabling him to fix his pictures after he has obtained them. Before this, however, Fox Talbot had achieved a partial fixation by the use of a concentrated solution of common salt, and a picture made by him in August, 1835, is preserved in the Science Museum, South Kensington.

As will be seen later, modern processes of photography are directly derived from the work of Wedgwood and Davy. But the processes which were first used were not based on the methods of these men; they were entirely different and are now extinct.

Two of these early photographic processes were

discovered by Niepce and Daguerre. Niepce was interested in lithography, and he desired to find a method of making lithographic printing plates by the action of light instead of drawing the picture on the stone. After much experimenting, he did this successfully. He owed his success to his discovery that asphaltum becomes insoluble after exposure to light. He coated metal plates with a thin layer of asphaltum and exposed them behind a drawing. He then removed the asphaltum from the parts which had been protected from light by the lines of the drawing and etched the metal. Niepce called this process *heliogravure*.

Niepce tried to record on his asphaltum-coated plates the images produced by a camera obscura. This camera was well known at that time and consisted of a small box with a lens on one side, which formed an image on a sheet of ground glass or translucent paper on the other side (Plate 2*a*). In the earliest type of camera obscura, a pinhole was used instead of a lens, but Robert Boyle, the great chemist, frequently employed a camera with a lens to observe natural objects. After his time, the instrument is often mentioned by scientific writers, among them Sir Isaac Newton. In the eighteenth century, the camera was often used as an aid to sketching, and it was therefore natural that Wedgwood and, later, Niepce should try to record on their light-sensitive material the images which the camera produced.

In 1822, Niepce finally succeeded in producing a

photograph of sorts, using a coating of asphaltum upon glass, but the process was quite useless for photographic purposes owing to the extreme insensitivity of the asphalt, although it was satisfactory as an engraving process and is still in use.

Niepce became acquainted with a French painter, Daguerre, who was also trying to record the images given by a camera obscura, and after making a legal agreement with him Niepce communicated his asphalt process to Daguerre, who seems to have improved it somewhat. Niepce died in 1833, and Daguerre continued his work alone although he was in commercial partnership with Niepce's son as to any results which might be obtained.

Daguerre, in his search for sensitive materials to be used in the camera obscura, had experimented in 1831 with silver plates. He treated these with iodine vapour, thus coating them with a layer of *silver iodide*. About six years later, an exposed plate which had been left in a cupboard overnight was found to have developed a visible image in the morning. This was finally found to be due to some quicksilver, the vapour of which had condensed on the exposed parts of the plate.

Niepce's exposures and those which Daguerre had been using had been of the order of hours, the only pictures which Niepce got at all in a camera obscura being apparently profiles against the sky after an exposure of twelve hours. The use of mercury for development, however, made it possible to obtain an

image with an exposure of only a few minutes, and Daguerreotypy and practical photography were born in 1839.

The results of the Daguerreotype process were extremely satisfactory from a technical point of view. The pictures were of good quality and at once interested the public in the art of photography, so that for the next fifteen years the process which Daguerre had invented was that used by photographers throughout the world. The use of silver salts carried in a coating upon glass then entirely displaced the use of silver plates, and Daguerreotypy became only of historical interest.

The modern methods of photography derive from that of Fox Talbot, an Englishman. Like Niepce and Daguerre, he became interested in photography because he was using a camera obscura as an aid to sketching, and he desired to record permanently the images shown in the camera obscura. First, he repeated the experiments of Wedgwood and Davy, apparently without knowing that he was doing so. He prepared paper coated with common salt and then brushed over it a solution of silver nitrate, which formed a layer of silver chloride. The paper so prepared was quite satisfactory for taking a photographic impression of flat objects, such as leaves, lace, etc., but exposures of even an hour in the camera obscura produced only a faint profile of objects seen against the sky. In 1835, by using alternate washings of silver and salt and exposing while the chemicals

were wet, Talbot managed to take a photograph of a
latticed window on silver chloride paper. This is
still preserved in the Science Museum, South Ken-
sington (Plate 2*b*). In 1840, he discovered that silver
iodide in the presence of weak reducing agents,[1] such
as gallic acid and silver nitrate, was far more sensitive
to light than silver chloride. More valuable still was
the discovery that it was not necessary to expose the
paper in the camera until a clear image was obtained;
an image that was barely visible could be developed
further by the application of a further quantity of the
gallic acid and silver nitrate solution. An exposure
of over an hour was no longer necessary; a picture
could be taken in half a minute.

This building up of a faint or invisible image into a
picture is now called *development*. If we expose an
ordinary film and then, after the shutter has allowed
the light to act for a fraction of a second on the
film, look at the film in red light, which will not
affect it, we shall not be able to see any change in
the film. But if we put the exposed film into a
developing solution, the invisible image, which was
produced by light and which in photographic books
is called the *latent image*, will be developed into a
negative representing the scene that was photographed
(Plate 3).

Fox Talbot was not only the first to develop a faint
or invisible image; he was also the first man to make
a negative and use it for printing. After a film has

[1] See Chapter IV, p. 73.

PLATE 2

(a) A camera obscura. Made about 150 years ago and of the type used by Wedgwood. (p. 5)
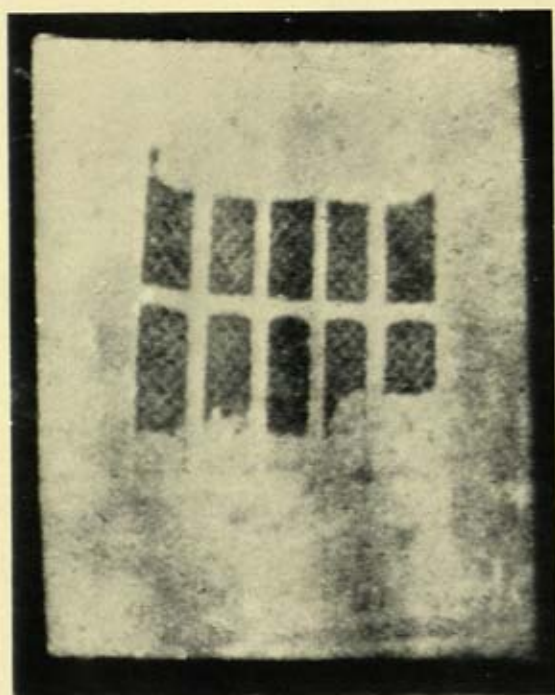
(b) Reproduction of the earliest existing paper photograph: A negative of a latticed window made by Fox Talbot in August 1835, and partially fixed by the use of a salt solution. *By courtesy of Science Museum, South Kensington.* (p. 8)

PLATE 3

A negative (*above*) and the corresponding positive (*below*). (*p.* 8)

been exposed and developed, the bright parts of the scene appear dark; the dark parts, bright. The sky, for instance, which was bright when the picture was taken, will appear very black, while any shadows in the picture will be transparent. Fox Talbot printed his negatives upon salted paper sensitised with silver nitrate, and he called the process the *Calotype* process.

Because in the Calotype process a latent image was developed to a negative and printed, this and not the Daguerreotype process must be considered the

DAGUERREOTYPE	CALOTYPE
IODISED SILVER PLATE	SILVER IODIDE PAPER
EXPOSED	EXPOSED
IMAGE DEVELOPED	DEVELOPED NEGATIVE
TO POSITIVE WITH	PRINTED ON SILVER
MERCURY	CHLORIDE PAPER

Fig. 1. The processes used in photography in 1840.

ancestor of modern photography. At this time, two photographic processes were in use: first, the Daguerreotype process, in which the sensitive material was on the surface of a silvered plate. In this process, the developed picture was not transferred to paper but remained on the plate. Second, the Calotype process, in which the negative was made on paper carrying silver iodide and the print was made on paper carrying silver chloride in the presence of an excess of silver nitrate (Fig. 1).

The next advance in photography came from the substitution of glass for paper as a carrier for the

light-sensitive material. This resulted from the work of Niepce de Saint-Victor in 1847. He coated glass with albumen and then used the albumen layer as a carrier for the silver iodide, incorporating potassium iodide in the albumen, drying the plate, and then immersing it in a silver nitrate bath. After exposure, the plate was developed with gallic acid, for which

Fig. 2.   A photographic camp in 1876, showing a photographer and his assistant carrying out their operations.

pyrogallol was later substituted. These plates were very slow but gave beautiful, transparent negatives of fine grain.

In 1851, Scott Archer replaced the albumen by collodion, and the wet collodion process which he introduced remained the standard method of making photographic negatives for more than twenty-five years.

Collodion is made by dissolving nitrated cotton, such as is now used for the film base, in a mixture of ether and alcohol. The worker of the wet collodion process had to make his own plates at the time when he wanted to take a picture. He would clean a piece of glass and coat it with collodion in which chemicals were dissolved and then put the plate in a bath of nitrate of silver, which formed silver iodide in the collodion film and made it sensitive to light. The plate had to be exposed in the camera while wet, and the developer had to be poured over it immediately after exposure. It was then fixed and dried.

In order to carry out these operations, a landscape photographer had to carry with him a folding tent which he could set up in the open air. The tent was dark except for a yellow or red window by which he might see to make the plates and develop them (Fig. 2).

Some astonishing work was done with this difficult process. On one occasion, an explorer took hundreds of sheets of plate glass up the River Nile to Khartoum in the Sudan and there made negatives 12 by 15 inches in size. Thirty years later, many of his negatives were still in existence and were very good indeed.

It was well recognised, however, that it would be an advantage if the sensitive plates could be prepared in advance and developed at home after the photographer had returned from his expedition.

The difficulty of producing a dry plate which would be practical and satisfactory is shown by the competition organised by the Marseilles Photographic

Society in 1862, when a prize of 500 francs was offered for a ready-sensitised plate which could produce a 'photograph in full sunlight of a street scene showing action and movement.'

The first efforts in this direction made use of *preservatives*, which were largely drawn from the kitchen cupboard and included such materials as honey, tea, and beer. Any hygroscopic substance, of course, would prolong the life of a wet plate by keeping it moist and preventing crystallisation of the silver, and by the use of such materials it was possible to make excursions for short distances without carrying the otherwise inevitable tent.

J. Hill Norris sensitised collodion wet plates in the usual way and dipped them in a solution of gelatin, after which the plates could be allowed to dry and, provided that sufficient exposure was given, they could be used in a dry state. Such plates were, in fact, sold and were probably the first dry plates to be sold in a prepared condition. They gave excellent results but required much skill in use and needed long exposures. Dr. Eder refers to such a plate prepared in 1872 in Vienna and exposed in September in Siberia, the exposure required being one and a half hours in sunlight. This plate was developed with pyrogallic acid and silver nitrate on the photographer's return to Vienna in December.

An important step was made by Major C. Russell, who washed the silver nitrate out of his plates, treated them with tannin, and developed them with alkaline

pyrogallol. It was the knowledge of alkaline development which eventually made the present gelatin emulsion process practicable. In 1864, Sayce and Bolton had prepared plates without the silver bath by adding both the salts and the silver nitrate to the collodion itself and thus prepared a collodion emulsion, but the low sensitivity of collodion emulsions, as of the washed and preserved collodion plates, prevented their displacing the wet collodion process, which remained master of the field until nearly 1880.

The negatives made by wet collodion had at first been printed on the salted paper formerly used for Calotype, but in 1850 Blanquart-Evrard suggested the preparation of printing paper with albumen, and this resulted in the displacement of salted paper. The albumenised paper was coated with white of egg containing sodium chloride and was sensitised by immersion in silver nitrate just before printing. The printed-out image was toned with gold, which was deposited on the silver and made the print more stable and of much better colour, and was fixed with hypo. Albumenised paper held its own until it was displaced by gelatino-silver chloride about 1890 (Fig. 3).

In 1871, Dr. R. L. Maddox started experiments to replace collodion by gelatin and prepared an emulsion which would give fairly good images. His process differed radically from that which was used later, in that, following the practice of collodion, the silver was in excess and the emulsion was unwashed; that is, the emulsion had not been set and washed in

shreds in running water in order to remove the soluble salts formed by the precipitation of the silver bromide.[1] Soon after this, however, the practice of washing emulsions was adopted, and this made it possible to dry the coating on the plate without the salts crystallising and spoiling the coating. In 1873, Burgess made

1839–1851

DAGUERREOTYPE	CALOTYPE
	SALTED PAPER

1851–1878

WET COLLODION

SILVER IODIDE HELD
IN COLLODION
DEVELOPED NEGATIVE
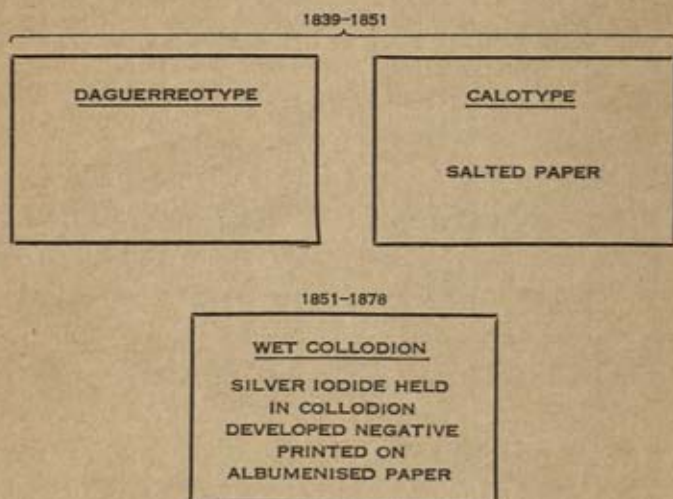PRINTED ON
ALBUMENISED PAPER

Fig. 3.   The processes used in photography from 1839 to 1878.

gelatin emulsions of which he did not disclose the formula, thus anticipating the practice of emulsion makers to this day, but he undoubtedly used soluble bromide in excess in making his emulsion since he used an alkaline developer. He sold gelatin emulsions ready for use by photographers. A curious incident of that time is due to Richard Kennett, who made a

[1] See Chapter II, p. 40.

gelatin silver bromide emulsion which he coated on glass in a thick layer and dried. This dried layer was then stripped off the plates and cut up and sold under the name of *sensitive pellicle* (Fig. 4). Kennett also sold ready-made gelatin silver bromide plates on

Fig. 4. An advertisement from the *Almanac of the British Journal of Photography* for 1875.

glass in 1874, but his plates were not very satisfactory.

Step by step, improvements were made in increasing the sensitivity of gelatin silver bromide until, in 1878, Charles Bennett showed pictures in which figures in movement were included and published his method of making an emulsion in which the silver bromide had

been *ripened* by heating in the presence of an excess of potassium bromide. With Bennett's exhibition and publication, the gelatin dry plate was born, and this marks the passing of the wet collodion process, which had held sway since 1851.

The sensitivity of a silver bromide emulsion is still obtained by ripening the silver bromide at high temperatures in the presence of an excess of bromide or by digestion[1] at lower temperatures in the presence of ammonia. The first method was that originally adopted by the majority of the English plate makers, while the second was used by the German manufacturers, nearly all of whom used the ammonia process. The sensitivity depends very much upon the gelatin, and, both in England and in Germany, the manufacturers of gelatin made special gelatins for photographic use.

The chief difference between the emulsions obtained in the early days and those made at present lies in the uniformity with which emulsions can now be made.

The first successful gelatin dry plates were put on the market by several manufacturers about the year 1877, in which year B. J. Edwards & Company and Wratten & Wainwright advertised dry plates commercially (Fig. 5), the Wratten plates being made continuously from 1877 to 1913, first in London and then in a factory at Croydon, England. These first

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[1] 'To digest,' in this chemical sense, means to maintain a fluid mixture for some length of time at a state of moderate heat.

dry plates were about ten times as sensitive as wet
collodion and gave images of great vigour and clarity,
although they were less contrasty[1] than the wet plates
which they were supplanting. Their sensitivity was
regarded as a disadvantage. Photographers were used
to the exposures required for wet plates, and they
over-exposed the new gelatin plates and then com-
plained of their quality. It was more than five years
before the photographic world accepted the gelatin

WRATTEN & WAINWRIGHT'S
LONDON GELATINO-BROMIDE DRY PLATES,
Prepared by a New and Original Method.
Prices and particulars may be had on application. *Specimen Negatives may be seen.*

SEND FOR NEW ILLUSTRATED CATALOGUE FOR 1878,
*With Notes : including Practical Hints on the Working of the Gelatino-
and Collodio-Bromide Processes to date.* Post Free, 6d.

Fig. 5. An advertisement of gelatin dry plates from the
Almanac of the British Journal of Photography for 1878.

plate as superior, except in convenience, to the
collodion process.

By 1882, the plate makers were striving to increase
the sensitivity of their product and were making plates
of a speed comparable with that of the slower negative
materials used to-day, while by 1895 a competition
in speed had started, each firm claiming that its own
plates were the fastest. Names such as 'Flashlight,'
'Lightning,' and 'Speed' were being used on the
boxes of materials (Fig. 6).

Once the manufacture of photographic materials

[1] A photographic term which is applied to images showing marked con-
trasts of tone, or to materials which tend to yield such images.

Cp

The Mawson "Celeritas" Plate

"Quick as Thought"

For X-Ray and Flashlight Work, also for Dark Studios on dull days, use our 'Lightning' Brand. The Quickest in the World.
For Transparencies our Lantern Plates are unsurpassed.

CADETT & NEALL,
ASHTEAD, SURREY.

Fig. 6. Advertisements from the *Almanac of the British Journal of Photography*. Above, back cover for 1896, and below, inside cover for 1897. Illustrating the competition in making plates of high sensitivity.

was established as a commercial industry, improvements in manufacturing methods followed in steady succession. The first great step was the invention of the plate-coating machine. Several types of machine were made, differing in their methods of conveying the plates and in their methods of applying the emulsion. B. J. Edwards and James Cadett in England built coating machines, but the machine most widely known and generally used was that designed by Dr. J. H. Smith, an Englishman living near Zurich, who not only built his own machines but supplied machines and instruction in the manufacture of photographic plates to firms throughout the world. In Smith's machine, the plates were carried on wet belts made of felt. The plates were first carried under the coater on a hot belt, from which they were transferred to a long belt chilled with ice water. Frequently, felt-covered rollers were used instead of belts. The emulsion was allowed to flow down a step weir, from the bottom of which a flap protruded which rested lightly on the surface of the plates. This system of plate coating is still among the best of those available.

For the treatment of the emulsion, steam kettles were adopted, and after the emulsion was set it was put into a hydraulic press and the jelly shredded by pressing it through a perforated plate, so that the salts could be washed out of it easily. For cutting up the finished plates, various types of cutting machines were designed.

These early photographic gelatin plates were exposed mostly in field cameras mounted on tripods, now used only for commercial photography. Cheap field cameras with simple shutters were very popular about 1900, and most photographers used such cameras on stands. Simple box cameras were also made in which the plates were held in sheaths and dropped by the motion of a lever (Fig. 7). These
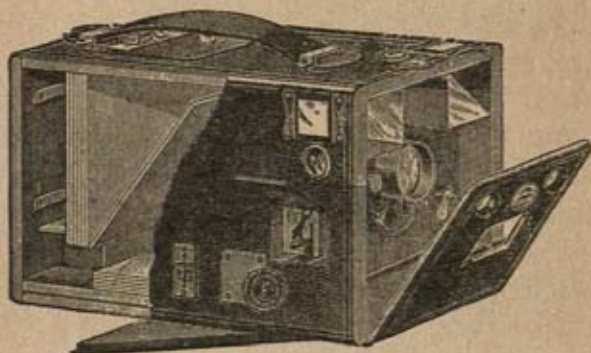
Fig. 7. Box camera holding plates in metal sheaths.

cameras played the part filled later by the box cameras for roll film and, being sold at a modest price, enabled the younger generation to start photography.

At that time, it was customary for an amateur photographer to develop and print his own pictures, usually in the family bathroom, with the aid of a lamp consisting of red parchment in which a candle was lighted.

The early dry plate negatives were printed on albumenised paper and later on gelatino-silver chloride paper. This was introduced by W. de W. Abney in

1882 and took the place of albumenised paper about 1890. This paper, known in England as *printing-out paper*, was made by preparing a gelatin emulsion of silver chloride with a free acid, such as citric acid, and an excess of silver nitrate. The printing was done by means of sunlight, and the prints were toned with a solution of sulphocyanide and gold chloride, which deposited gold on the image, after which they were fixed and washed. This paper has survived only for the making of professional proofs.

A large number of other printing processes were used at this time and, because amateur photographers did their own printing, a great deal of activity was displayed in the development of printing processes.

Collodion silver chloride paper[1] had been made even before the gelatin paper, but its use was somewhat limited by the difficulty in handling collodion solutions in coating, which required the recovery of the solvents. It gave very excellent results, however, and in the United States was much used for professional work under the name of 'Aristotype.'

Bromide paper had been made as early as dry plates. A bromide emulsion which had been washed was coated on paper. In 1874, Peter Maudsley, the founder of the Liverpool Dry Plate Company, pointed out the possibility of utilising gelatin silver bromide papers for photographic printing. In 1879, Joseph Wilson Swan undertook the manufacture of bromide printing paper on a large scale. This paper

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[1] Printing-out paper containing silver chloride in a collodion layer.

was used chiefly for enlargements and for the making of photographic prints on automatic machines in large quantities, these being used for advertising purposes and for picture postcards (Fig. 8).

Another process which required exposure to sun-

1839–1851

DAGUERREOTYPE	CALOTYPE
	SALTED PAPER

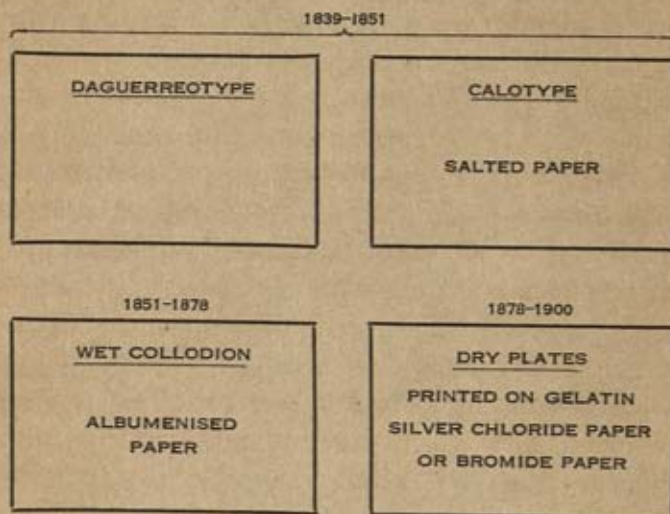| 1851–1878	1878–1900
WET COLLODION	DRY PLATES
	PRINTED ON GELATIN
ALBUMENISED	SILVER CHLORIDE PAPER
PAPER	OR BROMIDE PAPER

Fig. 8.   The processes used in photography
from 1839 to 1900.

light should be mentioned here: the carbon process, invented by J. W. Swan and depending on the insolubilisation of bichromated gelatin on exposure to light. This process gave very beautiful prints and had the advantage that any pigment could be imbedded in the gelatin so that prints could be made of any colour. Carbon prints are quite permanent, and the author possesses a carbon print of a lion's

head. It is about 24 by 20 inches in size and looks as if it had been made quite recently, the photographic gradation being excellent and the print in excellent preservation. It is, however, signed in the corner 'T. J. Dixon, 1879.' It was made on a Wratten dry plate about $2\frac{1}{2}$ by $3\frac{1}{2}$ inches in size, from which a 24-by-20-inch enlarged negative was made on a dry plate, and the carbon print was prepared from the enlarged negative (Plate 4a).

Other processes depending on the sensitivity of bichromate were the gum-bichromate process and the oil process. In the gum-bichromate process, which is still largely used for pictorial photography, a sheet of paper is coated with gum arabic containing pigment and sensitised with bichromate. After exposure, the print is developed by washing off the unexposed gum with water. In the oil process, bichromated gelatin is exposed to light and then, after swelling in water, is pigmented with printing ink, This process is of the same nature as the photo-mechanical collotype process.

A process which gave beautiful prints and for which the utmost permanency could be claimed was the *Platinotype* process invented by William Willis in 1873. This process depends upon the light sensitivity of ferric oxalate, which is reduced to ferrous oxalate on exposure to light. The paper is coated with a mixture of ferric oxalate solution and potassium chloro-platinite. After being printed in daylight, the faint buff image is developed by immersion in

potassium oxalate solution, which dissolves the ferrous oxalate formed, producing a powerful reducer which precipitates metallic platinum in the exposed parts of the image. When pure paper having good stability is used, these prints are extremely permanent, and their quality is of the very highest. The Platinotype process was used very largely from 1890 to 1910 for the reproduction of pictures in monochrome and for the making of professional portraits of the highest grade.

It is often inconvenient to make prints by daylight because it varies so much in intensity. On the other hand, bromide paper has the disadvantage that it must be worked in a very dark room. In 1894, Dr. Baekeland introduced under the name of 'Velox' a slow paper made with an unwashed emulsion of silver chloride. This was advertised as a *gaslight paper*, thus suggesting that it could be worked conveniently in ordinary rooms illuminated by the weak and yellowish gaslight of that time, and it very soon became successful. Velox and, later, chloride papers made on the same principle rapidly displaced the daylight printing processes. Dr. Eder of Vienna had suggested a chloride paper for development many years before Velox was made, but Eder's paper differed considerably from the modern type of printing papers and from the Velox paper because the emulsion was washed to remove the soluble salts, and its properties were in practice very different. At the present time, practically all contact prints are made on paper coated with unwashed chloride emulsions.

In 1880, when so many dry plate factories were starting to supply materials for the amateur and professional, George Eastman in Rochester, New York, U.S.A., started on a small scale to make dry plates. By 1884, his business was sufficiently promising for the Eastman Dry Plate and Film Company to be incorporated. This company introduced the first form of what is now the well-known film roll system of photography. The first materials for this system were made of paper; later, a transparent film base was substituted for the paper base. The paper used at the beginning was coated with a gelatin emulsion similar to that used for dry plates. Evenly coated, long, continuous strips were required, and a continuous coating machine for photographic paper was invented in 1885. The light-sensitive paper was used in a roll holder which could be attached to the back of a camera in the same position as a plate holder. The material was not entirely satisfactory because the grain of the paper was likely to be reproduced in the print made from it. It was supplanted, therefore, by what was known as a *stripping film*, consisting of a temporary paper base coated with soluble gelatin, which in turn was coated with the gelatin emulsion. After exposure and development, the film was laid face down on a sheet of glass and, when the gelatin layer had been softened with warm water, the paper support was stripped from the film negative. This stripping film, which was patented in 1884, came into general use and was applied to the first Kodak (Plate

4*b*), which was marketed in 1888. This camera was a box type with two rolls, one the supply spool and the other the wind-up roll. The pictures taken were circular and about $2\frac{1}{2}$ inches in diameter. The simplicity and convenience of this camera appealed to people who had never taken any photographs, and it created the snapshotter, since, at the time of the introduction, the Eastman Company agreed that it would do the developing and printing for the amateur as well as reload his camera, the programme being embodied in the familiar phrase, 'You press the button; we do the rest' (Fig. 9).

While the stripping film was an advance, the stripping of the picture from its paper base was a disadvantage. Experiments were continuously carried on for the production of the ideal film, and in August 1889 the first transparent film in rolls was marketed.

This film was made originally by spreading a solution of nitrocellulose on a glass table 200 feet long by 42 inches wide made up of ten glass plates, 20 feet long, joined together at their ends. When dry, the base was coated with a *substratum* of silicate of soda to make the emulsion adhere to it and then coated with gelatin emulsion. The new nitrocellulose film was transparent and grainless, and it could remain as the permanent support for the negative.

In 1891, the amateur transparent film was further improved so that it could be loaded into the camera without using a darkroom. This was accomplished
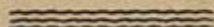
THE ✳ ✳ ✳ ✳

KODAK

✳ ✳ ✳ ✳ CAMERA.

THIS wonderful little Camera has conquered the world. Those who are at all interested in Photography who have not made themselves the owner of one of these remarkable instruments, have missed more real pleasure than they could ever imagine possible to get out of photography. It is the only Camera that is always ready and never a burden. It is exactly what we claim for it, **"a photographic note book,"** and no larger Camera can ever take its place in its especial field.

"*You Press the Button, We do the Rest.*"

It affords the simplest and easiest means for making Photographs, and can be used by novices as well as experts.

Send for a KODAK PRIMER.

THE EASTMAN DRY PLATE ℰ FILM CO.

Rochester, New York.

No. 115 Oxford St., London.

Fig. 9.   An advertisement from the *American Annual of Photography* for 1890.

by winding it on a wooden core inside a light-tight box and attaching black cloth leaders to the ends of the film. Later, it was wound inside a protective sheet of black paper with a sufficient overlength of the paper so that the camera could be loaded as it is to-day, without exposing the sensitive film itself to light.

In 1895, the first Pocket Kodak was designed. The first lot of these cameras manufactured amounted to 25,000. In 1898, a further improvement in cameras was made in that they were made collapsible. The first of these was known as the 'Folding Pocket Kodak.' In 1900, the first 'Brownie' camera intended for children was put on the market.

The development of roll-film photography produced a situation very different from that which had existed previously. Until the coming of the Kodak and Brownie cameras, the photographer had been a more or less skilled craftsman; he developed his own negatives and made his own prints and was, perforce, interested in the technical aspects of the subject. The new photographers who used the simple roll-film cameras were not troubled about the technique of photography nor were they interested in its craftsmanship; they were concerned only with getting photographs of subjects which interested them. The manufacture of film developed as an industrial operation, while the finishing of the pictures was undertaken by thousands of small establishments all over the world which developed and printed the rolls of exposed film.

PLATE 4

(a) A carbon print made in 1879. The original was a dry plate negative about $3\frac{1}{2} \times 2\frac{1}{2}$ inches in size, from which a 24×20-inch enlarged negative was made. (p. 23)
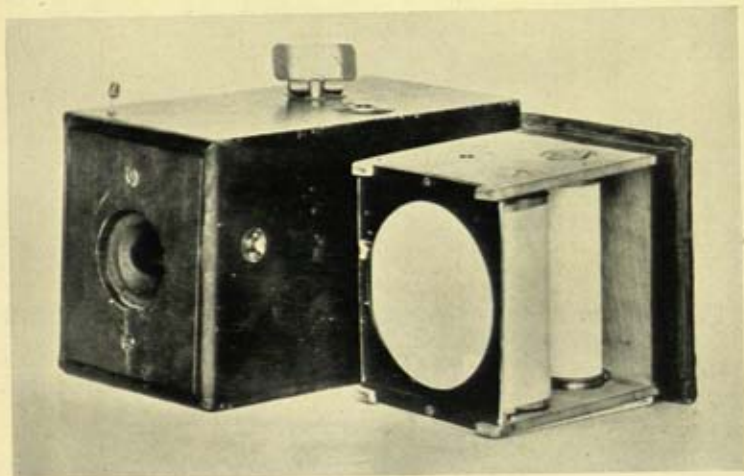
(b) First Kodak, using a long roll of negative paper, reloaded by the makers when necessary. (p. 26)

PLATE 5

(a) Centrifugal machines in which cotton is nitrated. (p. 36)

(b) Putting nitrocellulose into a mixer to be dissolved for the production of film base. (p. 37)

The professional photographer continued to use dry plates until 1912, making his prints on chloride papers. The development of photographic processes
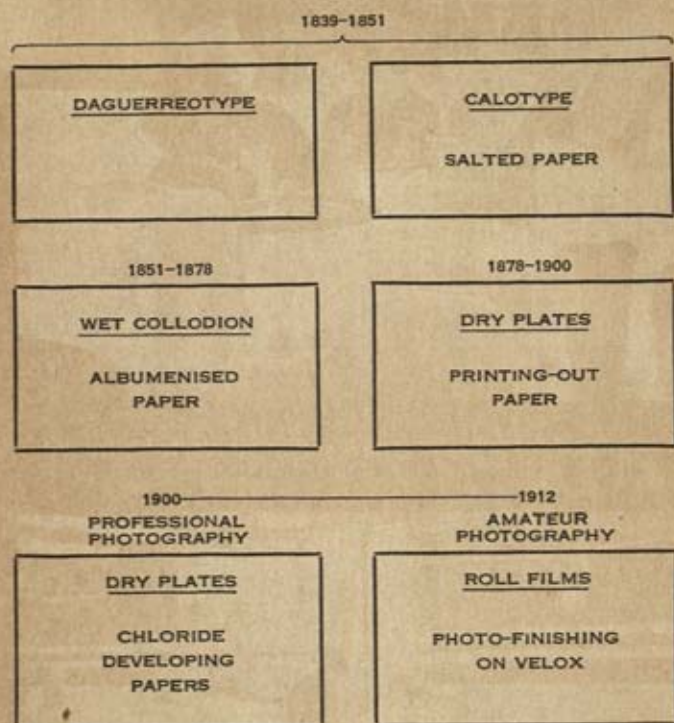

1839–1851	
DAGUERREOTYPE	CALOTYPE SALTED PAPER
1851–1878	**1878–1900**
WET COLLODION ALBUMENISED PAPER	DRY PLATES PRINTING-OUT PAPER
1900	**1912**
PROFESSIONAL PHOTOGRAPHY	AMATEUR PHOTOGRAPHY
DRY PLATES CHLORIDE DEVELOPING PAPERS	ROLL FILMS PHOTO-FINISHING ON VELOX

Fig. 10. The processes used in photography in 1839 and up to 1912.

up to 1912 may therefore be divided into two main sections: professional photography, for which dry plates were used; and amateur photography, for which roll films were employed, the finishing of the picture being done by a photo-finisher (Fig. 10).

In 1912, the Kodak Company introduced flat film in the place of glass plates for making negatives. The film offered advantages from a manufacturing .point of view and was convenient in use because it was light in weight, thin and unbreakable. These advantages were particularly manifest in the case of radiography because the film could be coated on both faces. The X-rays, passing through the film, produce fluorescence on calcium tungstate intensifying screens, which assist in shortening the exposure and make it possible to make the radiograph in much less time than is necessary with glass plates.

Early photographic materials were sensitive only to the blue-violet and ultra-violet region of the spectrum. It was not until 1873 that H. W. Vogel discovered that the addition of dyes to an emulsion made it sensitive to the spectral region which was absorbed by the dye. The preoccupation of the photographic world between 1873 and 1883 with the introduction of the gelatin process prevented this discovery being followed up very actively, but before 1900 a large number of dyes which sensitised to some extent were known. *Orthochromatic* plates, as they were called, came into general use, these being coated with emulsion sensitised by the addition of erythrosine, which confers some added sensitivity in the yellow-green. Unfortunately, the addition of dyes to an emulsion did not improve its general photographic properties. Erythrosine itself was practically harmless, but most dyes, and especially those which

sensitised the emulsion to red light, caused a great deterioration in keeping power, a tendency to fog, and some loss of sensitivity. For these reasons, colour-sensitive materials were used only where they were absolutely necessary, as in experimental work on three-colour photography, and even where they were very desirable, as in the photography of paintings, it was usual to avoid materials sensitive to the red and to use only the orthochromatic plates.

In 1904, however, the Hoechst Dye Works introduced a series of cyanine dyes which made it possible to prepare *panchromatic* materials free from fog and having a reasonably good life. Panchromatic plates were introduced first on the English market and were used chiefly by commercial photographers to obtain colour rendering and the rendering of colour contrasts. The general use of panchromatic materials remained somewhat in abeyance until 1927, at which time the general introduction of panchromatic film for motion-picture work coincided with the adoption in the studios of tungsten lamps in the place of the previous arc lamps, and panchromatic film displaced the older type of material almost entirely for motion-picture photography.

In 1931, the development of new sensitising dyes made it possible to prepare panchromatic materials of improved quality which had higher general sensitivity than the basic emulsions from which they were made. These *supersensitive* panchromatic materials are rapidly displacing the older non-colour-sensitive

1839–1851

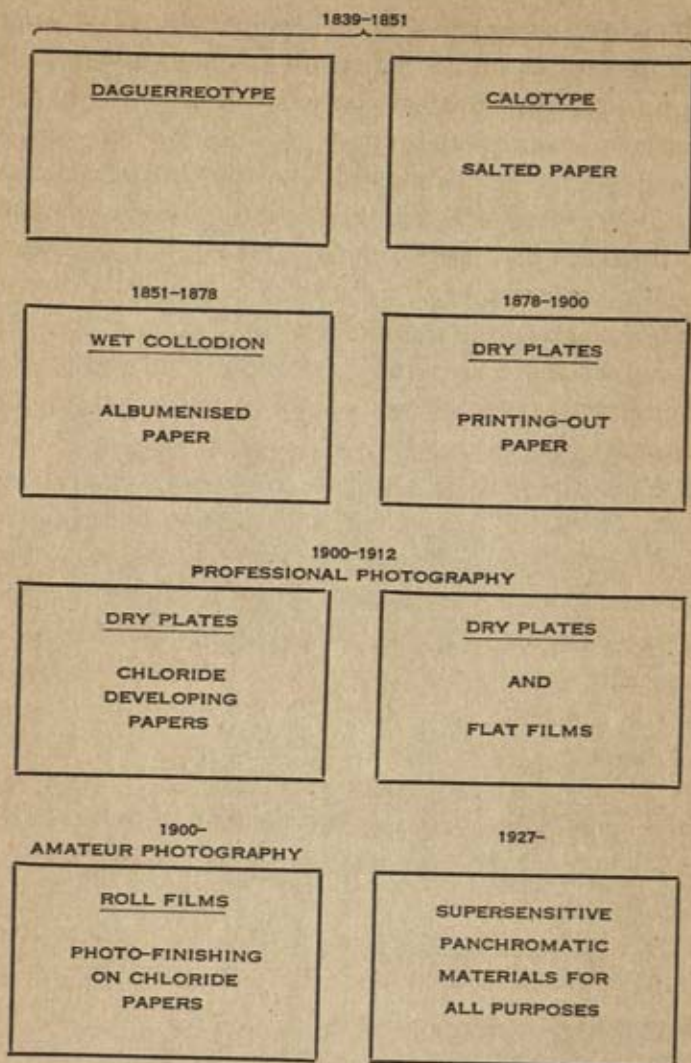| DAGUERREOTYPE	CALOTYPE
	SALTED PAPER

1851–1878	1878–1900
WET COLLODION	DRY PLATES
ALBUMENISED PAPER	PRINTING-OUT PAPER

1900–1912
PROFESSIONAL PHOTOGRAPHY

DRY PLATES	DRY PLATES
CHLORIDE DEVELOPING PAPERS	AND FLAT FILMS

1900–ㅤAMATEUR PHOTOGRAPHY	1927–
ROLL FILMS	SUPERSENSITIVE PANCHROMATIC
PHOTO-FINISHING ON CHLORIDE PAPERS	MATERIALS FOR ALL PURPOSES

Fig. 11. Chart showing processes chiefly used in photography up to the present time.

films. At the present time, practically all motion picture camera film is panchromatic, and a very large proportion of the materials used by professional photographers is now panchromatic. The only stronghold of the older type of material is in the field of amateur photography, which is in transition. There seems to be little doubt that eventually throughout the world negative materials will be of the panchromatic type. So marked has this change been that we may consider that 1927 represents the beginning of a new era in photographic history – that of the panchromatic materials (Fig. 11).

THE MANUFACTURE OF
PHOTOGRAPHIC MATERIALS

THE photographer had to make his own materials in the early days of photography. When using the wet collodion process, for instance, he cleaned his glass, coated it with collodion, and sensitised the plate by dipping it in a bath of silver nitrate, which was done in a portable darkroom. Then, after making the exposure in a camera, he developed the negative on the spot before the film had time to dry. When he wanted a print from the negative, he prepared his paper. Sometimes, he used paper which had been coated by a manufacturer with albumen; sometimes, he coated his own paper with white of egg containing the necessary salts. In any case, he sensitised the paper by floating it on a bath of silver nitrate and dried it, and then he printed the negative, washed, toned, and fixed the print, and could say with truth that he had made a photograph.

When the first gelatin emulsions were made, photographers prepared their own emulsions and coated them on glass plates, which they dried with care in a special darkroom.

Some five years after gelatin emulsions were made

experimentally, however, people began to make dry plates for sale. As a general rule, a photographer who was making a particularly excellent plate for his own purpose would start to supply some to his friends and before long would place them on the market. It was in this way that the photographic industry arose.

Until 1900, photographic manufacture was usually carried on in small factories under the direct personal control of the founder, and for a very considerable number of years small factories existed, each of them making plates or papers of a few special types.

At the present time, photographic manufacture is organised chiefly in modern factories manufacturing on a large scale and using specially designed machinery at every step of the process. In these factories, many thousands of people are employed; thousands of miles of film are made per week; millions of pounds of cotton are used each year for the manufacture of film; and silver is devoured by the ton.

A photographic factory is an interesting place to see. It is distinguished especially, perhaps, by the extreme cleanliness required. Any foreign matter that gets into the film base, paper, or emulsion during manufacture is cause for trouble to the photographer. Photographic factories have clean, tidy streets and well kept buildings that are pleasant to work in. The darkrooms, especially, although necessarily only dimly lighted, are so arranged that the work can be done without any strain on the eyes; they are not only well

ventilated but are maintained at a uniform temperature in summer and winter.

