STEREOSCOPIC PHOTOGRAPHY

ITS APPLICATION TO SCIENCE, INDUSTRY AND EDUCATION

By

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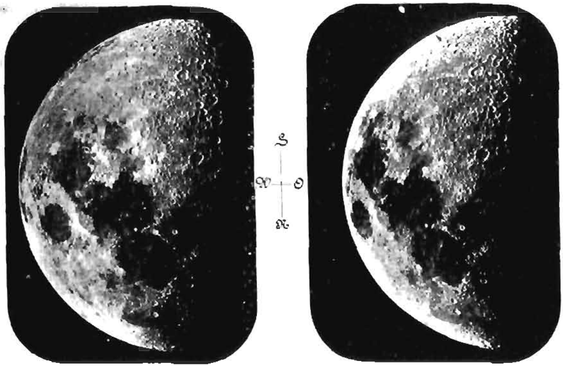

(C. Zeiss.)

STEREOSCOPIC PHOTOGRAPHS OF THE MOON. TAKEN WITH EQUATORIAL COUDÉ TELESCOPE IN PARIS. ONE VIEW TAKEN IN APRIL, 1896, AND THE OTHER IN FEBRUARY, 1900.

*Made and Printed in Great Britain by
C. Tinling & Co., Ltd., Liverpool,
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AUTHOR'S PREFACE

THE subject of stereoscopy and its photographic applications to the various sciences and to industry is one which has been sadly neglected in modern photographic literature, for, with the present exception, there does not appear to be any recent work on the subject, in our language, although a certain amount of attention has been given by the French and German authorities to stereoscopic literature.

In view of this fact, and also because of the growing interest in applied stereoscopy, it was felt that the present was an appropriate opportunity to publish such a book.

Not only is stereoscopic photography being taken up again with increasing zeal—as judged by the activities of the stereoscopic societies, and by the sales of apparatus—but its principles are finding greater application to microscopy, radiography (X-ray work), astronomy, aerial and land survey, optical instruments, to educational purposes and also to magazine and catalogue illustration. Already on the Continent, the anaglyph is being used to an increasing extent for the stereoscopic illustration of commercial catalogues, and for books and magazines. In this country also the enterprising proprietors of *The Illustrated London News* have added considerably to the value of their publication by the regular inclusion of excellent anaglyphs. There is little doubt that when once the value of this realistic method of illustrating solid objects is realised, it will find a firm place in art, industrial and engineering catalogues; it is the next best thing to viewing the actual objects depicted. There is no comparison, for instance, between a stereogram, or an anaglyph of a piece of machinery, an automobile chassis, a piece of apparatus, a group of statuary, or an architectural object, and the commonplace flat photographic illustration of any of these. The enterprising manufacturer who has the foresight to equip his travellers with a set of stereograms and a viewing stereoscope, will undoubtedly score over his competitors not similarly equipped.

Not only in industry and literature illustration has st an important field, but also in science. By its aid the microscopist, for example, is able to observe stereoscopically and to photograph the minute solid objects revealed under his microscope and eventually, in the stereo. photographs to obtain permanent records in relief of these objects. The astronomer employs stereoscopic principles not only to detect the presence of faint stars and binaries, but also to show in realistic relief the features of the moon, comets, certain of the planets and also the proper positions in space of stars of greater magnitudes forming the constellations. The radiographer is enabled by stereoscopic X-ray pictures to locate exactly foreign bodies in the human system, to show the position of flaws, air-pockets or defects in castings, metals, or other materials, and to reveal the internal structures of organic bodies and interiors of composite bodies and mechanisms. Numerous other applications could be cited, did space permit.

In education also the use of the stereoscope has proved a valuable means of representing objects, places, scenes, peoples, industries and similar subjects, in their true relief, to pupils in elementary schools. It is found that a more lasting impression and a much better idea of the subject is obtained by the scholars than when ordinary single photographs are employed.

In advanced schools and in colleges also, the stereogram has unlimited possibilities in enabling the student to visualize complex diagrams and objects. He can obtain a valuable reference record, in this manner, to assist his studies. Thus the anatomical student can retain realistic impressions of dissections; the geometrical student, three-dimensional objects, curves and diagrams; the chemical student, atomic diagrams, crystal formations and the like; the engineering student, realistic views of machines, engines and constructions.

Having outlined very briefly the wide range of application of stereoscopy it may be as well to add a few words regarding the scope of the present book.

Realising the necessity of maintaining a popular as well as a technical interest in stereoscopy, the theoretical and analytical sections have been kept to minimum proportions, and the treatments and accounts given made as simple as possible. It would easily have been possible to fill this volume entirely with matter relating to stereoscopy of a theoretical or hypothetical nature; such a work would, however, have only a very limited field of appeal. We trust, therefore, that the more advanced reader of this book, will withhold any criticisms of technical incompleteness, or lack of more serious treatment of the principles involved, but will bear with the author in his avowed objects. It is hoped that the bibliography at the end will provide useful references for those wishing to pursue the subject more thoroughly.

As regards the photographer, enough has been said, we trust, to convince those who have not experienced the fascinations of stereoscopy to make the experiment. No one who has once taken up stereoscopic photography in earnest will willingly revert to "flat" photography. It is shown in this book how stereoscopic pictures can be made with the simplest of single-lens or two-lens cameras, and as there are in existence one or two Stereoscopic Societies, in this country to look after his interests, there is no valid excuse for not taking up this attractive hobby.

The Royal Photographic Society has also a section devoted to Stereoscopic Photography; the Annual Exhibitions of the Society show a rapidly increasing interest in the stereoscopic exhibits.

In conclusion, the author wishes to place on record his appreciation of the assistance of *English Mechanics and The World of Science*—a pioneer paper which publishes stereoscopy articles, Messrs. The City Sale and Exchange, Underwood Keystone Stereographs Ltd., Watson, Baker, Atha Swift, Beck, Sands Hunter, and the other firms which have kindly loaned illustrations, and also to Col. van d'Albada (Wide-Angle Stereograms), Charles Benham (Miscellaneous), Capt. McCaw (Aerial Photography), Mr. Hollis (Astronomy), Mr. Taverner (Microscopy), Mr. Dowdy, and others who have been kind enough to help.

A very convenient stereoscope for viewing the illustrations in this book is the "Lothian," particulars of which will be found in the Instruments and Apparatus Section.

A. W. JUDGE.

"Sandhurst,"
Farnham.
January, 1926.

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CHAPTER I

INTRODUCTORY.

THE value of photography to mankind depends almost entirely upon the truthful records which it gives of different subjects as the eye sees them. Leaving out of these considerations the question of photographic manipulation for artistic, or impressional effects, it will be evident that the ordinary, flat photograph *does not* depict the subject as the eyes perceive it, but only as one eye does, and that it loses thereby a good deal of its value and interest. The ordinary photograph, invaluable as it is for many purposes, fails to provide a truthful impression of the picture seen by the eyes.

A moment's reflection will indicate the reason for this, for one has only to remember that the objects composing the subject photographed, possess solidity or depth, and are situated at different distances from the camera; the ordinary photographic print depicts these three-dimensional objects, and their distances from the camera, in two dimensions, only. That is to say it endeavours to record *volumes* in an *area*.

Fortunately, there is a redeeming feature in connection with our interpretation of flat photographs, namely, in the association in the picture of our impressions of light and shade, relative sizes of objects, and perspective effects. Each of these factors is concerned with our experience of viewing with the two eyes (binocularly) the actual objects shown. Thus we are able to identify solid objects by their light and shade effects, distances of objects by their relative sizes; the more distant objects form images of relatively smaller size; the well-known principles of perspective are also of great help when viewing flat photographs.

There is, however, a vast difference between the real or visual picture and the "flat impression" one of any subject. Similarly it can be stated there is a great difference between the viewing of the binocular, or stereoscopic photograph and a monocular, or single photograph.

Gaze at any subject, say, a landscape, group of objects on a table, or at the foliage of a tree, with one eye, for a time and then open the other eye; the result will be surprising, more especially if one dissociates one's binocular impressions of the subject, as far as it is possible, in the former case. The result will be even more marked if one is confronted with a new scene when one eye is kept closed, and the other is afterwards opened. There is just as much difference between the single and double eye views as between the single and stereoscopic picture.