By far the greatest amount of photographic material made is in the form of film. Next, follows the sensitive paper on which prints are to be made; the glass dry plates, with which the industry started, now represent only a small proportion of the total production.

Film is made in two distinct stages. The first step is the preparation of a flexible, transparent *base*. The second is the coating of this base with an emulsion which is sensitive to light. The base is made from cotton by treating it with nitric acid or with acetic acid (Plate 5*a*). The cotton used is the form called *linters*; that is, it is the short fibre which sticks to the hull of the cotton seed after the long fibres used in making cloth have been removed.

Linters are less valuable than the long fibred cotton because they will not spin into thread, but they are still cotton and are quite suitable for making film base. The linters are washed and bleached very thoroughly, so that they form a clean white powder, which on close examination is seen to consist of tiny threads. This powder is treated with nitric and sulphuric acids, which do not change its general appearance but which turn the cotton into nitrocellulose. This is then washed free from all traces of acid and freed from water by the use of chemical dehydrating agents, because the nitrocellulose is very inflammable and cannot be dried by heating. The nitrocellulose is next dissolved in chemicals, and a

quantity of camphor is added so that it will later form a plastic, transparent sheet (Plate 5*b*). The nitrocellulose solution now forms a viscous liquid which looks something like very clear honey.

Nitrocellulose would be an almost ideal substance for making film base if it were not so inflammable. For many purposes, this does not matter; it causes no trouble, for instance, in the case of ordinary camera films, and it is quite easy to take the necessary precautions to ensure against fire in a properly designed motion-picture theatre. But when motion-picture film is to be used at home, as for amateur motion pictures, it would be very dangerous to use the highly inflammable nitrocellulose base, and all the film for 'home movies' is made on a special, slow-burning stock made from *cellulose acetate*. To make cellulose acetate, the cotton linters are treated not with nitric acid but with acetic acid, of which a very dilute solution is ordinary vinegar. The acetic acid is used in its strongest possible form, which is known to the chemists as *acetic anhydride*. The linters are treated with a solution containing acetic acid, anhydride, and some such acid as sulphuric, for a long time, during which they slowly go into solution. Then, the thick solution is poured into water, and the cellulose acetate separates and can be washed and dried. This is then used for making the film base in exactly the same way as nitrocellulose.

Cellulose acetate film is not non-inflammable, but it burns rather less rapidly than ordinary thick paper

and, as a general rule, if ignited it will go out of its own accord before it has burned far. The 'safety' film is no more dangerous in use, therefore, than if it were a roll of paper.

The machines used in making film base are large and very complicated. They are of many forms: in one form, the surface of a big cylindrical wheel is covered with polished silver. As this wheel rotates very slowly, the solution is run on to it, and, by the time it has gone through one revolution, enough of the solvents have evaporated for the film to have formed so that it can be stripped off as the wheel rotates and passed over other drums to dry (Plate 6a). The whole machine has to be enclosed, and all the drying air is passed through a recovery system to recover the solvents. The base is wound up into rolls, often more than three feet wide and some two thousand feet long, weighing 250 or 300 pounds; these rolls are then transferred to the building where they are coated with emulsion.

The second stage in film making is the coating of the base with an emulsion which is sensitive to light. The emulsion consists of silver bromide suspended in a viscous solution of gelatin.

The first step in making silver bromide is to dissolve the silver in nitric acid. After the silver has been dissolved by the acid, and the solution has been evaporated, flat, plate-like crystals of silver nitrate are left. These crystals of silver nitrate dissolve in water quite easily, but if some common salt solution

PLATE 6

(*a*) Machines making film support from the nitrocellulose
solution.   (*p.* 38)
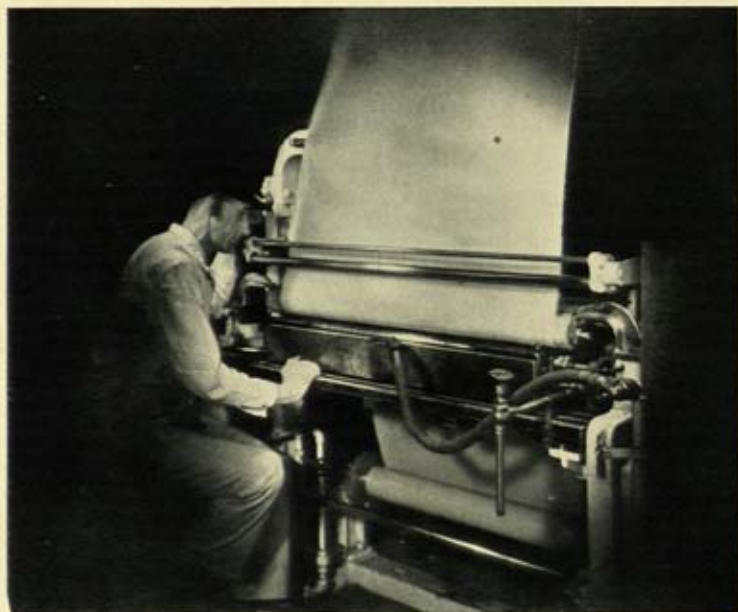
(*b*) Coating the film base with emulsion.   (*p.* 41)

PLATE 7
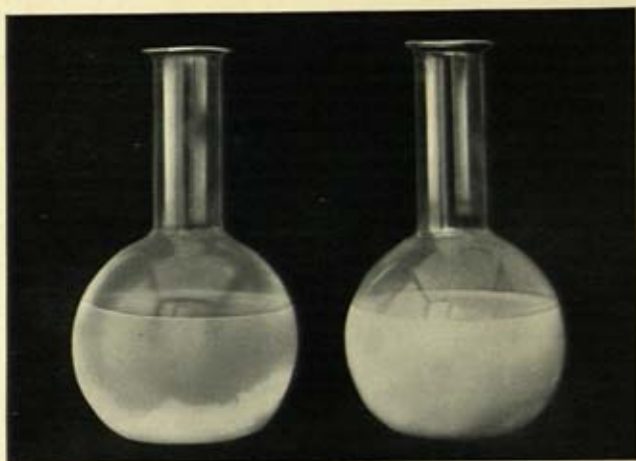
(a) Two flasks containing precipitated silver bromide. *Left*, without gelatin; *Right*, with gelatin. (p. 39)

(b) An emulsion kettle made of silver, with a copper jacket. (p. 39)

is added to the silver nitrate solution, the silver combines with one of the components of the salt, called *chlorine*, and the silver chloride that is produced is not soluble in water, so that it will be visible as a sort of white mud in the solution.

Chlorine is one of a group of elements which, because they occur in sea salt, are called *halogens*, from the Greek name for the salt sea. Two others of this group are bromine and iodine, and the silver compounds of these three elements are distinguished by their extreme insolubility in water and their sensitivity to light. Silver bromide is pale yellow in colour while silver iodide is strongly yellow.

When silver bromide is precipitated, it will settle down to the bottom of the vessel, but this may be prevented by using some gelatin, like that used for cooking (Plate 7a).

The gelatin is soaked in water, and when it is swollen it is dissolved by putting it in warm water and gently warming and shaking until all of it is dissolved. Then the right quantity of potassium bromide is dissolved in the solution. Meanwhile, the right amount of silver nitrate to act with the amount of bromide chosen has been weighed and dissolved in water. The gelatin and bromide are held at a very even temperature, usually in a water-jacketed kettle, the inside of the kettle being made of pure silver (Plate 7b). The silver nitrate solution also is held at a fixed temperature and is run in while the mixture is stirred continuously. Then the emulsion is digested for a certain time,

partly in order to allow different sizes of crystals to come into equilibrium and partly because some changes appear to occur, perhaps in the gelatin, which affect the ultimate sensitivity of the emulsion. The silver bromide is sensitive to light, so that, before adding the silver nitrate to the bromide and gelatin, all the white lights are turned out and the silver is added by the light of a photographic red lamp. All further operations are carried out in the same light until the film is packed.

Under a very high-power microscope, the silver bromide is seen to be in the form of tiny crystals. The photographic properties of the emulsion depend on the different sizes of the crystals which are produced in it. One of the important parts of the art of emulsion making, therefore, is to produce crystals of the range of sizes required for a particular emulsion. It is in this way rather than by controlling the chemical proportions of the mixture that the emulsion maker obtains the kind of emulsion that he desires and makes it time after time with uniformity.

If the emulsion made in this way were coated on glass or film and allowed to dry, its surface would be covered with crystals. These crystals consist of potassium nitrate because, when silver nitrate reacts with potassium bromide, the silver unites with the bromine to form insoluble silver bromide and the potassium and nitrate are left behind; when the emulsion dries, crystals of potassium nitrate separate out. To get rid of the potassium nitrate and any excess of potassium

bromide, the emulsion must be washed, after having first been set to a jelly. This is done by chilling it, and the set jelly, which looks exactly like the familiar blancmange, is then shredded, usually by forcing it through the holes in a metal plate at the bottom of a hydraulic press. The shredded emulsion, looking like broken-up macaroni, is washed for several hours in running water, until all the soluble salts have been washed away. Then the emulsion is melted again, and usually some fresh gelatin is added, and it is given a further digestion, during which the emulsion increases very markedly in sensitivity.

The film base is coated with emulsion by being passed under a roller which dips into a trough full of the emulsion (Plate 6b). Then the film travels through a section full of cold air, where the emulsion sets, and it is then hung up to dry, continuously moving forward as it dries until it can finally be rolled up in the dry form.

The finished film is cut up and packed in light-tight containers in the various forms in which it is used, of which one of the most common is the roll which fits into the ordinary film camera. In this form, the sensitive film is rolled up with an opaque paper, usually red or green on the outside and black inside, which protects the film from the light. In this way, the camera can be loaded in the light. The backing paper is threaded through and carries the sensitive film with it. After exposure, as the backing paper winds up, the film is wound up with it and is protected

from the light when the camera is opened and the exposed film is taken out. In order that the exposures may be properly spaced, the backing paper is printed with exposure numbers, which are visible through the red window at the back of the camera.

In addition to the roll film, film packs are made in which flat sheets of film are interleaved with black paper, so that the sheets can be exposed one at a time and the finished pack then withdrawn from the camera.

For professional work and for those amateurs who do not mind loading their cameras in a darkroom, film is supplied in flat sheets. These are carried in holders similar to those used for glass plates. At the present time, films are used very largely in professional photography because of their small bulk, lightness, and freedom from breakage. In England, however, the greater part of professional work is still carried out on glass plates, in the production of which this country has always occupied the foremost position.

Photographic plates are made by coating upon glass the same sort of emulsion as is used for film. The glass is selected from commercial window glass for flatness and freedom from flaws and, for coating, is cut into appropriate sizes, $8\frac{1}{2}$ by $6\frac{1}{2}$ inches or larger. By old tradition, a plate of this size is known as a whole plate, and the quarter plate used in small plate cameras is a quarter of this size; that is, $4\frac{1}{4}$ by $3\frac{1}{4}$ inches. Curiously enough, the so-called *half plate* is not half a whole plate; it is $6\frac{1}{2}$ by $4\frac{3}{4}$.

The glass is cleaned by passing it through revolving

brushes which scrub it with soda solution, and then it is coated with a very thin layer of gelatin or sodium silicate as a substratum to make the emulsion stick, and the glass is dried; after that it is handled very carefully to avoid all dirt. The glass is coated by carrying it under an emulsion spreader on a belt or rollers kept warm with water, and, when the emulsion has been coated on the plates, they are carried on to another belt or series of rollers where they are chilled with ice water and the emulsion sets to a jelly. Then they can be lifted off and put in racks, which are transferred to a drying room.

The emulsion on photographic plates has to be dried quite slowly and uniformly. Any interruption of the drying or a direct current of air falling upon the plates is likely to produce differences in sensitivity. As a rule, plates are allowed to dry all night, the temperature being raised after the normal drying is completed, so that the gelatin is dried out thoroughly and as little moisture as possible remains in the plates when they are packed.

When the plates come from the drying room, they are inspected carefully and rejected if the coating shows any defects. When necessary, they are cut to smaller sizes by means of a diamond, which makes a surface crack along which the plates can be broken. The plates are then boxed and sealed in such a way that they will be protected as much as possible from moisture.

The raw paper used for making photographic printing paper has to be of very good quality. It is

made either from wood or from cotton rag, specially purified and prepared by a chemical process. Care has to be taken at every stage of this process to avoid any contamination, especially from metals, which would later produce spots in the prints.

The paper is first coated with a layer of *baryta* (barium sulphate) held in gelatin. This is spread evenly over the paper and gives it a clean, white surface. It also prevents the emulsion from sinking into the paper and causing dull prints.

Two kinds of emulsions are used on photographic paper. In the case of paper used for enlargements and, to some extent, for paper used for making contact prints, the emulsion is of the same type as that used for slow plates, such as lantern slide plates; that is, it is a bromide emulsion from which the extra salt is removed by washing. This type of paper has to be used by red light and is of fairly high sensitivity. The paper normally used for making contact prints, however, and especially for the printing of ordinary film negatives, is coated with an emulsion made with chloride instead of bromide, and this is not washed at all, the nitrate produced by the precipitation not crystallising in the case of photographic papers. It does not crystallise partly because the emulsion contains much less nitrate than a negative emulsion and partly because the paper is somewhat absorbent and holds the nitrate and chloride in its fibre. The formulæ used for making chloride emulsions are often quite complex, because the properties of the paper, and especially the colour

and quality of the print, are very dependent upon the addition of small quantities of various materials in the process of making the emulsion.

Photographic paper is coated in the same way as film; that is, the paper base is coated continuously by passing it under a roller which dips into a trough of emulsion. The coated paper travels in loops down the drying room and is then taken down from the loops and rolled up (Plate 8a).

The manufacture of papers is in one way much more complicated than that of films or plates, because papers are made in a great number of grades. It is usual to make four or five grades of contrast, for instance, for a printing paper, which will be marked by some term designating the contrast, such as 'Vigorous,' 'Hard,' 'Extra Hard,' 'Soft,' or 'Extra Soft.' Also, the paper base and its baryta coating are prepared with various surfaces. The surface may be glossy or smooth or semi-matt, which is sometimes called 'Velvet,' or quite a dead matt. These different surfaces are obtained by variations in the preparation of the baryta coating and, in the case of the matt varieties, by the addition of substances such as starch to the emulsion itself. Consequently, a single type of paper may have to be made in at least four grades of contrast and in perhaps six surfaces, making twenty-four different kinds of paper. When we consider that each of these has to be stocked in a great number of sizes, it is easy to see how complex the making and keeping of a stock of photographic papers become. Perhaps the thought

of this will make a photographer a little more lenient when he finds that his dealer is out of stock of the particular grade and surface of the paper that he favours in the particular size in which he wants it !

The present manufacture of photographic materials employs about twenty thousand people in various parts of the world. The raw materials required annually may be estimated to amount to some 500 tons of pure silver, 6,000 tons of cotton for the making of film base, 3,000 tons of specially prepared gelatin, and 12,500 tons of wood pulp for the production of paper.

Photographic materials are used for many different purposes. The greatest quantity is used in the making of motion pictures, which consume about half a million miles of film a year. Amateur photographers need about 1,500 tons of film to make their snapshots and another 7,000 tons of paper to print them on; professional photographers use about 8,000 tons of film, 8,000 tons of glass plates, and 9,000 tons of paper to make portraits and advertising pictures.

In contrast to these great figures, the most important uses of photography sometimes require only a very small amount of material; in one investigation, Sir William Huggins, the great astronomer, made a single plate, 4 by 5 inches in size, last for a year, cutting it up into narrow strips each of which was exposed for several weeks ! Nevertheless, Harvard College Observatory has in its files approximately 400,000 astronomical negatives, each 8 by 10 inches, weighing about 100 tons.

PLATE 8
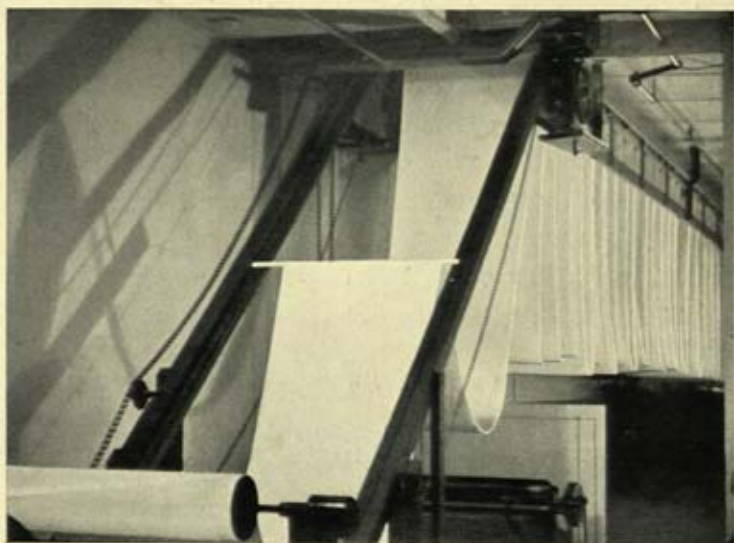
(*a*) Paper leaving the coating machine and forming loops for drying. (*p*. 45)

(*b*) A professional photographic studio. *By courtesy of Mr. George Bushell, Henley-on-Thames.* (*p*. 47)

PLATE 9

An original and a retouched photograph. *Left*, enlargement from original photograph; *Right*, enlargement showing details of retouching. (*p.* 47)

CHAPTER III

MODERN PHOTOGRAPHIC PRACTICE

MODERN photographic practice differs somewhat according to the type of work which is being done – professional photography, serious pictorial or record photography, or snapshotting for amusement.

The professional works in a studio, which is provided with electric lighting equipment (Plate 8*b*). His camera is of a heavy type, mounted on a stand which can be moved about on rollers and adjusted to any position. He makes his negatives on flat films or glass plates, exposing a number of these by electric light on each sitter, and then develops them by placing them in individual holders which can be immersed in tanks, so that a dozen negatives or more are developed at one time.

A great deal of work is done on a professional negative to prepare it for printing. There is first the *retouching* of the negative itself, by means of which minor defects are eliminated and the appearance of the picture (and sometimes of the sitter!) is improved (Plate 9). Usually, some modifications are also made in the background to repress the unessential details and direct attention towards the portrait itself.

Professional negatives are usually printed by

artificial light upon chloride paper. The printer is designed to give the maximum possible control over the lighting of the negative and is arranged so that masks, etc., can be inserted, rather than being designed for speed of operation, as is the case with the printers intended for the commercial production of prints from snapshots.

The professional photographer often specialises in commercial and advertising photography instead of portraiture, and in this field great advances have been made in the last few years. Advertising photographs are usually made by photographing professional models, but some of the most interesting advertising pictures are built up by the combination of a number of separate photographs. The picture shown in Plate 10 was made by Mendoza of the London *Evening Standard* from two photographs, one of which is shown in the centre, while the horse was a photograph of part of a china ornament, as shown at the right. The two pictures were modified by hand work and combined to make the illustration showing the Arab on horseback, the actual posing of which would have involved a good deal of cost.

Another broad field of professional photography is that by which pictures are provided for the daily Press. Press photographers are distinguished by their ability to face all sorts of conditions – by their daring and, might one say, their nerve. The skilful Press photographer, however, rarely makes himself objectionable but is able to get his pictures without exciting

PLATE 10

A composite advertising illustration. *Left*, Mendoza's finished picture; *Centre*, Mendoza's original photograph; *Right*, china ornament which completed Mendoza's illustration. '*Photographic Journal*,' *April* 1935.

(p. 48)

PLATE 11

(a) A folding roll film camera. (p. 50)

(b) A photograph of a reflex camera cut away to show its interior. (p. 51)

(c) Artificial light photograph in the home, using Photoflood lamps. (p. 54)

notice. One of the most remarkable photographs that was ever taken was a picture of the funeral procession of Queen Victoria in Westminster Abbey. At that time, the plates used required an exposure of not less than ten seconds in the dim light of the Abbey. A resourceful and somewhat unscrupulous Press photographer succeeded in arranging for the procession to pause for that period without anyone realising what had occurred.

The ranks of the professionals are generally recruited from those who have taken up the practice of photography as a hobby. From the earliest days, photography has attracted those who felt a desire to make artistic pictures. Not infrequently, pictorial photographers have been artists of a considerable degree of skill, but they have found that photography with its automatic drawing enabled them to secure compositions with a minimum of labour, and this appealed to them.

There are a great number of pictorial photographers in the world who make pictures primarily for their own satisfaction and also because they are interested in submitting them in open competition for the judgment of their fellows. In almost all of the major countries there are exhibitions of pictorial photographs in which it is not only an honour for a picture to be accepted but from which pictures are selected for publication in the various pictorial annuals.

At the present time, cameras for amateurs are designed primarily for use in the hand, and these

EP

cameras fall into three main groups: folding cameras, using roll film; reflex cameras, using roll film, plates, film packs, or cut film; and miniature cameras using either roll film or the same type of film as is used for the making of motion pictures.

The ordinary folding film camera (Plate 11a) is fitted with a lens working at a fairly large aperture, so that the exposures can be short, varying from one second to perhaps 1/300th of a second.

The aperture of lenses is expressed as a fraction of the focal length; that is, a lens which has a focal length of 6 inches and an aperture of 1 inch is said to have a 'relative aperture' of f/6. For hand cameras used by skilled amateurs, the minimum relative aperture is about f/6 and the maximum may be as much as f/3·5.

Such cameras, as a rule, do not take very large pictures; the most popular size in Europe makes pictures $2\frac{1}{4}$ by $3\frac{1}{4}$ inches, while in the United States an equally large number of cameras make pictures $2\frac{1}{2}$ by $4\frac{1}{4}$ inches. A number of years ago, larger sizes were used; the $3\frac{1}{4}$ by $4\frac{1}{4}$ size was very popular in England, and the $3\frac{1}{4}$ by $5\frac{1}{2}$ size was used, especially by amateurs who were anxious to obtain the best possible results. Improvements in the camera and in the quality of the film, however, have diminished the advantage of these larger sizes, and at the present time the two sizes mentioned above dominate the field. The so-called *vest pocket* camera, which makes a picture half the size of the $2\frac{1}{4}$ by $3\frac{1}{4}$, is very popular but is not used to the same extent as the larger sizes.

Folding cameras of the highest grade are becoming more complicated, and many of them are beautiful specimens of workmanship. The use of large-aperture lenses makes it necessary to focus the cameras very exactly, and the arrangements by which the film is held accurately in the focal plane have been much improved in recent years. With a camera of this type and with the modern high-speed film, it is possible to take satisfactory pictures under almost all daylight conditions, while, with supersensitive pan-chromatic film, pictures can be taken indoors with only a small amount of additional artificial light.

Reflex cameras are so arranged that the image is reflected by a mirror on to a focusing screen, where it can be observed up to the moment of exposure. When the release is pressed, the mirror flies out of the way, and the exposure is made by a curtain shutter, called a *focal-plane* shutter, the aperture of which is driven across the face of the film. The reflex camera has the advantage that it enables the picture to be composed and focused exactly as it will appear when taken. For really serious pictorial work, as also for much professional photography, such as Press photography, the reflex camera is very valuable (Plate 11*b*). The Press photographer, however, often prefers a type of camera, having a focal-plane shutter, which can be used at eye level, since it is often easier to work quickly with a camera in this position.

The most recent type of camera to attract public attention is the so-called *miniature camera*, which is

about 4 inches wide, 3 inches high, and 2 inches thick. The use of these cameras has grown with startling speed. Essentially, they are very small roll-film cameras in which advantage is taken of the small size to use large-aperture lenses, often working at as high an aperture as $f/2$. The exposure required by a photographic material diminishes as the aperture is increased, in proportion to the square of aperture, so that an $f/2$ lens requires only one-ninth of the exposure needed for an $f/6$ lens.

The rapid growth in popularity of this camera is due to three factors: large aperture, which makes short exposures possible; the relative cheapness of its film; and the fact that it is easy to carry. On the other hand, its pictures are too small to be of much value unless they are enlarged. For the enthusiast who finishes his own pictures, this is not much of a disadvantage, but for those who prefer to have their pictures finished by commercial firms, the cost of enlargement detracts from the advantage of the low cost of the film.

The greatest number of photographs are made by amateurs who take pictures for their own interest and amusement – records of journeys and pictures of their families and friends. Their cameras are either of the folding type or are simple box-form cameras in which the lens and shutter are mounted in front. With these cameras, no focusing is necessary owing to the small aperture of the lens system, which gives great depth of focus; the film is held in its focal plane at the back of the box, so that the camera is always ready for use.

Several millions of these box cameras are made every year, and many millions of pictures are taken with them, especially during the bright holiday months of summer.

Indoor photography has grown very much in recent years. The light needed for indoor work may be secured from ordinary electric bulbs of high power. Two kinds of bulbs, however, are made especially for this purpose, and these make the problem of artificial lighting a very simple one. One of these, the *Photoflood* lamp, looks like an ordinary house lighting bulb and costs the same. It gives as much light as all the bulbs in an ordinary house put together and lasts about two hours. When two or three of these lamps are used, preferably in reflectors, snap-shots on panchromatic film at 1/25th second may be made on a camera having a lens of aperture f/6·3 or faster. Cameras without fast lenses, such as box cameras, but loaded with panchromatic film, may be used with these lamps by setting the camera on a table or tripod and giving an exposure of about one second.

The second type of lamp bulb gives a single flash of great brilliance. This bulb is filled with very thin aluminium foil in oxygen. A fuse is heated by a small electric current and sets fire to the foil. The current from a pocket electric torch is enough to set it off. The foil burns in 1/50th second, which allows the camera to be held in the hand. This short flash also permits clear pictures of people moving about.

These lamps do not cause any smoke or noise or risk of burns or fire.

Those who have done indoor photography with either of these lamps find that some things may be done which are very difficult to do in daylight. The direction from which the light comes, for example, may be arranged as desired, so that many beautiful effects may be obtained (Plate 11c). Correct exposure is simplified, as it no longer depends on the sun's position or on the clearness of the day or on the amount of shade. The greatest advantage is that people who are busy during the day can take pictures after the sun goes down by using these lamps, together with panchromatic film.

The pictorial photographer is usually supplied with a well-equipped darkroom in which he can develop his films and make prints and enlargements (Plate 12a). Pictorial photographs intended for exhibition are usually of considerable size and are almost invariably obtained by enlargement from the original negative.

The enlarger may be of a very simple type, consisting of a lamp and condenser for the illumination of the negative and an ordinary photographic objective by which the enlarged picture is thrown on to an easel to which is attached a sheet of bromide paper. At the present time, however, the most popular form of enlarger is a vertical instrument in which the illuminating lamp is at the top and the lens points down to a table or copyboard on which the image is thrown. With these vertical enlargers, it is not difficult to use a

PLATE 12
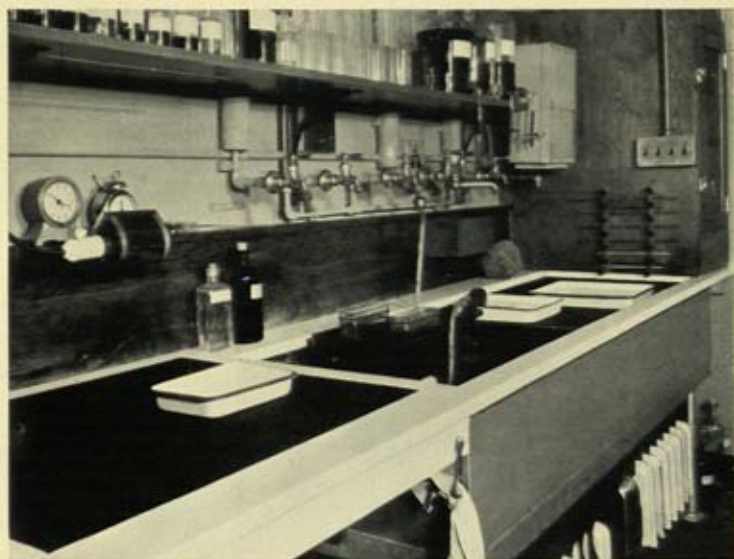
(a) A well-equipped darkroom for general photographic work. (p. 54)

(b) A small film-developing room. (p. 55)

PLATE 13

(b) Printing amateurs' negatives. (p. 56)
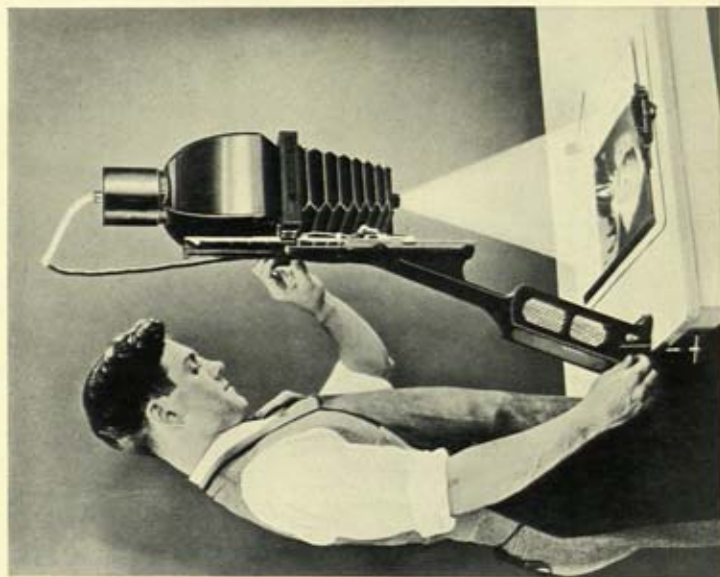
(a) An autofocus enlarger. (p. 55)

mechanical device by which the extension of the lens depends on the distance between the negative and the paper, the extension usually being controlled by a lever riding on a cam; and when this is done, the enlarger is automatically focused. With this convenient arrangement, the negative is inserted and the enlarger is raised or lowered until the picture is of the size required. The use of these *auto-focus enlargers* has greatly simplified and extended the making of enlarged pictures (Plate 13a).

When the photographer does not do his own developing and printing, the exposed films are sent to a developing and printing works, which is especially equipped for the rapid and economical handling of the work. As the films come in from the chemists' shops and other depositories where they have been collected from the public, each one is numbered for identification with the order. Then, in a darkroom, the outer paper is stripped off and the films placed on hangers. The arrangement of a typical developing room for a small works is shown in Plate 12b. The hangers are first placed in the tank of developer, which is surrounded by cool water and thus kept at the proper temperature. The films must be moved up and down when they are placed in the tank and at intervals until development is completed, in order to ensure even development and freedom from streaks and spots. When the necessary development time has elapsed, the films are transferred to the rinse tank and then to the fixing bath, from which, after fixation

is complete, they are put in the washing water and washed thoroughly. Finally, they are drained and transferred to a drying cabinet, in which the films are hung in a current of warm, dust-free air forced through the cabinet by means of a fan.

In the larger works, the film hangers are placed on a machine which moves them through the various tanks, the whole operation being handled automatically. The machine finally passes the negatives through a drying cabinet.

As soon as the negatives are dry, they are sorted and placed with the order in an envelope, all the negatives from a given order thus being kept together. An essential of a developing and printing works is that direct track be kept of all films, from beginning to end, without unnecessary delay or expense.

The negatives now go to the printer. A typical printing machine is shown in Plate 13b. The operator puts the negatives on the printer and from their appearance judges the grade of paper that should be used and the exposure necessary. These operators require a considerable amount of training; they are taught the fundamental principles of printing and given sufficient practice to acquire accuracy in judging negatives. As the paper is printed, it is transferred to another operator, who takes care of the developing and fixing. The prints are generally washed in a separate room, often in rotating washers or in large tanks through which water runs continuously, and then they are passed on to a drying machine in which

they are held against a heated drum on a moving belt. The prints coming from the drying machine are sorted into the original envelopes, where they are placed with their negatives and sent back to the customer.

More and more, this developing and printing business is becoming mechanised. Improved printers are available, and perhaps before long photoelectric cells may replace human judgment for the exposure required for prints. Often the whole arrangements for developing paper are mechanised, the paper going from the printer on to a moving belt, on which it is carried to the developing, rinsing, fixing, and washing tanks. There is no question that these improvements in operation should, and usually do, result in better pictures and in lower costs, so that the photographer can rely on obtaining thoroughly satisfactory results from his snapshots when he entrusts them to the D. & P works.

CHAPTER IV

THE FORMATION
OF THE PHOTOGRAPHIC IMAGE

LET us turn now from the practice of photography to the nature of the photographic image and to the method by which the image is produced. When a photograph is taken, the photographic film coated with the light-sensitive emulsion layer is exposed in the camera. The silver bromide of the emulsion must be changed in some way by the action of the light because, when the film is developed, the exposed area of the film darkens and reproduces in negative form the image to which the film was exposed in the camera. After exposure and before development, therefore, the film must carry some kind of image, although no trace of image can be seen if the film is examined in red light. This image, which must be produced in the camera but is only revealed during development, is called the *latent image*. During development, the latent image is transformed into an actual, permanent image composed of metallic silver.

Suppose we examine such an image, magnifying it step by step until we can see of what it is composed. In the figure, we see (Plate 14) a single picture which happens to be taken from a motion-picture film.

This looks quite continuous, but, if we enlarge a part of it, we see that the continuity is only apparent and that a sort of roughness or granularity begins to appear. Still further enlargement makes this granularity very clear, while enlargement of a very small area with the full power of the microscope shows us that the image really consists of separate particles. The particles are so small and so close together that to the naked eye the image seems continuous. The emulsion, in which the image is produced during development, is also not continuous. When the silver bromide was precipitated during the making of the emulsion, the precipitate consisted of microscopic crystalline grains the size of which depended upon the exact way in which the emulsion was made. Those of the crystalline grains which have been exposed to light form the latent image, and during development they are transformed into particles of silver. The structure of the developed image, therefore, depends upon the structure of the emulsion layer from which it was derived; because the silver bromide is in the form of definite crystalline grains, the developed image consists of separate particles of silver.

The crystalline grains are seen, under a powerful microscope, to be chiefly triangles and hexagons with an occasional rod-shaped grain (Plate 15a). These crystals are very small and very thin; their thickness is never more than one-fifth of their diameter and usually not more than one-tenth. In the emulsion, the grains are, of course, in every direction, but, after

the emulsion has been coated on the film base and
dried, it contracts to about one-fifteenth or one-
twentieth of its thickness, which naturally flattens all
the grains as the contraction occurs, so that in the
dry film they are parallel or nearly parallel to the face
of the emulsion.

The grains are very small indeed, and there are a
very great many of them in an emulsion; in fact, on
an area of film about the size of the thumbnail, there
are as many grains as there are people in the world.
Although all the grains are very small, they vary in
size from that of crystals ten thousand million of which
would cover less than a square inch to crystals having
a diameter of about $1/5,000$th inch. The smallest
grains are almost invisible under the most power-
ful microscope, and a good instrument is necessary
to see the shape of even the largest. In a film, there
are many layers of grains, perhaps ten to fifty.

The photographic properties of an emulsion, its
speed and its contrast, for example, depend upon the
size of the crystal grains and the proportion of the
grains of each size. This is measured by making
photographs under the microscope of small samples
of the emulsion, the photographs looking like that
shown in Plate 15a. These photographs are enlarged,
the areas of the individual grains are measured with a
rule and are then classified according to size, so that a
table can be prepared giving the proportion of the
grains which are of each class size. In Fig. 12a is
shown a chart prepared in this way from an emulsion

PLATE 14
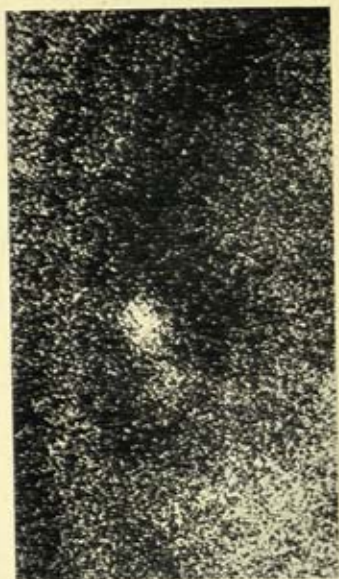
Gradual magnification of a photographic image. (p. 58)

PLATE 15
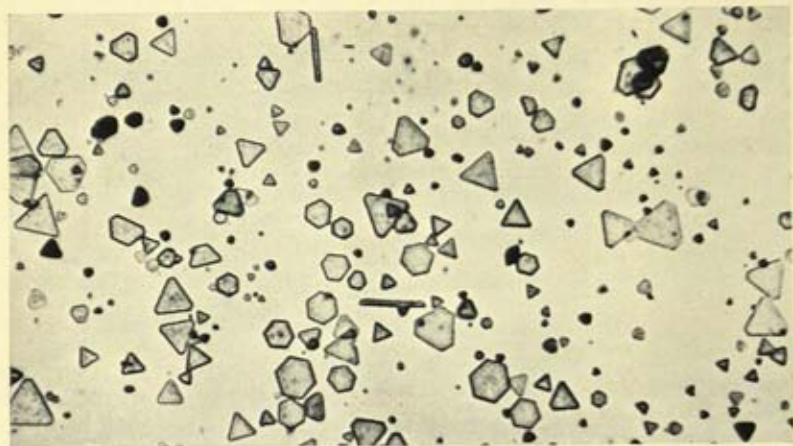
(a) Grains of silver bromide in a photographic film as seen under the highest power of a microscope (magnification 2,000 diameters). (p. 59)
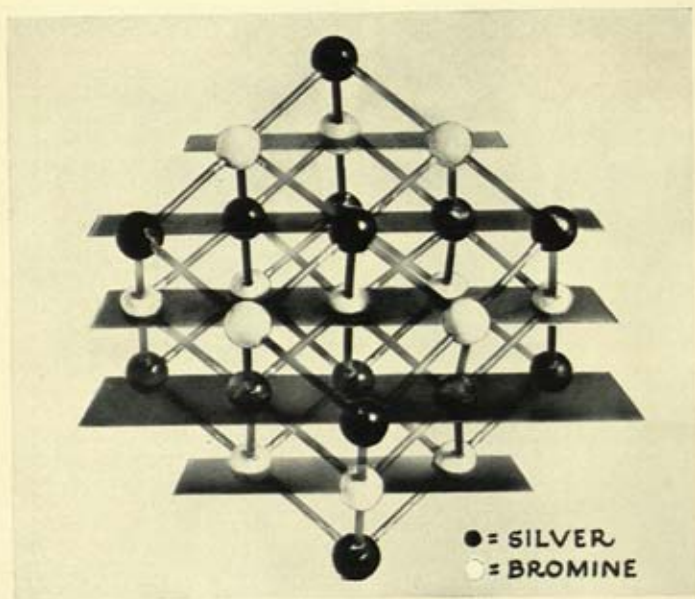
● = SILVER
○ = BROMINE

(b) The structure of a silver bromide crystal consisting of a network of alternate atoms of silver and bromine. (p. 65)

in which two or three thousand grains were measured. For really accurate work, it is necessary to measure twenty thousand grains or more. It is seen that most of the grains fall in the class having an area of 0·3 square microns. (A micron is about 1/25,000th inch.)
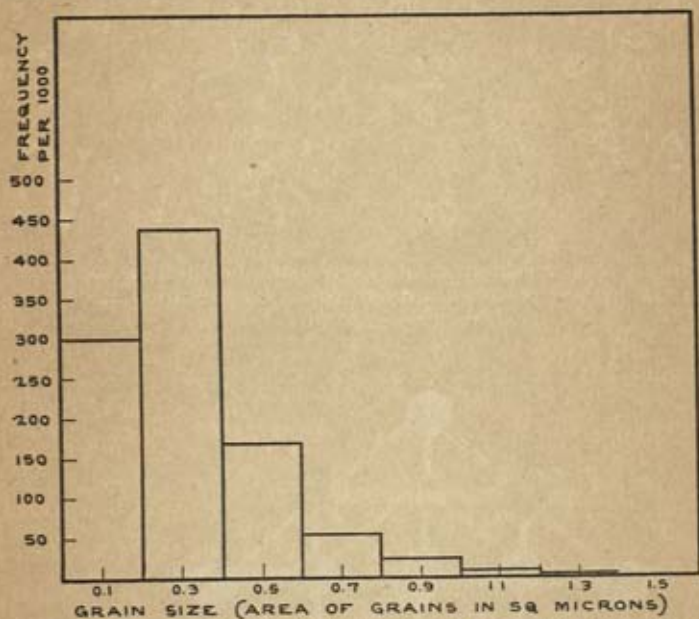
Fig. 12*a*. Classified distribution of grains in a typical photographic emulsion.

The results obtained in this way can be plotted on a curve of a special shape and will give the result shown in Fig. 12*b*. This is known as a *frequency curve*, and is used for classifying the frequency with which different characteristics are found repeated in objects of the same kind.

In Fig. 13, a frequency diagram is shown by a photograph of piles of shells arranged so that all the shells in any one pile contain the same number of
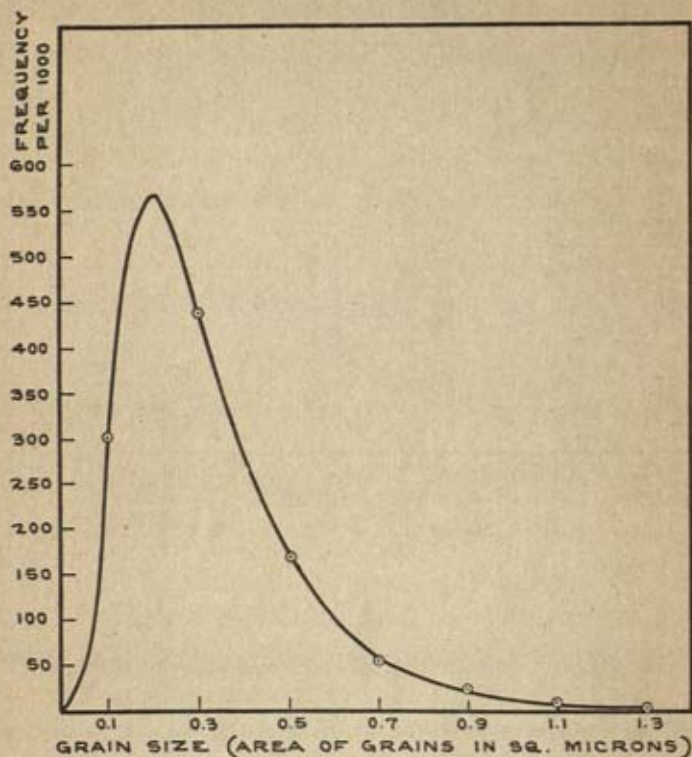
Fig. 12*b*. Curve showing the distribution of grains in a typical photographic emulsion.

ribs. The pile at the extreme right, made up of those which have the highest number of ribs, contains only one shell. The middle pile shows that most of the shells have seventeen ribs; there is a fairly large

number in the pile with sixteen ribs, and a somewhat greater number in the pile with eighteen ribs. The reader will be able to understand from this illustration the general principle on which frequency curves are based.

When frequency curves are made for the grains of different kinds of photographic emulsions, it is possible to see a direct connection between the shape of the frequency curve and the property of the photo-
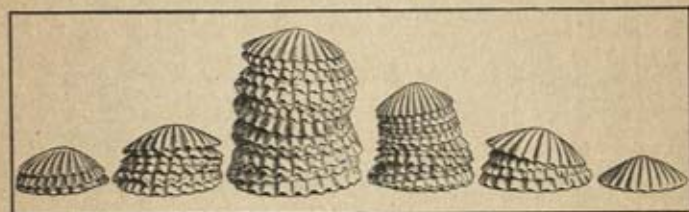
Fig. 13. Frequency chart based on the number of ribs in scallop shells.

Based on an illustration by C. B. Davenport in 'Popular Science Monthly.'

graphic emulsion. For instance, in Fig. 14, A shows the distribution of the different sizes of grains in a fast emulsion used for taking pictures in a camera, and B a slower, fine-grained emulsion, such as that of positive film, on which the pictures are printed. It will be seen that, in the fast emulsion, the average size of the grains is greater than in the slower emulsion, but also that there is more diversity in the sizes of grains. In the slower emulsion, the grains are more uniform in size, and this uniformity is associated with the greater contrast of the slower emulsion.

In the early days of photography, silver bromide emulsions were made with collodion as a vehicle.[1] When gelatin emulsions were made, they were much more sensitive to light. The origin of the greater sensitivity of emulsions made with gelatin has always been an interesting problem. Soon after gelatin emulsions were first made, it was found that the exposure required in the camera was greatly lessened if the emulsion had been cooked for some time at a high temperature or if it had been treated with ammonia. It was observed that the grains had grown larger during this treatment, and it was concluded that their greater sensitivity was due to their greater size. This is true, but it is by no means the whole story! For a long time, it had been known that if an emulsion were treated with some chemicals, such as chromic acid, it lost its sensitivity even though the size of the grains was not changed. Also sensitivity depends very much upon the particular kind of gelatin used in making the emulsion. Some gelatins easily give very sensitive emulsions, while others, even with prolonged cooking, will not give good sensitivity. This problem has been studied by emulsion makers ever since gelatin emulsions have been made, but no clue was found until about ten years ago, when Dr. S. E. Sheppard studied systematically the various fractions obtained at each stage in the preparation of photographic gelatin.

Photographic gelatin is made from clippings from

[1] See Chapter I, p. 10.

the skins of calves. For this purpose, the skin of the face and ears is used because these parts are of no value for leather. These clippings are first washed and then treated with lime for a long time to remove the fat and hair. The lime is removed by long washing with weak acid and then with water. Then the material is cooked in steam kettles until the gelatin is extracted, and the extract is concentrated if necessary and allowed to set to a jelly; the blocks of jelly are cut into thin slices and stretched out on nets to dry.

Sheppard found that in the acid liquors in which the limed clippings had been washed there seemed to be a concentration of some sort of sensitiser. When this liquor was added to a gelatin which did not give sensitivity, it at once increased the sensitivity of the emulsion. From the acid liquor, he extracted a very small quantity of a fatty substance, but when this substance was identified and prepared in a pure state, it had no sensitising power; the sensitiser was merely associated with it as a slight impurity. A material like the fatty substance could be obtained from the seeds of plants, and extracts of those seeds were found to sensitise, the most effective being mustard seed. This led to the identification of the sensitising substance in gelatin as being mustard oil, which contains sulphur. Presumably, the animals obtain the oil from the plants they eat, so that the amount present depends upon the pasturage that they have had.

When mustard oil is treated with alkali, it breaks down into allyl thiocarbamide. If silver bromide is

treated with a solution of allyl thiocarbamide, the surface of the silver bromide is attacked and grows a mass of white needles containing both allyl thiocarbamide and silver bromide. When these are treated with alkali, they break down into little black spots which must consist of silver sulphide because of the chemistry of the reaction.

The amount of mustard oil in an emulsion is very small. A ton of emulsion contains only a couple of drops, and our evidence for the existence of the sulphide specks is therefore indirect.

In Plate 16a is shown the action of allyl thiocarbamide on the crystals of silver bromide in an emulsion. At the top are shown the original crystals; in the lower left-hand picture, small specks are formed on these crystals (these can be seen in the microscope to be whitish); and in the right-hand circle they have been changed by alkali into black specks of silver sulphide.

As early as 1917, M. B. Hodgson showed that when the development of grains was observed under the microscope, it started from specks (Plate 16b), these increasing in number and size until each grain was transformed from its original crystalline character into a coke-like mass of silver. This was studied by T. Svedberg, and there was an active discussion as to whether these centres of development existed before exposure or came into existence when development started. Sheppard's work put the whole matter beyond doubt. Sensitivity depends upon the existence of specks probably far too small to be seen in the

PLATE 16
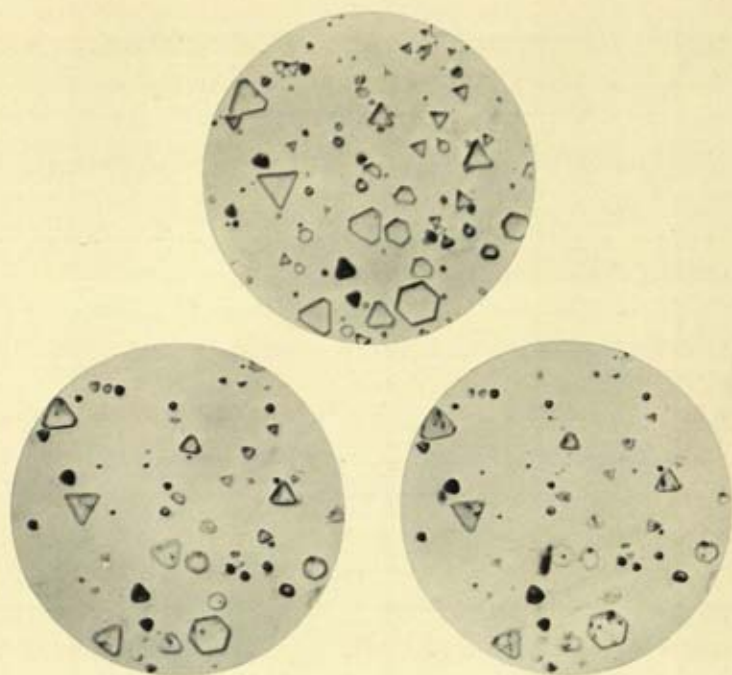
(a) Action of allyl thiocarbamide on emulsion. *Top*, Original crystals; *Left*, Specks on crystals; *Right*, Black specks of silver sulphide. (p. 68)
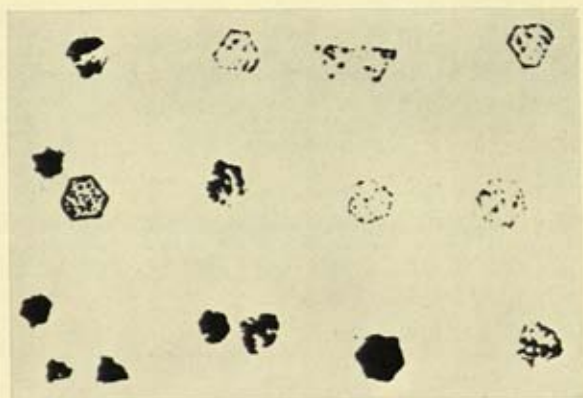
(b) Hodgson's picture of single grains seen under the microscope after partial development. (p. 68)

PLATE 17
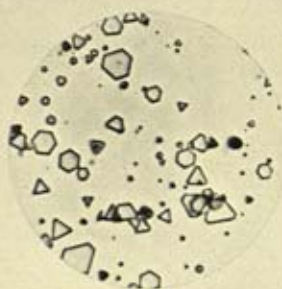
ORIGINAL
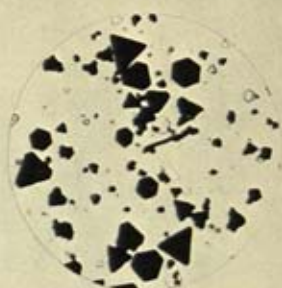
HYDROQUINONE
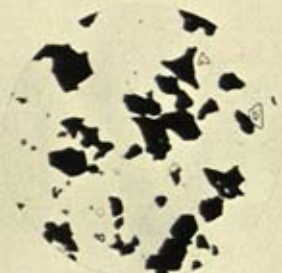
METOL

AMIDOL
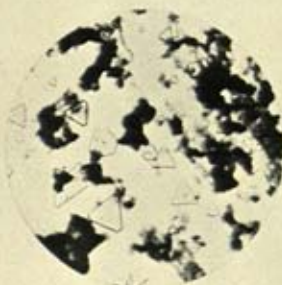
PARAPHENYLENE
DIAMINE
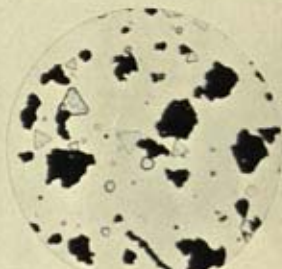
METOLHYDROQUINONE
10X DILUTED

Structure of developed images produced with various
developing agents. (*p.* 75)

microscope, and these specks consist of silver sulphide, probably derived from the mustard oil in the gelatin.

It has already been stated that when a film is exposed to light, an invisible image is produced in the emulsion. To understand how this image is formed, we must know how the sensitising specks act during exposure and what the light does to the silver bromide.

When Sheppard found that the sensitising specks consisted of silver sulphide, he and his colleagues advanced a theory of the action of light which they called the *concentration speck theory*. The silver sulphide specks, they suggested, are formed on the surface of the silver bromide crystal and must in some way enter into the lattice of atoms of which the crystal is composed. They produce strains in the crystal, therefore, and these strains stretch into the surface of the crystal as a sort of area of weakness.

Sheppard thought that when light fell on such a crystal, it liberated electric charges, and that these charges were transferred through the crystal until they reached the boundary of the speck. At this boundary, owing to the sudden change in structure, metallic silver was set free from the silver bromide. The sensitising speck thus acted as a nucleus for collecting or concentrating the energy throughout the whole area of the crystal and for liberating metallic silver at the speck itself.

Another theory was put forward by J. Eggert, who suggested that individual silver atoms, which form

anywhere on the surface of the grain, may wander and coagulate on the nucleus after exposure.

A. P. H. Trivelli visualised the sensitivity specks as resembling a small electric battery consisting of silver and silver sulphide in an electrolyte of silver bromide. His theory was that, when light shines on the grains, the silver bromide becomes a better conductor of electricity, and the voltage between the silver and silver sulphide increases. This little battery electrolyses the silver bromide, building up silver around the nucleus in the same way that silver is deposited on objects in a silver-plating bath.

More recently, F. Weigert presented the theory that sheaths exist around the grains and that these consist of a mixture of silver, silver sulphide, and other things. When the emulsion is exposed to light, some rearrangement of these materials follows, causing them to react more readily to a developer.

The nature of the latent image has always been a favourite subject for speculation among photographers. There is no need to go into the theories which have been advanced from time to time, because, while there are still many theories as to how it is produced, there is now a general consensus of opinion as to the nature of the latent image. Its chemical reactions both in development and in the way in which it behaves when treated with chemical solutions, show fairly definitely that it consists of metallic silver and that the action of the light upon the silver bromide grains produces invisible specks of metallic silver from which development starts.

It is possible that silver sulphide itself may also act as a nucleus for development, so that if the emulsion happens to be oversensitised and the silver sulphide specks therefore grow to too large a size, the grains will develop without exposure. When a photographer finds that his films develop without exposure, he says that they are *fogged*. Moreover, in the process of ripening, it is quite possible that, in addition to the silver sulphide speck, a small trace of metallic silver is produced.
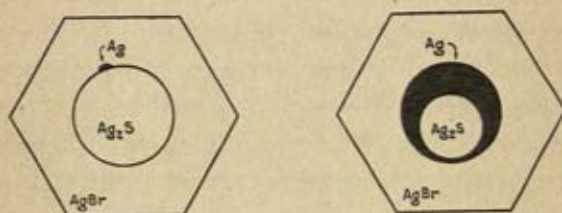
Fig. 15. Imaginary diagram of a grain (left) before and (right) after exposure. The size of the sensitive speck and of the silver latent image is enormously exaggerated in comparison with the grain.

We must imagine, therefore, that the sensitising specks consist of silver sulphide with possibly a small trace of metallic silver and that the effect of light is to increase the amount of silver until the speck of silver reaches a size which can act as a nucleus for development. We can see this imaginary effect depicted in Fig. 15, in which we see on the left a grain before exposure with a silver sulphide nucleus (enormously exaggerated in comparison with the grain) and a trace

of silver, and on the right the same thing after exposure, the silver having grown, possibly at the expense of the silver sulphide and possibly without affecting it.

When a photographic film is developed, each crystalline grain behaves independently of its fellows unless it happens to be touching another grain; that is, each grain separately is developable or not developable according to whether it is exposed or not exposed. If a grain is developable, it is completely developable provided the developer is allowed to act for a sufficient time.

The starting of development evidently depends on the existence of a nucleus on which the deposition of silver can start, and it is because this nucleus is produced by the exposure of the emulsion to light that development occurs only on the exposed grains. The necessity for a nucleus before deposition can start is quite well known in other cases. Suppose, for instance, that we make a solution of sodium sulphate in hot water and allow the solution to cool; there will be more sodium sulphate in solution than can remain there permanently, and the solution is said to be *supersaturated*. If the solution is quite clean and is not disturbed, it can remain supersaturated for a long time. The moment, however, that any nuclei are introduced on which crystals can form – even specks of dust are sufficient – crystallisation will start and will continue until the whole vessel is filled with a semi-solid mass of sodium sulphate crystals. In the same way, water vapour in the air will condense on

floating particles of solid matter, and a London fog owes its density to the smoke nuclei on which the moisture condenses. Just how the nucleus produced by exposure induces the development of the grain, we do not know. It has generally been thought that the silver bromide goes into solution and in that state is reduced by the developer, so that around the grains there is a very thin skin of solution supersaturated with metallic silver and ready to deposit on the nuclei produced by exposure; but there is some evidence against this theory, and another suggestion is that the developer itself concentrates in a layer on the grains and there changes the silver bromide into silver wherever there is a nucleus of silver present to start the reaction.

A photographic developer is a *reducer* – a material which can be easily oxidised. Reducing agents are extremely important in chemistry because by means of them, for instance, we get the metals from their ores. If we heat mercuric oxide, the oxygen is driven off by the heat and the mercuric oxide is reduced to metallic quicksilver, but generally reduction cannot be accomplished by heat alone, and some oxidisable substance must be present. To reduce iron from its oxide, of which iron ore is chiefly composed, the ore is heated with charcoal or carbon, which is oxidised to carbon dioxide, the ore being reduced to metallic iron. But it is not always necessary to use heat in reduction; if we add an oxidisable substance, for instance, to a solution of silver nitrate, the silver nitrate will be reduced

to metallic silver, which will precipitate in a cloud throughout the solution. A photographic developer, then, is an oxidisable substance which can reduce silver compounds to metallic silver. But not all such substances are developers. It is necessary that the developer should be able to reduce exposed silver bromide to metallic silver but should not reduce unexposed silver bromide. This means that a photographic developer must have a certain strength of reduction. If it is too weak, it will not be able to reduce even exposed silver bromide, while, if it is too strong, it will reduce both exposed and unexposed silver bromide and so will not produce any image due to exposure. In spite of this restriction, there are quite a lot of substances which will act as developers, though naturally some of them are in practice much superior to others. M. Abribat has recently found that old Burgundy wine is a developer, though not a very good one!

It would be very nice if through the microscope we could observe or photograph a developer attacking the grains which had been exposed and leaving unattacked those which had not been exposed; but unfortunately so much light is required to see or to photograph silver bromide grains through a microscope that all the grains are necessarily exposed. However, motion pictures have been made of grains in the act of developing. Some of the emulsion was spread out thinly on a glass slide and the motion-picture camera was started; then a few drops of weak developer were

placed on the slide. The pictures show that specks of black silver appear in the grains and then the grains break up as the crystal structure is lost and the silver is produced. Generally, the whole crystal form is lost, and the silver growing out of the crystals presses against the gelatin and twists the grains so that they wriggle as if they were alive and then become motionless again as they turn into masses of coke-like microcrystalline silver.

The structure of the developed image depends upon the developer. Some developers, such as hydroquinone, deposit silver in exactly the form of the original grains, so that the image looks as if the original grains of silver bromide have turned black, while other developers break up the grains more or less, and some break them up so much that the structure of the deposited silver bears no relation to the structure of the original emulsion grain (Plate 17).

Let us sum up our knowledge of the production of the photographic image. The sensitive layer is composed of crystalline grains of silver bromide. The sensitivity of these to light depends upon their size and the presence of surface specks, probably composed of silver sulphide. In those grains which are exposed, the light transforms the silver bromide at the boundary of the speck into a very small amount of metallic silver; then this silver facilitates the attack of the developer on the grain so that the whole grain is reduced to metallic silver. These grains of metallic silver form the photographic image.

TONE VALUES AND THEIR REPRODUCTION BY PHOTOGRAPHY

WHEN a representation of a natural object is produced on a flat surface, the form can be represented only by differences in brightness or colour. Shape is possible only in sculpture. The painter uses differences of brightness and of colour, while the black-and-white artist uses only the differences of brightness. Photography is the art of making reproductions of natural objects by mechanical and chemical processes, and, except in the special branch of colour photography, it deals only with the reproduction of objects in their degrees of brightness.

We cannot speak of the *brightness* of paper or the *blackness* of velvet unless we have a standard of comparison by which to measure it; a piece of black velvet seen in bright sunlight is brighter than a piece of white paper in a darkened room.

The different degrees of brightness are spoken of by artists as *tones*. If a piece of white paper on which black marks have been made is photographed, the result will be a picture in two tones (Plate 18, top). Between these extremes can exist other tones spoken of as *half tones*. The centre figures show the effects

of additional tones. In the last figure, the six tones complete the representation of a cube, in which the degrees of brightness enable the form and substance to be realised. It is the function of photography to reproduce faithfully these different degrees of brightness, which may vary from white to black, so that the reproduction will present to the mind the same impression as would have been produced by the original object.

The differences of brightness which occur in Nature are produced by differences in the illumination of objects. If a plaster cast is lighted directly from the front, the outlines will be visible, but there will be little variation in tone. It will have a flat appearance. If the cast is lighted more from one side, shadows will be formed, there will be differences in the illumination, and in this way tones will be produced by shadows. Objects also differ very much in reflecting power. The brightest thing ordinarily met with is white chalk, which reflects 90 per cent of the light falling upon it. Snow does not reflect quite as much light as chalk. The ordinary red brick wall reflects only about 20 per cent. Good black printers' ink reflects about 10 per cent; and the blackest thing, black velvet, will reflect about 1 per cent or 2 per cent of the light falling upon it.

The brightness of natural objects can be measured by means of a photometer, in which the brightness is matched with that of a screen illuminated by a lamp of known power. A convenient form of the instrument

is shown in Fig. 16. The object is viewed through a hole in a piece of white paper, and the white paper, which must be backed on metal so that it is opaque, is illuminated by a small, movable lamp the distance of which from the paper can be varied. The instrument is used by holding it up to the eye so that the brightness of the object can be seen through the hole in the paper, and then the lamp is moved until the brightness of the paper is the same as that seen
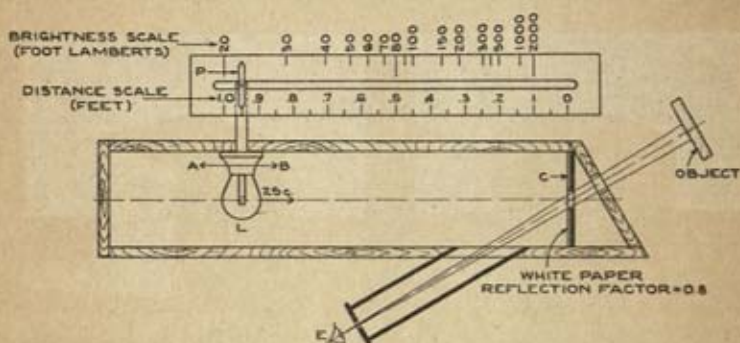
Fig. 16. A photometer to measure relative brightness.

through the hole. The brightness of the paper can be calculated from the distance of the lamp from it, and consequently the brightness of the object can be read on the instrument.

It is widely believed that the range of light intensities occurring in natural objects is very great, and that in an ordinary landscape, for instance, the sky will be enormously brighter than the shadows; but this idea is quite incorrect. In a bright landscape with

PLATE 18
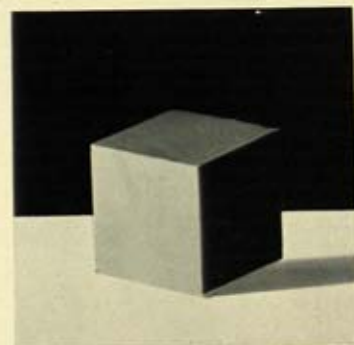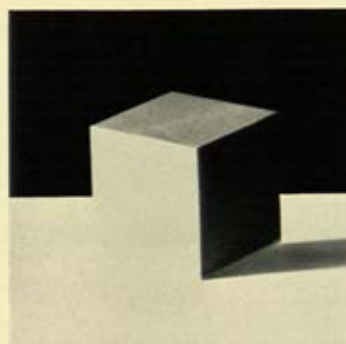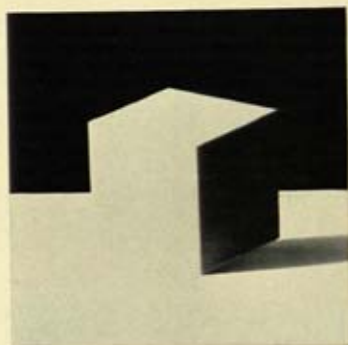
Reproduction of a natural object in an increasing series of tones. (*p.* 76)

PLATE 19
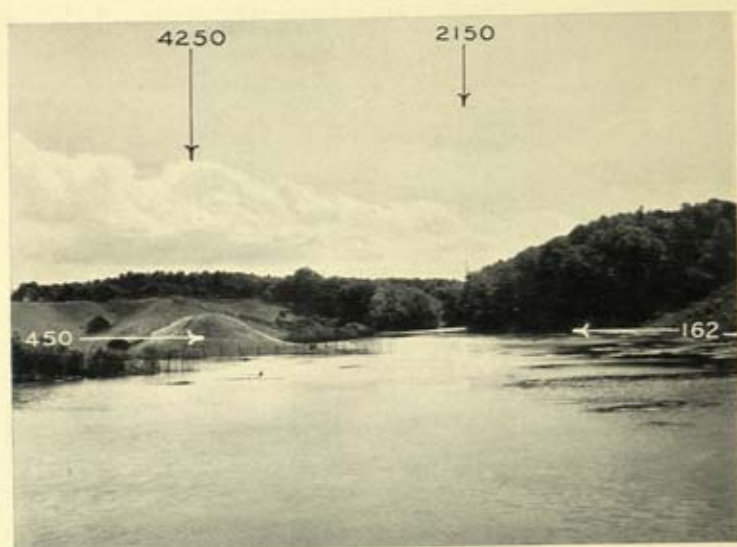
(a) A landscape with the brightness of various areas indicated.
(p. 79)
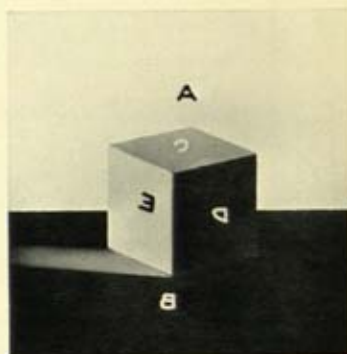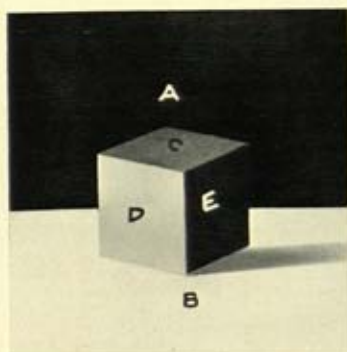
(b) A simple subject and a negative of it, showing the various
tone areas. (p. 81)

heavy shadows, the sky is only about thirty times as bright as the deepest shadows. In the case of open landscapes in which there are no close objects in the foreground, the range of intensities will be much less than this, and the sky will often be only five or six times as bright as the shadows. The range of light intensities, therefore, with which it is necessary to deal in ordinary photography will vary from, perhaps, one to four times as the least up to one to fifty as a maximum, and the brightest part of a landscape – the sky – will have a brightness of from 500 to 5,000 foot-lamberts. When the picture shown in Plate 19a was taken, the brightnesses of various areas were measured with a photometer. The highest brightness, 4,250 foot-lamberts, was found on a sunlit cloud, while the deepest shadow had a brightness of 162 foot-lamberts, the brightness contrast in this case being 26.

Our object in photography must be to get an accurate reproduction of the various degrees of brightness which occur in the original scene, thus keeping each tone in its same relative position in the scale. This, of course, is easier to do if the range of brightness is small than if it is very great.

When a photograph is made, the operation is completed in two separate steps: first, a negative is made upon highly sensitive material and a result obtained in which all the tones of the original are inverted. The brightest part of the subject is represented in the negative by a deposit of silver which lets through the least amount of light; whereas the

darker parts of the subject are represented by trans-
parent areas in the negative, which let through the
most light. This negative is then printed upon a
sensitive paper, in which operation the scale of tones
is again reversed. The bright parts of the subject,
which were represented by heavy deposits in the
negative, now appear as the light areas of the print,
and the dark portions of the subject, which were
transparent in the negative, are represented by dark
deposits in the print.

In order to find out how closely the tones of the
print follow those of the original subject, the changes
in tones must be followed through both steps: we
must study first how closely the negative reproduces
in an inverted form the tones of the subject and then
how accurately the printing paper inverts these again
to reproduce the original. Any silver deposit in the
negative will let through a certain proportion of the
light which falls upon it – a very light deposit may
let through half the light, a dense deposit one-tenth,
a very dense deposit one-hundredth or even only
one-thousandth. The amount of deposit through
which one can see depends, of course, upon the
brightness of the illumination at which one is looking,
but it is interesting to note that the sun can be seen
through a deposit which lets through only about one-
twenty-thousand-millionth of the light. The fraction
of the light which is let through is referred to as the
transparency of the deposit. The inverse of the
transparency is called the *opacity*, the opacity,

therefore, being the light-stopping power of the deposit. A deposit which lets through half the light, for instance, is said to have a transparency of $\frac{1}{2}$ and an opacity of 2; similarly, one which lets through one-tenth of the light has a transparency of $\frac{1}{10}$ and an opacity of 10.

The *density* of a photographic deposit is proportional to the actual amount of silver per unit area. A deposit which lets through one-tenth of the incident light has a *density* of 1; one which lets through one-hundredth, a density of 2.

If the negative is to be the exact inverse of the scale of tones of the subject, the opacities of the different areas must be in proportion to the brightness of the parts of the subject which produce them. On Plate 19*b* is a subject in which it is assumed that the black background has a brightness of 1, the brightest portion a brightness of 10, and the other portions in proportion. When a negative is made of this, the picture shown at the right will be obtained, and if the opacities of the negative are measured, they should be exactly the inverse of those at the left. The *transparency* of the background, A, should be ten times that of the table, B; or the *opacity* of the table, B, should be ten times that of the background, A. Not only this, but the relative opacity of the deposits in the areas C, D, and E should be the same as the brightnesses of C, D, and E in the original subject. It will be seen from the foregoing, therefore, that a technically perfect negative is one in

GP

which the opacities of its different gradations are exactly proportional to the light reflected by those parts of the original subject which they represent.

Let us now consider how closely we can fulfil this condition and what must be done to obtain a perfect negative of any subject. Let us suppose that a photographic film or plate is exposed to a series of known brightnesses; for instance, that we photograph a scale of steps of reflecting power. The exposure given to each step is doubled with regard to the next one because twice the amount of light reaches it. If the rendering is technically perfect, the opacities of the negative obtained would be the same as the brightnesses of the different steps of the original. The light let through each step of the negative should be half the amount of the step next to it, because each step received twice the light of the next step.
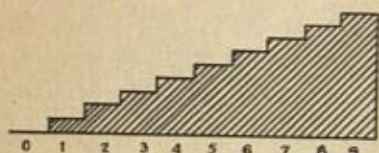
Fig. 17. A diagram showing the amount of the silver deposits in a graded strip.

This result would be attained if each step in the negative added the same amount of silver to the deposit, so that if we could represent the silver for each step as altering the thickness of the silver deposit (it does not really do this, of course; it adds to the number of grains in the same layer) and then could cut an imaginary section through the negative so as to show the height of the deposit of silver, it should look like Fig. 17. If we actually try this experiment,

however, we shall find that the silver does not rise
quite uniformly in this way as the exposure is in-
creased through the entire scale, but that we get the
diagram shown in Plate 20*a*. This diagram, which
represents the actual relation between the silver
deposit in a photographic material and the increase
of exposure, requires careful study.

Starting at A and proceeding to B, it will be noticed
that the first steps are marked by a gradually increas-
ing rise, and, therefore, in this part of the exposure
scale there will be an increasing gain in opacity for
each given increase of exposure. A negative, the
gradations of which fall in this period, will yield a
print in which an increasing contrast is shown between
tones of uniformly increasing brightness; that is to
say, it will appear what we term *under-exposed*. From
this period at B, we pass imperceptibly into the period
where the densities show an equal rise for each equal
increase of exposure, and here we have our technically
perfect negative; that is, one in which the opacities
are exactly proportional to the light intensities of the
subject. This is termed the *period of correct exposure*,
and only through this period of the curve, where the
opacities are directly proportional to the exposures
and where the densities show an equal increase each
time the exposure is doubled, shall we get a perfect
rendering of the original subject. From the point C
onwards, we have a gradually decreasing rise in the
steps with increase of exposure until, finally, the
increase of density with further exposure becomes

imperceptible. This is the period of *over-exposure*, in which the opacities of the negative fail to respond to increasing amounts of exposure and the correctness of rendering is again lost. It will be seen that only through the period of correct exposure, where equal increases of exposure are represented by equal rises in density, can the tones of the original subject be correctly reproduced in the print.
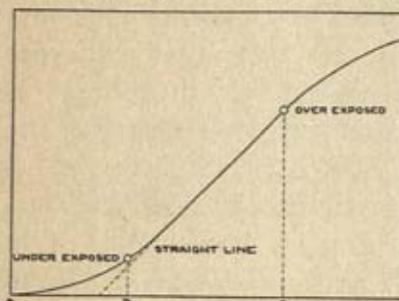
Fig. 18. A curve showing the relation between the density and the exposure.

If we join these points together, as is shown by the dotted line in Plate 20*a*, instead of representing them as a staircase effect, we get a smooth curve, Fig. 18, of which the straight-line portion (B to C) represents the period of correct exposure, while the more or less curved portions at the beginning and end of the curve correspond to the periods of under-exposure and over-exposure.

It must be realised that no ordinary negative can show the range of exposures from beginning to end of this curve. This is because the range of brightnesses covered by the whole curve is much greater than that which occurs in ordinary subjects. Consequently, it is quite possible to represent an ordinary subject entirely in the period of correct exposure, avoiding both the period of under-exposure and the period of

over-exposure. If we wish to obtain a technically
perfect negative, we must expose so that the subject
which we are photographing falls into this period of
correct exposure. Then we shall obtain a negative
in which there will be no wholly transparent film,
since this would mean that we had entered the period
of under-exposure, and there will be no blocked up
masses of silver, since this would mean that the nega-
tive was over-exposed.

The capacity of a
photographic material
to render the scale of
tone values correctly is,
therefore, entirely a
matter of the length of
the straight-line portion
of the curve. The
tones of a subject can
be correctly translated
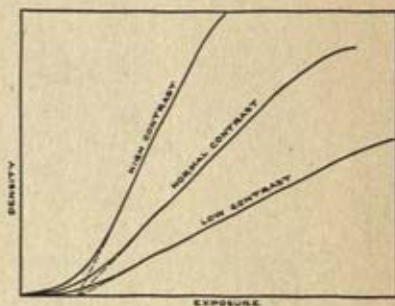
Fig. 19. The increase of contrast
with development.

into corresponding opacities in the negative (1) by
using material which has a long straight-line portion,
and (2) by using an exposure which will place the
shadows of the subject on the lower part of the
straight line.

In Plate 20a the opacities throughout the straight-
line portion are exactly proportional to the exposure
and also the ratio of the opacities of any two steps is
exactly the *same* as the ratio of any two exposures.
But this need not be the case; the ratio of the opacities
might be greater or less than the ratio of the exposures;

for instance, when the exposure is doubled, the resulting silver deposit might let through only one-quarter of the light instead of one-half. This is shown in Fig. 19, where the middle curve is the same as that of Plate 20a, and two others are shown – one of less and one of greater slope. The negatives corresponding to these curves are said to differ in contrast.
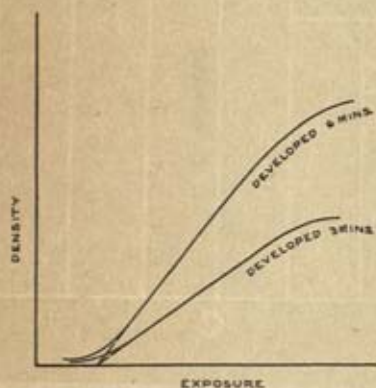
Fig. 20.   The effect of increased time of development on contrast.

The contrast of a negative increases during development. If we develop two films for different times – one for three minutes, let us say, and the other for six minutes – we shall find that the two curves will correspond in shape. In each curve, the straight-line portion corresponding to the region through which reproduction will be correct will cover the same range of exposures, but the steepness of the two curves will be different, the curve of the film developed for six minutes being much steeper than that of the film developed for three minutes (Fig. 20).

This means that, as development is continued, each density increases to the same proportional extent. The highlights do not gain density rapidly and then stop, nor does the shadow detail build up first and then the highlights gain upon it. An increase in
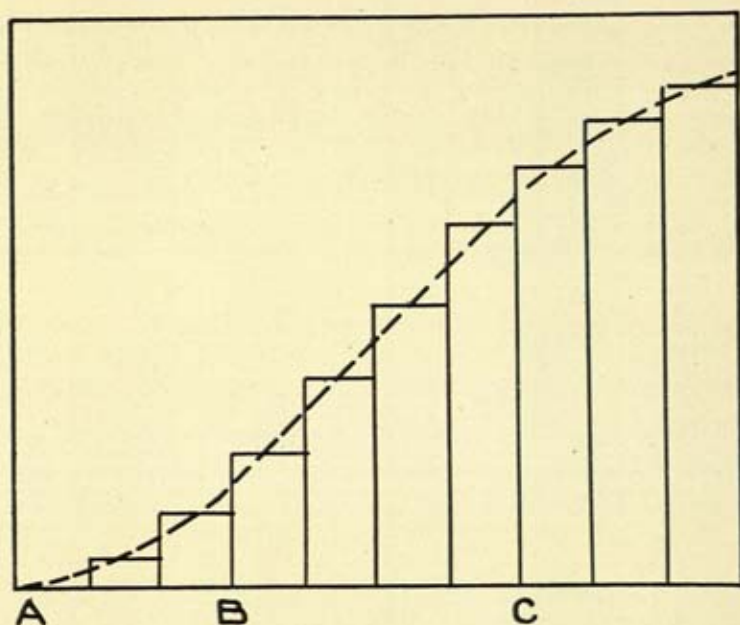
PLATE 20

(a) A diagram showing the relation between the silver deposit
and the exposure. (p. 83)

(b) The complete range of silver deposits on a paper. (p. 93)

PLATE 21
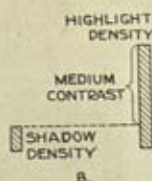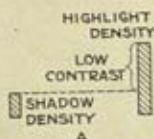
The effect of contrast of a negative on the choice of grade of a printing paper. (*p.* 96)

development results in a proportional increase in every part of the negative scale. If 50 per cent is added to the density of the shadow detail, 50 per cent will be added to the middle tones of the negative and 50 per cent again to the highlights; and since each density increases in the same proportion, there is an increase in the contrast between the highlights and the shadows. This contrast can be measured from the steepness of the straight-line portion of the curves; that is, by the rise in density which corresponds to a given increase of exposure. If, with the units chosen, the rise of density is equal to the increase of exposure, we have a contrast of unity. If another film gives twice as much density for the same increase of exposure, its contrast is 2; if it gives three

Fig. 21. The various degrees of contrast.

times as much, the contrast is 3, and so on (Fig. 21).

Therefore, during development the contrast increases. At first, it increases rapidly, then the rate of increase begins to fall off, and the contrast increases more and more slowly until finally no increase in the time of development will make any difference; the film has reached its maximum contrast, the amount of which depends upon the film, but beyond which the contrast cannot be pushed by prolongation of development. In Fig. 22, we see a number of lines showing

the contrast obtained by the development of a certain film for one, two, four, six, eight, and twelve minutes; it will be seen that these lines come closer and closer together. If we develop for a much longer time, we reach the limiting value, which is marked infinity, beyond which no amount of development will push the contrast on that material. If development be further prolonged, we shall only develop fog over the whole film.
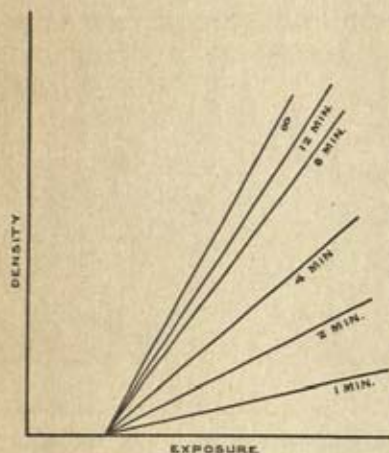
The limit of contrast obtainable depends upon the photographic material. High-speed portrait films have low values of contrast because no portrait requires a contrast exceeding unity. Films used for landscape work and commercial photography have higher values and will give greater contrast. They develop more quickly and easily and give contrasts exceeding the maximum to which fast materials can be pushed. The greatest contrast of all is obtained with the special slow emulsions made for process work, where every effort is made to get the greatest possible contrast so as to get clear lines on a completely opaque field. The maximum contrast given by process films is frequently as high as 4, which means

Fig. 22.　The increase of contrast with development.

that if we have in the original subject two tones one of which is twice as bright as the other, then in the negative they will be represented as having transmissions in the ratio of 1 to 16, namely 2 multiplied together four times. Fig. 23 shows us the curves of portrait, commercial, and process films, each developed to the maximum contrast available.

Although we cannot obtain a very contrasty negative upon an emulsion designed to give a low maximum contrast, we can obtain soft negatives upon a film having a high maximum contrast by developing for only a short time. In practice, however, every photographer knows that if he uses a film designed to give
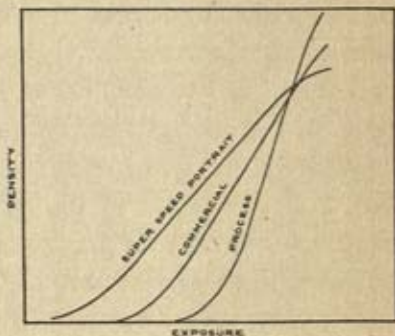
Fig. 23. Curves showing the maximum contrast given by different films.

great contrast, he will not get satisfactory portrait negatives upon it even if the time of development be short. The reason for this is that 'hard working,' that is, contrasty, films also have a short scale in the straight-line portion, so that only subjects of limited scale can be rendered on the straight-line portion of the curve. A process film, for instance, is able to render a contrast of only 1 to 4 correctly as compared with the great range of 1 to 256 obtainable on the high-speed film, so that if a process film be used for

portraiture, the quality of the negatives will be un-satisfactory even if soft negatives be obtained by short development.