The word "stereoscope" is derived from *stereo* solid, and *scopeo*—I view. In stereoscopic photography, the single lens of the ordinary camera, which corresponds to the single eye, is replaced by two exactly similar lenses mounted in the camera at a distance apart equal to that of the eyes in the head. In this way, the two pictures obtained correspond to the two pictures (or images) formed on the screen (or retina) at the back of the eye; as we shall see later, these pictures are not identical, but differ from one another in one or two important respects. Having obtained these dissimilar pictures it only remains to devise some convenient means of viewing them, or of merging them into a single picture impression as in the case of the eyes; although the latter see two dissimilar views, the mental impression is that of a single picture in relief. The familiar piece of optical apparatus, known as the *Stereoscope*, enables this merging to be done quite easily; the result of viewing these dissimilar pictures in the stereoscope, is then to receive the correct impressions of relief, similarly to binocular vision. As we shall mention more fully, later, it is not really necessary to use a stereoscope, for with a little practice the pairs of pictures (known as *Stereograms*) taken with the stereoscopic camera can be merged with the unaided eyes. Many stereoscopy workers never use a stereoscope when viewing prints.

As we shall show in the following chapters, the principles of stereoscopy find many important applications in education, science and industry.

It will be necessary, before proceeding to an account of these applications to become thoroughly conversant with the structure and use of the eyes, the principles of binocular vision and the photographic application of these principles, that is, in stereoscopic photography. We shall also indicate how stereograms can be drawn or constructed without the aid of a camera, and how they can be viewed without a stereoscope. The photographic apparatus employed for taking stereoscopic pictures of various kinds is described in the following chapters, together with the apparatus for viewing stereograms.

It is not proposed, in the present considerations to enter into any account of the history and development of stereoscopy, from the times of Aguilonius,* to those of the discoverer, Sir Charles Wheatstone, or to the admirable work of Sir David Brewster—to whom we owe the present form of stereoscope. Those who are interested in the historical side would do well to consult the original works, or records of François d'Aguillon, the Jesuit of Brussels (1613), Gassendus (1568), Baptista Porta (1593), Galen (1550), and the later works of Helmholtz, Alexandre Prévost, Johannes Müller, Wheatstone and Brewster. A useful bibliography is given at the end of this volume, which, although incomplete as regards individual papers, is fairly complete as regards original volumes. An interesting review of the subject is given in a Paper on "Stereoscopy Restated," by Dr. W. French, read before the Optical Society, May 10, 1923.

* Aguilonius Opticorum.

CHAPTER II

THE CAUSES OF STEREOSCOPIC VISION.

The Eye and Stereoscopic Vision.—In order to understand properly and to appreciate the subject of stereoscopic vision, and of stereoscopic photography in general, it is very essential that the reader be thoroughly acquainted with the basic principles of human vision. This involves a knowledge, not only of the manner in which the eyes are focussed and directed, but also of the internal structure of the eye itself. It is proposed, therefore, to give, as an introduction to the subject of stereoscopy, a brief description of the human eye and its functions.

The Human Eye.—The eye is a wonderful piece of optical apparatus, and possesses many remarkable adjustments and properties. It consists of an almost spherical ball situated in a spherical chamber; it is thus able to rotate or turn in any direction. It has a circular opening in front, through which light can pass to the lens which forms an image of the object viewed on a curved screen situated at the back of the eye.

Referring to Fig. 1, the transparent concavo-convex portion *A* is termed the *Cornea*, and is situated immediately in front of an adjustable aperture diaphragm, of annular form, known as the *Iris D*. The latter is coloured and is opaque, except for its central aperture *C*, which is known as the *Pupil*. This aperture is capable of being enlarged or contracted automatically, by means of certain involuntary muscles of the iris, in weaker or brighter light, respectively. Behind the cornea and iris, is situated a peculiar type of lens *E*, built up of layers or shells, increasing in density towards the centre; it is termed the *Crystalline Lens*. The index of refraction of the outermost layer of this lens is the same as that of the medium in contact with it, so that no loss of light by reflection occurs in passing into the lens. Behind this lens, there is a space *L*, or posterior chamber, filled with a transparent jelly-like substance termed the *Vitreous Humour*; this substance is enclosed in a thin, transparent membrane known as the *Hyaloid Membrane*. The space *B*, or anterior chamber between the crystalline lens and the cornea is filled with a watery substance of saline content, known as the *Aqueous Humour*. Enclosing most of the posterior chamber is a membrane *I*, called the *Choroid Coat* or *Uvea*; this is saturated with a black and opaque mucus, called the *Pigmentum Nigrum*. The screen upon which the images are formed by the crystalline lens is termed the *Retina*. It is shown at *K* in the illustration, and forms the lining of the choroid. The retina is a network or ramified system of nerve filaments connected with the *Optic Nerve*, *M*, leading to the brain. It is the action of light upon

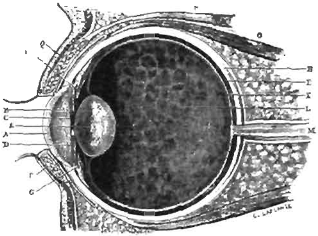

FIG. 1.—THE HUMAN EYE, IN SECTION (EVERETT).

these nerve filaments of the retina which gives rise to the sensation of vision. There is a yellow spot on the retina just above the optic nerve, which has a central depression known as the *Fovea Centralis*, and at which vision is most distinct. Vision is not distinct at the place where the optic nerve is situated; this is known as the *Blind Spot*.

The crystalline lens possesses the property of being able to alter the curvature of the front of its surface, so that objects situated at different distances can always be made to form sharp images on the retina; here we have a variable section lens of constant focal length for all distances of objects. The lens increases its convexity for nearer objects and reduces it for more distant ones. The image formed on the retina, in the case of normal vision individuals, is real and inverted; the mental impression is that of a real and erect image.

This adaptation of the eye so as to keep objects at different distances always in focus is termed its *Accommodation*. The nearer range of accommodation, or least *distance* of *distinct vision* is about *six inches**; within this distance objects cannot be seen distinctly. The furthest range of accommodation is a very great distance, incorrectly termed infinity, but usually taken as the distance at which rays incident on the eyes are parallel. Apart from the accommodation and pupil contraction and expansion of the eyes, the complete spherical ball system containing the cornea and crystalline lens can rotate in its socket so that the optical axes of the two eyes can be directed in any direction and to any distance, within the limits of movement. We shall refer later to the part which this convergence and also accommodation play in stereoscopic vision.

In connection with optical problems involving the use of the eyes, as in stereoscopy, these may satisfactorily be treated if the optical system of the eye be regarded merely as a convex lens of constant focal length, forming an image of the object viewed on the curved screen or retina of the eye. Specific calculations would, of course, involve a knowledge of the curvatures and refractive indices of the layers of the crystalline lens; and of the properties of thick lenses; this data is on record, and can be found in advanced works on optics.

An example of this simplified method of regarding the eye as a lens-screen combination is depicted in Fig. 2.

An Elementary Explanation of Binocular Vision.—In the present considerations, the principles underlying the subject will be dealt with; in this respect it must be emphasised strongly that only by a correct understanding of the optical principles can the reader hope to reap the full benefit in stereoscopic work.

Recapitulating, we see that each eye consists of an almost perfect optical system, comprising a lens system and a screen or retina upon which the image formed by the lens is projected. In effect, then, the eye may be regarded as a

* It is usual to assume this distance as 10 inches, in calculations.

camera—albeit more highly developed than any mechanically constructed ones—in which an image of the object observed is formed on the retina or screen. Instead, however, of forming a permanent image as in the case of a photographic plate, the retinal image is merely an impression, as it were, which is conveyed to the brain through the agency of the optic nerve, and there interpreted as the vision observed.

The eyes are capable of swivelling in their sockets, in the case of normal individuals, so that when any object is observed the optical axes of the eyes converge to that object. Further, the curvatures of the "lenses" of the eyes can be varied automatically so as to focus upon the retina either near or distant objects. In normal individuals the minimum distance for distinct vision is about six inches and the maximum, infinity. The eye thus scores over the photographic lens in that its "lens system" can vary its shape, or configuration, so as to maintain always the same focal length, irrespective of distance of the object; this is termed the "accommodation" of the eye.

The separation or distance apart of the human eyes is about 63 to 69 millimetres, in average cases, i.e., about $2\frac{1}{2}$ to $2\frac{3}{4}$ inches.

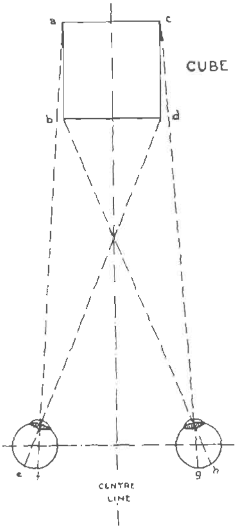

FIG. 2.
ILLUSTRATING THE DISSIMILAR VIEW OF THE TWO EYES.

When a near solid object is viewed, the left eye, being to the left of the centre line (Fig. 2), will be able to see rather more of the object than an eye situated on the centre line. Similarly the right eye will see more of the right side of the object.

In the illustration referred to, the left eye sees (at an oblique angle) the left side *ab*, and the normal face *bd* of the cube, but it cannot observe the right side *cd*. Similarly the right eye sees the right side *cd*, and the face *bd*, but nothing of *ab*. The image *cf* formed upon the retina of the left eye will, therefore, be slightly different from that of the right eye, as we have attempted to depict in Fig. 3, which represents the left and right eye images of a small cube seen at a short distance away.

FIG. 3.—LEFT AND RIGHT HAND VIEWS OF CUBE.
(This is a stereoscopic pair of images.)

Now since the brain combines these two dissimilar images into a single image, the result is that this latter image gives the appearance of solidity or depth, which we speak of here as a stereoscopic or binocular vision effect.

The degree of solidity will depend upon the size of the object viewed and upon its distance from the eyes. Thus a large object placed near the eyes will show much more solidity than a small object placed at a distance. That is the reason why distant landscapes and clouds appear to be flat, for the two images formed on the left and right retinas are practically identical, since the light rays from distant objects are almost parallel. In this connection it follows that if a flat surface, such as the face *bd* of the cube in Fig. 2, is viewed normally, the two retinal images will be identical, and no solidity effect will, therefore, be experienced.

Close one eye and view a solid object in the middle distance for a time with the other eye. No stereoscopic effect should be experienced, although to most people the inherent knowledge and impression that the object viewed *is* a solid one creates the false idea that one eye can experience the solid or depth effect; this false impression is assisted also by our knowledge of perspective and light and shade effects; we know that the size of an object appears to diminish the farther away it is, and associate image sizes of recognisable objects with distance.

That there is no single-eye solidity effect can be demonstrated by viewing against a dark background a number of unfamiliar objects of various sizes, with one eye *only*, and without having seen them with both eyes. It will be found difficult to place their sizes and distances from the eye correctly. Similarly, a picture taken with an ordinary camera, which comes into the one-eye category of unfamiliar objects, does not always give any true idea of sizes and depths; this picture corresponds to the single-eye view.

Reference to Fig. 4 will serve to show how stereoscopic effect diminishes with increased distance, The object *M* is situated at a greater distance than *N*; consequently it subtends a smaller angle *m* than that of *N*, viz., *n* at the eye, and the rays of light from *M* to both eyes are less convergent than those from *N*. When *M* is sufficiently far away the light rays from it become almost parallel, and, therefore, the retinas of both eyes have similar images.

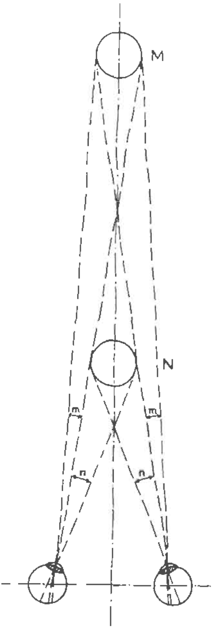

FIG. 4.

At this stage it becomes necessary to point out an important difference between binocular vision and stereoscopy, as we shall henceforth term true rendering by photography, or other artificial means, of solidity and depth.

The eye is capable of focussing only those objects which are situated at a certain distance or in a given normal plane; all other objects are out of focus when the eye views a definite object.

Consider two objects *M* and *N* (Fig. 4) and focus the eyes upon *M*, say. Then the images *N* will not only be out of focus and indistinct on the retinas, but these indistinct images will not fall on the corresponding points of the eye; the left-eye image will be displaced, as it were, to the left, and the right-eye image to the right. The practical result of this is that the image of *N* will appear double.

This effect can readily be demonstrated by placing a pencil, or finger, at about 8 to 12 inches from the two eyes, and centrally. If now a distant object be viewed there will at once appear to be *two* indistinct images of the pencil or finger. If the eyes be focussed on the pencil the distinct object will appear double.

As we shall show subsequently, stereoscopy renders all objects in focus, irrespective of their distance from the camera, whilst binocular vision shows only one set of objects in focus, namely those lying in a given normal plane. Thus the focus of the eye does not change in the case of stereoscopy (once the photographs are in focus) in viewing the images of objects situated in different planes, whereas in binocular vision the focus changes constantly.

On the Causes of Relief.—We have seen that the principal reason why it is possible with the two human eyes to perceive objects in three dimensions in relief, is due to the formation of dissimilar images upon the two retinæ, and to their recombination mentally. Thus it is that two "flat" pictures of a solid object, or series of objects at different distances can be recombined so as to give the well-known sensation of solidity and perspective.

The principal causes of the perception of relief, are believed to be the *accommodation of the eyes*, and their *convergence*; the exact part played by each of these factors is not agreed upon by all authorities, but it is generally conceded that whilst the convergence plays a part of secondary importance, there is a certain relation between the accommodation and convergence of the eyes when viewing objects of different size and at different distances. On the other hand some authorities* contend that the convergence and visual focus, and their variations as the eyes sweep over the field do not play any vital part in the appreciation of distance.

It is considered that the recognition of a familiar type of perspective system is important in assisting the "stereoscopic" impression. Further, it is believed that just as one does not require to assume any special mechanism by which the inverted image of an observed object upon the retina is erected before it is perceived, so one is led to think that there is nothing which can intelligently be called a "mechanism" of stereoscopic vision, which may simply be a manifestation of that remarkable cerebral faculty which receives, collects, co-ordinates and interprets all the sensory impulses which are continually reaching it, and employs them to build up the conception of the objects around us, which we commonly associate with stereoscopic vision.

The Accommodation of the Eye.—When the eye views an object placed at a definite distance from it, the image on the retina has a definite size. As the object is moved away from the eye, so the retinal image becomes smaller and smaller in size. There is another highly important fact about the eye, namely, that it is capable of altering its focal length, so that objects at widely varying distances can readily be focussed on the retina, i.e., seen sharply. Thus, as an observed object is moved away from the eye, it will always remain in focus. The curvature of the crystalline lens can be varied by muscular means so that the shape of the lens can be adjusted to always give the correct focus for objects seen at different distances; of course, only one object at a time can be observed clearly. The range of the *visual accommodation* of focus varies from about 6 to 12 inches, to infinity. The effort required to vary the visual focus and the curvature of the lens is different at different distances,

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* *Binocular Vision and Stereoscopic Sense.* R. J. Trump. Optical Society Transactions. Vol. 25, 1923–4, No. 5.

and it is thus conceivable that one of the causes of the impression of distance is the physiological and mental efforts called into play during the accommodation process. The eye will thus associate the focal length of its lens, i.e., the curvatures, with the particular distance of the object viewed.

Convergence of the Eyes. Parallax.—If a pair of similar objects such as *A* and *B* (Fig. 5) be viewed with a single eye *L*, (the other being shut) placed anywhere along the line *AB*, extended, only the object *B* will be seen. If, however, the other eye *R* be opened, it will observe the two points *A* and *B* in virtue of the images *a* and *b* formed on the retina. The nearer the objects *A* and *B* together, the smaller will be the angle *ARB* and the distance *ab* between the retinal images.

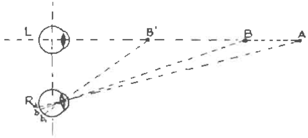


FIG. 5.—ILLUSTRATING THE PRINCIPLE OF PARALLAX.

Further, as the objects *A* and *B* recede, the one from the other, the angle *ARB* will become larger and larger. It will, in fact, form a kind of measure of their separation, or distance apart when the objects are within a certain range. Thus, if *B* be displaced to B^1, the larger angle ARB^1, and (the distance ab^1 on the retina) will form a measure of their relative distances apart.

Consider next the effect of an object (Fig. 5) receding gradually *from the eyes. Assuming that it is primarily at the minimum* distance of distinct vision B^1, the two eyes *L* and *R* must be so directed inwardly that their optic axes meet at B^1, the angle between them being LB^1R. For a minimum distance, of say 6 inches, this angle is about 23½ degrees. When the object is at *B*, the angle of convergence will be *LBR*, that is to say, less than LB^1R. Again, as the object recedes to A the angle is reduced in value to LAR. Ultimately, when the object is at a very great distance away, i.e., at infinity, the optic axes become parallel as shown. Each eye, then, in observing objects varying in distance from six inches to infinity, varies the convergence of its optic axis through an angle of about $11\frac{3}{4}$ degrees. It will, therefore, be apparent that the amount of convergence of the two eyes (used naturally) is an indication of the distance away of the object viewed, and that our stereoscopic perception of objects is to some extent dependent upon the convergence of the optic axes.