The relation of the contrast obtained in development to the scale of the original subject must now be considered. Suppose that the subject has a range of light intensities from 1 to 100. If the negative is developed to a contrast of unity, and if the length of the straight line and the exposure are such that perfect reproduction of those 100 tones is obtained in the negative, we shall have a negative in which the ratio of the highest transmission to the lowest transmission is the same as for the subject: namely, 1 to 100. If this scale is too great for printing on the papers which are available, the scale can be reduced by lowering the contrast of the negative; that is, by developing the negative for less time, which will reduce each tone in the same proportion. On the other hand, in the case of flat subjects, the available scale of the subject for the printing paper can be increased by developing the negative for a long time, thus increasing the scale of contrast. Provided that the contrast of the subject is not too great for the scale of the negative material, and that the exposure is such that the scale of the subject falls on the straight-line portion of the curve, development to a contrast of unity will make the scale of intensities of the negative the exact inverse of the scale of intensities of the subject.

Let us turn now to the paper print made from the

negative and to the reproduction of the scale of tones in the print. In prints, the photographer deals with reflected light, not with transmitted light, as in negatives. In the case of films, an increase in the silver deposit will always diminish the transmitted light without limit, but in the case of prints, an increase in the deposit will not produce a decrease in the light reflected after a certain deposit is reached. This is because the light is reflected from three surfaces: from the surface of the gelatin, from the surface of the silver deposit, and from the paper. Only the light reflected from the paper is affected by an increase in the silver deposit. The light reflected from the surface of the gelatin and that of the silver is not diminished by an increase in the silver deposit, and there is therefore always a certain minimum of light reflected from the blackest portions of a print. The total range of tones, therefore, which can be obtained by reflected light is none too great for the reproduction of natural subjects, and in a print we are forced to use the whole range of reflecting power available; we must have highlights which are almost white paper, and the deepest shadows possible. Thus, in printing, the whole scale of the subject cannot be placed on the straight-line portion of the paper curve; it is necessary to use the whole range of the curve.

When measuring the curve of a printing paper, instead of measuring the light transmitted by the various densities, the light reflected from them must be measured. In this way, a series of *reflection*

densities on paper corresponding to the *transmission densities* of the film are obtained and a curve can be drawn.

In Fig. 24, we see that the densities increase gradually at first, as shown on the lower portion of the curve; then grow in equal steps for equal increases of exposure, as with the film; and then the increase not only grows less but very soon stops altogether, as shown by the upper portion of the curve. This latter stage occurs only with a film having had very great exposures indeed, since with film over-exposure can continue for a considerable range before the increase of density with exposure actually ceases. With a paper, however, a point is soon reached where the maximum blackness of deposit is obtained and where no further increase of exposure will give a more intense black. The maximum black depends not only on the kind of emulsion but to a very great extent upon the surface of the paper, because it is limited by the light reflected from the surface.

Fig. 24. The increase of density with exposure for a printing paper.

A glossy paper (viewed at such an angle that the surface does not reflect light directly into the eye like a mirror) gives much the deepest black, the strongest

obtainable deposit on such a paper reflecting only
2 per cent of the light. A 'semi-matt' surface will
give a less intense black, reflecting about 7 per cent of
the light from the deepest shadows.

The total scale of contrast obtainable from a paper
depends upon the ratio of the light reflected from the
white paper (taken as 100 per cent) to that reflected
from the blackest deposit obtainable, so that this scale of
contrast will vary with the surface of the paper. For
matt papers, it will be 1 to 15; for semi-matt papers,
1 to 25; and for glossy papers, as much as 1 to 50.

In this scale of contrast, the eye can discern a
certain number of tones. Let us study a strip of
paper giving a complete range of deposits from white
paper to the maximum black, such as can be obtained
from a series of increasing exposures (Plate 20*b*).
How many distinct tones can be seen in such a strip?
With semi-matt papers, the eye can detect about 100
tones, with glossy papers as much as 150; perhaps
an average for printing papers would be 100 tones.

By the *scale* of a printing paper in exposure units,
we mean the range of exposures which will give all
these hundred tones; that is, if an exposure of one
second will just give the first perceptible difference
from white paper, showing the first trace of tint on
the paper, and an exposure of twenty seconds will
give the deepest black of which the paper is capable –
so that no increase of exposure will produce any
denser black – we may call the exposure scale of the
printing paper 1 to 20.

Different printing papers have different exposure scales to fit the negatives for which they are intended. Thus, the Velox papers, intended for amateurs' negatives, have their whole scale of tones within a short range of exposures. An exposure of from one to twenty units will give the whole tone range of Soft
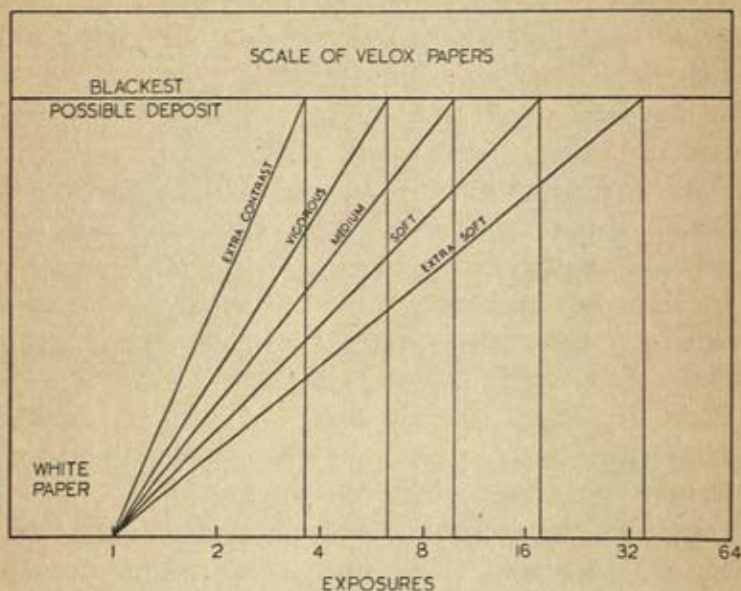
Fig. 25. Exposure scales for five grades of Velox papers.

Velox; from one to ten, that of Medium Velox; and from one to approximately six, that of Vigorous Velox. With Extra Contrast Velox, we get the maximum black which the paper can give with less than four times the exposure necessary to just produce a tint (Fig. 25). The *contrast* of a paper, in fact, depends chiefly upon

the scale of exposures which will give the full range
of tones from white to black.

It must be remembered that the scale of exposures
required to give the full range of deposits on a given
paper is not an indication of quality but only of the
contrast of the negative to which that paper is adapted.
It is sometimes suggested that a good paper will give
a full range of tones, but *all* papers will give a full
range of tones, from white
to the deepest black of
which they are capable.
The requirement for
quality is that they should
give this range evenly. In
Fig. 26, we see how two
different papers give their
scales of tones with varying
exposure. Both give the
same range of tones, both
require the same range of
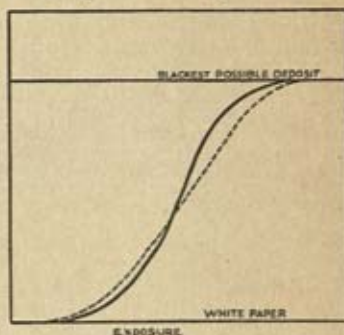
Fig. 26. Varying exposures
required for full range of tones
on two papers.

exposures to give the entire scale; that is, both have
the same exposure scale; but in the one the deposit
grows evenly with the increase of exposure, while in
the other the curve is not straight at all. The deposit
at first grows more and more rapidly and then gains
less and less rapidly, until the maximum deposit is
attained. The paper showing the even growth of
deposit has good quality; that with the uneven growth,
although it has the same maximum black and the
same scale, has poor quality. Its defect is that the

tones are compressed at each end of the scale, so that the highlight and shadow gradations tend to be lost.

It will be seen that *grades* of papers with different scales are required to fit negatives having different degrees of *contrast*; or, on the other hand, negatives can be developed to the degree of contrast required to fit the scale of the paper which it is desired to use. If we make four negatives of the same subject in succession, giving exactly the same exposure, and then develop these for different lengths of time – so that the first will be under-developed; the second, slightly under-developed; the third, fully developed; and the fourth, over-developed – the first negative will have a very low contrast; the second, medium contrast; the third, normal contrast; and the fourth, extreme contrast (Plate 21). The contrast range is shown by the graphs in the centre of the figure.

Now, if we print these negatives on papers selected to fit their contrasts, we shall get prints which are almost alike, as is shown along the right side of Plate 21.

If negatives of the same type of subject are given the same time of development, they will have the same contrast, but they may differ in *density* because of differences in the exposure and in the brightness of the subject. The only effect of differences in density is to change the exposure required in printing.

A series of negatives which have been given increasing exposures and have been developed for the same time is shown on the left side of Plate 22. All

of these have the same contrast range (density difference between the highlight and shadow), as shown by the diagrams in the centre of the figure. They differ in that the highlight in the very dense negatives is much denser than the highlight in the thin negative. Therefore, once the grade of paper is chosen, all four negatives can be printed on this grade, but each print will have to be given less exposure than the previous one, following the order of very dense to thin. The prints from these negatives are shown on the right side of the figure, and all appear alike, since the differences in density of the negatives have been compensated for by exposing the prints for different times.

Printing, therefore, consists essentially of two operations: (1) choosing the grade of paper to fit the contrast of the negative; and (2) choosing the exposure time which will print through the densest part, or highlight, of the negative, which must show detail.

The rule for correct rendering of tones on the paper is the same as for the negative; that is, the tones which fall on the straight-line portion of the curve are rendered correctly, and those which fall on the top and bottom portions of the curve do not reproduce the tones of the negative in their correct relations. As has already been said, however, the difference is that in the negative we can generally confine the scale of the subject to the straight-line part of the curve, while in printing we are forced to use the whole curve, including those portions which cannot give a perfectly correct rendering of the tones of the negative.

HP

The cycle of tone reproduction is illustrated in the somewhat fanciful diagram shown in Fig. 27. At the top, right, the sun is shown illuminating a black cross. This is viewed by the eye, which forms an image on the retina and an impression on the brain. When a photograph is taken, an invisible image of this cross is formed on film by a lens. The period of exposure is indicated as t_x, and this produces a latent image on the film. After the film is developed, fixed, and washed, a negative is obtained.

This negative is printed on paper. To make the process clear, the printing is shown to be done by means of a lens. The time of exposure of the paper is given as t_y. The print is developed, fixed, and washed, and the finished photograph shown at the top, left, is obtained.

The original subject was illuminated by the sun, but the finished photograph is illuminated by an electric lamp. There may, therefore, be a change in the subjective impression produced in the brain. If the viewing conditions are not the same, even perfect reproduction will not produce the impression made by the original subject.

All that can be done in photography is to reproduce the tones of the subject as faithfully as possible. This is accomplished as follows: (*a*) by an exposure which produces the image within the straight-line portion of the curve of the film; (*b*) by the development of this image to a contrast that fits the scale of the paper; (*c*) by the use of a paper that has as long a straight
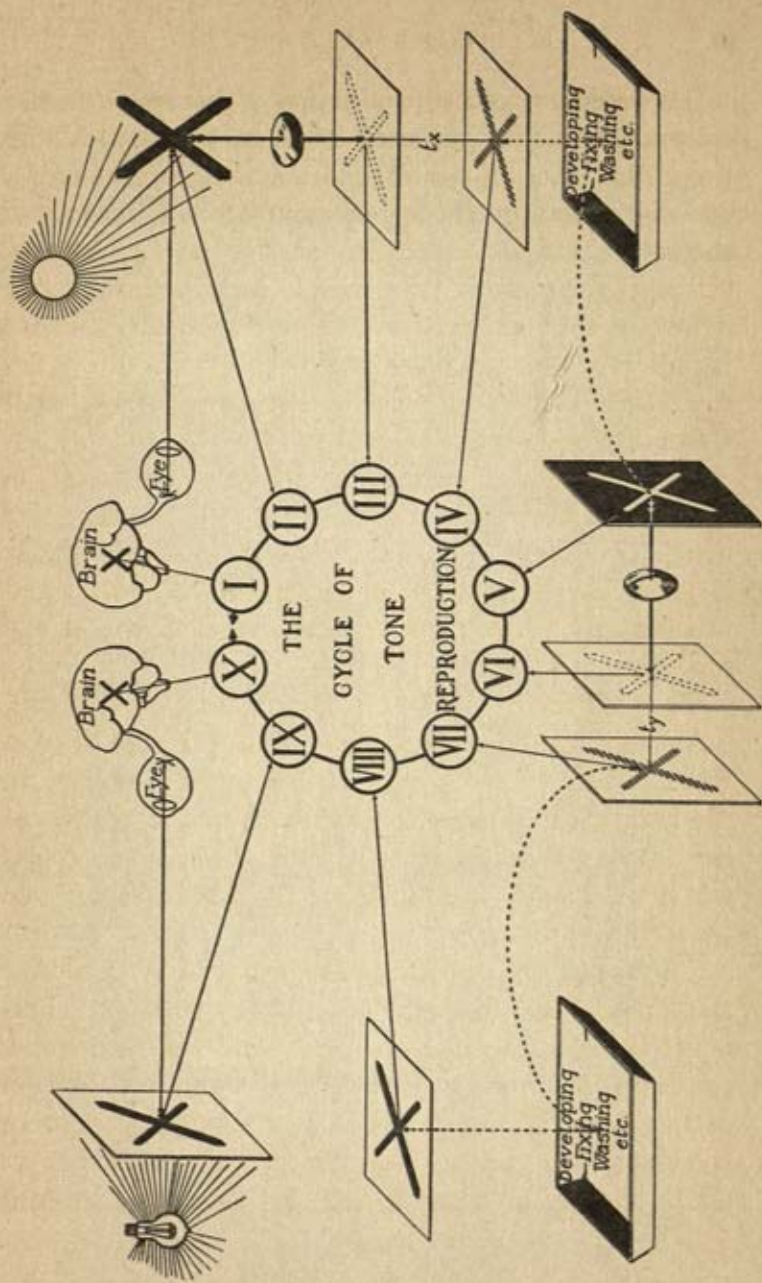
Fig. 27. A diagram of the cycle of operations in tone reproduction.

line as possible; and (*d*) by printing the negative on this paper with an exposure adapted to the density of the negative. In this way, and only in this way, can the truest possible reproduction of tone be attained.

PLATE 22

NEGATIVES

CONTRAST RANGE EQUAL
FOR ALL NEGATIVES

PRINTS

HIGHLIGHT
DENSITY

DENSITY
CONTRAST

SHADOW
DENSITY

5. VERY DENSE

E.

V. EXPOSED 20 SECONDS

HIGHLIGHT
DENSITY

DENSITY
CONTRAST

SHADOW
DENSITY

6. DENSE

F.

VI. EXPOSED 10 SECONDS

HIGHLIGHT
DENSITY

DENSITY
CONTRAST

SHADOW
DENSITY

7. NORMAL

G.

VII. EXPOSED 5 SECONDS

HIGHLIGHT
DENSITY

DENSITY
CONTRAST

SHADOW
DENSITY

8. THIN

H.

VIII. EXPOSED 1 SECOND

The effect of density of a negative on the exposure required
for printing. (*p.* 96)

PLATE 23

Silent (*left*) and sound (*right*) motion-picture positive films as used for projection. In the sound film, the sound track is between the picture area and the perforation. (*p.* 103)

CHAPTER VI

CINEMATOGRAPHY

IF a series of pictures are taken of a moving object so that they represent successive phases of the movement and are viewed in rapid succession at the rate at which they were taken, the object will appear to move. In order to get an appearance of movement without jerks, it is necessary to take a sufficient number of pictures in a given time; if at least sixteen pictures a second are taken, the movement blends smoothly and appears continuous. All the earlier motion pictures were taken at this rate – sixteen pictures a second.

Motion pictures are taken upon a continuous band of film which is perforated along the edges so that by means of sprockets it can be driven rapidly through the camera; the movement of the film is not continuous, however, because it is necessary for the film to stand still while the picture is taken and be moved only while the lens is covered. The film is therefore moved through the camera intermittently and, similarly, the pictures are viewed by being projected intermittently upon a screen. The film which is used is 35 mm. wide (almost exactly $1\frac{3}{8}$ inches); the height of the picture is $\frac{3}{4}$ inch; and the perforations

along the edges are $\frac{3}{16}$ inch apart, so that there are four perforations in the height of each frame. In a motion-picture camera, of which the diagram is shown in Fig. 28, the film is pulled from a supply roll by means of the sprocket, of which the teeth fit into the perforations of the film. The sprocket feeds the
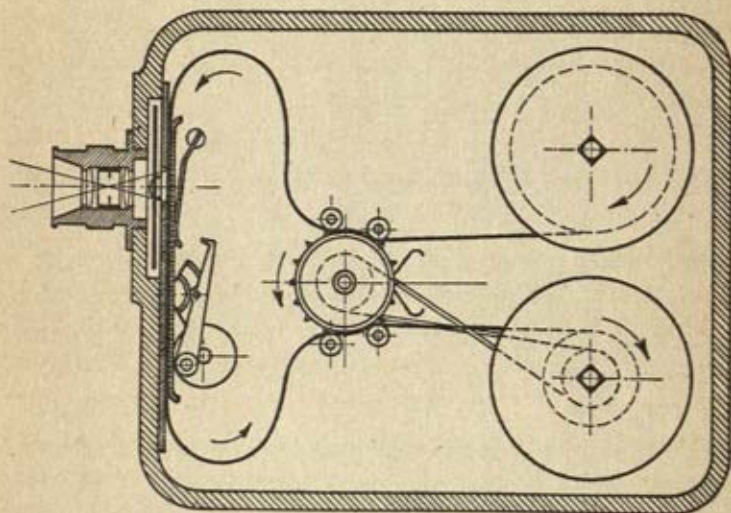
Fig. 28. Diagram of a motion-picture camera.

film forward continuously into an upper loop, which permits the necessary play in travel, and then the claw engages intermittently with the perforations in the film and pulls it down quickly through the *gate*, one picture frame at a time. From the gate, the film passes into a lower loop and from that is continuously passed under the sprocket on to a *take-up reel*, on which it is wound up. In operating, the claw suddenly pulls

the film out of the top loop into the bottom one, and then, while the film is still, the upper loop is again increased by the continuous feeding of film from the sprocket and, similarly, the lower loop is correspondingly decreased. Between the lens and the gate, where the picture is formed, there is a rotating shutter. While the open part of the shutter is in position, so that the image is falling on the film, the film is stationary; and then, when the shutter cuts off the light, the claw pulls down the film.

For silent pictures, the picture was exactly one inch wide, but at the present time pictures are always made to be accompanied by sound, and this has necessitated a reduction in the size of the picture, so that the positive film appears as is shown in Plate 23, where it will be seen that between the picture area and the perforations there is a *sound track*. When the negative film is exposed, a mask is put in the camera, so that the proper area of the film is used; and a similar mask is used in the finder, so that the composition can be exact.

The introduction of sound has also necessitated a change in the taking speed, and instead of sixteen pictures a second being taken, sound pictures are made at the rate of twenty-four pictures a second, and the camera is driven by a motor which is controlled very accurately to this speed, since any variation in speed would cause the motion to get out of synchronism with the sound.

The cameras used in motion-picture studios are

beautiful pieces of engineering work, costing hundreds of pounds, and are distinctly heavy and complicated. They are equipped with several finders, by which the scene can be viewed or focused on the film. The lenses are carried in a rotating turret or in changeable mounts, so that lenses of different focal lengths can be used on the same scene without the cameras being moved. They are fitted with auxiliary apparatus by which *dissolves* and *fades* can be made and by which portions of the scene can be masked out. Not infrequently, the camera is carried above the set on a crane, which accommodates camera and cameraman and can move them easily to different points. In Plate 24, the crane is carrying the camera, the director, and the cameraman, besides an auxiliary lamp, over water full of alligators, the actors posing on a bridge. For news and topical photography, portable cameras are employed. An important attachment to these cameras is that by which high-speed motion pictures can be made, these being taken usually at eight times standard speed. When such pictures are projected on the screen, everything appears to move at one-eighth the standard speed. This feature is used both for the analysis of motion and also to produce interesting or absurd effects. Sometimes, news photographers use portable hand cameras driven by spring mechanisms. Such a camera makes possible effects which would be very difficult to obtain in a standard camera. Thus, it can be placed on the ground in front of an onrushing train and a photograph obtained

PLATE 24

Crane carrying the motion-picture camera, the director, and the cameraman, as well as an auxiliary lamp. *By courtesy of 'International Photographer,' Hollywood.* (*p.* 104)

PLATE 25
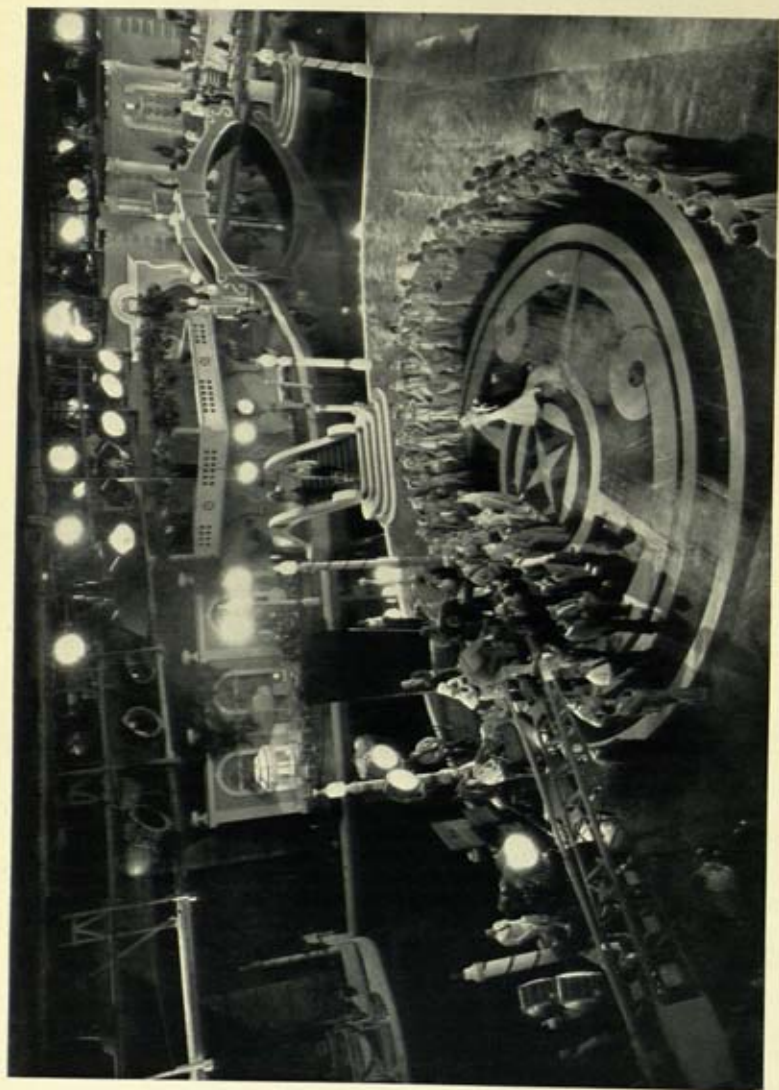
A set showing the lights and the cameras in the foreground.
By courtesy of Radio Pictures, Hollywood. (p. 106)

without any difficulty or danger, whereas an ordinary camera would require the excavation of a pit and a considerable amount of risk for the operator.

The lenses used on motion-picture cameras are almost invariably of large aperture, $f/3\cdot5$ being about the minimum for the standard lenses, while frequently greater apertures are used, up to a maximum of $f/1\cdot5$. The standard focal lengths are 2 inches (50 mm.) and 3 inches (75 mm.), although for special work lenses of longer focal length are often used, 4 inches and 6 inches being common. For the photography of wild animals, etc., very long-focus lenses are often used, it being possible, by the use of a very steady tripod and an auxiliary support for the lens, to use a focal length as great as 17 inches. All these lenses are of the anastigmat type, and every type of photographic objective, including tele-objectives, is used in motion-picture work.

In the early days, motion pictures were taken out-of-doors or in simple studios arranged so that sunlight could be used, but, as the art progressed, studios became more complicated and artificial light has been employed to an increasing extent. When the recording of sound became standard practice, it was necessary for the studios to be completely soundproofed and enclosed, and at the same time it was necessary for the light sources to be quiet; these requirements produced a very considerable change in motion-picture studio practice. At the present time, almost all scenes are taken in the studio, many of those

which appear to be taken out-of-doors being really taken indoors because of the advantage of the control of light and sound which the studio affords.

A modern studio in Hollywood is called a *lot*. On the lot are a number of buildings. In front are the offices and workrooms for the general staff and the technicians and perhaps a *laboratory*, where the film is developed and printed, as well as a number of projection rooms, in which the pictures can be viewed as they are made. The greater part of the lot, however, is occupied by large soundproof structures called *sound stages*. These are of a double wall construction that practically excludes outside sounds. There is an air space between the walls, and the walls themselves are covered on both sides with soundproof material. Most of the sound stages are about 100 feet wide by 50 feet high and 300 feet long, but sometimes they are larger than that. One stage has a width of 150 feet and a length of 450 feet. There are no windows, and the huge double doors are constructed like the doors of safes. These doors are big enough to permit entire walls of sets to be brought in from the carpentry shop without being dismantled. A complete system of artificial ventilation is provided. An idea of the appearance of one of these large stages will be seen in Plate 25. The great number of lights used will be observed; the cameras are scarcely visible, but they can just be recognised in the foreground. A somewhat more intimate picture will be seen in Plate 26a. Some of the lamps used for

lighting are arc lamps, which have been very effectively silenced, but most of them are tungsten filament lamps similar to those used in houses but very much bigger.

The first step in making a motion picture is to secure a satisfactory story, which is chosen usually by the executives of the company. This is adapted for the screen by a professional writer collaborating with the director of the picture, who will take full responsibility for it until it is ready for release. Under this director, there is built up the staff of the *production unit* – the cameraman, the art director (who designs the sets), and others, and as the *script* is prepared it is circulated for suggestions and criticisms. Next, the *production schedule* is prepared. It is usual not to *shoot* the scenes in the order in which they are finally to be assembled but rather to take all the scenes requiring a particular set or a particular company of characters at one time. Directors differ greatly in the way in which they work. Some follow the prepared manuscript exactly, while others make their plans largely as they go along. However, now that scripts contain dialogue, the director is forced to follow the copy fairly closely. When everything is ready, the casting director secures all the actors necessary for secondary characters, the principals having been assigned to the picture from the beginning. The actors who take no part in the dialogue are called *extras* and are engaged usually by the day, being told to report at a fixed hour for rehearsal.

When work on the stage starts, the cameraman arranges with the electricians to place the lights, and the sound technician places his microphones in the position required to record the sound. At the same time, the microphones are connected to the recording mechanism, and a specialist listens in from what is called the *monitoring room*, so that he can hear everything that will be recorded (Plate 26b). Quite often, the best position for the camera would include the microphone in the picture if it were placed in the best position for sound recording; in this case, the cameraman and the sound technician must settle between them, sometimes with the assistance of the director, how the scene is to be photographed and recorded at the same time. Next, the director explains to the actors exactly what he wants them to do, and the scene is rehearsed until everything is running smoothly. Meanwhile, the cameraman and his assistant check the lighting, and the sound technician checks all his equipment. The director is then notified that everything is ready; and the camera and recorders are started as the actors take their positions. But before the action starts, as the camera is running, a man steps in front of it and claps two boards, so that there will be a starting-point on the camera film and at the same time a sharp sound recorded by which the beginning of the scene can be synchronised (Plate 27a). He steps back quickly, the actors go through their lines, the synchronisation man steps in again, and the scene is ended. It often takes much of a

PLATE 26

(*a*) A 'close-up' of cameras on a set. *By courtesy of Radio
Pictures, Hollywood.* (p. 106)

(*b*) A sound-recording expert in a sound-proof glass booth.
The microphone is seen near the actor's head. *By courtesy of
Radio Pictures, Hollywood.* (p. 108)

PLATE 27

(*a*) Before each 'take,' an assistant holds the signal board where the camera can photograph information indicating the number of the sequence, the number of the 'take,' the date, the picture number, and other details. The use of a 'clapper' at this point ensures sound synchronisation. *By courtesy of Radio Pictures, Hollywood.* (*p.* 108)

(*b*) A miniature set. *By courtesy of Paramount Studios, Hollywood.* (*p.* 110)

day's work to obtain a few minutes on the screen, and not infrequently scenes are taken over and over again before the director is satisfied.

All the pictures made each day are developed at once, and a *rush print* is viewed by the director and his staff, so that, if necessary, scenes can be retaken before the set is dismantled. This procedure is carried through scene by scene and set by set until the picture is completed, a feature picture usually taking from three to six weeks.

When outdoor scenes are photographed, a whole company may go *on location*, that is, to a place where the scenery and surroundings are suitable for taking the pictures – the sea, for instance, or the mountains, or the desert. It is the convenience of its position which caused Hollywood to be selected as the centre of production for the American motion-picture industry. There is a great variety of scenery within a short distance and locations can be found for most purposes without going very far. For sound recording out-of-doors, the apparatus is carried on a special truck equipped with the mechanism necessary for the purpose.

The *sets* used in the motion-picture studios are marvellously accurate and are given a great deal of study by the art director and his staff. In one recent story, a village was required as a background for a picture, and it would naturally be thought that this village would either be chosen from existing villages or be erected in a convenient part of the lot. In actual

fact, the art director built the entire village indoors on one of the sound stages, and the cinematographer arranged his lighting so that he could control it and make morning, noon, or evening shots exactly as they would appear if the village were lighted by sunlight. The cost of lighting so large a set instead of using natural light was high, of course, but the avoidance of all delays due to weather and the complete control of both lighting and sound was so great an advantage that the cost of production was reduced.

Many of the pictures which appear to be taken in the most difficult places are actually photographed in the studio by the use of miniatures (Plate 27b).

Transparencies or projected pictures are often used as backgrounds to reduce the cost of making pictures. The scenes taken in this way are known as *process shots*. Various methods are used for combining the background shot with the action in the foreground. Let us suppose that a scene taken in Egypt is required. A picture made near the pyramids is obtained, showing Arabs on their camels. This scene is projected from the rear on a transparency screen in the studio, and the actors are placed in front of the screen with the lighting arranged to harmonise with that of the projected picture (Plate 28).

When all the scenes for a picture have been made, they must be assembled, and this involves not only assembling the scenes in the right order but supplying all the necessary accessory sound, which is now prepared for insertion into the final picture. Only the

PLATE 28

A set including a moving-picture background. *By courtesy of 'Photoplay' Magazine, New York City.* (p. 110)

PLATE 29

A film laboratory: *Above*, Film entering developing tanks; *Below*, Film leaving the drying cabinets. *By courtesy of Metro-Goldwyn-Mayer, Inc., of Hollywood.* (p. 111)

dialogue, as a rule, is recorded at the time that the scene is shot unless the essence of the scene is the recording of sound, such as music or song. The incidental music, and probably a number of accessory sounds, are recorded later and inserted in their proper places. The assembly of the picture is known as *cutting*, partly because the film is actually cut, and partly, no doubt, because the film is very much shortened in the process, it being usual to take a number of scenes which are not used finally. The cutter is an expert in that particular work, although often the director takes a great part in the assembly of the film to make sure that his ideas are carried out in the finished picture. The picture is usually cut first to a finished picture, with the scenes in the right order, and the sounds inserted, but of considerably greater length than would be feasible in its final form; this is reviewed by the production staff of the studio, the final cuts are made, the negative is assembled, and a final print is made for review and sent with the negative to the printing laboratory so that the release prints can be made. A *feature* picture to-day is, on the average, 7,000 or 8,000 feet in length (7 or 8 reels) and may have used from 100,000 to 200,000 feet of original negative film.

The factory where the film is developed and the prints are made is called a *film laboratory*. The negative film is printed by contact on to positive film which is run continuously with it through a printer, the exposure being controlled by variation in the

amount of light allowed to fall on the film. The positive film, after being printed, separates from the negative and comes into contact with the sound-track film, which prints the sound track. The print is then developed in a continuous machine, in which it passes through a series of tanks containing developer, rinse water, fixing bath, and washing water, and then passes through a drying cabinet (Plate 29).

The finished film is distributed through *film exchanges*, which supply the theatres with the films for projection, the theatres having already contracted with the distributors for the pictures. In order to prevent accidental interruptions during a performance, the film is very carefully inspected after each projection, and any doubtful joins are replaced.

Just as the introduction of sound involved great changes in the motion-picture studios, so it required a very notable modification of the theatres. The theatres had to be designed not only for seeing the picture but for hearing it, and this demanded a careful study of their acoustical properties. The walls are treated with sound-absorbent material to prevent undue reverberation, while at the same time it is important that the room should not be too dead; that is, there should be a certain amount of reverberation, since otherwise the sound would be unsatisfactory. The seats are arranged so that the size of the audience will not make much difference to the acoustical properties of the room. The screen itself is permeable to sound, and behind it is placed the

loud-speaker system by which the sound is reproduced. At the back of the theatre and above the audience is the *projection room*. Here will be found a group of projectors in which the picture is projected by means of an arc lamp, and the sound is picked off the sound track in a special gate. Two projectors are used, so that the picture can be projected continuously without interruption, one projector being started as the end of the film is reached in the other.

Just as the film is moved intermittently in the camera while the picture is being taken, so the finished picture is moved intermittently during projection, but in a projector the film is usually not pulled down by means of a claw but by means of a sprocket over which the film runs and which is operated intermittently by what is known as a *Maltese cross*

IP
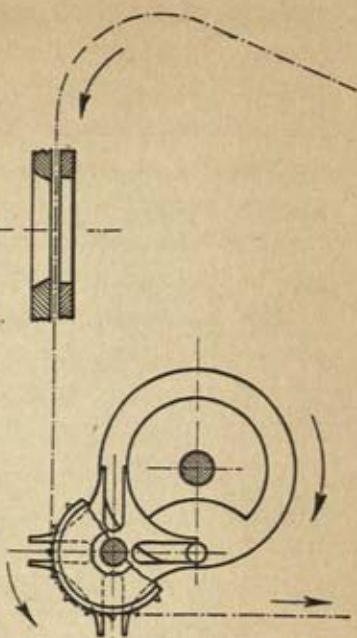
Fig. 29. Maltese cross intermittent movement in a motion picture projector.

The circular wheel rotates continuously, and the pin enters the slotted arms of the cross and carries it intermittently through a right angle. The cross is attached rigidly to a sprocket with sixteen teeth, which is moved through one-quarter of its rotation for each rotation of the driving wheel, and this moves the film through four perforations, the length of one picture frame.

movement, or *Geneva* movement. This is shown in Fig. 29, the cross-shaped piece being attached directly to the sprocket. The pin which is seen just entering the cross is on the rotating wheel, which is moving continuously, and after the pin enters the slot, it moves the cross through a right angle; and then the pin leaves the slot and does not enter it again until the wheel has gone through one complete revolution. In this way, the continuous movement of the projector operates the sprocket intermittently.

At the present time, the light sources used in the projectors are either high-intensity arcs having carbons loaded with chemicals or mirror arcs in which the crater of the arc is turned away from the gate and the light from it is thrown forward by a large concave reflector. For projection at a short distance or for small screens, good results are obtained by the use of high-intensity incandescent lamps.

A great deal of work has been done on continuous projectors in which the film moves through the gate continuously and the image is kept stationary upon the screen by means of some optical system of recti-fication, such as a rotating ring of lenses which com-pensate for the movement of the film, or rotating prisms or mirrors which hold the image still. These machines have not come into general use, though some of them appear to be mechanically satisfactory.

When motion pictures were first made, it was the intention of the pioneers to associate the representa-tion of motion with the reproduction of sound. In

some of the very earliest experiments a phonograph was linked with the projector, so that the sound would be reproduced in synchronism with the picture. The practical difficulty, however, was that the sound was not of sufficiently good quality and at the same time of sufficient loudness for its use in a theatre. The early phonographs, in which the record was reproduced from a disc on which a track had been traced, had a very limited volume and range of sound and produced a good deal of scratch noise, so that their use in the theatre was quite unsatisfactory.

The development of the reproduction of sound in connection with motion pictures was made possible by progress in electrical methods for the recording and reproduction of sound. This was because electrical methods enable the sound to be produced in any required volume, since the electric currents can be amplified by means of valves as are used for radio and for other electrical work.

When the first successful sound pictures were introduced, using valve amplifiers, the sound record itself was often recorded on a disc and reproduced in synchronism with the projected picture. The vibrations imparted to the needle operating in the grooves of the disc were used to cause variations in an electric current, which could be amplified and reproduced through an electric loud-speaker. At the present time, however, a photographic sound record on the edge of the picture film is almost invariably used.

The operations by which sound is recorded and

reproduced are illustrated in Fig. 30. The sound
shown emerging from the bugle falls upon the micro-
phone, and there the pressure waves of the sound are
converted into variations in an electric current. These
variations are then amplified and are used to control
the intensity of a light, so that the variations of sound
become variations in light intensity. These are
recorded on a film running at the standard speed of 90
feet a minute, and when the film has been developed
and dried, it is printed on to the positive film which
carries the picture. Care is taken, of course, to print
the sound so that it will be in synchronism. The
sound in a projector is not reproduced at the same
place as the picture but at a point 15 inches later,
where the film is moving continuously, the film passing
through the sound gate after it passes through the
picture gate. In the sound gate, where the film is
running continuously and quite evenly, the light of a
small lamp passes through the sound track and falls
on a photoelectric cell. The sound track produces
variations in the intensity of the light, which should
be exactly the same as those which occurred in the
intensity of the light by which the sound track was
recorded, and which in turn are the same as the
variations in the air pressure produced by the original
sound. This varying beam of light in the projector
falls on a photoelectric cell, from which there is
produced an electric current which varies in intensity
just as the light varies, and therefore in the same
way as the original sound. The current from the

XII
EARS OF AUDIENCE

XI
LOUD SPEAKER CONVERTING ELECTRICITY INTO SOUND

I
SOURCE OF SOUND

II
MICROPHONE CONVERTING SOUND INTO ELECTRICITY

AMPLIFIER X

III AMPLIFIER

IX
PHOTOELECTRIC CELL

REPRODUCER CONVERTING THE VARIATIONS IN TRANSMISSION OF THE FILM INTO ELECTRICAL ENERGY.

MODULATOR CHANGING THE INTENSITY OF A LIGHT IN ACCORDANCE WITH THE ELECTRICAL INTENSITY.
IV

FILM RECORDING THE LIGHT INTENSITY ON THE SOUND TRACK OF THE NEGATIVE.
V

DEVELOPMENT ETC. OF THE POSITIVE
VIII

VII

DEVELOPMENT ETC. OF THE NEGATIVE
VI

PRINTING THE NEGATIVE ONTO THE POSITIVE FILM CONTAINING THE PICTURE

Fig. 30.   Cycle of operations in sound recording.

photoelectric cell is amplified and passes into a loud speaker, in which the variations in electricity are converted back into sound. The whole cycle represents the most astonishing series of transformation of energy. We have

SOUND ENERGY
↓
going to
↓
ELECTRIC ENERGY
↓
going to
↓
LIGHT ENERGY
↓
going to
↓

CHEMICAL ENERGY (in the formation of the photographic image).

VARIATIONS IN THE IMAGE
↓
become
↓
LIGHT ENERGY
↓
going to
↓
ELECTRIC ENERGY
↓
going to
↓
SOUND
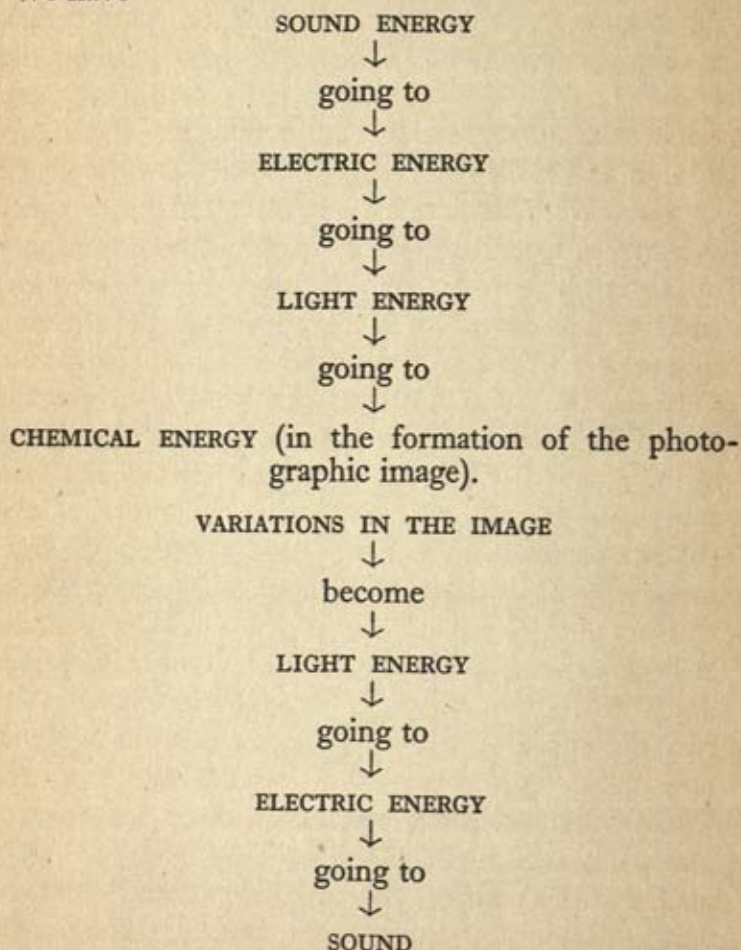
The transformation into electricity enables amplifiers to be used because we cannot directly amplify sound or light, but we can amplify the variations in an electric current.