Referring once more to Fig. 5 it will be evident that if the right eye be closed and the left eye be moved a little to the right, the object A will appear from behind B, and will also seem to be more to the right, relatively to B. When A and B are close together there will be only a small amount of relative movement as the eye is moved. On the other hand, if A is a long way behind B, the same movement of the eye to the right, say, will cause a much greater displacement of A, relatively to B. This lateral displacement of one object relatively to another is termed *Parallax*. In estimating, mentally (or visually) the different distances, or the solidity, or depth of an object, parallax plays an important part. A movement of the head sideways results in parallactic displacements of objects at different distances, and one is able to state which object is in front of another, and to form an impression of their relative dispositions.

What is true of one eye is, of course, true of both, so that any movement of the head sideways causes parallactic displacements of the images of objects situated in different planes, on the two retinæ. Similarly, when the two eyes view a solid object, the effect of parallactic displacements enables the different planes or depths of the object to be separated, and the impression of relief to be experienced.

In the case of a plane figure normal to the line of sight, the retinal images remain the same when the eyes are displaced laterally by a small amount, and, therefore, no parallactic movements occur and no stereoscopic effect is experienced; the two retinal images are not necessarily alike in this case, due to the two view points, unless, however the plane is to all intents, normal to both optic axes.

A Possible Explanation.—Binocular vision has been a controversial subject; even to-day there is no unanimity of opinion. It is not our purpose, however, to take up the cudgels, but we mention a probable explanation, which has been put forward by Prof. J. D. Everett, F.R.S., namely, that to each point in the retina of one eye there is a *corresponding point*, similarly situated, in the other eye. Under ordinary circumstances an impression produced on one of these points is undistinguishable from a similar impression produced on the other point. When both are similarly impressed, at the same moment, the effect is simply more intense than if one were impressed alone. In effect, then, we have only one field of view for our two eyes, and in any part of this field of view we observe only one image of greater brightness than when seen by the one eye, alone, or else we see two overlapping and usually indistinct images. The latter effect may be illustrated readily by the pencil experiment previously referred to; if the pencil or a finger be held between one's eyes and a wall, and the wall be focussed on, two transparent or out-of-focus images of the pencil will be observed; each image corresponds to that seen with the one eye. Our visual impressions do not, however, indicate which image corresponds to which eye.

One may ask, what, then, is the advantage in having two eyes in order to obtain apparently one image? The answer to this question is that the two eyes in order to see a point as single must rotate in their sockets, that is, must allow the optic axes to converge upon the point to a greater or lesser extent so that the two images of the point observed fall upon corresponding points on the retinæ. This convergence of the optic axes provides us with a valuable means for judging distances, which is more precise than that obtained by adjusting the foci of the lenses of the eyes. The parallactic displacement of distant objects relatively to near objects or *vice versa* also furnishes a useful aid in judging the comparative distances of two points. The overlapping of the different images seen by the two eyes enables the relief or solidity of the object observed to be distinguished, as distinct from the parallactic impression of perspective.

Field of Stereoscopic Vision.—We shall now consider briefly the region or field of view in which stereoscopic effects can be observed. If the head is kept in one position, the normal erect one, say, and the single eye is moved in its socket to its maximum sideways limits, it has a field of view of about 180° horizontally. If moved vertically up or down, it has a field of view of about 135°; both fields include indirect as well as direct vision.

When both eyes observe an object ahead, the two fields of view overlap, forming a distorted conical region. Referring to Fig. 6, this region is indicated by the letters *ABC*; *B* is point focussed on, and is the point of intersection of the optic axes, and *A* and *B* are points whose images fall *upon the corresponding points of* the retina. The corresponding points have been defined as those points on the retina whose nerve filaments are united, and which are equidistant in the same direction from the centre of the *yellow spot* (macula lutea). This yellow spot is actually yellowish in colour, and is destitute of blood-vessels except the finest capillaries. It is more sensitive to light than the rest of the retina, and is the central portion of the normal field of view. The important point with which we are here concerned is that *stereoscopic vision is only possible within the region ABC* (Fig. 6).

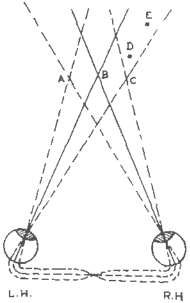


FIG. 6.—ILLUSTRATING THE FIELDS OF VIEW OF THE HUMAN EYES.

The angular size of this space is about 90° in man 34° in a rabbit, 15° in a fowl, and about 5° in a carp (in water).

Direct and Indirect Vision.—When any point, such as *D*, is observed and compared with the fixed point *B*, stereoscopic vision is said to be *direct*; if it is compared with any other point, such as E, the stereoscopic vision is *indirect*. In each case the precision of observation of depth is greater as the point E approaches D, and as D approaches B. The point B is, of course, constantly changing, each of the eyes rotating, about the centres of spheres of about 10 mm. radius; the lens, therefore, rotates about these centres.

The entrance pupil of the eye moves slightly in a horizontal and also a vertical direction as a consequence. This has led to experiments with the object of producing solidity or depth effects with a single eye, in consequence of the relative movements of the images from this cause. These movements only occur in indirect vision, and cannot give rise to a true perception of depth. In surveying an object with both eyes, we run our eyes quickly over the surface, so that we attain an instantaneous single vision of a particular point where the optic axes meet, but at the same time we receive a rather indistinct impression of all other points within our field of view; it is this impression which, when carefully analysed, gives rise to the three-dimensional or relief effect experienced.

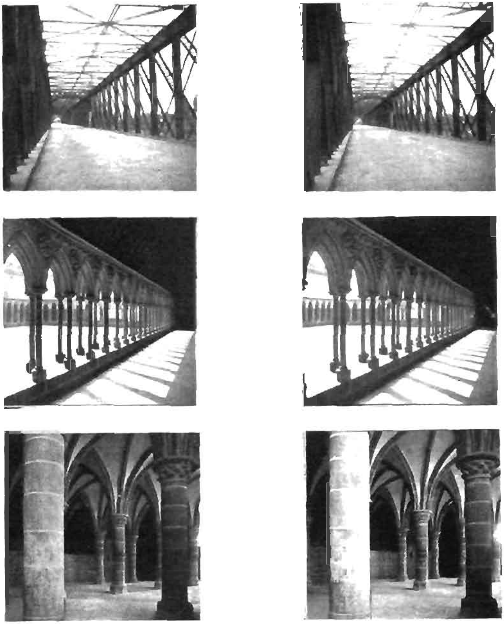
Before proceeding to some analytical considerations of the subject, an account will be given of the important, but secondary, causes of binocular vision effects.

Secondary Causes of Stereoscopic Relief.—We have referred to the principal causes of stereoscopic vision, namely, the accommodation and convergence of the eyes, and the parallactic displacement of their images. It is now fairly well established that stereoscopic vision is not due to any particular contributory cause, but rather to a number of simultaneously experienced effects, which are mentally interpreted as the sensation of distances, relief or solidity, and to which we give the name stereoscopic vision.

There is a number of minor, or secondary factors which also assist in creating the stereoscopic impression, and which by association and experience help us to appreciate the solidity and depth of objects viewed.

The principal of these secondary effects are *perspective* and *light and shade*.

Perspective.—If a row of posts, or trees, of equal height, be



SOME STEREOSCOPIC EXAMPLES ILLUSTRATING PERSPECTIVE AND LIGHT AND SHADE EFFECTS viewed from one end, it is obvious from the first principles of optics that the nearest post will form the largest image on the retina, and that the farthest post will give the smallest image. The intermediate posts give intermediate sizes of image, with a result that if the posts are equally spaced there will be a general triangular effect, the apex being at the remote post and the base at the nearest post, somewhat as shown in Fig. 7.

Whenever objects situated at different distances and having rectangular or straight portions are viewed from one position, this perspective effect occurs and is associated with distance, even in flat, two-dimensional views. The artist, when painting landscapes and scenes, introduces perspective effects to enable the eyes to appreciate the impression of distance. This association of perspective with distance is a valuable aid to binocular

FIG. 7.

vision; it is also very helpful even to the single eye, for with the latter the correct idea of depth and distance can be obtained; thus, the single eye can appreciate a picture or painting almost as well as when both are employed; in some cases the single eye can obtain a better idea of solidity and depth, in viewing a painting, than with both eyes. Plate 2 shows some stereoscopic examples in which the perspective principle is well illustrated. The lower illustration shows the influence of light and shade in assisting binocular vision impressions.

It is not possible, here, to discuss the geometrical principles of perspective; these are dealt with in appropriate works on the subject. It is sufficient to note that the general perspective effect consists of a series of real, or assumed lines radiating from a distant "infinity" point, giving a series of triangular impressions; in other words a series of lines converging towards the eye from a distant point.

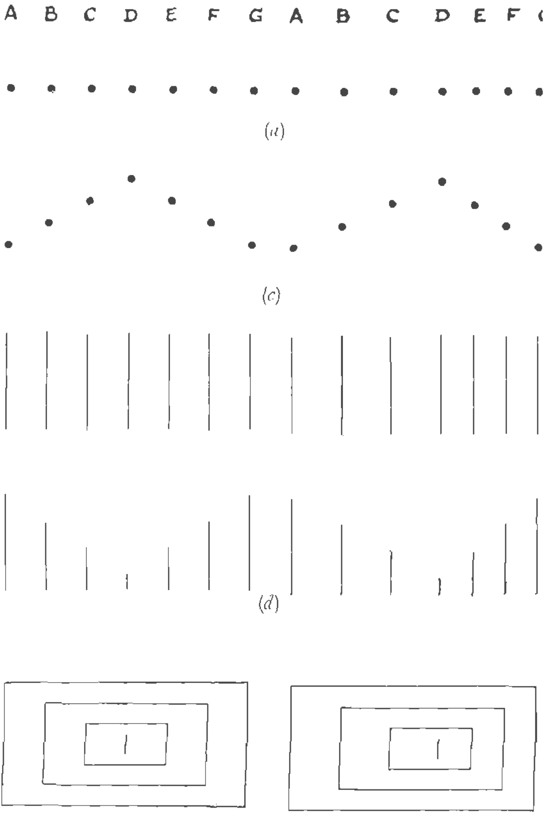


FIG. 8.—ILLUSTRATING THE EFFECT OF PERSPECTIVE IN STEREOSCOPY.

That perspective is a real aid to stereoscopic vision may be demonstrated by a few simple experiments: incidentally the method which we shall employ explains how stereoscopic line pictures may be constructed. We shall here assume that the reader is familiar with the use of the stereoscope. In Fig. 8 the left-hand dots are equally spaced, whilst the right-hand ones are separated from them by unequal distances or parallactic displacements. Thus the distances apart of the pairs of points *B*, *C*, *D*, *E* and *F*, are greater than those of *A* and *G* by the amounts 2, 4, 6, 4 and 2 mm. respectively; the distance between the pairs of points of *A* and *G* are 70 mm. *By increasing the separations* (or parallactic displacements) of pairs of points, relatively to that of a given pair of points, *the former will*, in the stereoscope, appear to be the *more distant* points. Similarly by reducing the separation distances, the points will appear nearer to the eyes. The two sets of points in the diagram (Fig. 8 (*a*)) form a stereoscopic pair, but some difficulty will be experienced due to these points lying in the same line.

It is here that perspective assists, for by arranging the pairs of points, with exactly the same separations as before, but at heights in proportion to their parallactic displacements (given above), the stereoscopic effect becomes much easier to obtain.

In a similar way, a series of parallel lines separated by the same distances as the points in Fig. 8 (*a*) does not, without some difficulty in viewing with the stereoscope, stand out in different planes; this will be evident from Fig. 8 (*c*).

If, however, the lengths of the lines are proportional to their parallactic displacements, as in Fig. 8 (*d*), it becomes much easier to observe the stereoscopic effect. It is in this manner, in general views, that the presence of perspective aids or guides the eyes, so that the necessary change of convergence occurs automatically.

It is these perspective effects which help the eyes to observe, in the binocular sense, long streets, buildings, avenues of trees, rivers and roads.

An interesting application of the method described and which is known as the *principle of parallactic displacement* is illustrated in Fig. 9. Here the two sets of letters in the left and right hand groups are exactly similar in size and shape, and are on the same line or level. Some of the letters, however, have been given a very small amount of displacement sideways, so that the actual distances apart of pairs of corresponding letters are not the same

STEREOSCOPE	**STEREOSCOPE**
SHOWS THESE	**SHOWS THESE**
LETTERS IN	**LETTERS IN**
DIFFERENT	**DIFFERENT**
PLANES.	**PLANES.**

FIG. 9.—A GOOD EXAMPLE OF PARALLACTIC DISPLACEMENT.

in every case. If this stereogram be viewed in a stereoscope the displaced letters will appear to stand out or to recede from those which have not been displaced.

Effect of Illumination.—Another contributory help to the stereoscopic sensation is the lighting of the objects viewed. If the object is illuminated from one side, there will be a pronounced gradation of tones and shadows, which will help, considerably, to throw out its solidity or depth; this is the basis of lighting for portraiture, where the half-tones give the proper sense of roundness or depth. On the other hand, if the same object is illuminated from both sides, there will be a loss of solidity and depth, due to the absence of, or reduction in, the half-tones. Similarly, when an object is photographed with a stereo-camera, lighting plays an important part. For example, if a simple object, such as a globe, be illuminated from one side, and observed, or photographed against a dark background, it will show a satisfactory gradation of tones, sufficient for the eyes to appreciate its roundness, or solidity. If, on the other hand, the globe be illuminated evenly all over, the solidity effect is greatly diminished or even lost.

Similar results are obtained when photographing objects which are strongly illuminated from the front, or from more than one direction. For example, if a round pillar or column be illuminated from one side, it will exhibit its roundness in the half-tones and darker portions of the unlit side. If, however, it be illuminated by a strong light in front, or by equal beams of light from two

CORRECT LIGHTING. ABOVE AND DOWNWARDS ILLUMINATION

(Messrs. General Electric Co. Ltd.)

INCORRECT LIGHTING FROM TWO SIDES SIMULTANEOUSLY

PHOTOGRAPHS ILLUSTRATING THE INFLUENCE OF LIGHTING OF THE SUBJECT.

sides, there will be fewer, or no half-tones, and the sense of roundness in both single and stereoscopic pictures will be lost.

The effect of the shadows and half-tones observed when the eyes are viewing solid objects, is to enhance considerably the stereoscopic effects observed; indeed, without such shadows, it would be impossible to distinguish crests and hollows on an object. Moreover, one associates the sensation of solidity with the shadings and variations of tone of objects viewed, so that even with the single eye it is quite easy when looking at different objects, to say which are solid, or have depth. The painter takes full advantage of this effect in executing his pictures, so that with the combined effects of perspective and light and shade, the eyes receive valuable assistance in identifying the sizes, solidities and distances of the component objects. This is one reason, also, why the single eye can obtain almost the same impression as both eyes, in the case of the actual subject, when viewing a picture.

As a further example of the effect of the tones of an object as a stereoscopic aid, may be mentioned the well-known fact of progressive loss of stereoscopic effect when viewing an out-door scene in fading light; in this case the half-tones become lost into a common, uniform illumination of fading intensity.

The Limiting Stereoscopic Distance.—It is a common experience that when viewing a number of objects at different distances, as for example, buildings, trees or even undulating and hilly ground, that the nearer the objects the greater are the relief effects experienced. On the other hand, objects a long way off appear flat and non-stereoscopic. Thus, if one is viewing a landscape, with trees and buildings in the foreground and middle distance, whilst the nearer objects stand out in relief or solidity, the distant trees and hills appear to be flat and without depth or solidity.

Let us examine the cause of this effect. Referring to Fig. 10 it will be seen that the more distant object P requires a smaller convergence of the eye than a nearer one M, and also that the farther away P is from the eye, the more parallel the optic axes become, and the more similar the two retinal images of objects in the plane of P. It is evident, therefore, from first principles, that stereoscopic effect becomes progressively less the farther away an object, of given size, is situated from the eye.

We have referred to *the size of the object*, for it is evident that if a large object such as a big building is seen at a distance, it will show more relief and depth than a smaller one at the same distance; a mountain some miles away will appear in good relief, whilst a smaller excrescence, hill or mound, much nearer, may appear fairly flat.

FIG. 10.

It is evident that the lateral width of any object subtends a certain angle at the observer's eyes, the angle being greater, for nearer objects and for those of greater widths. Thus a distant object, if sufficiently big, may subtend a greater, or the same angle at the eyes than a smaller and nearer one, and therefore, may give about the same, or even a better impression of solidity and depth.

As pointed out, on page 31, if the angles subtended at the eye, by *geometrically similar objects* at corresponding distances are the same, *the nearer objects will give the better impressions of relief*, owing chiefly to the fact that their linear dimensions are more comparable to the binocular separation.

Let us now consider what is the *limiting distance* from the eyes, at which the *sense of stereoscopic vision ceases.* Actually, there is a definite distance ahead, which represents the stereoscopic infinity, as it were, such that all objects situated between this range and infinity appear without relief; the eyes cannot distinguish, unaided by optical instruments, the planes in which these objects lie, or their distances.

The Horopter. Parallax.—We have seen that there is an upper limit to the convergence of the eyes; for a minimum distance of object, of 10 inches, this angle is about 15° to 16° for distinct vision. The angle subtended by the base formed by the distance between the two eyes (*interocular* distance) at the object viewed is termed the *convergence* or *parallactic angle*, or *parallax*. There is a lower limit to this convergence, fixed by the power of perception, or *acuity of vision*; this limit can best be demonstrated by reference to Fig. 11.