Two kinds of sound tracks are used, produced by different kinds of recorders. In one, the sound track is of constant width but varies in density along the film; while in the second, the track varies in width but is of constant density (Plate 30a). It will perhaps be sufficient if the recorder for a *variable density* record is described. In Plate 31 (top), we see the recorder as a whole. At the top, on the right, is the film supply magazine; below, the take-up magazine for the film; and in between, the box containing the driving mechanism. On the extreme left is seen the lamp box. Between the lamp box and the film is an electric galvanometer and a series of lenses by which an image of the lamp is focused on the galvanometer, and then the galvanometer on the film. The heart of the galvanometer is the light valve, which consists essentially of two narrow ribbons of wire. These ribbons of wire are held rigidly in position, and the electric current coming from the microphone passes down through one and up through the other. The two ribbons of the light valve form a slit with an opening of approximately 1/1,000th inch, and the whole valve is fitted in the field of an electromagnet so that the magnetic lines of force are at right angles to the plane of the ribbons. Thus, when the current from the microphone passes through the

ribbons, they move in accordance with the intensity of the current, because the two ribbons in a magnetic field are attracted or repelled, depending on the direction of the current passing through them; and so the slit widens and narrows in accordance with the variations in the intensity of the current, and this produces corresponding changes in the amount of light from the lamp falling on the film.
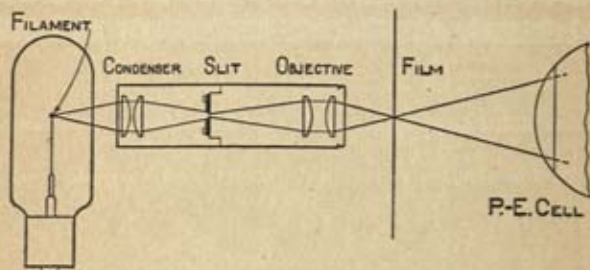
Fig. 31. Diagram of the sound reproducer.

The reproduction of the sound in the projector (Plate 30b) is effected by an apparatus of which a diagram is given in Fig. 31. As the film travels, the variation in the opacity of the sound track produces corresponding changes in the intensity of the light falling on the photoelectric cell and so regulates the amount of current flowing through the photoelectric cell and its associated electrical circuit.

Animated Cartoons

Animated cartoons are essentially burlesques of life, and by photographing drawings instead of actors,

PLATE 30
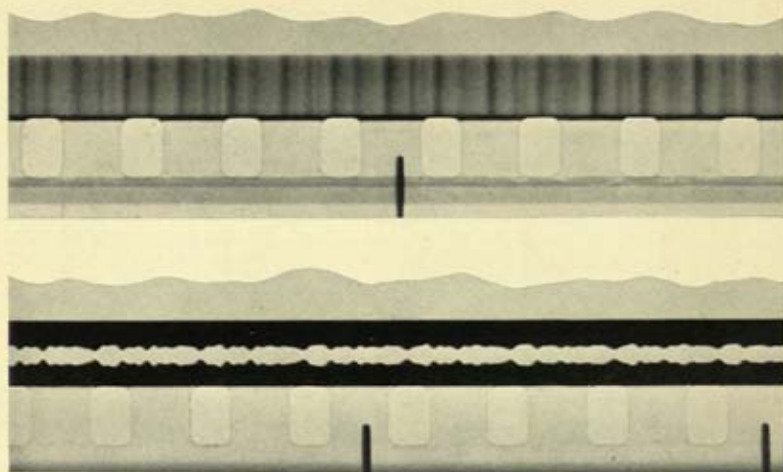
(*a*) Sound tracks of variable density and variable area types.
(*p.* 119)
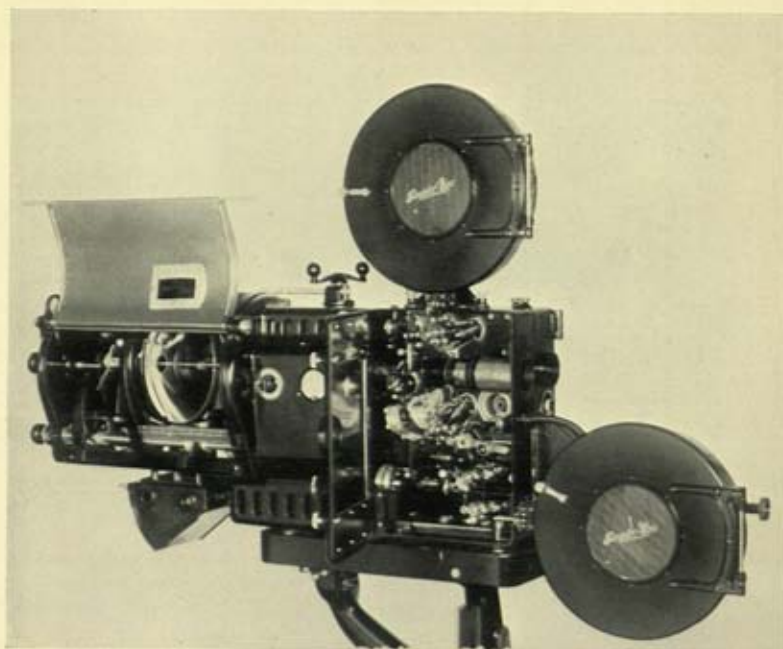
(*b*) A sound projector. *By courtesy of the International Projector Corporation, New York City.* (*p.* 120)

PLATE 31
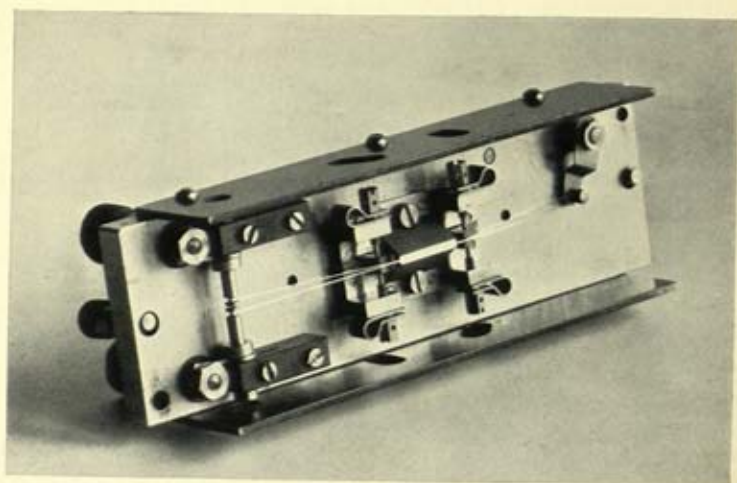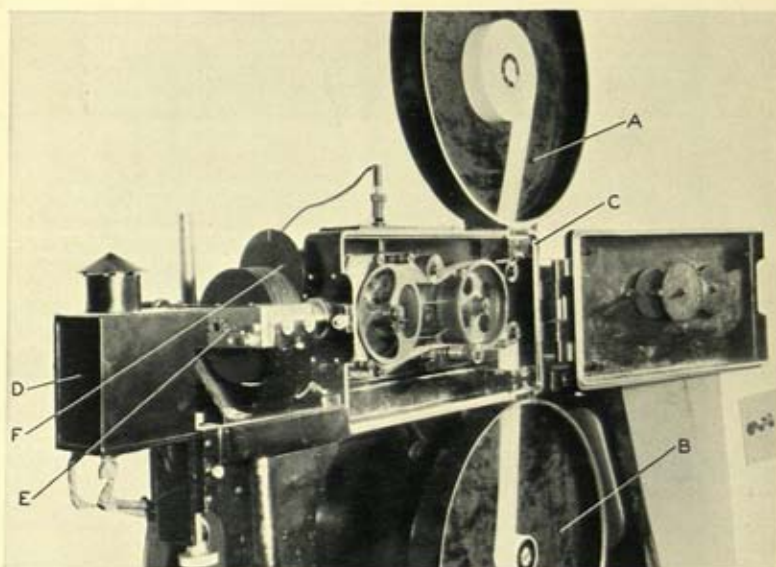
Above, A sound recorder: A, Film supply magazine; B, Film take-up magazine; C, Box containing the film driving mechanism; D, Lamp box; E, Light valve; F, Electromagnet for the light valve. *Below*, Enlargement of the light valve. (*p.* 119)

the range of possibilities is very greatly extended. The characters are drawn in pencil on paper, and for any change in position from frame to frame on the motion-picture film a separate drawing is required; that is, a drawing for almost every frame, so that a cartoon lasting about ten minutes on the screen may require from five to ten thousand separate drawings. The whole picture, of course, is not drawn each time. For each scene, the background is first drawn and then the drawings of the various actors are traced on sheets of transparent celluloid, which by the aid of registering pins are superimposed on the background. By means of these registration pins, which are used throughout the entire process, accurate registration of the action is maintained successively by the artist, tracer, and, finally, by the cameraman. Generally, a number of the sheets of celluloid or *cels* are used, the top one containing those parts of the picture which are moving most rapidly and which as a rule must be changed every frame, so that there must be twenty-four different top sheets for every second that the picture is run. A set of these drawings is shown in Plate 32. At the top left-hand corner is shown a completed scene as it appears on the cartoon. In the top right-hand corner is shown the background, which is stationary and is changed only when the whole scene changes. In the lower left-hand corner are shown two characters which move through the scene, and it will be seen that, from the bear, the head and arm are missing. These are the parts which move most

rapidly, and they are shown in the right-hand bottom corner. The finished frame can then be made up by superimposing the two cels on the background, where they are registered by the registering pins which fit into the holes in the celluloid sheets. The registering pins are fitted on a special table, over which the camera is placed. When all the drawings have been made and transferred to the celluloid, the camera photographs the pictures frame by frame on this table.

Soon after sound was applied to motion pictures, it was used in the production of animated cartoons. Either one of two methods may be used in recording. In the first, the sound may be added after the photography has been completed. A print of the picture is screened for the musicians and sound effect operators, who take their cue from an animated bouncing ball or metronome which appears in the area allowed for the sound track and which was photographed along with the picture. This method is not as accurate or as satisfactory as the alternative method, which is the one now generally used: in this, the artist and musician together plan the entire production – picture and sound – on a frame-to-frame basis. For certain scenes the picture is designed to conform to the music, while in other scenes the musician writes special music to conform to the action of the picture. By this means, it is possible to produce the two elements separately and secure absolutely accurate synchronisation later, when the two negatives are combined. It is necessary that the movement of the cartoon
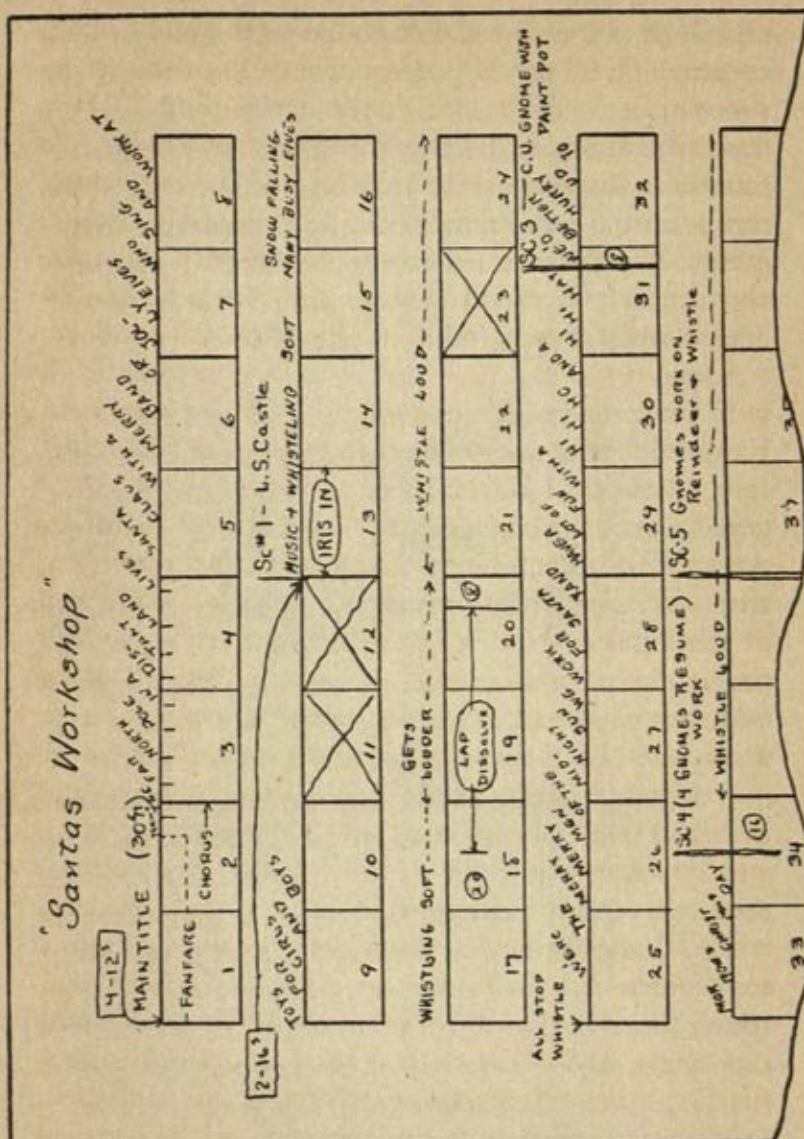
Fig. 32. A lay-out sheet used for planning an animated cartoon.

should fit the tempo of the music and therefore this is determined at the beginning for each scene of the picture; for instance, the fastest tempo will be four beats a second, and in this case we must have six frames of the picture for each beat of music, and the action must be split into multiples of six-frame movements. Since there are twenty-four frames a second, six frames a beat will give us four beats a second. The slowest tempo used is one beat every twenty frames.

In order to make a cartoon, a draft of the story is prepared, and then this is planned on what is called a *lay-out sheet*. One of these is shown in Fig. 32, which shows the beginning of the lay-out sheet for the Silly Symphony *Santa's Workshop*. On this, each space represents a bar of music, and the tempo at the beginning is indicated as four twelves, so that each bar covers forty-eight frames of action. The musical director writes his preliminary score, and the action is planned for each scene. Then the background sketch is made, which serves as the stage set, and the animator makes a series of progressive drawings that tell the story and the ideas incidental to it. The animator makes drawings of only the extreme action, and an assistant makes the intermediate drawings, all of these being on a piece of paper the size of the celluloid, on to which they are traced in Indian ink; then the back of the figure on the celluloid is blocked out to make it opaque, so that the background will not show through. Dialogue is recorded before the drawings are made

and is analysed into terms of frames, so that the drawings can be fitted to it as they are to the music.

In many of the earlier cartoons, figures produced by animation were introduced into backgrounds produced by direct photography, and in this case the moving picture showing the background was projected from below, and the sheets of celluloid carrying the figures were placed above the projected image, sheet by sheet, so that the whole could be photographed at one time. The opaque figures served as a mask which left unexposed the areas which they covered. The negative film was then rewound, a black mat substituted for the background, and the action of the figures illuminated from above was photographed for the second time. It was in this way that Fleischer's pictures showing the little clown coming out of the inkwell were made. At the present time, however, animated cartoons are purely fanciful and, with the addition of colour, are tending more and more to be illustrations of fairy stories which hitherto have chiefly been drawn from the world's stock of old tales. It is not improbable that in the future the artists who are engaged in this work may find it necessary to create their own fairy stories.

Amateur Cinematography

Motion-picture photography was developed entirely for professional purposes, being used almost exclusively for the preparation of films to be shown in

theatres; very few amateurs undertook to make their own films. Perhaps the greatest reason for this was the cost of the apparatus and the expense involved in using it. In addition, professional motion-picture cameras are large and heavy, and motion-picture projectors, even of the so-called portable type, occupy a good deal of space.

The general use of motion-picture film by amateurs dates from 1923, when small portable cameras were introduced on the market. These used a smaller size of film and, at the same time, the pictures were finished by a method which greatly lowered the cost.

When a small film is used, the need for accuracy is increased, although, fortunately, the strains both on the film and on the mechanism are decreased. The lenses must be of the highest quality, since the small pictures will be enlarged to a greater degree than big pictures and must consequently be sharper. The mechanical accuracy must be higher, since any failure in perfection of register will be perceptible. The photographic quality must be at least as good as that of standard pictures if the user is to be satisfied with the result. The quality thus depends upon three conditions:

1. The optical perfection of the systems used in the camera and projector, on both of which depends the sharpness of the pictures;

2. The mechanical perfection, on which depends the steadiness of the pictures on the screen;

3. The photographic quality of the emulsion and

PLATE 32
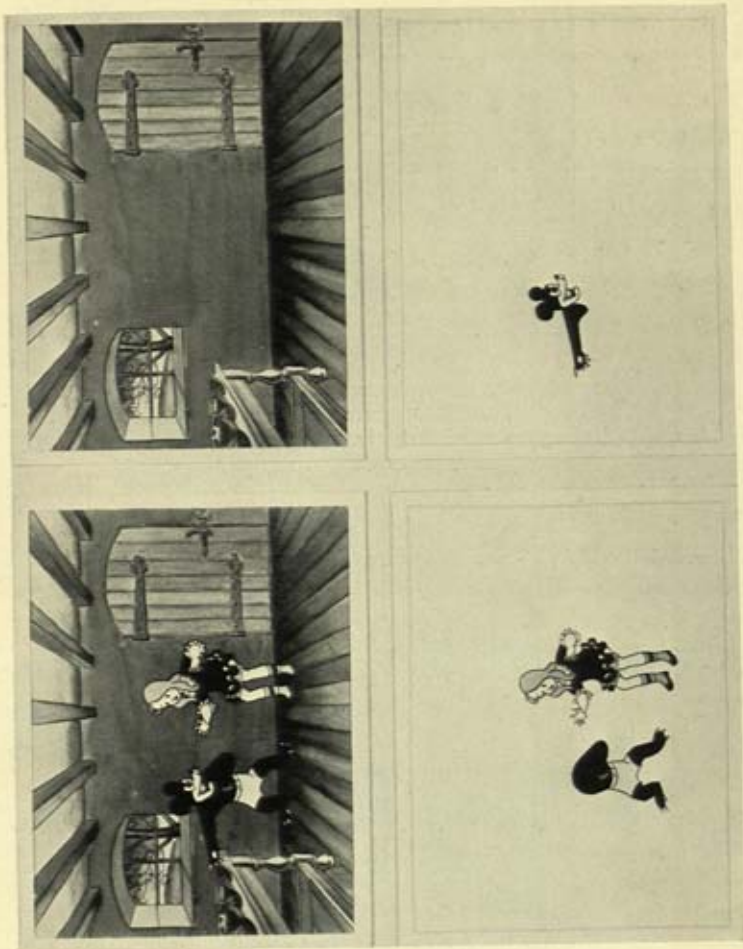
Original drawing for an animated cartoon. (p. 121)

PLATE 33

(a) The graininess shown by an ordinary camera image when greatly enlarged. *A*: Representing original, small image. At right: Enlargement of small image to 55 diameters; showing graininess. (*p.* 127)

I   II   III

(b) Sizes of amateur motion picture film: I, 16 mm.; II, 9.5 mm.; III, 8 mm. Unslit and therefore double width. (*p.* 132)

the finishing process used, on which depends the faithfulness with which the brightnesses in the light intensities in the original pictures are reproduced and the consequent fidelity to Nature and, also, the appearance on the screen as regards any structure or graininess in the picture.

A photographic image is composed of small clumps of the microscopic silver grains, and when it is very much enlarged, these clumps show. In Plate 33a we see at the left, at A, a very small image, and on the right an image of that size enlarged fifty-five diameters. It will be seen that the detail of the image is lost owing to the graininess shown. The graininess in ordinary motion pictures is very slight but is visible when the observer stands close to the screen, and it is clear that if pictures are used which are much smaller and they are enlarged to the same size on the screen as standard pictures, the results will be inferior. Unless something is done to diminish the graininess, the results will not be satisfactory in comparison with the pictures shown at the theatres. Moreover, even when a smaller film is used, the cost, although diminished, is still high; a negative must be developed and a positive printed from it. This printing requires very skilled work. It is rare in standard motion-picture practice for the first print from a negative to be entirely satisfactory, and to get a single print of high quality from every negative would be very difficult. The use of a small film treated like the regular film would, therefore, present two difficulties – high cost,

or low quality of results and the graininess of the image.

The ideal process for amateur use is clearly one in which the original picture is available for projection on to the screen. In still photography, it is an advantage to make negatives because usually a number of prints are required of each picture; but in motion-picture work, in most cases, an amateur is interested in getting only a single print, and there are great advantages in a process which enables a positive to be obtained by the direct treatment of the original exposure. In the *reversal process*, the exposed image is developed, and then the developed silver is dissolved in a *bleaching* bath, which oxidises the silver. This leaves behind the undeveloped silver bromide, which was not affected by the developer because it was not exposed to light. After a fresh exposure to light, this remaining silver bromide is developed in its turn and gives a positive. This is illustrated in Fig. 33, which is a drawing made from pictures taken through the microscope. In Section A, we see the grains of the light-sensitive silver bromide in the emulsion, and in Section B there are marked, by cross-hatching, those which have been affected by light during exposure in the camera. They would not show any change to the eye, of course, because the change by light is not visible. These grains form the latent image.[1] After development, these exposed grains turn into black metallic silver, and this is shown in

[1] See Chapter IV, p. 58.

Section C of the diagram. Then the bleaching bath removes all the silver and leaves behind the silver bromide grains which were not exposed, as shown in Section D. These are re-exposed and developed and make the final positive, as we see in Section E.

The processing is done on machines consisting of a number of tanks which carry racks with rollers by means of which the film is fed continuously through the solutions. The machines are entirely automatic, the films being fed in as they come from the customer and taken out of the drying cupboard as positives ready for projection. As the film travels through the machine, it is first

KP
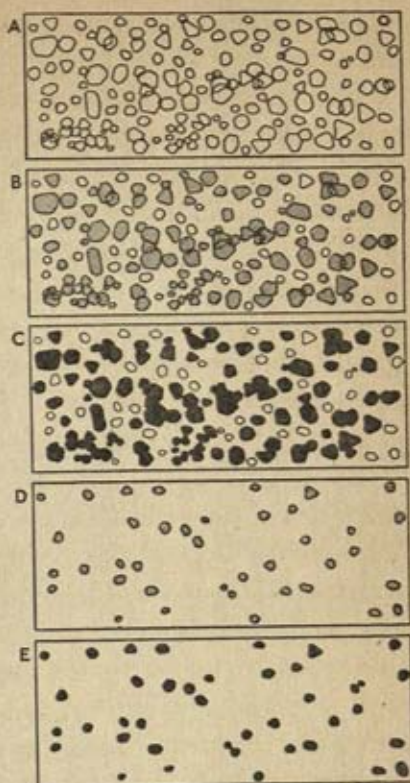
Fig. 33. Progressive steps in the reversal process.

A. Diagram showing the unexposed grains of silver bromide in the film.

B. The largest and most sensitive grains are exposed in the camera.

C. The exposed grains are developed to form a negative image.

D. The developed grains are removed by a bleaching bath which dissolves silver, leaving the undeveloped grains, which are now exposed.

E. These grains are now developed, forming a positive image.

developed to a negative, the developed silver is then removed in a bleaching bath, the film is cleared of the bleach and re-sensitised, and it is then exposed to an extent dependent upon the original exposure and controlled by the optical density of the film itself.

If in the camera heavy exposure is given, much of the silver will be developed at the beginning, and when this is removed there will be only a small amount of silver bromide left to be used for the production of the positive. It is necessary, therefore, to give a very heavy exposure in order to make all this developable and so get enough density in the image. On the other hand, if the camera exposure is light, there will be a great deal of undeveloped silver bromide available to form the final image, and it is necessary to give only a short second exposure, as otherwise too dense an image will be produced. The control is effected by the passage of the film between a source of red light and a thermopile. The heating effect of the red light passing through the film produces a current in the thermopile. This current controls a galvanometer vane, which is interposed in an optical system, by means of which a beam of white light is projected upon the film. The second exposure is thus dependent upon the current in the thermopile and, consequently, upon the transmission of the red light by the film. After this second exposure, the new image is developed as a positive. As the film travels forward through the machine, it is fixed,

washed, and dried, and is ready for projection about an hour after entering the machine.

The pictures made by this reversal process are very satisfactory, and the control over variations of exposure is quite as good as if a negative were developed and a positive printed from it in the ordinary way. Moreover, these reversed pictures are astonishingly free from graininess. The graininess of ordinary negatives is due to the large clumps of silver bromide grains present in the emulsion. These large clumps are more sensitive to light than small clumps or widely separated grains, and, therefore, when a short exposure is given, the large clumps are the first to become exposed. These are removed in the reversal process, and the final image is made up of the grains of the least sensitivity. Since these are the smallest grains and the smallest clumps of grains, such a direct positive image shows very little graininess.

From these original films, duplicates are made by the same reversal process. A print is made in a contact printer upon a fine-grained positive film prepared for the purpose, and this is then developed by the reversal process in an automatic machine, so that, from the original positive, any number of prints can be made in the same way and with the same ease as prints are made from a negative.

In photography, it is, of course, more rational to use a positive than a negative as an original, since the negative is only a means to an end and is of no value in itself. The earliest photographic portrait process,

Daguerreotype, gave positives, and when processes were used in which a negative was obtained, which had to be printed in order to get a final result, the fact that a direct photograph was not produced was regarded as a defect – a defect, of course, which was more than compensated by the ease with which copies could be multiplied. Provided, as is the case with the reversal process, that prints can be obtained from positives as easily as they can from negatives, the use of positives has the additional advantage that the original is of value as well as the prints made from it.

Three sizes of amateur motion-picture film are now in general use, of which two were introduced almost simultaneously in 1923. These are (*see* Plate 33*b*):

(I) A film 16 mm. wide, in which the picture area is 10 by 7·5 mm., so that there are forty pictures to a foot, the edges of the film carrying the perforations.

(II) A film 9·5 mm. wide, the picture area being 7·5 mm. by 6 mm., and in which there are also forty pictures to a foot, the perforations being in the centre of the film between the pictures.

(III) The third size of amateur motion-picture film available is that known as 'Ciné-Kodak Eight.' In this, the film is 16 mm. wide but has twice the number of perforations, there being a perforation every 3·75 mm., and the picture occupies only a quarter of the area of a 16-mm. picture. The Ciné-Kodak Eight film is run through

the camera twice: first one row of pictures is taken and then, after the reloading of the film in the camera, the other row in the opposite direction; after the film has been processed, it is slit down the middle, so that a film results having a single row of pictures with a line of perforations on one side of the film only.

A comparison of the 16-mm. film with the standard film is shown in Plate 34a. It will be seen that its area is approximately one-sixth that of the standard picture and that in the length covered by five pictures on the small film there are two pictures on the standard film. On the screen, a foot of 16-mm. film, carrying forty pictures, lasts two and a half seconds, because the standard speed of projection is sixteen pictures a second. (In the case of sound pictures, of course, this speed is increased to twenty-four pictures a second.) The small size of this film and the fact that it can be reversed makes it cost much less than standard film. In order to get some idea of what this means to the amateur, we must remember how long a shot should be. Experience has shown that a view of a stationary object or one in which the movement is repeated, such as a waterfall, and in which there is no action to be followed, should last on the screen for between five and ten seconds. This may seem short, but trial has shown that if a scene of this type lasts for more than ten seconds the audience wearies of it. When taking 16-mm. pictures,

therefore, it is desirable that seven or eight seconds' exposure be given to each scene, and the cost of such a scene will be about 10*d*., which is only slightly more than the cost of an ordinary photograph when the negative has been developed and the print made.

Most of the description of the 16-mm. film also applies to the 9·5-mm. Pathé Baby film. Originally, it was intended that the user should process this himself by a reversal process, for which formulæ were given, but later the manufacturers of the film undertook the processing, as has always been the case with 16-mm. film.

Sometimes, amateur cinematographers use negative film and develop it themselves or have it developed by a trade laboratory and have prints made on 16-mm. positive film. On the whole, however, the low cost of reversal processing and the satisfactory results obtained have tended to discourage the use of negative-positive processes in this field.

The Ciné-Kodak Eight film is used in a very small camera (Plate 35*a*). By making this film 16 mm. in size and slitting it after processing, the cost of Ciné-Kodak Eight pictures is reduced to about a third of that of 16-mm. pictures. Small as these pictures are, they are of very satisfactory quality on the screen. An enlargement from a single frame of a Ciné-Kodak Eight film is shown in Plate 34*b*.

The film base used for making amateur motion-picture film is the slow-burning film made from cellulose acetate. The nitrocellulose film commonly

PLATE 34

35 mm.   16 mm.

(*a*) 16-mm. and 8-mm. film, compared with standard
35-mm. film.*

8 mm.

(*b*) Enlargement from single frame of Ciné-Kodak
Eight film. (*p.* 134)

* In the standard film, the pictures are ¾-inch high, so that there are sixteen pictures to a foot, while in the 16-mm. film there are forty pictures to a foot, and eighty pictures in the 8-mm. film. 100 feet of standard film, running twenty-four pictures to the second, are projected in 67 seconds; while 100 feet of the 16-mm. film, running sixteen pictures to the second, last four minutes on the screen. (*p.* 133)

PLATE 35

(a) Using an 8-mm. Ciné-Kodak camera. (p. 134)

(b) Magazine Ciné-Kodak camera. The camera is just being closed after loading with a magazine. (p. 135)
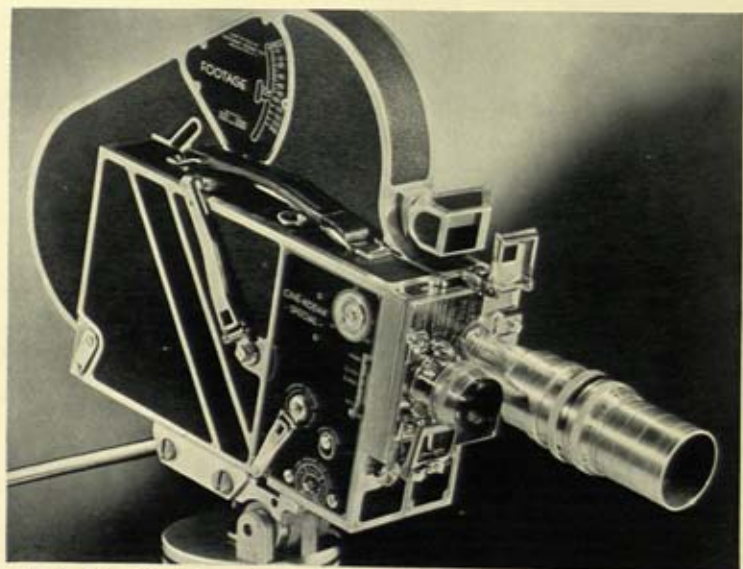
(c) A Ciné-Kodak special, advanced amateur motion-picture camera for 16-mm. film. (p. 135)

used for professional motion pictures is safe where proper precautions are taken to prevent any risk of fire and to quench a fire should it arise; but the introduction of such film into the home or school is most unwise. One of the great advantages of using a special size of film is that this size film is never made of nitrocellulose. For the same reason, though to a lesser degree, it is an advantage that this new film cannot be cut from film of standard size by any simple operation.

Many types of cameras have been introduced for use with these small substandard films. The earliest cameras were rather heavy and cumbersome, but later cameras are portable and convenient in use, being little bigger than an ordinary hand-camera. One of the smallest and most convenient cameras is that shown in Plate 35b. This is loaded with a magazine carrying 50 feet of 16-mm. film, and the film can be changed simply by opening the camera, removing the used magazine, and substituting a fresh one. In spite of the small size of this camera, it is fitted with interchangeable lenses of different focal lengths, and the speed can be varied so that slow-motion pictures can be taken. Some of the cameras are quite complex and have many of the facilities available for professional cameras. One such complex camera is shown in Plate 35c. With this, almost everything can be done that can be accomplished with any professional camera, and the size and weight are still small enough to permit its use in the hand, although much of the

work with this camera is done on a tripod to ensure the greatest possible steadiness.

The instruments used for the projection of small-size pictures are more convenient and, on the whole, more satisfactory than those for theatrical motion pictures. They are invariably motor driven and are characterised by extreme reliability. As in the case of cameras, a wide range of quality and cost exists.

In one respect, amateur cinematography has been in advance of the professional art; that is, in the use of direct colour processes. The nature of these colour processes is discussed in Chapter VIII, and three of the processes described there have already been used on an extensive scale for amateur motion pictures, although their use in the theatres is still in the early experimental stages. These are the *Dufaycolor*, *Kodacolor*, and *Kodachrome* processes. The reason that these processes found application in the hands of amateurs before they were used on the motion-picture theatre screen is that the amateur is content with one copy of his picture and that it was not necessary to work out the complicated systems required to print duplicates. In addition to this, the transition to colour for professional motion pictures requires a great deal of organisation, while an amateur can buy a roll of special colour film for any of the three processes mentioned and use it without any serious change in his working methods. It seems quite likely that colour films will very largely displace black-and-white for amateur use.

There have been many developments in the field of amateur cinematography. Thus, at first, titles were made by photographing a printed title by means of an ordinary camera. By the use of typewritten titles and special cameras photographing them at high speed in the film processing stations, the cost of titles has been very greatly reduced and their use increased, so that at the present time it is easy for an amateur to insert appropriate titles in his pictures and thus give them a more permanent value for projection.

Soon after the small film was introduced on the market, libraries were formed to rent out for home use reduction prints from standard professional pictures. These were later supplemented by the sale of prints from standard short-length negatives.

The small film has made possible the use of motion pictures for teaching purposes on a much larger scale than would be possible if the expensive, standard-width film were the only one available; and complete programmes of class-room films for the instruction of children are now obtainable.

CHAPTER VII

THE PHOTOGRAPHY OF COLOURED OBJECTS

WHEN we discussed in Chapter V the way in which the various tones of natural scenes are reproduced by photography, we deliberately ignored the fact that most scenes are coloured; we treated them as if they were only black and white. But, in Nature, there is a great variety of colour, and if we are to understand the extent to which a photograph resembles the original, we must consider the effect of colour upon the reproduction. This is the more necessary because photographic materials differ from the eye in their sensitivity to colours, and, also, they differ from each other. There is a wide range of colour sensitivity among photographic materials.

When white light is analysed by being passed through a prism, the light spreads out into a band of different colours, which is known as a *spectrum* (Plate 36). White light contains a mixture of waves of light of various lengths (Fig. 34). These different waves are affected differently by the prism and are spread out into a band in which the shortest waves are at one end and the longest at the other. The colours of the light waves correspond to their length, so that to each colour in the spectrum there corresponds a definite

length of wave. A simple arrangement of the normal spectrum is shown in Fig. 35, the numbers representing the lengths of the waves in units, which are millionths of millimetres, and the colour ranges being indicated. This shows the extent of the visible

WAVE-LENGTHS

RED
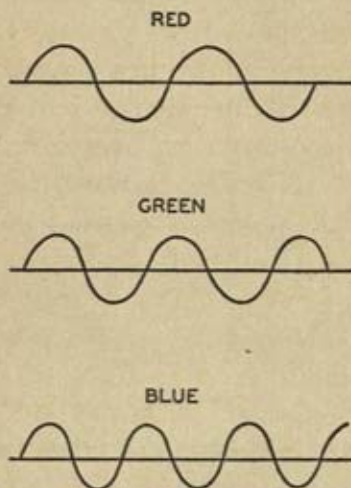
GREEN

BLUE

Fig. 34. A diagram showing the wave-lengths of light of different colours.

spectrum, from 400 units to 700, and its division into regions which may be broadly termed:

Blue-violet	400 to 500
Green	500 to 600
Red	600 to 700

Broadly speaking, we may consider that white light is made up of three components – red, green, and

blue-violet light – which are known as the *primary colours.*

In Plate 36*a*, it will be seen that the light entering the spectroscope is reflected from white paper. If the white paper is replaced by coloured paper, some of the light-waves in the spectrum will be missing or weakened; that is, the coloured paper absorbs some of the light-waves more than others. The colour of a natural object results, therefore, from the selective absorption of part of the spectrum. If all the different waves in the spectrum are absorbed equally, the object is grey; it is only when they are absorbed

BLUE VIOLET	BLUE GREEN	GREEN	ORANGE YELLOW	RED
400 450	500	550	600	700
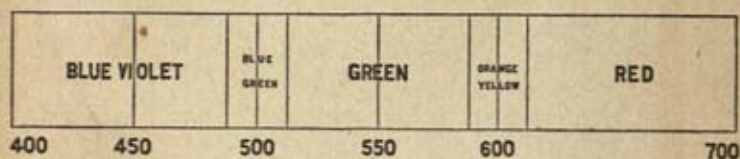
Fig. 35. A diagram of the visible spectrum.

unequally that an object is coloured. A piece of red paper examined in the spectroscope is found to reflect the red light and absorb the blue and the green light.

This aspect of colour, namely, that objects are coloured because they absorb some part of the white light, must be clearly and definitely kept in mind in order to understand the principles of the photography of coloured objects. The conception of colour as an absorption is not a common one, although it is the most useful, and it is necessary, therefore, to elaborate this idea.

We should form the habit of considering a red object

PLATE 36
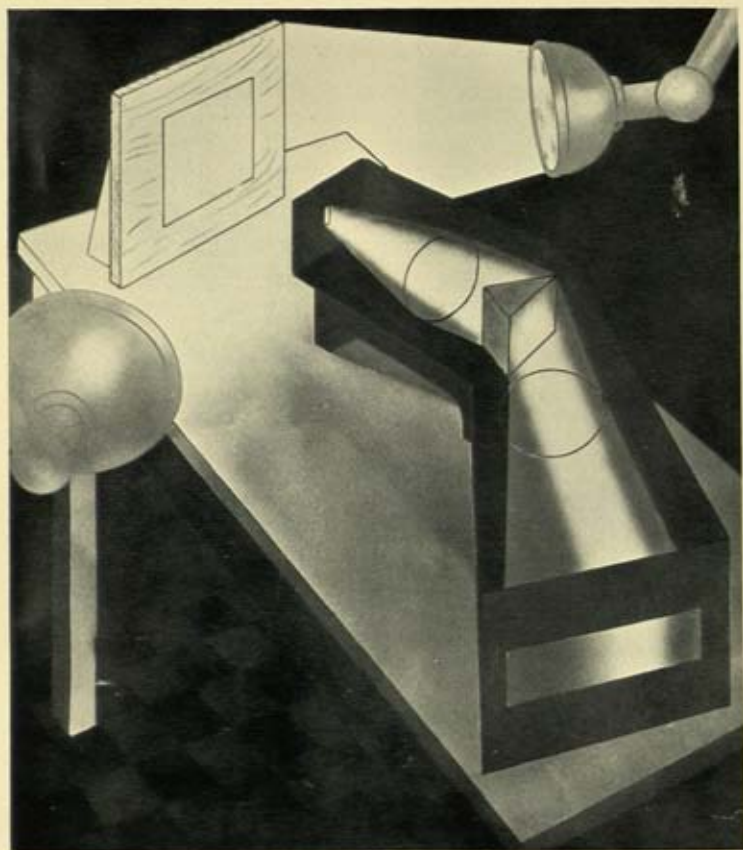
(a) The dispersion of light in a spectroscope. (p. 140)

Limit of Visibility   Limit of Visibility

(b) The luminosity value of the spectrum as it appears to the
eye. (p. 143)

PLATE 37

(a) Daffodils and narcissi photographed on an ordinary plate. (*p.* 144)

(b) Daffodils and narcissi photographed on a panchromatic plate with a filter. (*p.* 148)

Limit of Visibility   Limit of Visibility

(c) The luminosity value of the spectrum as photographed on an ordinary film or plate. (*p.* 143)

Limit of Visibility   Limit of Visibility

(d) The spectrum photographed on an orthochromatic film. (*p.* 146)

not as one that reflects red but as one that absorbs blue-violet and green. The importance of this definition is that it defines *red* without reference to the colour of the incident light. If we examine a scarlet book by a light containing no red, such, for instance, as the mercury vapour lamp, in which red is almost entirely wanting, the book no longer reflects red light because there is no red light for it to reflect, but it still absorbs the blue-violet and green light of the lamp and looks black; it has not, of course, changed its nature, and we should still be justified in saying that it is 'red' if red is defined as the absorption of green and blue-violet.