Let R and L be the positions of the right and left eyes, respectively, and b the distance between them. The distance of an object B from R and L is d_1 and d_2 respectively; the angle RBL is evidently the convergence, or parallax. Let a circle LRB be described through these points; this circle is termed the *Horopter*.

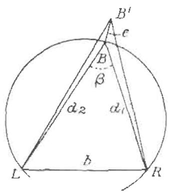


FIG. 11.

Referring to Fig. 11, and considering a point B¹ outside the horopter, and calling the angles LBR and LB^1R, θ and θ_1, respectively, and $\theta-\theta_1, =-\Delta\theta$, we have for the line BB^1 which is normal to the horopter.

$$\text{length } BB^1 = e = -\Delta\theta \,.\, d_1 \,.\, d_2 \,/\, b \quad . \quad . \quad . \quad . \quad . \quad (1)$$

If the interocular distance b is small compared with the distance of the object B, we may assume that $d_1=d_2=d$ (say), and (1) reduces to the form

$$e = -\Delta\theta \,.\, \frac{d^2}{b} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

There e is the *depth* of the object viewed, d its distance from the eyes, and b the distance between the eyes (2½ ins.)

The quantity $\Delta\theta$ is the change in the convergence between the front and the rear of the object. It is termed the *Differential Parallax*. The smallest limit of the differential parallax, it will be seen, corresponds to the smallest depth of a distant object which can be seen.

Limit of Stereoscopic Perception.—Helmholtz considered the minimum value of the differential parallax, in the case of the human eyes to be *one minute of arc*. Later investigations show that in the best trained observers, this limit may be as low as 8 to 10 seconds of arc. The usually accepted normal value of the differential parallax is 20 seconds of arc.

With this information it is easy to compute what is the maximum distance of stereoscopic perception, or in other words what is that distance of an object, beyond which no sensation of relief is experienced; all small objects between this distance and infinity will not be resolvable as regards depth.

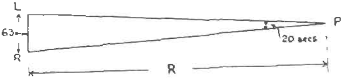


FIG. 12.

Referring to Fig. 12. and using the previous notation, the distance R (known as the *Stereoscopic Range*) of the object P, when the differential parallax is 20 seconds, is given by the relation

$$a = R . \Delta\theta, \quad \text{where } a = 65 \text{ mm.}$$

$$\text{or } 65 = R . \frac{1}{10{,}300} \text{ mm.}$$

Whence $R = 10{,}300 \times 65$ mm. $= 670$ *metres* (very nearly).

This is the limiting distance of stereoscopic perception.

We can now simplify the formula (2), for this special case to

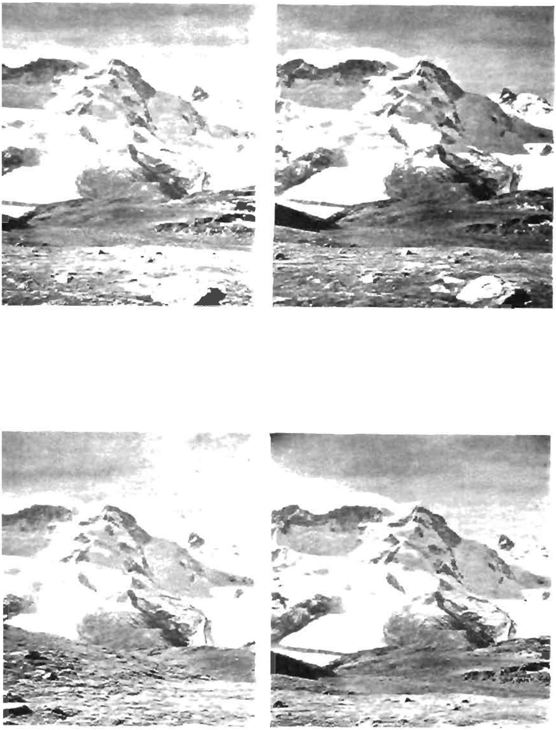
$$c = \frac{d^2}{670} \text{ metres} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

The above result shows that if the differential parallax is taken as being 20 seconds, the greatest distance to which stereoscopic perception is possible is about 670 metres, that is about $\frac{2}{5}$ mile.

For finer perceptions than this the limiting distance is greater. The formula given in (3) can be applied to any given examples. Thus, if an object has its nearest point, at, say 200 metres, from the observer, the greatest depth c which can be distinguished stereoscopically is given by

$$c = \frac{200 \times 200}{670} = 60 \text{ metres (approx.)}$$

Methods of Increasing the Stereoscopic Range.—It is possible by employing optical aids to vision, which introduce *greater separation* between the viewing points of the two eyes, and *magnification*, to extend to a considerable degree the range



BREITHORN.

ISTRATING THE PRINCIPLE OF THE EXTENDED PHOTOGRAPHIC BASE.

ABOVE. STEREOSCOPIC VIEW TAKEN WITH NORMAL LENS SEPARATION (2½ INS.).
BELOW. STEREOSCOPIC VIEW TAKEN WITH LENS SEPARATION OF 150 FEET.

of stereoscopic perception. It is not difficult to show that if the separation between the eyes (a) be increased n times i.e., to a distance $= na$, by optical means, and lenses be introduced into the instrument to give a magnification of distant objects of m times, then the stereoscopic range will be increased $m \times n$ times.

Thus, if the inter-ocular base be increased, artificially, by ten times, and telescopes of 30 times magnification be employed, the stereoscopic range will be increased 30×10 times $= 300$ times; in this case the limiting distance will be $670 \times 300 = 201,000$ metres, or about 125 miles.

The general formula for such optical instruments is as follows:—

$$e = \frac{d^2}{670\ mn} \text{ metres} \quad . \quad . \quad . \quad . \quad (4)$$

This formula is applicable to the case of the range-finder, and binocular telescope.

The *error of estimation* of distance e for such instruments is given by the formula (4).

Thus in the case of a range-finder ($mn = 300$) focussed on an object at 6000 metres, we have

$$\textit{Error of Estimation } e = \frac{6000 \times 6000}{300 \times 670} \text{ metres}$$
$$= 179 \textit{ metres.}$$

Formula 4 shows that the error of estimation increases as the square of the distance.

Similarly the degree of stereoscopic perception varies *inversely as the square of the distance*; i.e., it decreases at a greater rate than the distance.

Stereoscopic Distance Relations.—The relation between the distance of an object and its reference plane, from the eyes, is important. It can be expressed in another way to that of the preceding method.

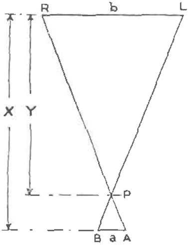


FIG. 13.

If a point such as P (Fig. 13) be situated in front of a given plane AB, and observed by the eyes L and R, separated by a distance b (=65 mm.), then the left eye will appear to see the projection of P on AB, viz., at B, and the right eye its projection on AB at A.

Then we have the relation $\frac{a}{X-Y}=\frac{b}{Y}$

$$\text{or}\quad \frac{a}{b}=\frac{X-Y}{Y}=\frac{X}{Y}-1$$

Now we have seen that the minimum stereoscopic angle is 20 seconds of arc, so that the separation a at any given distance X, is given by the relation

$$X=\frac{180\times 3600}{\pi\times 20}\cdot a=10310\,a.$$

Combining these two relations, and substituting for b its value 65 mm., we have

$$\frac{X\times 1000}{10310\times 65}=\frac{X}{Y}-1 \text{ (in metres.)}$$

$$\text{Whence } Y=\frac{X}{1+\frac{X}{670}}$$

This may be written in the form $Y=\frac{1}{\frac{1}{X}+\frac{1}{670}}$

When X is infinite, we have $\frac{1}{X}=0$, and therefore

$$Y=670 \text{ metres.}$$

This is the limiting stereoscopic range, as before.

The relation between Y and X can be expressed in the form

$$Y=\frac{X}{1+\cdot 00149\,X} \text{ metres.} \quad . \quad . \quad . \quad . \quad (3)$$

It holds for all cases of stereoscopic vision, and enables the distance of a point P (Fig. 13) namely $(X-Y)$ to be determined for any given distance of the reference plane AB, for stereoscopic relief to be possible.

For example, suppose it is required to find the distance at which a statue must be placed in front of a screen situated at 50 metres from the observer, so that stereoscopic relief will just be apparent.

Here $X = 50$ and $Y = \frac{50}{1 + \cdot 00149 \times 50} = 46 \cdot 5$ metres.

The distance of the statue from the screen is $X - Y = 50 - 46 \cdot 4 = 3 \cdot 6$ metres. The *farther the* screen *is away from the observer, the greater will be the distance of the statue from the screen,* for stereoscopic relief.

The expression $(X - Y)$ deduced from the above relation (3) is as follows

$$X - Y = \frac{X^2}{670 + X} = \frac{\cdot 00149 X^2}{1 + \cdot 00149 X} \quad . \quad . \quad . \quad . \quad (4).$$

For rough purposes we may neglect the term in X; when we have the relation $X - Y = \cdot 00149 X^2$, which expresses the fact that the *possibility of stereoscopic vision decreases inversely as the square of the distance from the observer to the principal plane of the object.*

CHAPTER III

PHOTOGRAPHIC PRINCIPLES IN STEREOSCOPY.

BEFORE any useful application can be made of stereoscopy in its various branches, it is necessary for the reader to be quite conversant with some of the underlying, or basic principles. Since the subject of stereoscopy is bound up, as it were, with photographic optics and also with the physiology of the human eye, it is necessarily somewhat complex. It is no wonder, therefore, that the exact interpretation of the relief and perspective effects experienced by the human eyes, has not yet been really satisfactorily explained, although a number of important facts have accumulated.

The General Principle of Stereoscopy.—The human eyes receive what may be termed surface images of objects in three dimensions, *i.e.*, solid objects. The combination of the two eyes, their mechanisms and the brain interprets these impressions in such a way that the well-known perspective and solidity effects are experienced. Now, in stereoscopic photography, the two lenses of the camera, or if a single lens camera is employed, the two positions of the lens, form similar images, and the stereoscope enables the eyes to recombine these images so as to give stereoscopic vision.

From the photographic view-point, it is essential therefore that the photographic images formed be accurate scale reproductions, without distortional or other defects, of the object. The optical centres of the lenses must be given the same separation as that of the human eyes viewing the results.

Focal Length of Viewing Lenses.—In order that the stereoscopic photographs (*stereograms,* as we shall term them), may reproduce physiologically the same impressions as regards the relative sizes of objects in different planes, and of the solidity of these objects, it is essential that the angles subtended by these objects at the eyes, shall be reproduced in the stereoscope. This necessitates the following important condition that *the stereoscopic prints or transparencies shall subtend the same angle at the optical centres of the photographic lenses*, as the object subtends at the eyes.

If a stereoscopic negative has been obtained with lens of a

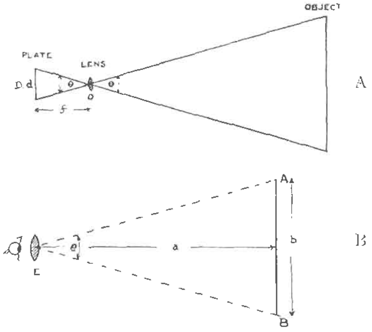


FIG. 14.—ILLUSTRATING PRINCIPLE OF VIEWING LENS OF STEREOSCOPE.

given focal length f (Fig. 14A), then the angle subtended at each lens by its picture is given by the relation

$$\tan\frac{\theta}{2} = \frac{d}{2f}$$ where d is the diagonal of the plate.

This relation is true for distant objects.

Now for near objects, the distance OD, that is the camera extension will be greater; call it f^1. Then we have

$$\tan\frac{\theta}{2} = \frac{d}{2f^1}$$

It is necessary when viewing prints made from these negatives to select the focal length of the lenses that the angle subtended by each print at the optical centre of each lens shall be the same as θ.

Thus in the lower figure the angle AEB must be equal to θ.

Then we have

$$\tan AEB = \tan \theta.$$

$$\text{and } \tan \frac{AEB}{2} = \frac{b}{2a}$$

where b is the diagonal of the similarly shaped stereoscopic print, and a the focal length of the viewing lens.

Enlargements from Negatives.—This result leads to an important conclusion in connection with enlargements from small stereoscopic negatives, namely that if the prints are enlarged, say, three times, they must be viewed in a stereoscope having approximately three times the focal length of the taking lenses. If enlarged n times, then the focal length of the stereoscope should be n times that of the taking lenses (or camera extension).

This is the condition for a correct impression of the object as seen in the stereoscope.

If a magnified stereogram be viewed in a stereoscope with lenses equal in focal length to the taking camera extension, the result will be *too large a viewing angle*. The *objects viewed will appear to be brought nearer to the point of observation, and flattened or fore-shortened* in depth. In other words there will be an erroneous impression of perspective, distance and solidity.

If the stereogram *is reduced in scale* from the negative, and viewed with lenses of focal length equal to the extension of the stereo camera used for taking the view, than *the image will appear to be farther off, and exaggerated in its fore-and-aft dimensions*, i.e., *the relief or solidity effect will be enhanced.*

Hyper-Stereoscopy.—The method of employing a different lens separation instead of that of the human eye (65 mm. say), in order to obtain the most natural relief, when viewing the pictures in a stereoscope, is termed *hyper-stereoscopy*. Its application in practical stereoscopy is important.

The principle of the method will be understood from Fig. 15. Suppose it is required to photograph an object B, with a stereo camera having its lenses FF placed at a distance apart equal to the normal eye separation. Then the images dc will subtend a certain angle at the lens, which we shall term θ.

Next suppose that another similar object, of twice the linear dimensions of B, be placed at twice the distance from the plane of the lenses FF. In order to obtain the same size of image on the plate, or what is more important the same subtended angle of the image at the lens, each lens will have to be moved sideways to the position F_1. In each case, therefore, the object (A or B) will subtend the same angle θ at an eye (or lens) placed at F_1 or F.

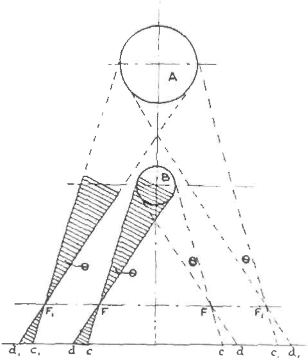


FIG. 15.

We can generalise, by stating that if one object, n times the size of another is to be photographed stereoscopically so as to give the best relief, the lens separation must be n times that of the smaller object, and the distance away, n times.

Another way of expressing the results is that *when we take a stereoscopic photograph with a lens separation equal to n times that of the eyes, the stereoscopic effect will be that of an object* $\frac{1}{n}$ *the size seen at* $\frac{1}{n}$ *the distance.*

Actually, it is found that the smaller model at the shorter distance gives a more pronounced or realistic effect ; the larger model shows a flatter result, more like a bas-relief, whereas the smaller one gives a better fore-and-aft relief effect, and accentuates the hollow and projecting parts.

The principle of hyper-stereoscopy is of much assistance in obtaining a true impression of distant hill or mountain scenery, without actually exploring it, by employing the extended base method.

Formula for Stereoscopic Work.—*Lens Separation.*—In order to obtain the most natural stereoscopic effect in the case of an object of known dimensions situated at any given distance from the camera, it is necessary to vary the lens separation according to the distance and depth of the object, and also its actual length or lateral dimensions.

Colardeau* gives the following useful formula, based upon a rational analysis of the problem :—

If B = length of base, D = distance of principal plane in object to camera (or eye), and P = the depth of the object, then

$$B = \frac{2}{100} \cdot \frac{D}{P} \ (P + D).$$

For example, if a statue is situated in front of a dark curtain at a distance of 10 feet from the camera, the depth of the object (from the statue to the curtain) being 2 feet, then in order to ascertain the length of the base, that is the lens separation, which will give pictures showing, when viewed in the stereoscope the *most natural relief*, we have $D = 10$, $P = 3$.

$$\text{and } B = \frac{2}{100} \cdot \frac{10}{3} \ (10 + 3)$$
$$= {\cdot}86 \text{ feet} = 10{\cdot}4 \textit{ inches}.$$

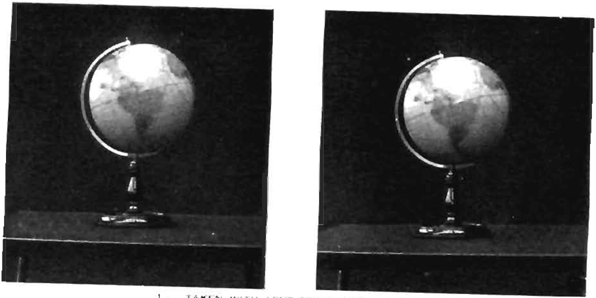
The above formula may be applied to distant objects such as hills, or mountains, to obtain the lens separation giving the best relief effect.

Image Size and Lens Separation.—There is another aspect of the method of employing a different separation of the stereo-camera lenses to that of the normal eyes, namely, upon the size of the image seen in the stereoscope.