In the same way, a yellow object is not one which reflects yellow light; if an object reflected only the yellow light of the spectrum, it would be so dark as to be almost black. A yellow object is one which absorbs blue light; the other two components of white light – green and red – appear yellow when reflected together, so that we should be justified in saying that yellow light consists of green light plus red light; but for our purpose we may consider yellow simply as a lack of blue. Yellow is white minus blue; if we have a beam of yellow light and add blue light to it, we get white light.

Since white light consists of blue light, green light, and red light, green is clearly white light minus red and minus blue; and a green body is one which absorbs both red and blue. The difference between a green object and a yellow object is that the yellow object

absorbs blue only, whereas the green object also absorbs most of the red light, which the yellow object reflects.

We can now make clear what is meant by *complementary colours*. The top line of the diagram shown in Fig. 36 represents the components of white light. The next line shows the blue-violet component blotted out, leaving the mixture of green and red –

BLUE	GREEN	RED
BLUE	YELLOW GREEN	RED
BLUE	GREEN	RED
BLUE	GREEN	RED

Fig. 36.   A diagram of the complementary colours.

that is, yellow. We should say, then, that yellow is complementary to the blue. In the same way, in the next line, all blue and green are blotted out, leaving only red, so that red is complementary to blue-green. In the bottom line, all blue and red are blotted out, leaving only green; green is complementary to this blue-red mixture, which is usually known as

magenta. In general, then, the light absorbed by an object is complementary to that reflected by it.

If we look at the spectrum of sunlight reflected from white paper, the green portion of the spectrum will appear brightest; the yellow, orange, and red light on one side and green, blue-green, and blue on the other appear progressively darker until the violet is very dark, and the visible spectrum ends. This is represented in Plate 36*b*. It can be represented also by a curve showing the sensitiveness of the eye to the
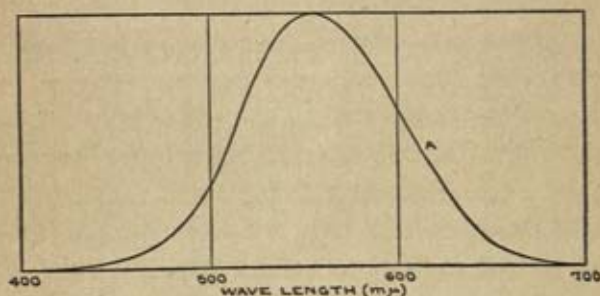
WAVE LENGTH (mμ)

Fig. 37. The visibility curve of the eye.

different wave-lengths of the spectrum. As will be seen from Fig. 37, this curve has a maximum at about 554 units.

Just as the eye is unequally sensitive to light of different colours, so is a photographic film. If we photograph the sunlight spectrum on ordinary photographic materials, we get the result shown in Plate 37*c*. It will be seen that the sensitivity of photographic materials to different colours differs very markedly from that of the eye and, indeed, extends beyond it.

The eye can see waves of no shorter length than 400 units; photographic materials can 'see' very much shorter waves and can detect light which is quite invisible to the eye, this light being called *ultra-violet* because it is beyond the violet. The maximum of sensitivity of the early films and plates was in the violet; and all the red, orange, and nearly all the green light was invisible to them; that is to say, they perceived objects only by the blue and violet light which they reflect. This is a grave fault in a material when regarded as an instrument for recording coloured objects, because the record is not the same as that which the eye sees.

As a simple example of a coloured object, let us use a yellow daffodil. If on an ordinary plate or film we photograph side by side a daffodil and a narcissus, we find that, although to the eye the yellow daffodil appears almost as bright as the white narcissus, in the print (Plate 37a) the daffodil appears much darker. The yellow colour of the daffodil is due to the absorption of blue and violet light, to which the photographic material is strongly sensitive. The absence of this absorbed light is therefore much more noticeable in the photograph than to the eye.

For many years, photographers were so accustomed to the incorrect photographic rendering of coloured objects that a sort of photographic convention was set up in their minds. A picture of a landscape in which grass was rendered as a dark patch and a blue sky was almost white paper, was accepted without

any consciousness of its incorrectness. The more experienced a photographer, indeed, the more fixed this convention became. Photographs taken under conditions which correctly reproduced the luminosities of the subject sometimes even appeared wrong to a worker who had become accustomed to a 'photographic rendering,' and in whose mind the reproduction of a scarlet as dead black would raise no question whatever.

Photographers have become more critical, and it is now generally recognised that, so far as possible, photographs should translate correctly into monochrome the luminosity values of colour as seen by the eye.

If some dyes are added to the photographic emulsion with which films are coated, so that the silver bromide is stained with the dye, the light absorbed by the dye becomes effective and produces an image. Thus, if the dye is pink and absorbs green light, the green light becomes effective in producing a photograph. This was first noticed by Vogel in Berlin in 1873. While taking photographs of the spectrum with some English plates made of collodion emulsion, he noticed that they were sensitive to green light. He traced this to the addition of a dye intended to prevent halation. He tried the effects of a great many dyes and found that some of them made the emulsion sensitive to the light which they absorbed.

When gelatin dry plates were first made, the best dye for making them sensitive to green was found to

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be erythrosine, which is a pink dye containing iodine, and plates sensitised with erythrosine were said to be *orthochromatic* or *isochromatic*. These orthochromatic materials soon largely replaced the materials which were sensitive to only the blue-violet and ultra-violet.

Orthochromatic materials give a photograph of the spectrum of the type shown in Plate 37*d*. On comparing this with the appearance of the spectrum to the eye (Plate 36*b*), we see that, although the orthochromatic film is better than the ordinary film, its sensitivity cannot be described as comparable with that of the eye. It has an enormous excess of sensitivity to the blue and violet; it has the sensitivity to the ultra-violet which the eye has not at all; it has little sensitivity to the blue-green, a second maximum of sensitivity to the yellow-green, and an absence of sensitivity to the red. It may be said that, if we suppose the blue to include the whole spectrum up to 500, the green to cover the spectrum from 500 to 600, and the red from 600 upwards, the sensitivity of the orthochromatic film is distributed in the ratio of twenty parts in the blue, four parts in the green, and none in the red. If we assume, for the sake of argument, that the eye sees the three parts of the spectrum as of equal intensity, the orthochromatic material, besides being insensitive to the red, has only one fifth of the sensitivity to the green that it would require to equal the sensitivity of the eye. Nevertheless, orthochromatic films and plates are very useful in photographic practice, since they render green and

yellow objects more truthfully than is possible with unsensitised materials.

In the early years of the twentieth century, a number of new sensitising dyes were discovered with which photographic materials could be made sensitive to the whole of the visible spectrum, including the red. In 1906, plates of this kind were put on the market under the name of *panchromatic* plates. These panchromatic plates represented a very great advance over the orthochromatic plates and over any of the panchromatic materials which had been made by the use of less satisfactory dyes. With the aid of light filters, which will be discussed later, the photography of coloured objects on panchromatic plates was developed on a scientific basis.

At that time, only a very limited number of sensitising dyes were known, and it was thought that only a few substances were available for sensitising photographic materials. About 1920, however, a very complete study of sensitising dyes was commenced, and as a result it was realised that a much greater number of the dyes could be made. Since then there have been great improvements in sensitising for all colours visible to the eye and also for the infra-red light, which cannot be seen by the eye.

Following this work on sensitising dyes, photographic manufacturers now make panchromatic films and plates which they call *supersensitive* or *hypersensitive*. Some of them are very sensitive to red light; others are especially sensitive to green and

yellow light, without excessive sensitivity to red.

If we make a photograph on a panchromatic plate or film, we shall obtain a result which approximates much more closely to the truth than if we use an ordinary plate or even an orthochromatic plate, but the rendering will still be incorrect, and, especially, blue and violet objects will be too bright because the panchromatic materials are still very much too sensitive to the blue and violet light and to the invisible ultra-violet rays.

Owing to the great intensity of these blue, violet, and ultra-violet rays in sunlight, most of the photographic action, even on a panchromatic plate, is produced by them, and we can only get a rendering of the brightness of colours corresponding to that which we see by making these rays less effective. This can be done by absorbing them with a piece of yellow glass or gelatin put over the lens of the camera.

Such an absorbing material is called a *light filter*, and one which absorbs the right amount of the blue and violet light and all the ultra-violet light (which, being invisible, must not be used) is called an *orthochromatic filter*. Plate 37*b* shows a photograph of the daffodils and narcissi taken through such a filter on a panchromatic plate. It will be seen that the daffodil is now reproduced as only slightly darker than the white narcissus, the tone rendering of the different colours in the photograph corresponding to that which is seen by the eye.

The orthochromatic filter increases the exposure

necessary because, if we remove those rays to which the material is most sensitive, we must compensate for it by exposing for a longer time to the action of the remaining rays. The amount of this increased exposure will depend on both the proportion of the violet and the blue rays which are removed by the orthochromatic filter and on the sensitivity of the material for the remaining rays (green, orange, and red), which are not removed by the filter. The number of times by which the exposure must be increased is called the *multiplying factor* of the filter, and this varies according to the material with which it is used, and the light source.

The ideal orthochromatic filter absorbs *all* the ultra-violet and as much as needful of the violet and blue light but transmits all the green, orange, and red light which falls upon it. If a filter transmits any of the ultra-violet light, which it should absorb, or absorbs any of the green, orange, or red light, which it should transmit, then it will be more or less inefficient. An inefficient filter has a high multiplying factor compared with the correction which it gives, while, on the other hand, a filter may have a low multiplying factor because of insufficient correction. An efficient filter will have a low multiplying factor but will also give good correction.

Since the purpose of a filter is to compensate for the excess sensitivity to the violet and ultra-violet rays of orthochromatic or panchromatic materials, it follows that materials of different degrees of sensitivity will

require filters of different absorptions to produce the effect seen by the eye. In the first place, it is clear that, no matter what filter is used, orthochromatic materials, which are not sensitive to red, can never render tone values as they appear, from the very fact that the materials are red-blind and that, except for a few unfortunate cases, the eye is not. The most perfect filter, in fact, with such a plate, can only give a result similar to that seen by a colour-blind person. Even so, it is not a matter of indifference what filter is used with a non-red-sensitive orthochromatic material. If the filter is too strong, the photograph appears over-corrected. This over-correction shows itself chiefly in that the atmosphere in the distance is lost; but, also, other unpleasant effects may be observed: in landscapes, the sky may appear too dark (this is also the effect of under-exposure), and light grass may appear almost white; in flower photography, yellow flowers may be indistinguishable from white ones. These defects are produced by a filter which removes too much of the violet and blue light.

Provided that a filter does not produce over-correction, while at the same time it removes ultra-violet light completely, little is gained by adjusting a filter to a special orthochromatic material.

When panchromatic materials are used with a yellow filter, only a moderate increase of exposure is required, and very pale filters give quite satisfactory results. For proper correction, it is of more importance that the film or plate should be strongly sensitive to the

green, orange, and red light than that the filter should be efficient and of sufficient depth. Panchromatic material used without any filter in most cases gives results superior to those obtained with the much less colour-sensitive orthochromatic material used with a filter which increases the exposure four or five times. Moreover, the correcting action of weak filters increases with the colour sensitivity, and the more colour-sensitive the material, the lower the multiplying factor of the filter. Consequently, for satisfactory colour rendering, the first essential is to have a material of the right type, and then the choice of filter must be governed largely by the exposure which can be given.

With panchromatic films, full correction in daylight is obtained by the use of a clear yellow filter. Where short exposure is of greater importance than full correction, a very pale filter can be employed, and even such a pale filter will notably improve the colour rendering as compared with that given without it.

Sometimes, we do not require correct rendering of the visual brightness of different colours. For instance, in a field of grain which is bright green or yellow, there may be flowers which have the same absolute brightness to the eye as the grain but which are very visible because of their colour. Now, if we make a photograph on a panchromatic plate with a filter, so that the relative brightness is correctly rendered, the flowers will be invisible. Consequently, we must sacrifice correct colour rendering in order to

show the general appearance of the field. In order
to make the matter clearer, let us suppose that we
have a piece of green paper on which are printed red
letters and that the brightness of the colours is chosen
so that the two are of the same visual luminosity. If
we photograph the paper on a green-sensitive material,
such as an orthochromatic plate, the red letters appear
dark on a brighter ground (Plate 38, I). If we photo-
graph them on a panchromatic material with a filter,
so that we get a rendering of both colours in their true
luminosity, the contrast disappears and the lettering
is not seen clearly (Plate 38, II).

What, then, must we do to obtain a satisfactory
rendering of this colour contrast ? Clearly, it is not
possible to render the colour contrast accurately in
monochrome so long as we retain the rendering of
correct luminosity values for our colours, and,
consequently, we must sacrifice correct rendering of
either the red or the green. If we use a paler filter or
a green filter, the green appears the brighter, and the
red, the darker; if we use a deep orange filter (Plate
38, III), the red is brighter, the green, darker; and which
we shall use must be governed by circumstances. As
a general rule, if we must sacrifice correct rendering
for the sake of colour contrast, it is usually better to
over-correct towards the red, since red is a strong
colour, while green is weak.

Sometimes, it is necessary to photograph something
very strongly coloured, and we do not care about
obtaining *correct* colour rendering; we want to obtain

PLATE 38

THIS INSCRIPTION IS

MADE IN RED INK ON

A GREEN BACKGROUND !

(I)
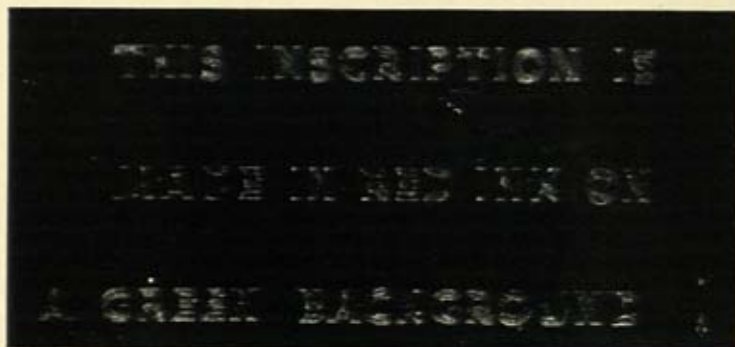
(II)

THIS INSCRIPTION IS

MADE IN RED INK ON

A GREEN BACKGROUND !

(III)

Red lettering on a green ground, photographed: (I) on an orthochromatic plate sensitive to green light but not to red; (II) on a panchromatic plate with a yellow filter; (III) on a panchromatic plate with a deep orange filter. (*p.* 152)

PLATE 39

THIS INSCRIPTION IS
MADE IN BLUE INK ON
A WHITE BACKGROUND

(I)

THIS INSCRIPTION IS
MADE IN BLUE INK ON
A WHITE BACKGROUND

(II)

(*a*) Pale blue ink photographed: (I) through a deep orange filter; (II) through a blue filter. (*p.* 153)

(*b*) Group photograph taken in total darkness. (*p.* 153)

a particular effect. If a colour is to be rendered as black, it must be photographed by light which is absorbed as completely as possible, so that if we want to photograph a drawing in pale blue ink, we photograph it through a red filter (Plate 39a). On the other hand, if the best rendering of a uniformly coloured thing is to be obtained, it must be photographed not by the light which it absorbs but by the light which it reflects. For instance, if we want to photograph mahogany furniture, we can use a panchromatic film and a red filter, and the grain then shows up beautifully (Plate 40).

There are rays of light having wave-lengths which are shorter than those of ordinary light, such as the invisible rays of ultra-violet light. There are also rays having wave-lengths which are longer, such as those of infra-red rays. The rays of light at the infra-red end of the spectrum are practically invisible to the eye; and the far infra-red rays are quite invisible.

By using plates sensitive to the far infra-red light, it is possible to take photographs in total darkness. This was done on October 7, 1931, at the Kodak Research Laboratories at Rochester, N.Y., U.S.A. A large group of visitors sat in an auditorium, on one side of which a booth had been erected. In this booth were fifteen 1,000-watt lamps, in reflectors which pointed toward the ceiling. Over the top of the booth, very deep filters were placed: these transmitted only invisible infra-red light. There was no visible ligh

in the room, but an exposure of about three seconds gave the picture shown in Plate 39b.

The discovery of dyes which sensitise for the infra-red part of the spectrum has made it possible for us to see how the world would appear if our eyes were sensitive to this light. A picture taken by infra-red light is shown in Plate 41 in comparison with a picture taken of the same scene by blue light; that is, on a non-colour-sensitive film.

The earliest photographs of landscapes by infra-red rays were taken in 1910 by Professor R. W. Wood. In pictures taken by infra-red light, the clear blue sky becomes black at the zenith, lightening somewhat towards the horizon. This is owing to the absence of scattered red radiation in sky light. The shadows are rendered extremely black. Further, the leaves of trees in full sunlight are almost white, owing to the high reflecting power of chlorophyll for the infra-red, so that foliage presents a very remarkable appearance against the black sky, in which clouds are seen with startling contrast.

The principal use of infra-red rays in landscape work is for the penetration of haze. When distant landscapes are photographed on non-colour-sensitive plates or films, the distance always appears hazy (Plate 42, I); and a very slight amount of mist in the atmosphere causes the absence of all detail in the distance. The reason is that the suspended particles of water vapour, which are transparent for the longer waves of light and, therefore, affect vision only slightly,
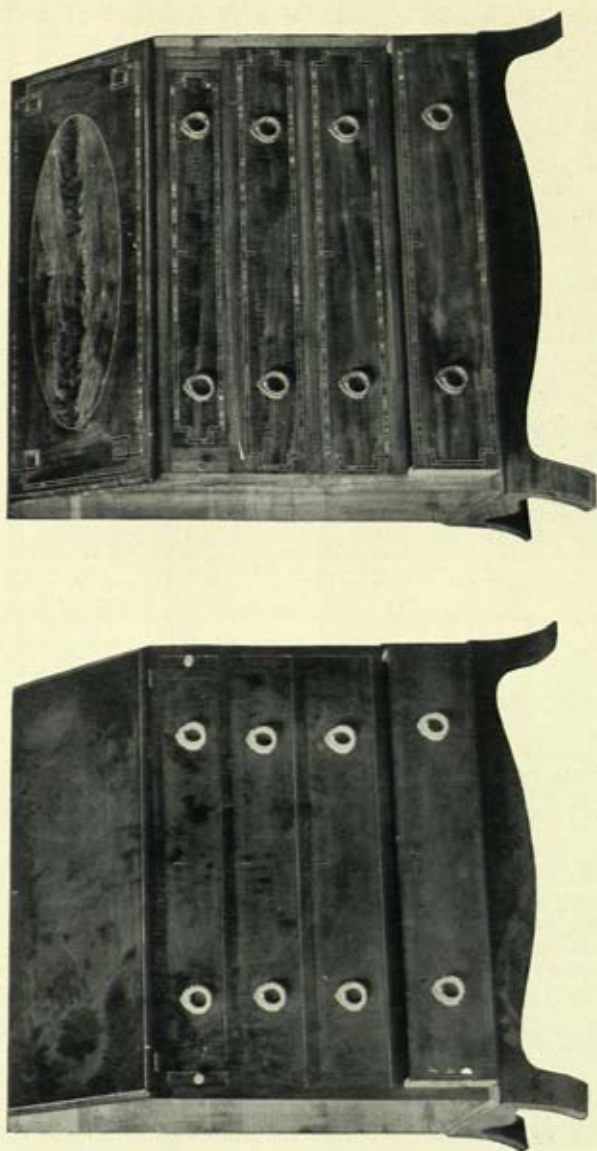
PLATE 40

Furniture photographed on (*left*), ordinary plate; (*right*), panchromatic plate through the Wratten 'A' filter. (*p.* 153)

PLATE 41

(I)

(II)

A landscape photographed: (I) by infra-red rays; (II) by blue-violet rays. (*p.* 154)

PLATE 42

(I)

(II)

Distant landscape photographed on: (I) an ordinary plate; (II) an
infra-red-sensitive plate. (*pp.* 154–155)

PLATE 43

BIG HORN MOUNTAINS

STRATOSPHERE BOWL

RAPID CITY

BAD LANDS
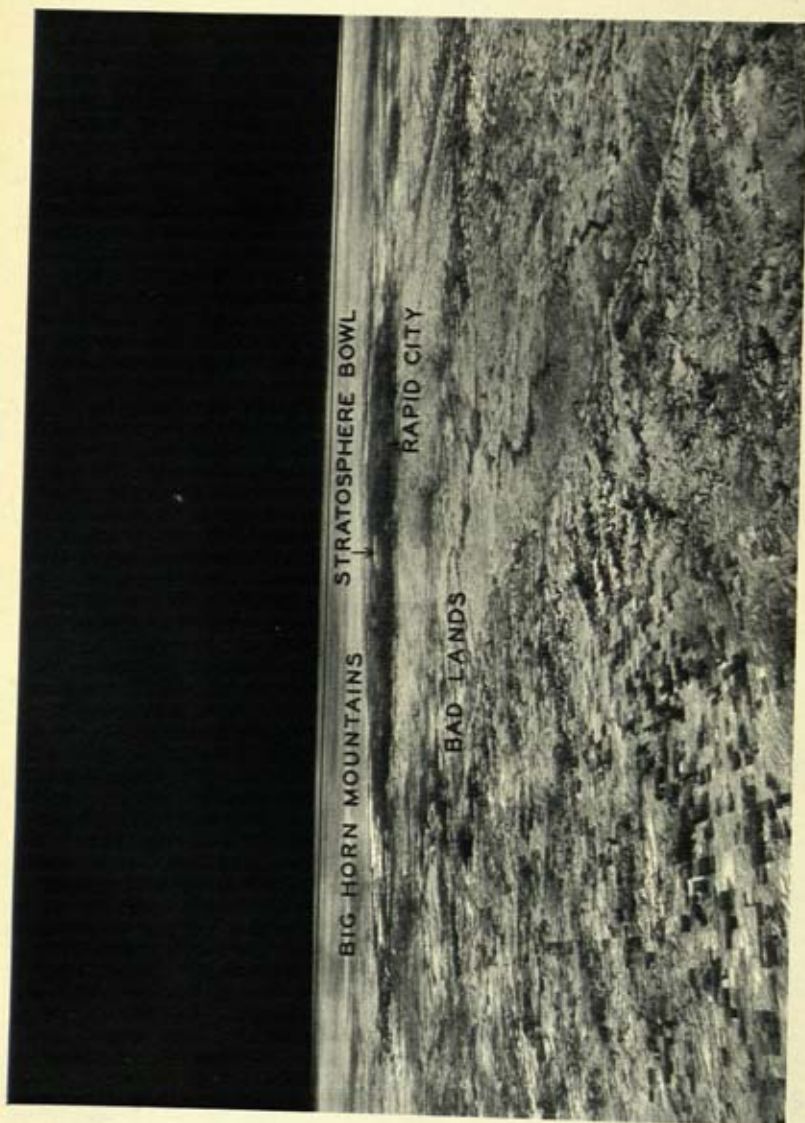
Photograph made from a stratosphere balloon from a height of 72,395 feet. The curved horizon shows the division between the stratosphere and the troposphere (lower air). Photographed by Captain A. W. Stevens. *By courtesy of the National Geographic Society, Washington, D.C., U.S.A.* (p. 156)

act as a very turbid medium for the deep violet and ultra-violet waves, scattering them and producing much the effect that would be seen if one were to try and look through a sheet of finely ground glass. It is for this reason that the sun appears red when viewed through a mist or fog. The scattering effect of mist is at a maximum in the ultra-violet and decreases as we pass towards the red. In addition, when the sky is blue, the mist reflects this light and therefore appears blue. This scattering by mist can be removed by the use of filters which absorb the scattered ultra-violet and violet light, and the extent of the removal of the scattering will increase progressively as deeper and deeper filters are used (Plate 42, II). When photographs are to be taken at great distances, panchromatic materials are used with yellow or even red filters, and for the very greatest distances the best results are obtained by the use of infra-red sensitive materials.

The most remarkable results in distance photography have been obtained in photography from the air. Captain A. W. Stevens of the United States Army Air Corps has taken a large number of photographs at very great distances. One famous photograph taken in 1931 in South America, showing the line of the Andes at a distance of 320 miles, was noteworthy because the line of haze over the Pampas lying in front of the Andes showed at this distance a very distinct lateral curvature owing to the curvature of the earth's surface. The same effect was shown even more clearly in the photograph taken from the

stratosphere balloon by Captain Stevens in 1935. This is shown in Plate 43. The photograph showing the most distant object of which there is any record at the time of writing is a picture of Mount Shasta taken by Captain Stevens in 1932. The mountain was 331 miles from the camera, being visible at this distance by reason of its great height and the fact that a great portion of the intervening country was occupied by the Sacramento Valley.

CHAPTER VIII

COLOUR PHOTOGRAPHY

THE history of colour photography begins with a lecture which Clerk-Maxwell gave in 1861 at the Royal Institution in London on his theory of colour vision. In this, he demonstrated the fact that all colours may be matched by mixing in various proportions light of the three primary colours – a pure red, a pure green, and a blue-violet. To illustrate this, Maxwell had taken three photographs – one through a red solution, one through a green solution, and the third through a blue solution. From these three negatives, he had made three positives in the form of lantern slides, which he projected on to a screen on top of one another by means of three lanterns, each one projecting its slide through the solution which had originally been used for taking the negative. In this way, he obtained a coloured picture on the screen. The three lanterns were adjusted in intensity so that the screen illuminated with the three beams of light was seen to be white, and any required colour could be produced by a proper adjustment of the intensities of the separate beams. Thus, as we see from Colour-Plate I*a*, the admixture of the red and green beams of light produces yellow, the admixture

of the green and blue-violet produces a blue-green, and all three colours together produce white.

The additive method of obtaining colour photographs – by making three negatives through three colour filters, making from them three positives, and then projecting these through filters similar to those through which the negatives were exposed – has been utilised by many inventors since the time of Maxwell. F. E. Ives employed it, using a very ingenious projection lantern in which the light from one arc was separated by mirrors and projected through a condenser and then through the three positives lying side by side. Ives, indeed, took the three negatives on one plate in a repeating back camera and printed a positive from this which was then made to register in the projection lantern. Professor Miethe in Berlin again exploited this process. He used a triple projection lantern consisting essentially of three lanterns, one over the other, like an old-fashioned triple lantern. The negatives were taken on one plate which was allowed to fall in a repeating back, so that the negatives were one over the other, and from this plate a positive was printed which was put into the projection lantern.

The greatest objection to this process is that the pictures can be seen only when projected in a rather elaborate lantern. In order to overcome this objection, Ives in 1900 designed his *chromoscope*, in which the pictures were placed over filters and superimposed by means of mirrors, all three pictures being seen simultaneously.

PLATE I
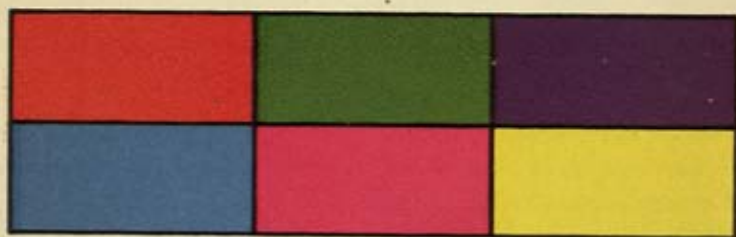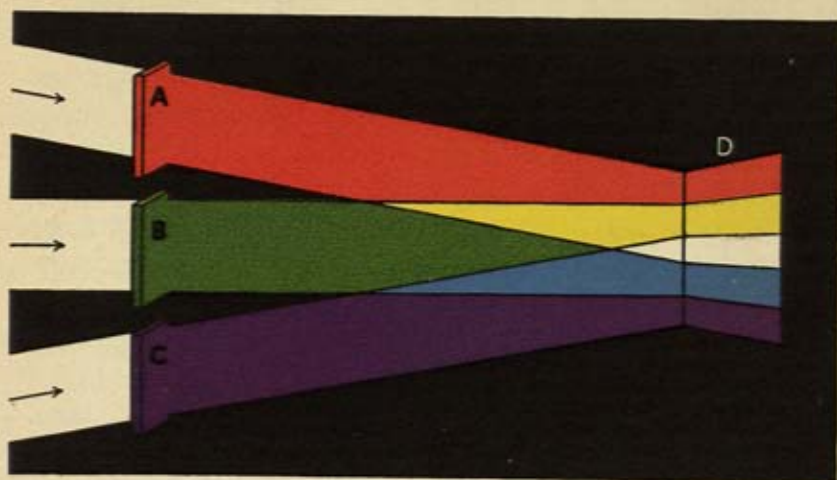
(a) *above*, Additive synthesis of the three colour primaries.   (*p.* 157)
(b) *below*, Primary and complementary colours.   (*p* 163)

Most people, however, want pictures either to put on the walls of their rooms as prints or in such a form that they can hold them in their hands and examine them; so that the efforts of inventors in colour photography have been directed toward getting some form of colour photograph which could be viewed apart from a projection lantern. In 1869, a very wonderful little book called *Les Couleurs en photographie* was written by a Frenchman, Louis Ducos du Hauron, and in this book du Hauron outlined many of the possible processes of colour photography which have since been reduced to practice. One of these processes which has since become of importance is
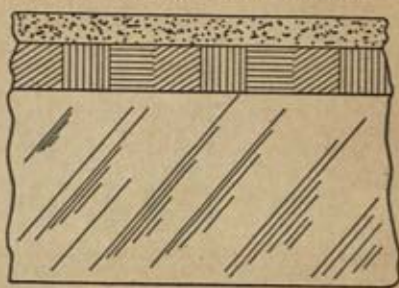
Fig. 38. A diagram of the screen plate.

known as the *screen plate process*. Du Hauron suggested that the surface of a support might be covered with tiny filters, and the colour-sensitive emulsion could be coated on the top of the filters. Such a material can be used to take a direct colour photograph in which the image is cut up into a lot of little sections, each of which is taken through one of the three filters. In the figure (Fig. 38) is shown a diagram of a screen plate; the support is covered with filters – blue, green, and red – and on the top of the filters is coated the sensitive emulsion. In the next

diagram, shown in Fig. 39, it is assumed that blue
light only is falling on the plate; that is, we are taking
a photograph of a blue object. The blue light is
stopped by the red filters and by the green filters, but
it passes through the blue filters and produces an
effect upon the emulsion.

When the material is developed, the part of the
emulsion which covers the red and green filters is not
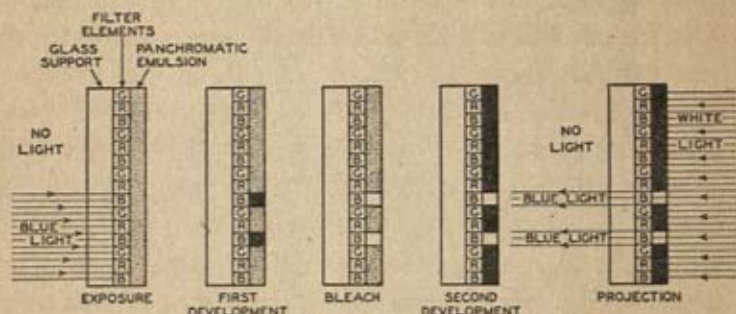
Fig. 39. A diagram of the working of the screen plate process.

affected and only that over the blue filters is developed.
Then, if we use a reversal process, we can remove the
silver from behind the blue filters by bleaching it with
acid permanganate, leaving the emulsion behind the
blue filters devoid of silver, while that behind the red
and green filters carries the original silver bromide
which was not exposed to the blue light and, therefore,
did not become developable. Now we can expose the
whole film to light and develop the silver bromide
behind the red and green filters; and, if we then look
through the plate, no light will come through the red

and green filters, but the light will come through the blue filters where the silver was first developed and then removed, and so the blue object will be represented by a blue area in the picture.

The problem in working this method in practice was to make the plate with the filters. This may be done by ruling lines with coloured ink, and the first successful attempt to do it with fine lines was made in 1894 by John Joly at Dublin. By means of a machine, Joly ruled alternate lines of red, green, and blue-violet on a glass plate and then with this glass plate registered the necessary colour-sensitive plate, making a lantern slide from the negative so obtained and again registering the lantern slide with a screen to obtain a coloured picture. Joly got good results, although his ruling was somewhat coarse, but the process did not succeed as a commercial process, partly owing to the difficulty of obtaining plates of sufficient sensitivity.

Following Joly, many other attempts were made to prepare screen plates commercially which might be applied to the production of photographs in colour.

The earliest successful colour screen unit process was that invented about 1904 by the Lumière Company in France, who coated the surface of a glass plate with dyed starch grains derived from rice. The little spherical grains of starch were dyed red, green, and blue and then mixed thoroughly, scattered over the surface of the plate, and squashed into flat discs. The interstices were filled with carbon black, the

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coating varnished, and then the emulsion coated on the face of it. These plates were put on the market thirty years ago under the name of *Autochrome* plates, and with them many beautiful colour photographs have been made. The Agfa Company in Germany has used similar particles of resin, dyed and coated so as to obtain a grain screen of the same kind.

For some time in England, a series of inventors have prepared plates in which a regular pattern is printed in a collodion layer in three colours by using bichromated coatings to print the lines, and these are used quite extensively for making colour photographs under the name of *Finlay* plates. In the Finlay process, the emulsion is not coated on the screen. Instead, a suitable sensitised plate is exposed in contact with the screen and developed to a negative. From this negative, a positive is made on an emulsion coated on a viewing screen to give the finished picture. The Finlay process has been notably successful for the preparation of illustrations because it is possible to use a master key plate to block out two of the colours at a time and thus separate the negatives according to the sections which were taken through the red, blue, and green units, respectively. The separations can then be used to make three printing plates which can be used for ink printing.

The most recent of these screen unit processes is the *Dufaycolor* film. This is prepared by dyeing the film in one colour – blue, for instance – then printing a pattern of lines in a greasy ink, bleaching the film

PLATE 44

Above: A set of colour-separation negatives taken through red, green and blue-violet filters respectively.

Below: A set of positives printed from the negatives above.

Rendering of colours by the three-colour process. (*p.* 164)

between the lines, and re-dyeing, so that now the film has two colours on it. Then another ink resist is printed at right angles to the first, and the process repeated, so that the three dye colours are in the surface of the film. The Dufaycolor screens are sold both in the form of 16-mm. film and of sheet film for the production of transparencies in ordinary cameras.

In the screen plate processes of colour photography, as in the method of triple projection, the colours are formed by the admixture of coloured light of the three primary hues. In nature, however, objects appear coloured because they absorb some of the components of white light (see Chapter VII, p. 140). In Colour-Plate I*b* we see the three primary colours – red, green, and blue-violet – and just under these are printed patches of the colours which are obtained when each of these primary colours in turn is absorbed from white light and which are therefore said to be *complementary* to them. Thus, we have blue-green, or *minus-red*, which is complementary to red; blue-red, or magenta, *minus-green*, which is complementary to green; red-green, or yellow, *minus-blue*, which is complementary to blue-violet.

If in one of the beams of a triple lantern, say red, we put a positive made from the red-filter negative, on the screen we shall get a blue-green image of the positive formed by the blue and green light, the red being absorbed by the positive. Clearly, we can obtain exactly the same result if, instead of making a black positive from the red negative and projecting it in the

triple lantern, *we print the red negative in a blue-green dye*. Similarly, we can duplicate the projection of the positive from the green negative by printing it in a magenta dye and that of the positive from the blue negative by printing it in a yellow dye, and when these three prints are superimposed, they will give exactly the same result as the triple lantern, a picture in natural colours. Thus, in Plate 44, we have at the top three negatives taken through three colour filters – red, green, and blue-violet. Below them, we see three positives, and if these were projected on a screen by means of red, green, and blue-violet light, respectively, we should get an *additive* colour picture.

Instead of doing this, we can print the red negative in blue-green ink, the green negative in magenta ink, and the blue-violet negative in yellow ink, and when these are superimposed, we get a *subtractive* colour picture (see Colour-Plate II).

Thus, there are two distinct methods of making colour pictures from the triple negatives: the *additive* method, in which the three colours are added in projection; and the *subtractive* method, in which the colours are produced by the superposition of prints.

The subtractive processes of colour photography are those used for the preparation of colour pictures for use in illustrations; e.g. for commercial and advertising photographs. The negatives can be made in an ordinary camera, but care must be taken that the three negatives are of identical size, of equal sharpness, and have been taken from the same point of view. Also,

PLATE II

Reproduction by the three-colour subtractive process. The three pictures are printed in inks of colour complementary to that of the filter through which they were taken. (*p.* 164)
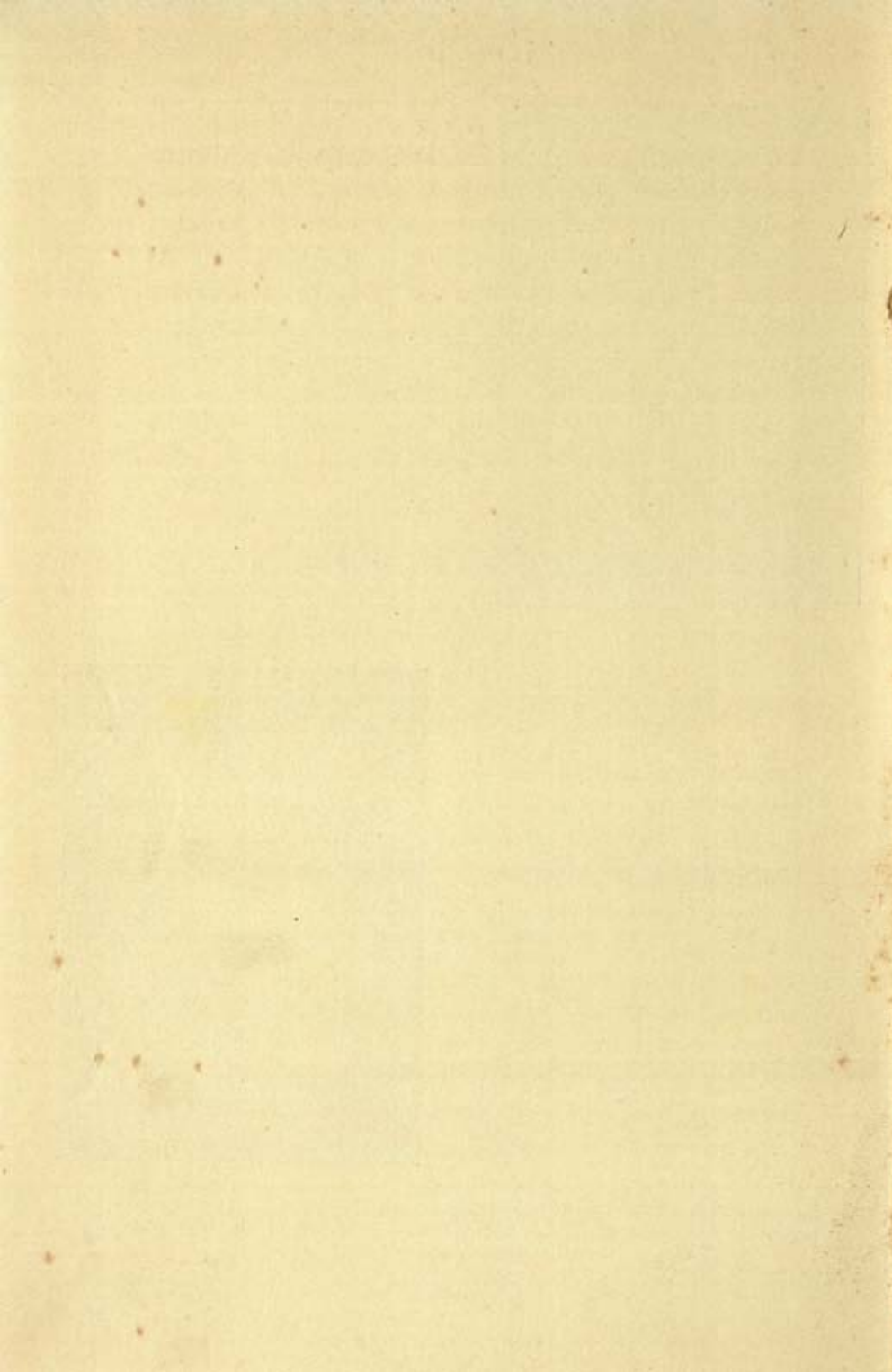
the subject must not appear differently in the three negatives as the result of its motion. The necessary conditions by which these requirements are fulfilled depend somewhat on the nature of the subject to be photographed. The simplest subjects to photograph are still objects. For these, an ordinary camera may be used. Three separate exposures are made on three separate plates or films, one through each of the tri-colour filters. Care must be taken that the lighting does not change during the time the three exposures are being made. A rigid tripod is indispensable.

An improvement over the ordinary camera with separate plate or film holders is available in the repeating back. The plate holder of the repeating back takes a plate long enough for three exposures to be made on the one plate, one above another or side by side. One of the tricolour filters covers the space for each exposure. The repeating back may be operated by the same mechanism that operates the shutter, so that after the first exposure is made the holder auto-matically drops to the next position, and, likewise, after the second exposure. Certain automatic re-peating cameras use roll film instead of plates and carry the filters on a revolving shutter behind the lens.

For general work, however, some form of single exposure camera is necessary (Fig. 40). Such a camera has the advantage that, if the subject moves during the exposure, the movement is the same in all three negatives and no colour fringes are introduced.

Some form of optical light-dividing device is

necessary in order that all three negatives may be made from the same point of view. Such a light-dividing device is called a *beam splitter*. It usually consists of one or more partly transparent reflectors placed in the path of the rays so as to bring about the
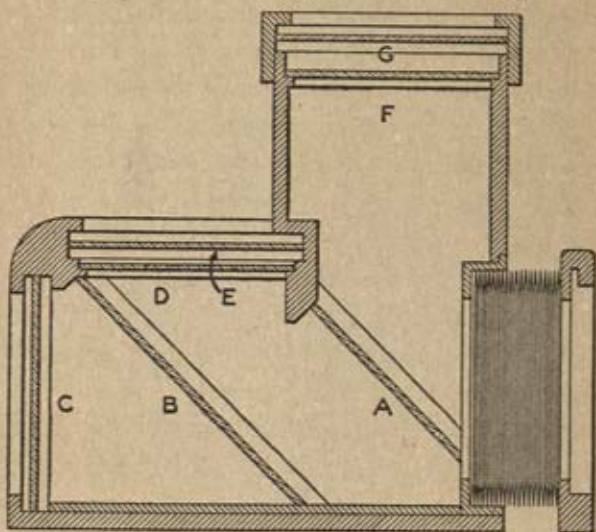
Fig. 40. A diagram of a camera for taking colour photographs using one lens and splitting the beam to produce three separation negatives.

A.	Reflector and minus-green filter.	D.	Red filter.
		E.	Red-sensitive plate.
B.	Reflector and blue filter.	F.	Green filter.
C.	Blue-sensitive plate.	G.	Green-sensitive plate.

formation of three identical optical images in place of one. It may be placed between the subject and the camera lens, making necessary the use of three objectives of identical focal length. More often, however, it is placed between the lens and the photographic

plates, making necessary the use of only one objective. Sometimes the surfaces of the reflectors are coated with an extremely thin, semi-transparent layer of metal, such as aluminium or gold, to increase their reflecting power. These semi-transparent metal-coated reflectors, however, are difficult to prepare satisfactorily and are expensive. Many cameras have been designed, therefore, to utilise only the surface reflection of optical plate glass or of very thin *pellicle* reflectors made of collodion.

From the separation negatives, the colour prints can be made in several ways: paper may be obtained coated with gelatin containing coloured pigments; these sheets of so-called 'carbon tissue' can be made sensitive to light by soaking in bichromate of potash. Then they are printed under the negatives, with the result that the portion which is exposed to light becomes insoluble in hot water, while the unexposed gelatin remains soluble. If the exposed tissue is soaked in cold water and laid face down on a sheet of paper coated with gelatin and then placed in moderately hot water, the unhardened coloured gelatin in the lower part of the tissue will soften. The back of the tissue can then be stripped away and leaves on the coated paper a coloured gelatin image which must, of course, be of the colour complementary to the filter through which was taken the negative from which it was printed. Corresponding prints are made in the other two colours from their appropriate negatives and transferred in register on top of each other, a three-colour

print thus being finally obtained. In a useful modification of this process known as *Carbro*, the colour prints are produced from three bromide prints made from the separation negatives.

Another method of obtaining paper prints is to prepare the three reliefs on film and bathe them in suitable dyes which will transfer to gelatin-coated paper. This is known as the *imbibition* process. The film is coated with a yellow-dyed fine-grained emulsion soluble in warm water. Contact prints or enlargements from the three colour-separation negatives are made on to this film through the support. The film is then developed and treated in such a manner as to harden the gelatin of the emulsion in the regions of the silver image. By placing the films in warm water, the soft gelatin is dissolved away, leaving an insoluble relief image in hardened gelatin adhering to the support. The three relief positives are then dyed in solutions of the corresponding printing dyes. The dyed films may be superimposed in register and bound between glasses as a transparency or the dyes may be transferred by imbibition to a suitably prepared paper coated with gelatin. The advantage of this method is the fairly low cost of a number of prints although the cost of preparing the original matrices is high. This process applied to cinematograph work is that which is used by the Technicolor Company and will be described later.

The most widely used subtractive colour process is that which is employed for the production of colour

prints in books and magazines. From the separation
negatives, three half-tone blocks are made which can
be printed on an ordinary press in printing ink, and
these are printed in the three coloured inks – blue,
magenta, and yellow – often with the addition of a
black *key* to give strength to the image.

Most of the processes of colour photography which
have been described are applicable to cinematography.
Cinematograph processes are, like other processes of
colour photography, divided clearly into additive and
subtractive processes. As in the case of 'still' photo-
graphy, the additive processes developed first. In
cinematography, however, there are two methods of
additive synthesis: one may either project the three
pictures simultaneously upon the screen, as is done
in the triple-projection lantern, or the colour units
may be projected successively, persistence of vision
being relied upon for the blending of colours.

The earliest cinematograph colour process was the
Kinemacolor two-colour process utilising persistence
of vision for the addition of two colours. The use of
two colours instead of three effects a very great simpli-
fication. The two colours chosen are always an
orange-red and a blue-green. In the additive process,
it is essential that these colours should be approxi-
mately complementary because otherwise they do not
give a white on the screen. In the subtractive pro-
cess, there is a somewhat greater latitude in the choice
of the colours and a wider range of intermediate hues
is possible. When only two primary colours are used,

it is obvious that all natural colours cannot be correctly
rendered; and in the two-colour subtractive process,
the colours for which the process fails are the blues,
violets, magentas, and purples. Light blues appear
blue-green, and true violets appear black; magentas
appear pink; and purples, brownish-red. There is
little differentiation between the yellow-greens and
the true greens. A buff or yellow will appear light
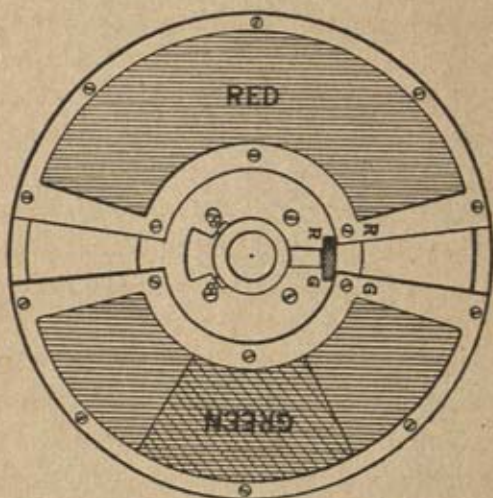
Fig. 41. Rotating colour filter disc on
Kinemacolor projector mechanism.

red, but the psychological effect of such a light red
under the existing conditions is so close to that of
yellow that, as a matter of fact, yellows appear to be
satisfactorily rendered by the process. Flesh tints
of all kinds and all shades of red, orange, and most

greens, greys, and blacks are well rendered; as these are predominant in portraits, the results are very satisfying for this class of work. Many of the pictures appear to show blues fairly well, but this is because, by contrast with green, blue-greens look blue; and especially by artificial light, the eye is accustomed not to expect very much of blues.

In the Kinemacolor process, by means of a rotating disc of colour filters placed in front of the camera, pictures were taken on panchromatic film alternately through a red and a green filter at twice the normal speed, so that for each finished frame two negatives are made – one through each filter. The positive from this negative is projected by a machine similarly equipped with a rotating shutter (Fig. 41) which is made to operate synchronously with the picture, so that each picture taken through the red filter is again projected through a red filter, and the green pictures, similarly, through a green filter. The succession of red and green pictures upon the screen produces complete synthesis by persistence of vision and gives the effect of a two-colour additive picture.

The Kinemacolor process is now obsolete. Its great disadvantages are that the flicker produced by the alternation of red and green light upon the screen is distressing and that rapidly moving objects show as a band of coloured images. This effect occurs because, when an object is moving sufficiently rapidly, it is in an appreciably different position when photographed through the green filter from that which it

occupied when photographed through the red filter, and the eye cannot blend the two images.

A motion picture process that was adapted to show the accurate and beautiful results that can be obtained by the three-colour additive method was the *Gaumont* process. Three colour-separation negatives were taken simultaneously, one above another, in the space of two and a quarter standard frames on panchromatic motion-picture negative film. Three lenses were required in the camera, each covered by one of the tricolour filters. The positive prints were then projected on to the screen by three lenses also equipped with filters.

The practical difficulties with the Gaumont process were fatal to it; it required special projectors and special registering devices. Also, which was more serious, it required special film which could not be run in ordinary projectors, so that before a theatre could use any films, it had to be equipped with the special projectors; and no theatre owner could afford to equip his theatre until he was assured of a supply of pictures. Again and again in the history of colour cinematography, this problem has defeated a process which appeared promising.

The only screen unit process which has been tried seriously for cinematograph work is the recently introduced Dufaycolor film. Pictures of the Silver Jubilee in 1935 were made by this process, and release prints were supplied as part of a news reel.

In 1908, R. Berthon patented a process which

realised most of the advantages of a screen film process
without involving too great practical difficulty in
making the film. In this process, the colour filters
are placed in the lens, while the film is embossed
on the support side with a number of small lenses.
A section through the film, on a greatly enlarged
scale, is shown in Fig. 42. The corrugated edge
represents the surface of the film base, embossed
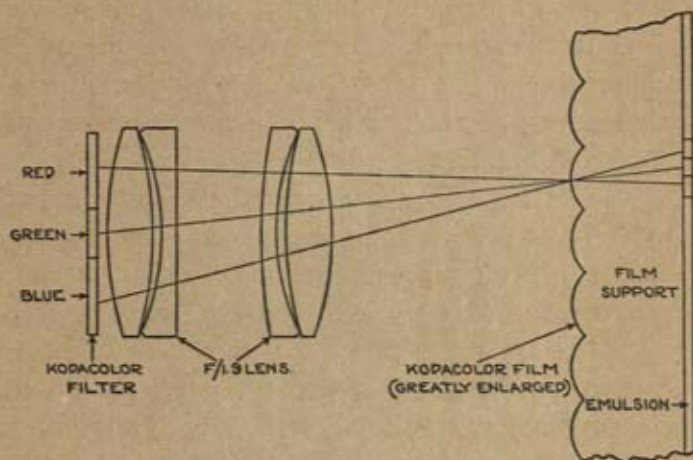
Fig. 42. A diagram of the Kodacolor process.

so that cylindrical lenticules are formed on it. We
see below this the thickness of the emulsion. When
the film is exposed in the camera, the embossed
lenticules form miniature images of the filters on the
film emulsion (Fig. 43). Suppose, for instance, that
the camera lens contains a stop with three holes in it
– one covered by a red filter; a second, by a green;
and a third, by a blue filter. Then, behind each

lenticule there would be formed on the emulsion a group of three dots – one dot corresponding to the red filter, another to the green, and the third to the blue filter.   In this way, the effect produced by the embossed film and the filters in the lens is similar to
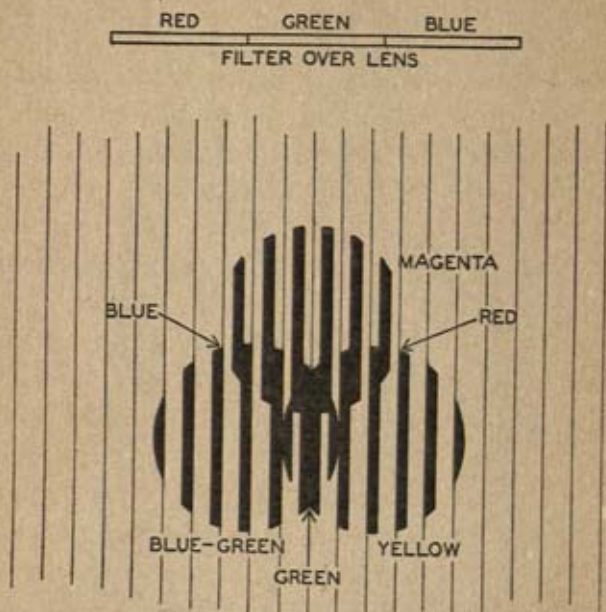
Fig. 43.   A magnified image of three overlapping filters as recorded on Kodacolor film.   The dark areas correspond to silver deposit in the reversed image.

that obtained by the use of a screen film in which the filter units are in contact with the emulsion, but the process has the advantage that the film is much easier to make and to use.

After exposure, the film is processed by the reversal

process, so that it is transformed into a positive, and the exposed areas behind the lenticules are occupied by the silver deposit. This film is then projected through the same optical system as is used on the camera. Behind the film is the usual condenser and the source of light, and the lens of the projector is fitted with a colour filter containing the three primary colours arranged in the same way as in the filter used in the camera. In projection, the light passing through the areas behind the lenticules passes through the filter corresponding to that by which the areas were exposed; that is, the areas in which the picture was taken by red light are projected through the red filter and, correspondingly, for the areas exposed by green and blue light. Thus, the image on the screen is made up of a mosaic of coloured areas produced optically but corresponding in effect exactly to that which would be obtained by the use of a screen film. Rights in this process were purchased by the Kodak Company in 1925, and it was placed on the market in 1928 under the name of the *Kodacolor* process for use with amateur 16 mm. film.

Adaptation of this process to professional work involves some very considerable difficulties. One is the preparation of copies, but this problem can be solved. The taking of Kodacolor pictures, however, and, still more, their projection involves a very special technique; they require a considerable modification of the current practice in the studio as well as the provision of special equipment for the theatres. It is not

yet certain whether the process will prove to be feasible commercially for use on a large scale.

For theatrical use, the subtractive colour processes have many advantages over the additive processes, especially in that they obviate all, or nearly all, the difficulties of projection. The subtractive film can be handled in exactly the same way as black-and-white film; it can be projected in the ordinary projectors, and no special equipment is involved in the theatres. Moreover, subtractive colour films give as bright a screen as black and white films, whereas any additive process involving the use of filters cuts the light down very greatly – in the case of the three-colour processes to about one-fifth of that available with the same optical system and black-and-white projection.

All the earlier subtractive films were of the two-colour type. It is clear that, since there are two sides to a film, it is possible to coat an emulsion on each side and to print the red image on one side and the green on the other. This process was worked out to a practical end in several ways, colour images being produced by mordanting a dye upon an image obtained by conversion of the silver into some suitable substance, or by the imbibition of a dye into the gelatin, or by toning silver images by chemical means.

By far the most successful of all processes of colour cinematography have been those which have been developed by the Technicolor Company, who for nearly twenty years have been working on the practical

development of colour cinematography. The earliest *Technicolor* process was a two-colour subtractive process in which the red and green images were formed on separate films of half the standard thickness and cemented together back to back. This was replaced by the process which is now being used except that for many years it was a two-colour one.
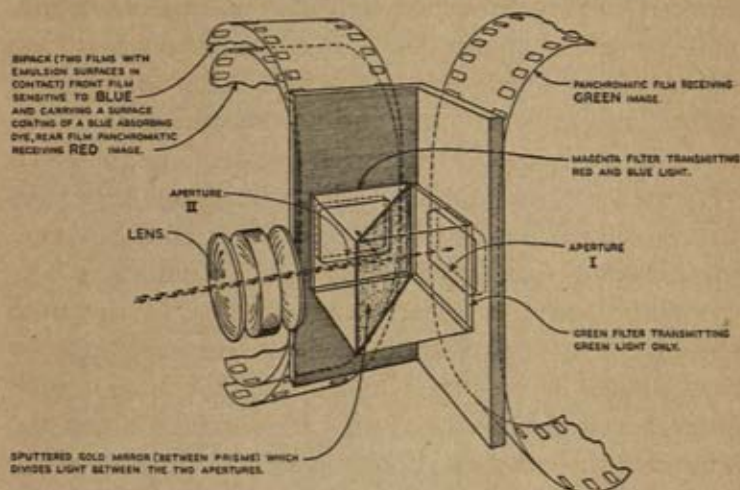
Fig. 44. A diagram of the Technicolor camera.

At the present time, the Technicolor pictures are produced by a three-colour imbibition process. The negatives are taken in a special camera on three films, two of them being placed face to face, while the third film, which receives the green-filter image, is supplied with light by means of a prismatic beam splitter (Fig. 44). From the three negatives, there are printed three silver images lying close to the base of a special

NP

matrix stock, and these silver images are used to harden the gelatin of the matrix emulsion, so that, after they are washed out, relief images in gelatin remain. These are then dyed, and the three dye images are transferred by imbibition to an ordinary positive film which contains a faint key image in grey silver, the function of which is to aid registration and to improve the definition. At the same time, this positive film carries the sound track in developed silver. The three-colour Technicolor process is a triumph of technical skill and an enormous improvement in quality over the earlier two-colour process.

A subtractive process which is being worked successfully, especially for the preparation of cartoons in colour, is that invented by Dr. Bela Gaspar. It depends upon the fact that many dyes can be destroyed by chemical action when they are closely associated with a silver image. In the *Gasparcolor* process, the film is coated on one side with a layer of blue-sensitive emulsion containing blue-green dye and on the other side with two layers of emulsion, one red-sensitive containing yellow dye, and the other blue-sensitive containing magenta dye. Positives are made from the three-colour negatives; that from the red-filter negative is printed on the blue-green dyed coating, that from the green-filter negative on the magenta-dyed coating, and that from the blue-filter negative through the superimposed magenta layer on the yellow-dyed coating. The printings are made successively and in register on an ordinary motion-

picture printer.   During the printing of the two outer
layers, the yellow dye present in the middle layer
restricts the effect of the printing light to the outer
layers.   The middle layer is printed by red light, to
which the superimposed magenta layer is not sensitive
but which it transmits.   The film is then developed
so that negative images are obtained, and, after fixation
and washing, these images are treated with a chemical
solution which does not affect the dye where no silver
is present, but, where there is silver, chemical reaction
occurs, which destroys the dye in proportion to the
silver image.   Where there is a negative silver image,
a corresponding positive image in dye is obtained.
The remainder of the silver is then dissolved out and
the film containing the three dye images shows bril-
liant colours.

The ideal colour process would be one in which the
photographer could use any cinematograph camera,
could expose his film under any condition suitable for
taking pictures, and, after processing, would obtain
a film in which the pictures themselves were in colour
produced by a subtractive process, and in which the
definition of each colour was equal to that obtained in
black-and-white photography.   This ideal is most
nearly achieved by the new *Kodachrome* process,
which is of an entirely new nature so far as processes
which have reached the stage of commercial pro-
duction are concerned.

The new Kodachrome process is a subtractive
process, but the separation of the light into three

components is not accomplished by placing the separate sensitive layers in juxtaposition; they are separated in depth. The film for this process is coated no less than five times ! Nearest the base is an emulsion coating which is strongly red-sensitive. This is overcoated with a separating layer of gelatin containing dye to act as a filter. Above this is coated a green-sensitive emulsion. This is overcoated again with another separating layer. Finally, there is

RAW FILM   COLOUR POSITIVE

BLUE SENSITIVE EMULSION   YELLOW IMAGE
GREEN   "   "   MAGENTA IMAGE
RED   "   "   BLUE-GREEN IMAGE

                                             SAFETY FILM SUPPORT

ANTIHALATION
BACKING
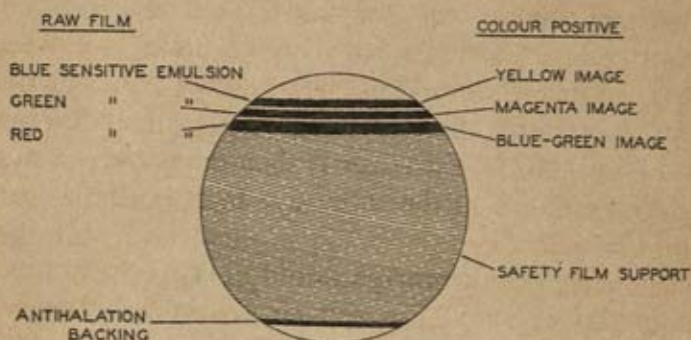
Fig. 45. A cross section of Kodachrome film.

applied a top coat which is blue-sensitive and which contains yellow dye. The five coatings are so thin that the total thickness of the film is little more than that of ordinary film (Fig. 45). The emulsions are so adjusted that the sensitisers do not wander from the layer in which they are coated; the bottom layer remains red-sensitive with very little green sensitivity, the middle layer is green-sensitive and is free from red sensitivity, while the top layer is sensitive only to the blue. When a picture is taken upon such a film, the

three components are automatically separated in the depth of the coating. The red component is formed in the red-sensitive emulsion, that nearest the base; the green component is formed in the middle layer of emulsion; and the blue component forms the image in the top layer.

For a colour picture to be obtained with this film, it will be seen that it is necessary to transform each component image into a positive image consisting of a suitable dye. The image formed in the red-sensitive layer is transformed into a blue-green positive; the image formed in the middle green-sensitive layer, into a magenta positive; and the image formed in the top, blue-sensitive layer, into a yellow positive. This is accomplished by an extremely complex processing system. The images in the three layers are first developed to a negative, as with ordinary black-and-white film, and this image is removed, as in the usual reversal process, by a bleach which dissolves the silver, leaving in the film the residual silver bromide which has not been developed because it was not exposed. The whole film is now exposed to light and re-developed with a *coupler* developer. A coupler developer is one in which the oxidation product of the developing agent combines with a chemical agent in the solution to form an insoluble dye. Thus, as the silver bromide is reduced to silver, the developing agent at this precise point is oxidised; and this oxidised developing agent is transformed into a dye, which is deposited along with the grains of silver.

After the second development, therefore, the silver bromide through the whole film is transformed into metallic silver and a blue-green dye. The film is then fixed, washed, and dried. It next passes into another machine in which a special bleaching solution transforms the silver back into silver halide and at the same time destroys the dye; but this bleaching solution is allowed to penetrate through only the two top layers and stops in the second intermediate layer without attacking either the dye or the silver which has been developed in the bottom layer. After washing, the film passes into another coupler developer, where the silver halide in the two top layers is redeveloped to silver and at the same time a magenta dye is deposited on the image along with the silver. Then the film has to be dried again and is put into the third bleach bath, which acts just as did the second one which destroyed the blue dye. It turns the silver back to silver halide and destroys the red dye; but the composition and time of action of this bath are so adjusted that it operates only on the top emulsion layer, stopping in the first intermediate layer and not attacking the magenta image in the middle layer. Finally, the film is developed for the fourth time in another coupler developer, which redevelops the silver halide in the top layer of silver and deposits a yellow dye. Now the silver through the whole film is transformed by a fourth bleach bath into silver halide, which can be removed by fixing, the solution which does this being chosen so that it has no effect on the dyes, and the

PLATE III

PROCESSING KODACHROME FILM

Explaining the sequence of operations in processing Kodachrome: a cross-section of the film is shown at the completion of each main stage in processing. In the case illustrated, the film was exposed in the camera to a red object on a black ground.

(a) Exposure

(b) 1st Development

(c) 1st Bleach

(d) 2nd Development

(e) 2nd Bleach

(f) 3rd Development

(g) 3rd Bleach

(h) 4th Development

(i) 4th Bleach
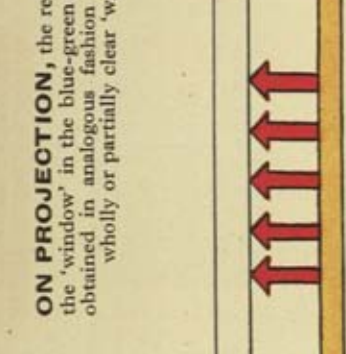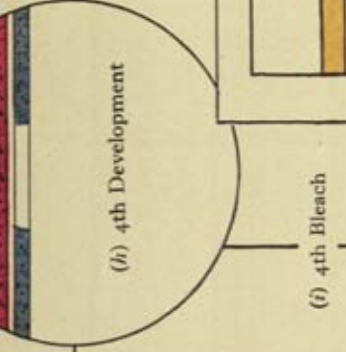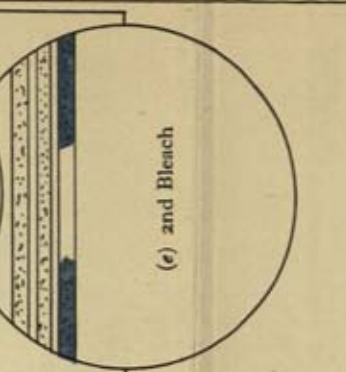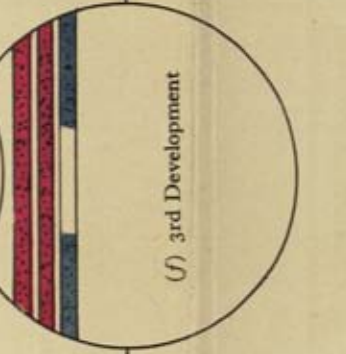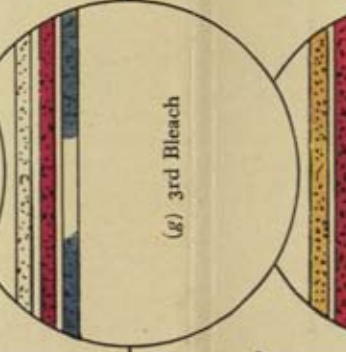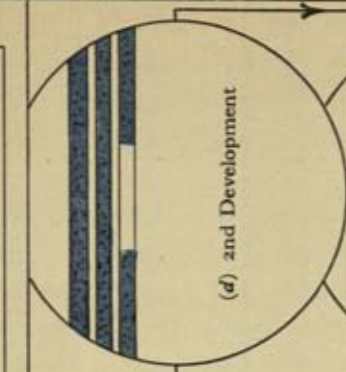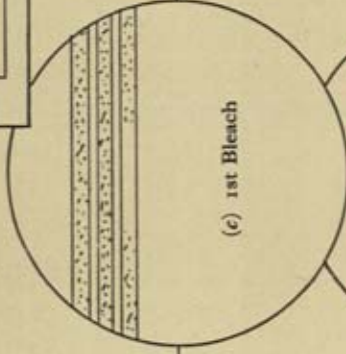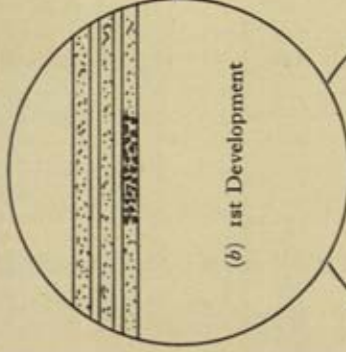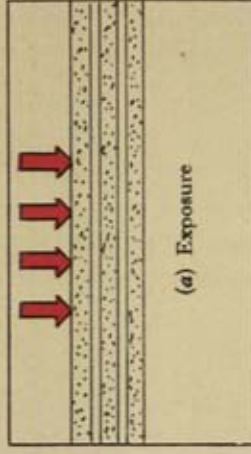
ON PROJECTION, the red colour is obtained by reason of the 'window' in the blue-green layer. Any other colour may be obtained in analogous fashion by a different combination of wholly or partially clear 'windows' in the three layers.

WHITE LIGHT

The Processing of a Kodachrome Film
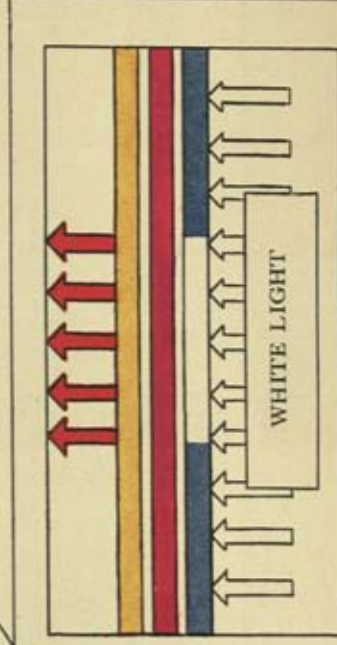
final film has three dye images – a blue-green image in the bottom layer, a magenta image in the middle layer, and a yellow image in the top layer (Colour-Plate III).

It will be seen that this process is extremely complicated and involves the treatment of the film upon three separate machines. Experience has shown, however, that it can be performed with certainty and that the commercial production of the colour pictures presents little more difficulty than the production of black-and-white pictures, although the complex processing treatment and the expensive chemicals used in it naturally increase the cost considerably.

SOME APPLICATIONS OF PHOTOGRAPHY

ALTHOUGH photography is used chiefly for entertainment, it also serves very serious purposes in the commercial, social, industrial, and scientific fields. It has played a prominent part in the developments which have made possible our present comfort and convenience.

Technically, photography is used for two purposes. It is used to give a simple record of an object or an event, or to give a record which can be subjected to measurement. The camera can be likened to the human eye, although it possesses a number of advantages over the eye, and it is these which make it of such value in various fields of application. Photography can go on building up a record of a faint object until an image is obtained which can be studied. It can show clearly transient events which occur too rapidly to be studied in detail by the eye. It can also utilise wave-lengths of light to which the eye is not sensitive. It provides a lasting record which can be put away for consultation at some future time.

The simplest application of photography is the making of records. A photograph of a building, of a

PLATE 45
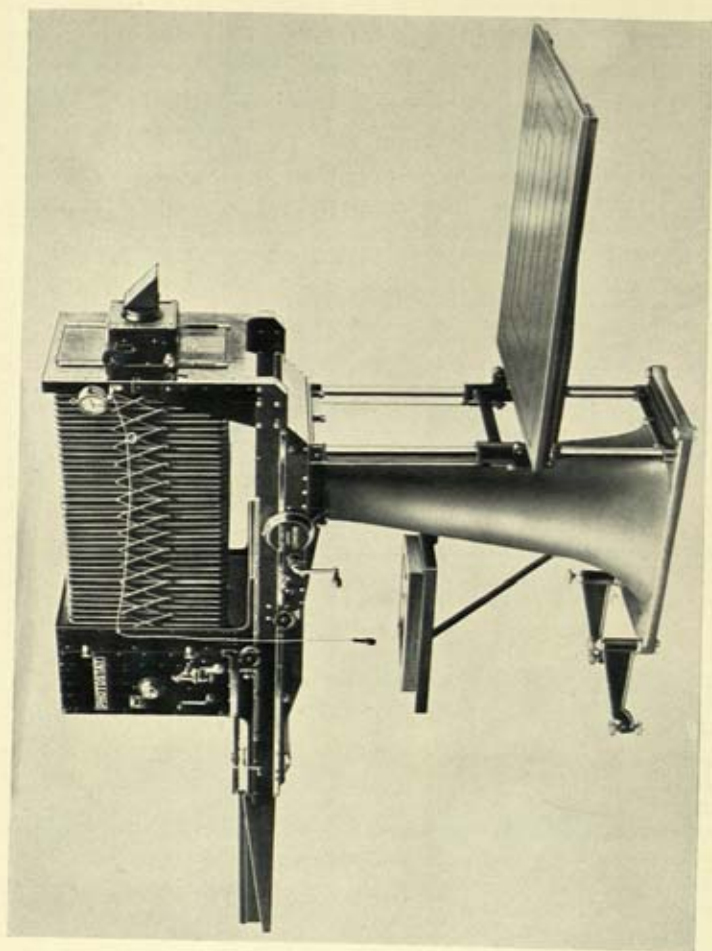
A Photostat machine, complete with semi-automatic developing and fixing equipment for the reproduction of documents on photographically sensitised paper. (p. 185)

railway engine, a piece of scientific apparatus, of a cliff at the seashore – all these are records. If the object is in a state of change, such as a building under construction, a machine in motion, or a cliff that is being worn away by the sea, a series of photographs taken over a space of time will record the change.

A common use of photography is the copying of books, manuscripts, and other documents. Copying by hand or by means of a typewriter can be long and tedious, and mistakes in copying can readily creep in. A photograph provides a true copy, not only of the matter written but also of the style of writing – the typography and the appearance of the document.

Copying can be carried on to some extent automatically. Some semi-automatic cameras are now available in which copying can be done very rapidly. The best known of these is the Photostat machine, which makes photographs directly on to sensitised paper held in roll form, which can be cut off and developed in the machine itself (Plate 45). The Photostat camera gives a reproduction in white on a black ground if the original was black on white. It is used extensively in libraries and for copying commercial documents.

A simple way of copying printed matter in which no camera is used is known as *reflection copying* or *Playertype*. A sheet of especially contrasty bromide paper is placed with its sensitive side in contact with the page to be copied, and a uniform exposure to light is given through the back of the paper. When it is

developed, a negative is obtained from which photographic prints can be made.

In recent years, there has been a growing interest in copying on to cinematograph film owing to the large amount of materials which can be copied on to a small amount of film occupying very little storage space. The amount required to keep a set of film books is exceedingly small compared with the space occupied by the original volumes. A book can be copied at the rate of one page to one frame of cinematograph film, with fairly simple apparatus, but the process is slow. By the use of a special book-copying machine, however, the work can be done very rapidly, a whole volume being photographed in an hour. A print on film from the negative produced in this way can be issued to readers who read from it by means of a small projector fitted to the table of the reading-room or, alternatively, enlargements from the negative can be made upon photographic paper.

A method of copying documents which is increasing in use each year is by means of 16-mm. film in the *Recordak* machine, which was originally marketed for copying cheques in banks. The cheques are fed into the machine one at a time and are automatically photographed on to 16-mm. film (Plate 46). They are placed on to the conveyor belt (A) and fall into the receiver (G). Illumination is provided at (E), and the driving motor (B) operates the camera (F) in synchronism with the movement of the cheques. When the reel of film has been exposed, it is developed in

PLATE 46
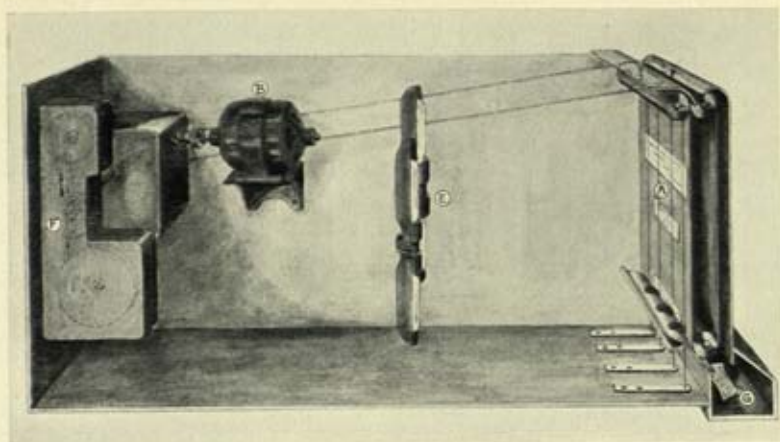
(*a*) Diagram of the Recordak.　(*p.* 186)

(*b*) Photographs of cheques obtained with the Bank Recordak.
(*p.* 186)

PLATE 47

(b) Reading newspaper films by the aid of a special projector. (p. 187)

(a) Operation of the Newspaper Recordak. (p. 187)

the usual manner, and a permanent record of all the details of the cheques passing through the bank is thus obtained. A special projector is provided for viewing enlarged images of the cheques one at a time.

Since the introduction of the Recordak for use in banks, new models have been brought out for copying commercial documents, and recently the apparatus has been applied to the copying of newspapers (Plate 47*a*). The newspapers are photographed on cellulose acetate film of the professional width, i.e. 35 mm. The picture on the film is 1/256th of the size of the original page (Plate 47*b*). Much study has been devoted to this problem over a period of years, for it seems to solve not only the great question of the preservation of newspaper records but, at the same time, that of housing the immense accumulations of such material which results if the original newspapers themselves are stored. The storage space required for newspapers in film form is less than 1/50th of that required for the originals.

Some documents in the course of time or use become changed, so that they are difficult to read. They may merely be worn or faded, but, on the other hand, they may be deliberately erased, charred by fire, or damaged in some other way. Photography can often help in deciphering them. Before the invention of printing, toward the end of the fifteenth century, documents were written by learned people, usually by monks, on sheets of parchment. Very often when fresh parchment was lacking, the writing was erased

from old documents in libraries, and the parchment was used again (Plate 48). Such parchments which have been re-used are called *palimpsests*, and it is generally impossible to see the writing which was originally on them. By making use of a particular property of the parchment, however, the old writing can often be revealed by photography. If a palimpsest is 'illuminated' with invisible ultra-violet light, it glows with a soft bluish visible light known as *fluorescent* light. The parts which have never been written upon glow more strongly than the parts which carry ink or those which originally bore ink which was later erased. A photograph can thus be made of the fluorescent light from the parchment, and in this way the original writing is recorded. Photographs made in this way are often of value in detecting forgeries and in studying changes in old paintings.

Infra-red light has proved of use in photographing the writing on papers which have become illegible through being charred in a fire (Plate 49), in deciphering old books in which passages have been deleted with black ink by the censor, in determining the authenticity of paintings, and so forth.

The scientist and engineer make photographs of many subjects merely as records of their characteristic appearance. If these pictures are properly made, however, they can also be used for making measurements. For example, a photograph of a landscape might be used for measuring the distance between two features on it instead of using a chain along the

PLATE 48
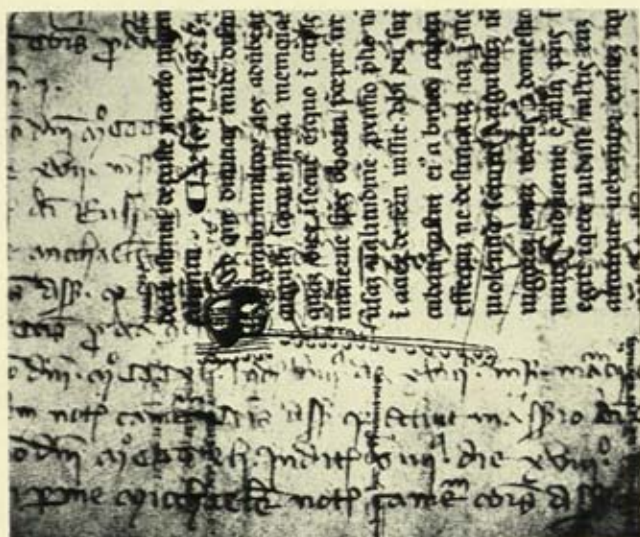
(II)
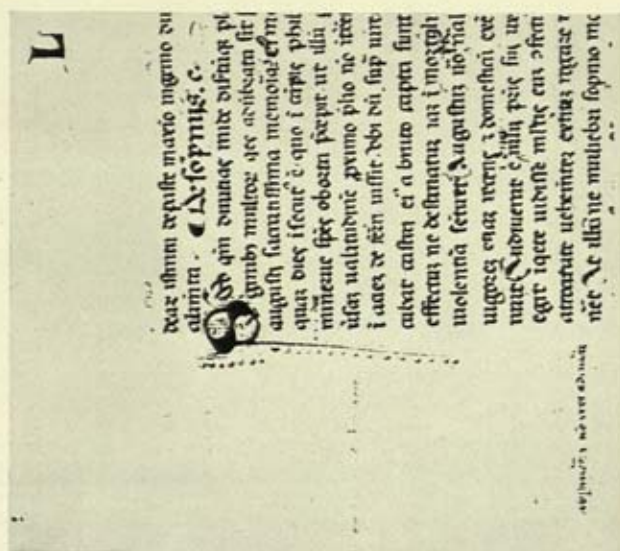
(I)

A palimpsest manuscript (I), as it appears; (II), as photographed by fluorescent light, showing the original writing. *By courtesy of Dr. L. Bendikson, Huntington Library. Pasadena, California.* (p. 188)

PLATE 49
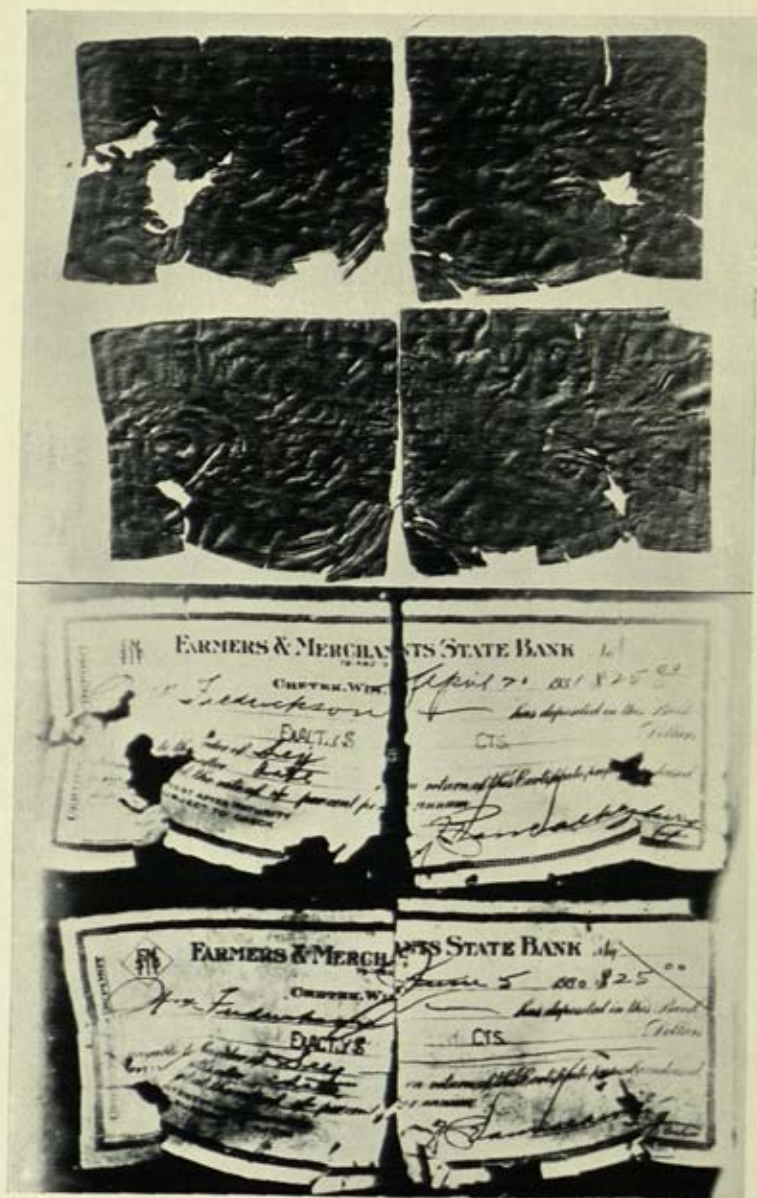
Charred cheques: (*above*), as they appear; (*below*), as
photographed by infra-red light, revealing the original
writing. *By courtesy of Mr. John F. Tyrrell, Milwaukee,
Wisconsin.* (*p.* 188)

ground for the purpose. The camera can thus be of help to the surveyor; in fact, much map-making at the present time is done by means of photography. The sciences of *photo-surveying* and *photogrammetry*, as they are called, are very well developed; the pictures used for measurement can be made either from the ground or from an aeroplane. The pioneer in the application of photography to surveying was Colonel Laussedat of the French Army, who in the second part of the last century published a number of valuable treatises. It is natural that photographic surveying should develop most rapidly in countries where there are good landmarks, and, for this reason, the Alpine region of Europe and the mountain chains of north-west Canada were the first large areas to be surveyed by photography. Much work has since been done in Russia, Africa, India, and South America.

A photographic survey is made by taking two photographs of the same area from different positions and plotting them on the map. Lines are drawn from these positions to each point and object which can be identified in the photograph until the complete survey is accomplished. This is very similar to the plotting which is done by the usual method of surveying using the plane table, but it has the advantage that the detailed plotting can be done indoors, the only work done outside being the photography. The cameras used are of very rigid construction and have levelling mountings so that they can be levelled accurately and used after the manner of the *theodolite*.

An extension of this method of *ground photo-topography*, as it is called, uses the principle of stereoscopy. Two photo-theodolites are used at opposite ends of a measured base line, and exposures are made in which the same objects are included. From these photographs, distances can be measured by using an instrument called a *stereo-comparator*, and maps can be plotted directly from the photographs by using the *stereo-autograph*. The accuracy of surveying by these methods is very high, but it must be controlled by a preliminary triangulation.

For rapid survey, especially in areas which have few landmarks or where travel is difficult, aerial photography is now very much employed (Plate 50). It received its great impetus for military purposes during the World War, when thousands of photographs were taken every day from the air by the opposing armies. The first aeroplane cameras were modifications of ordinary cameras in which the plates could be changed rapidly. Semi-automatic plate cameras were later designed in which the operation of the shutter set in motion a mechanism for changing the plate as soon as the exposure had been made. At the end of the War, film cameras were developed carrying rolls of film giving one hundred exposures each 18 × 24 cm. These cameras were entirely automatic, the changing of the film and the exposure being carried out by means of a motor operated electrically or driven by the wind. Automatic film

PLATE 50

An aerial survey of an area in Worcestershire covering approximately
$\frac{3}{4} \times \frac{1}{2}$ mile. Eight aerial photographs were used in the construction
of this aerial map. *By courtesy of Aerofilms Ltd.* (*p.* 190)

PLATE 51

(a) An oblique photograph taken from an aeroplane.

(b) A plan view of the same subject. The converging lines show the area embraced by the oblique photograph. Photographs of the recording instruments are included to show date, time, altitude, compass, and other particulars. *By courtesy of Aerofilms Ltd.* (p. 191)

cameras are very widely used at the present time for aerial survey work.

In one way of making a map by photography from the air, the aeroplane flies back and forth over the territory taking a series of pictures vertically. The prints from these negatives are joined by piecing them together to form what is called a *mosaic*, which is re-photographed to obtain a single negative of the whole region surveyed.

In addition to taking vertical photographs from which maps can be made, pictures can also be taken at an angle. This is known as *oblique* photography. Much of the work involved in drawing the map consists in correcting the distortion introduced when a photograph is deliberately taken obliquely or when the aeroplane is tilted somewhat in making vertical photographs (Plate 51).

From the photographic point of view, one of the most important phenomena encountered when working from a great height, as from an aeroplane, is the scattering of the light by the atmosphere, an effect known as *haze*. As was explained in Chapter VII, the scattering is greater for light of the shorter wavelengths and can be eliminated by the use of filters which absorb the blue and violet light. By the use of a red filter with panchromatic film, great penetration through a hazy atmosphere is possible, and there is much better reproduction of detail than is obtained without a filter (Plate 52).

One of the branches of science in which photography

is of the greatest value is astronomy. The earliest star photographs were taken as far back as 1850, but it was not until the introduction of the present type of photographic plate about 1878 that astronomical photography was practised to any considerable extent. Visual observation through the telescope has now been replaced almost entirely by photography. A plate holder is adapted to the telescope, and the work of the astronomical observer consists largely in directing the telescope towards the object to be photographed and in correcting small irregularities in the drive which produce a shift in the position of the image on the plate.

One of the great pieces of astronomical photographic work commenced toward the end of the last century, was the making of a complete star map by the co-operation of a number of observatories throughout the world. This star map, known as the 'Astrographic Chart,' is still being compiled (Plate 53*b*).

In addition to recording the position of the stars, it is possible to obtain an idea of their size or distance from a measurement of the size or density of the image. A system has been worked out for a scale of photographic *magnitudes* of the stars, in the determination of which a plate is exposed for an equal time on the stars being studied and on a number of stars near the Pole of which the magnitudes have already been carefully determined. In the photograph, the stars are represented as small dots, the diameters of

PLATE 52
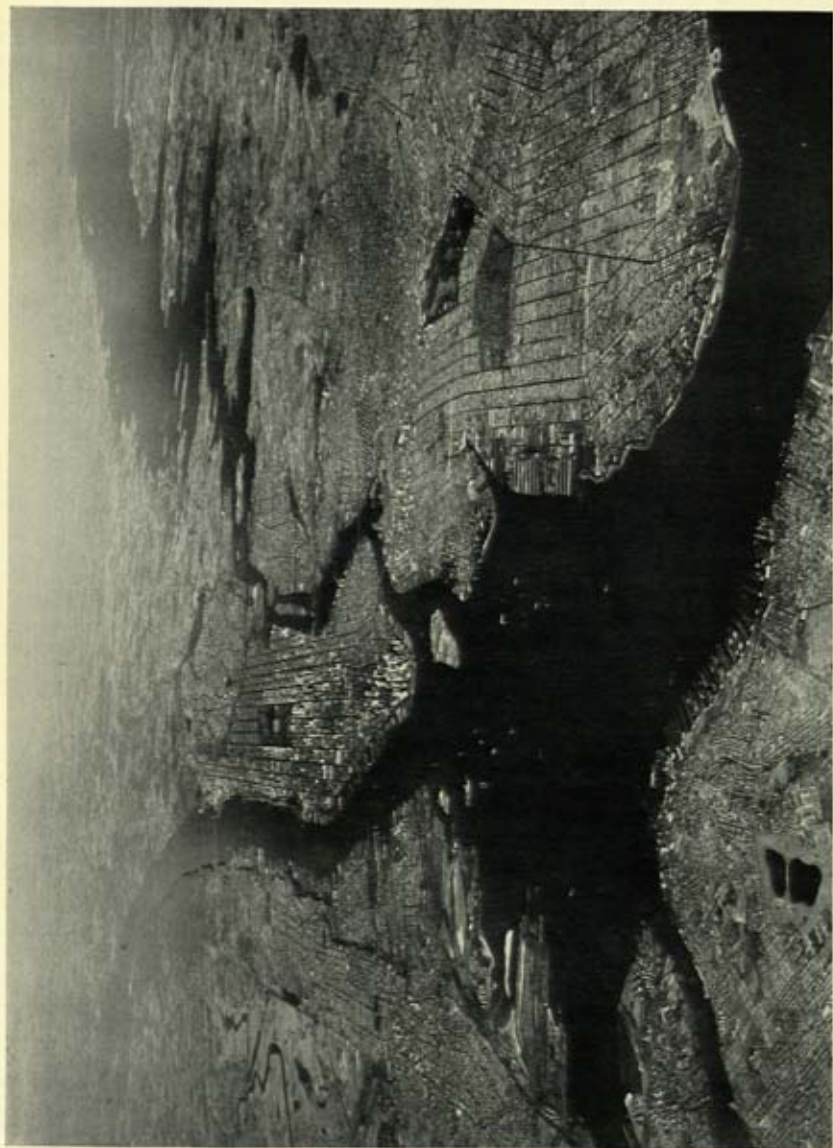
Photograph of the New York City area from a height of 26,000 feet. Taken by Captain A. W. Stevens, U.S. Army Air Corps, using supersensitive panchromatic film and a red filter. (*p.* 191)

PLATE 53

(a) The Constellation of Orion. Exposures of 30 and 150 minutes, showing the cumulative effect of light on the photographic plate. *By courtesy of Yerkes Observatory, Williams Bay, Wisconsin.* (p. 193)
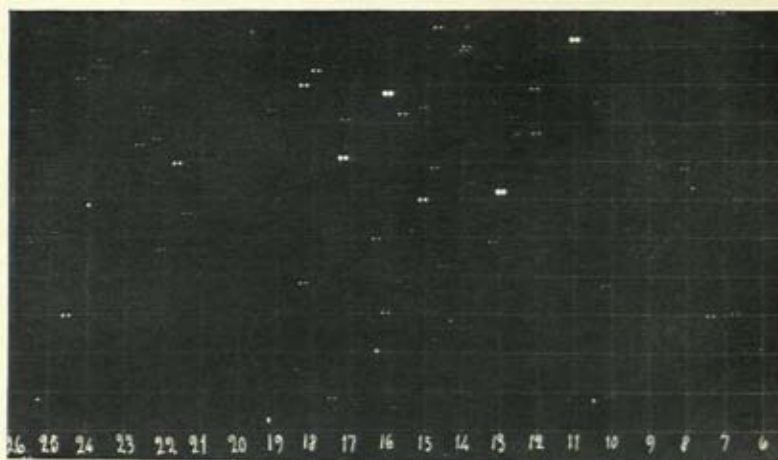
(b) A portion of the astrographic chart. The star images are duplicated in order that they may be distinguished from dustmarks which might otherwise be measured as stars. (p. 192)

which vary with the brightness of the stars; and from the diameters of the star images and a knowledge of the brightness or magnitude of the standard stars, it is possible to determine the magnitudes of the stars under examination. There are other photographic methods of determining the magnitudes of bright stars. Out-of-focus images of the stars are obtained, and their density is measured by means of a micro-photometer.

Because the effect of light on a photographic plate is cumulative, the images of stars obtained in a photograph taken through a telescope increase as the exposure is prolonged; with short exposures, only a few of the brightest stars are recorded (Plate 53a). When the exposure is continued for ten minutes or so, images of all the stars visible in the telescope will be found on the plate, and when the exposure is continued for many hours, the plate will be filled with images of stars fainter than the eye can see through the greatest telescopes. A practical limit to the continuation of exposure is the general diffused light from the sky, which with many hours of exposure fogs the whole surface of the plate. Near cities, this diffused light comes from the artificial light which is reflected by dust and water vapour in the air. But even in the absence of any terrestrial source, there is light from the sky background, which is partly scattered starlight but partly of unknown origin – possibly electrical in nature and akin to the aurora. The greatest telescopes will show the eye stars about 100,000 times fainter

Op

than those visible to the naked eye while, in photographs taken through these instruments, the faintest stars recorded are ten times fainter than those which are visible, or a million times fainter than those which can be seen without a telescope.

When photographs of the heavens are taken through a telescope, two types of objects will be recorded which are not observed with the naked eye: one is the great nebulæ or star clouds which cover great areas of the heavens and are now known to be very numerous (Plate 54). The study of these has shown that they are agglomerations of stars relatively near each other, as compared with the distances between the nebulæ. The Milky Way itself is such a nebula, of which the sun is one of the constituent stars, and it appears to cover the heavens because we are in the midst of it. Outside the Milky Way are other nebulæ at enormous distances, and recently it has been found possible to photograph nebulæ at such distances that the light by which they are recorded started toward the earth more than one hundred million years ago. Besides these bright nebulæ, the photographs show that between the stars, and blocking out some of the stars of the Milky Way, there are dark clouds which probably consist of gas or of particles absorbing light and occupying vast areas of space.

Turning to the nearest and brightest of the stars – our own sun – photography has shown us that its surface is in a state of constant, violent agitation from

PLATE 54
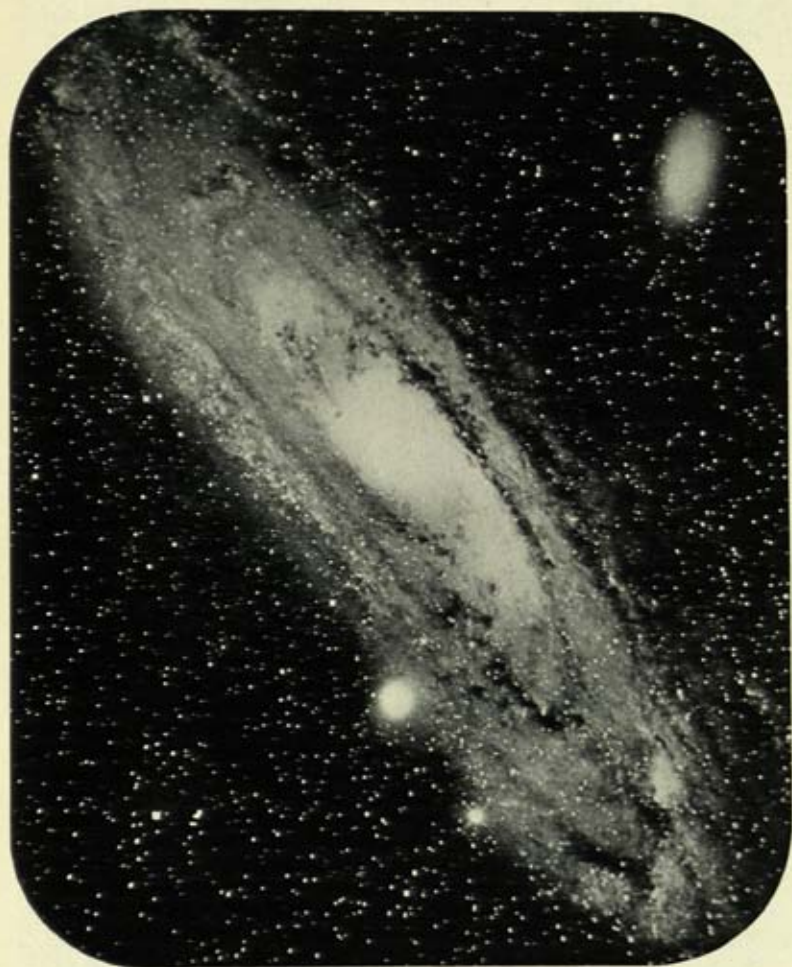
The Great Nebula in Andromeda. *By courtesy of Yerkes Observatory, Williams Bay, Wisconsin.* (p. 194)

PLATE 55
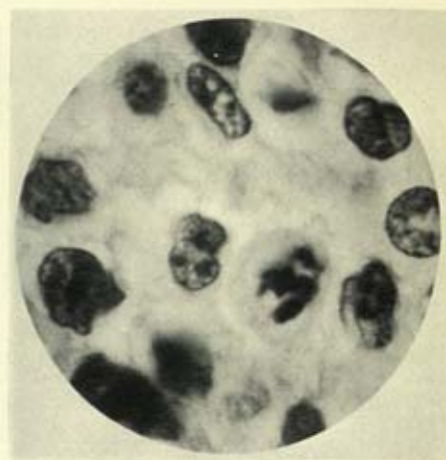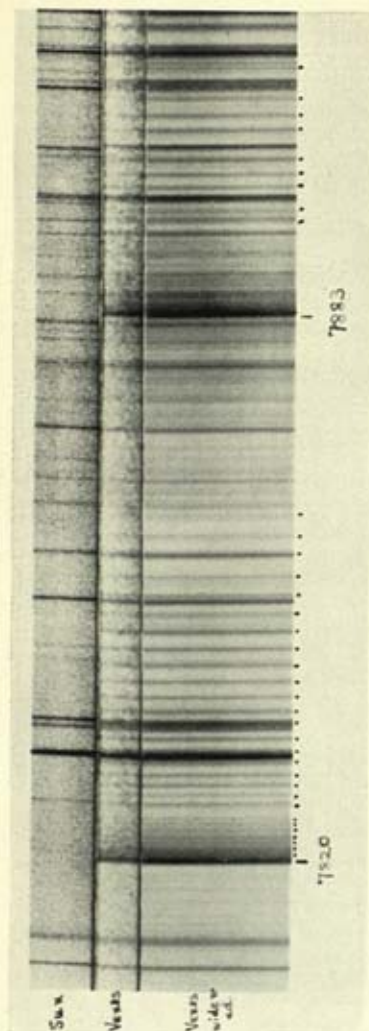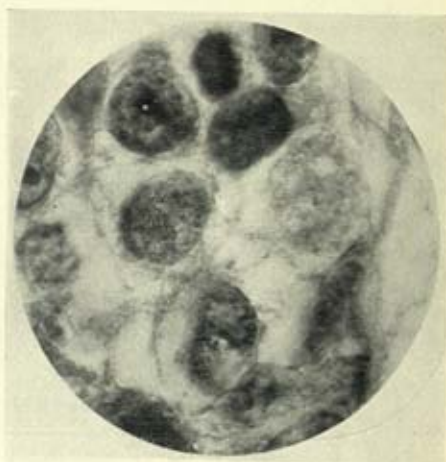
(a) Bands in the spectrum of Venus showing the presence of carbon dioxide. *By courtesy of Mt. Wilson Observatory, Pasadena, California.* (p. 195)

(b) Photomicrograph showing carcinoma of the appendix. (I), Using the best system with visual light; (II), Photograph with ultra-violet light. *By courtesy of Dr. F. F. Lucas, Bell Labs., 463 West Street, New York.* (p. 198)

great eruptions of hot gas and whirlpools into which the surface seems to be drawn.

The best photographs of the sun's surface are taken by means of an instrument called the *spectrohelio-graph*, by means of which photographs can be taken by monochromatic light. Recently, Professor George E. Hale has introduced his *spectrohelioscope*, which can be used to watch the sun's surface continuously. Through this, cinematograph pictures can be taken showing the projection from the sun of masses of gas in volume greatly exceeding that of the earth, these being flung out for distances from the sun equal to that of the moon from the earth.

By the use of a spectrograph together with the telescope, much information can be obtained about the composition and nature of the stars, and recent improvements in the sensitivity of photographic materials to the longer wave-lengths of the spectrum have been of the greatest value in this connection.

The photography of the spectrum in the infra-red has been particularly valuable in the study of the atmospheres of the planets. In the atmosphere of Venus, for instance, the spectroscope shows the presence of absorption lines due to great quantities of carbon dioxide (Plate 55a). The spectra do not show oxygen present in the atmosphere of Venus, and it is possible that Venus is in the state that the earth may have been in before the coal measures were laid down, when the plants absorbed the carbon from the carbon dioxide to produce coal and so liberated the

oxygen which the animals in due time came to breathe. It has been thought that there was an atmosphere around Mars and that the atmosphere contained oxygen, which is essential for the support of life as we know it. 'The Man in Mars' was often a popular figure with imaginative novelists. Recent measurements, however, show that the chance of life of higher forms on Mars is very small indeed because, if oxygen is present in its atmosphere, there is no more than one quarter of 1 per cent of that present in the atmosphere of the earth. It is possible to study the surface of Mars directly because clouds rarely surround it. It has a reddish desert-like appearance, and it is probable that the oxygen once present in its atmosphere has been used up in oxidising the surface materials, the reddish hue being due to iron oxide so formed.

The study of planets more distant and less bright than Mars has shown results even more startling, for in the atmospheres of the cold planets – Jupiter and Saturn – there has been found certain evidence of the gases ammonia and methane. These are gases which might be formed if a mass of gas having a composition like the atmosphere of the sun were to cool slowly to a very low temperature.

Turning from the study of the vast and remote stellar universe to the smallest and nearest things, photography with the microscope is of nearly as much value as it is with the telescope. Small cameras can be fitted to ordinary visual microscopes to make records of value for reference purposes. In more

elaborate apparatus for serious photomicrography, it is usual for a special camera and a microscope to be mounted on a large stand or on a rigid optical bench together with the source of light used for taking the pictures. The ordinary microscope itself may be replaced by a part of the optical bench, such apparatus being particularly designed for the *photomicrography* of the surfaces of metals by reflected light. The photomicrographic outfit of medium power is an indispensable tool for the botanist in studying the structure and diseases of plants, for the zoologist, the doctor, and other scientists. For many years, the highest powers of the microscope were used only for examining bacteria and test objects, such as the minute structure of diatoms, but at the present time the demands of those engaged in the study of the structure of metals and alloys also require the highest magnification possible from the microscope.

Strictly speaking, there is no limit to the *magnification* of the microscope, but there is a very definite limit to what is known as the *resolving power* of the microscope system. The resolving power is stated as 'the number of lines per millimetre which can be clearly separated by the microscope.' It depends upon the length of the waves of light; that is, the colour of the light used in making the photomicrograph. The shorter the wave-length, the higher the resolution obtained, so that better separation of fine detail is secured when using blue or ultra-violet light than green or white light. In addition, a microscope

objective of large aperture gives better resolution than one with a small aperture. Dr. F. F. Lucas, using blue light and a microscope objective lens of very high aperture, has recently achieved the highest order of resolution ever attained. Working at magnifications of 4,000 to 6,000 diameters, he has photographed isolated particles which are only 200 to 300 atom diameters in size. The technique developed is being applied to the study of the hardening by hot treatment of alloys, such as tool steels, etc., and much has been learned about changes which occur in such steels when they are heat treated and quenched and the relation between these changes and the hardness or other properties of the steels.

One noteworthy advance in photomicrography has involved the use of ultra-violet light because this enables very high resolving power to be obtained (Plate 55b). Further, much use has been made of the motion-picture camera in conjunction with the microscope, and very instructive *motion-photomicrographs*, as they may be called, have been made of such subjects as the movements of bacteria, the growth of living cells by subdivision, and the circulation of the blood through the arteries.

While, for the best photomicrographs, elaborate and expensive apparatus is necessary, valuable records can be obtained with very simple apparatus, all that is required being a simple camera mounted over the microscope. An apparatus which has recently been introduced and which has the advantage that it may be

PLATE 56

(b) Golf ball hit by a mashie, 1/75ooth second exposure. By courtesy of Dr. H. E. Edgerton, Massachusetts Institute of Technology. (p. 201)
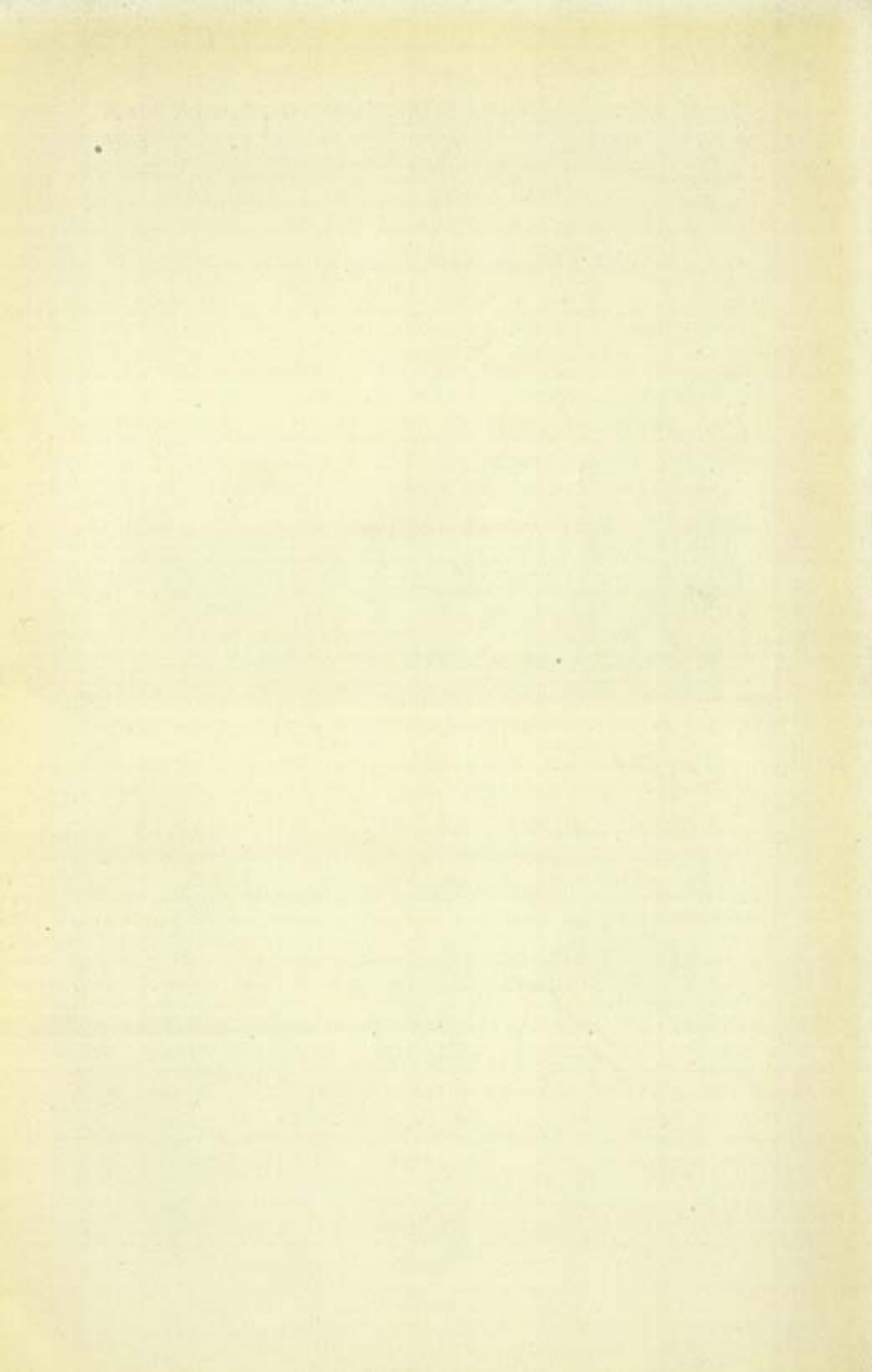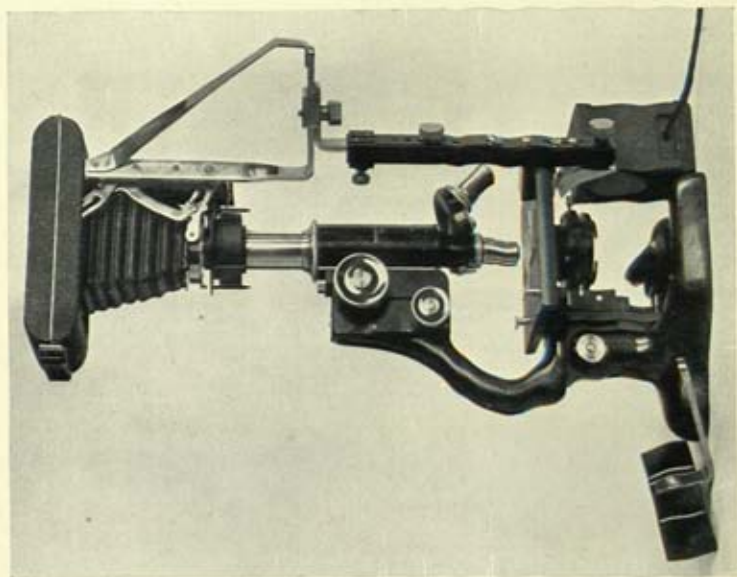
(a) The Microdak mounted on a microscope. (p. 199)

clamped on the stage of the microscope so that it can instantly be attached or withdrawn is shown in Plate 56a.

Although photography through the microscope is of such importance for the biological sciences, ordinary photography is also used to a considerable extent in medicine for the purpose of making records for instruction or of rare and interesting cases. For the teaching of medical students, cinematograph films of operations are of considerable importance, the technique of the operation being shown very clearly in such pictures.

It is possible that infra-red photography may be of help in the future in the diagnosis of some maladies. Infra-red rays possess the property of penetrating the skin and thin layers of fat near the surface of the body in the same way that they penetrate atmospheric haze. If a photograph is taken of the arm, for instance, by means of infra-red rays, the rays penetrate through the surface layers and show in the photograph the network of veins lying beneath the skin. Many diseases are accompanied by changes in the size of the veins, and photographs of them made by infra-red rays are thus of help in diagnosis.

The cinematograph picture enables us to do one thing which can be done in no other way: it enables us to change the rate at which events occur in time. This can be done by changing the number of pictures taken per second while still projecting these pictures at the standard rate. Suppose, for instance, we

project sixteen pictures a second; if the scene we are projecting was taken at sixteen pictures a second, the action on the screen is at the same speed as the original action; but if we took only eight pictures a second, the action appears to be speeded up when projected; and if, on the other hand, we took sixty-four pictures a second, the action is slowed down, and we get what is called *slow motion*. In order to study the growth of plants, it is interesting to take pictures very slowly. If, for example, pictures are taken at the rate of sixteen per *minute*, and are then projected at the normal speed, the plants are seen to grow, bud, and blossom before our eyes.

On the other hand, valuable information may sometimes be obtained from photographs made with very high-speed cameras of events which occur so rapidly that the exact action cannot be followed by the eye. Sometimes, it is sufficient to make a single instantaneous photograph, or it may be desirable to make a succession of such photographs in order that the entire movement may be analysed.

The well-known applications of high-speed photography include the study of splashes, the photography of bullets and other projectiles in flight, photographs of sound waves and pressure waves of gases ejected from nozzles, the driving of a ball in golf and tennis and similar actions. A golf ball struck by an average player in making a drive leaves the club at a speed of about 180 feet a second, whereas the shortest exposure available with the best cameras, such as those used by

Press photographers, is 1/1,000th of a second. In this short interval of time, the golf ball moves 2 inches, and the photograph of it would appear as a white blur 2 inches long. If the photograph is to look reasonably sharp, the movement of the ball should not be more than 1/50th of an inch. The ball, however, moves 1/50th of an inch in 1/100,000th part of a second, and an exposure of this duration would be quite unattainable with a mechanical shutter on a camera. Even if it were attainable, we should be faced with the problem of providing enough light to give a good photograph in such a short time. Fortunately, there are means available which can produce very bright flashes of light of exceedingly short duration. One of these is the electric spark, another is a discharge through a mercury arc-lamp. Using these, very interesting snapshots of high-speed phenomena can be made. Dr. H. E. Edgerton of the Massachusetts Institute of Technology made a study of what happens to a golf ball when it is struck by a club (Plate 56b). The ball before it moves from the tee becomes considerably compressed and flattened at the side in contact with the club. The club and ball travel together for a short distance before the ball races ahead of the club.

Much faster than a golf ball struck by a club is a bullet fired from a revolver or some kinds of explosions in mixtures of explosive gases. By using the electric spark method of making high-speed photographs, it is possible to study bullets during their flight. The

earliest work of this kind was carried out by Professor C. V. Boys. An intense spark of very short duration is used to take the snapshot of a bullet travelling at a rate of perhaps half a mile a second, and elaborate electrical apparatus is necessary to ensure that the camera gets the record at the right moment and to provide the two-millionth of a second flash necessary (Plate 57).

The photographic study of explosions is of considerable importance both for those who wish to make use of explosions, as in the design of motor-car engines and the manufacture of explosives for blasting purposes, and for those who desire to eliminate explosions, as, for instance, in coal mines.

There are two ways of studying the rapidly moving flames which occur in explosions. In one, a series of photographs of the flame is made in succession at very short intervals on a plate or film. These show the consecutive stages in the propagation of the flame. In the other method, a film is made to move rapidly in a direction at right angles to the path of travel of the explosion. An image of the flame is focused on the film by a lens, and a trace is obtained, from which the speed of the flame can be calculated. In an explosion in a mixture of gases, the flame may travel at velocities varying from 0·3 to 3,500 metres a second, or, say, 0·5 to 7,000 miles an hour. But, whatever the velocity, the rate and characteristics of the explosion can now be studied.

In an ordinary cinematograph camera, the film is

PLATE 57
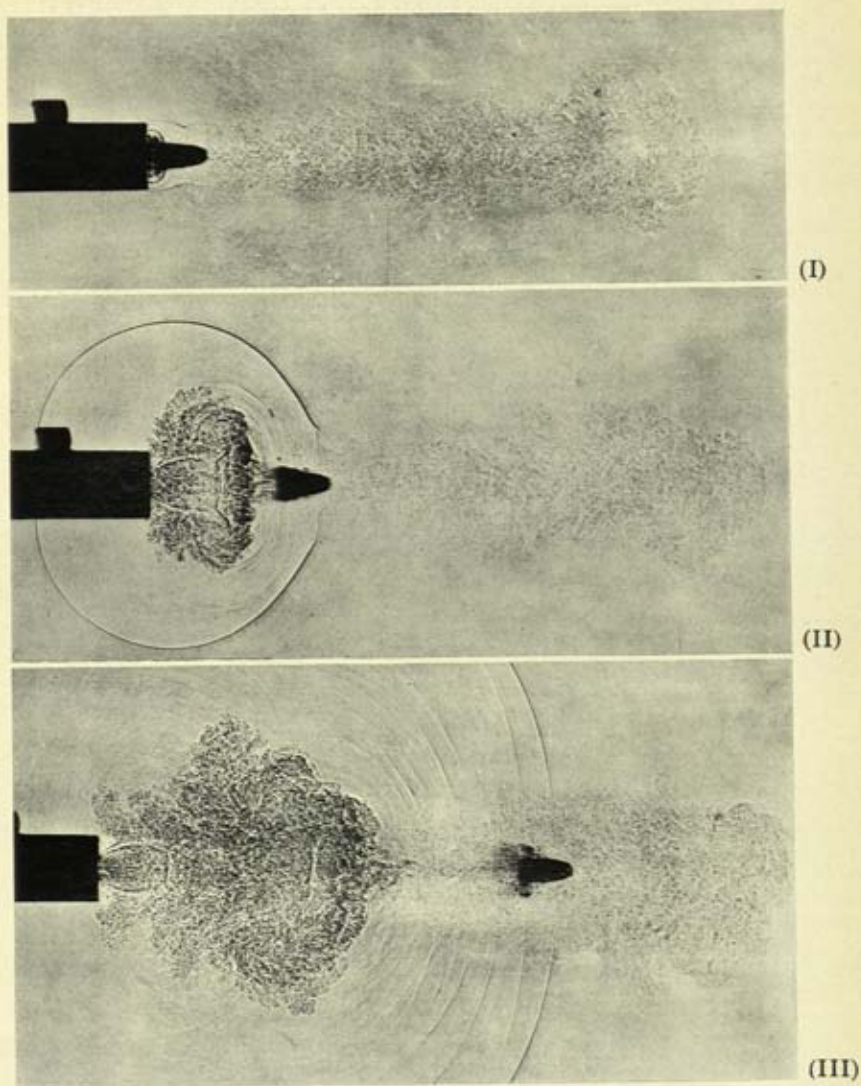
Bullets in flight. (I) Bullet just emerging from muzzle, sound wave just beginning to form; (II) Bullet 1¼ inches clear of muzzle, sound wave grown to three inches; (III) Bullet well clear of muzzle and passing through the sound wave. *By courtesy of Mr. Phillip M. Quayle, Peters Cartridge Company.* (p. 202)

PLATE 58

The finish of a horse race. Two successive pictures, 1/100th second apart, showing the winning horse passing the finishing post. The time indicator is shown at the side. (*p.* 203)

moved intermittently. It is still while each picture is being taken and is then moved down into position for the next picture, the lens being covered by a rotating shutter during the movement.[1] When pictures are taken very rapidly, this intermittent movement involves strain on the film and on the mechanism, so that the greatest number of pictures which can be taken intermittently is 128 a second. While this is sufficiently rapid to show the movement of athletes, race-horses, and so forth, it is quite useless for the analysis of many physical phenomena. A camera designed to take one hundred pictures a second is now being applied to timing horse races and athletic events. The camera is so arranged that, in addition to the picture, a time record is thrown on the film so that, as the winner passes the mark, the record shows the reading of an electric clock which started automatically when the race began. In this way, athletic events can be timed to 1/100th of a second, about twenty times as accurately as is possible with a stopwatch, and experience has shown that in many cases the timing camera may assist the judges as to the winner.

In cases where it is necessary to make public the result immediately, the film passes from the camera to an automatic developing machine, and in less than two minutes the picture can be examined and an enlargement prepared which will demonstrate the actual position at the finish (Plate 58).

[1] See Chapter VI, p. 103.

For taking pictures at a still higher rate, a camera is used in which the film moves continuously, the pictures being produced by the help of an optical device consisting of a rotating cube of glass which holds each image steadily on the film while it is travelling through the gate and then allows the next image to fall in its proper place. With this type of camera, very high speeds can be attained, 2,000 or more pictures a second being made; and it is possible that with 16-mm. film nearly 10,000 pictures a second may be reached. With such speeds, it is impossible to stop the film because the inertia is far too great and a 50-foot roll of film carrying the 2,000 pictures is driven by an electric motor through the camera in the fraction of a second. With such an apparatus, studies can be made of the meshing of gear wheels or the operation of cams and followers. More dramatic illustrations are the breaking of lamp bulbs or the splashing of liquids. Such a camera is a kind of time-microscope with which we are transported into a new world where the swiftest of birds drag their slow way, and the winking of an eye endures for minutes.

In addition to allowing us to modify the action of time, photography makes it possible to see with invisible rays. We have already mentioned the infra-red and ultra-violet rays, but there are rays much shorter than the ultra-violet and far more penetrating than the infra-red. These are the X-rays, discovered by Röntgen. The X-rays do not affect the eye and therefore cannot be seen, but they produce images on

photographic films. In other ways, X-rays differ from light; they are not refracted by lenses, nor are they reflected as light is; so that optical images cannot be produced by X-rays; a camera cannot be used with them. But, just as Wedgwood made prints from lace and the skeletons of leaves, so, if an X-ray tube is placed above a photographic film and the hand is put on the film so that the X-rays pass through it, a *shadowgraph*, or *radiograph* as it is called, will be obtained. But the radiograph will not show only the visible outline of the hand; it will show the bones and even the structure of the bones (Plate 59).

X-rays have an extraordinary power of penetrating matter; they are absorbed only by the *atoms* of which substances are made; and their absorption depends upon the weight of the atoms, so that bones cast shadows much deeper than does the surrounding flesh, and even very small differences in composition are shown in the radiograph.

This has been of the greatest value in medicine and dentistry. Conditions which cannot be seen in the ordinary way, such as those of the teeth, particularly in relation to the condition of the roots, can be revealed by X-ray photographs; bone fractures and the position of foreign substances can be detected. Small changes even in the soft tissues are shown in the radiographic pictures, so that, in the course of a medical examination, it is common to examine the lungs for any appearance indicating the possible presence of tuberculosis. Sometimes, the structure of

the softer parts of the body can be made visible by the use of inert substances which absorb the X-rays. Barium sulphate, for instance, mixed with cooked food or with milk, can be administered, and as it is very opaque to X-rays, its progress through the entire intestinal tract can be followed. The element iodine has heavy atoms which absorb X-rays, and substances containing iodine can be administered which will pass in the body to the gall bladder and thus enable its outline to be photographed.

X-rays are also used for the examination of the interior structure of metal castings, aeroplane struts, and other materials which would involve danger if they contained any flaws. X-rays have greater penetration when they are produced by higher voltages of electricity, and in order to penetrate and reveal the structure of metals, it is often necessary to use more than 200,000 volts.

Even more penetrating than the X-rays are the shorter, so-called *gamma-rays* of radium. They will penetrate as much as fifteen inches of steel, compared with a few inches in the case of the X-rays. They have the advantage over X-rays that no apparatus is required to generate them.

Less penetrating than the X-rays normally used are the so-called *Grenz* rays. They do not penetrate the glass walls of the tubes used for the generation of the normal rays, and special tubes with a very thin glass window are required for them. They can be used to show the structure of materials, such as

PLATE 59

(b) Radiograph of a child's wrist. (p. 205)

(a) Making the radiograph shown in (b)

PLATE 60

Grenz ray photograph of a columbine flower. (*p.* 207)

paper, leather, cloth, leaves, flowers, and insects, which are too transparent to the usual X-rays to show any detail in the photograph. (A picture taken by means of the Grenz rays is shown in Plate 60.)

The uses of photography are innumerable, and it has been possible in this chapter to describe only a few of the more striking and interesting ones. Year by year, the applications increase, so that photography is of service in all the activities of mankind – in industry, in business, in government, and, most important of all, in the discovery and knowledge of truth.

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