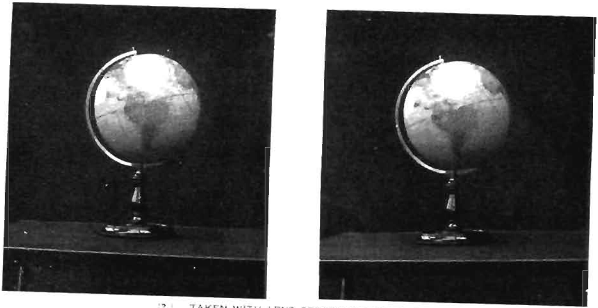
If the image viewed, or the impression obtained, is to be that of

* 'Traité Général de Stéréoscopie' (E. Colardeau).

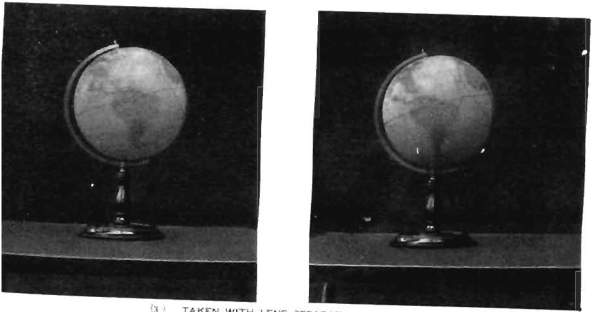
PLATE No. 4



(1) TAKEN WITH LENS SEPARATION OF 1¼ INS.



(2) TAKEN WITH LENS SEPARATION OF 2½ INS.



(3) TAKEN WITH LENS SEPARATION OF 5 INS.

NOTE FLATNESS IN (1) AND DISTORTED, OR ELLIPSOIDAL APPEARANCE IN (3).

TO SHOW THE EFFECT OF DIFFERENT SEPARATIONS, ON THE STEREOSCOPIC RESULT.

To face page 32.

the same size as the object, then *the lens separation must be equal to that of the eyes.* If the image viewed is to appear larger than that of the object, the lenses must be closer together, and if it is to appear smaller, farther apart. This leads to the following general rule: *The linear dimensions of the image seen in the stereoscope are inversely proportional to the lens separation employed when taking the photographs.* The object is, of course, assumed to be at the same distance.

The above results can readily be understood, by considering the actual angles subtended at the lenses, by a given object. Thus in Fig. 16, *B*, *C* and *D* represent, respectively, the lens

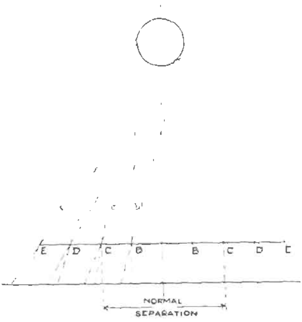


FIG. 16.

positions corresponding to lens separations less than, equal to, and greater than that of the eyes. It will be observed that when less, as in *B*, the subtended angle *b* is greater than the normal angle *c*, whilst in *D* it is less than *c*. Since the impression of magnitude depends upon the angle subtended by the object at the eye, it follows that in *B*, the object will appear, in the stereoscope, greater, and in *D*, smaller than the real size. If the stereoscopic image is to be seen at a *definite distance, the scale,* or size, *of the object* photographed *will vary inversely as its distance* *from the lenses.* This fact is sufficiently apparent that it requires no further explanation.

Print Width and Separation.—It is very important when mounting stereoscopic prints, that each print be of the correct width, and further that corresponding points on the two prints be at the correct distance apart; otherwise undesirable overlapping or loss of view will occur.

Space will not permit us to deal with the geometrical aspects of the question, but it can be shown that the separation of corresponding points on stereoscopic prints depends upon the eye-separation, the stereoscope lens focus and also upon the distance at which the image is to be seen in the stereoscope. Thus, if a=stereoscope lens focal length, or distance of the print from the viewing lens. D=the distance at which the stereoscopic image is seen and X=the distance between the eyes (or separation)

$$\text{Then Maximum Width of Image} = \frac{D-a}{a} \cdot X$$

$$\text{Separation of Corresponding Points on Prints} = \frac{D-a}{D} \cdot X$$

For example, if $D = 36$ ins., $a = 4$ ins., and $X = 2\frac{1}{2}$ ins., then the maximum image width will be $\frac{36-4}{4} \times 2\frac{1}{2} = 20$ ins., and the separation of corresponding points on the print will be $\frac{36-4}{36} \times 2\frac{1}{2} = 2{\cdot}22$ ins. In this case, it will be seen the scale of the prints will be $\frac{4}{36} = \frac{1}{9}$th that of the image.

The *maximum width of the print is equal to the separation of the corresponding points on the two prints*, as a little consideration will show. In the example given this width is 2·22 ins.

In order to permit of the widest images being seen, it is obvious that the focal length of the viewing lens must be small. Thus, in the above example, if the focus, a, had been 3 in. instead of 4 in., then the width of image seen in the stereoscope would have been $27\frac{1}{2}$ in. instead of 20 ins.

Magnified Views of Objects.—From what has gone before, it will be evident that the method to be employed for obtaining a stereoscopic impression, showing objects much larger than they actually are, depends upon the distance of the objects from the camera, and upon the distance apart of the lenses. Thus, if it is desired to obtain a view in the stereoscope, of, say a piece of mechanism, such as the works of a watch, *three times* the natural size, the lens separation must be *one-third* the normal eye separation (63 mm.), that is 21 mm. The image will then appear at three times the distance away of the actual object photographed. Similarly for a five times magnification, the lens separation must be one-fifth of 63 mm., i.e., 12·6 mm.; the image will appear at five times the object's distance.

In general, for a magnification n times that of the original object we have:

$$\text{Separation of Camera Lenses} = \frac{1}{n} \text{ times eye separation.}$$

$$= \frac{65}{n} \text{ millimetres.}$$

$$= \frac{2{\cdot}5}{n} \text{ inches.}$$

$$\text{Distance of Image} = n \text{ (Distance of Object)}$$

In the limiting case for an infinite magnification, the separation of the camera lenses will be zero, but the distance of the image will be at infinity. Obviously stereoscopic vision ceases with zero separation, and the above rule has then no real significance.

Further reference is made to the subject of magnified views in connection with the Chapter on the stereoscopic photography of small objects.

CHAPTER IV

STEREOSCOPY WITH A SINGLE LENS CAMERA.

THE ordinary photographer who has not yet taken up this interesting branch of photography usually runs away with the idea that it is necessarily expensive and complicated. Many amateurs who are interested are afraid to make a start for this reason, although if they had an idea that is was as simple and as inexpensive as ordinary photography, there would be little hesitation in making the initial plunge.

At the outset we can state that it is just as easy to obtain stereoscopic prints as it is to take ordinary photographs, and as inexpensive, for the ordinary single plate (or film) camera can be employed, with the addition of a small accessory readily made. The developing and printing processes are, of course, the same as in flat photography; it is only the trimming and mounting of the prints which require a little care.

To those who wish to take up stereoscopic photography in preference, or supplementary, to ordinary photography, and desire to use one of the special two-lens cameras, there is a range of these from the cheapest models costing two or three pounds (i.e., no dearer than an ordinary hand camera) up to the highest grade cameras (corresponding with the high price reflex and other focal plane ordinary cameras) costing from twenty to sixty pounds. The initial cost of a stereoscopic camera is not always a criterion as to the quality or reality of the results; one has seen equally good results obtained, under suitable conditions, with a Dioscope, Glyphoscope, and similar stereo-cameras, as with reflex and focal-plane wide-aperture lens expensive stereo-cameras. It is a gratifying fact that any camera, provided with suitably spaced lenses of equal foci, will give just as good stereoscopic relief and perspective as any other camera, irrespective of price. The cheaper models of stereo-cameras, similarly to the ordinary cheap cameras, are limited as regards focussing range and exposure latitudes ; whilst these features limit their usefulness, they give the very important property of 'fool-proofedness,' for the beginner or amateur can always obtain suitable photographs of intermediate and distant objects in ordinarily good light. He knows that it is not possible to get nearer objects in focus, or to photograph in bad light, and, if wise, does not attempt to. On the other hand, if he were given a camera fitted with a wide-aperture lens (f/4.5 say) and focal-plane shutter giving speeds up to 1-1,000 second, he would get a very small percentage of good results, due to the very wide latitude or range of lens stops and shutter speeds ; he might hit on the correct stop and speed for a given subject, but would be just as uncertain about other subjects and conditions. We do not wish these remarks to be interpreted as an indication of the unsuitability of expensive apparatus, but merely as to the inadvisability of the beginner or amateur using such apparatus in the early stages ; the competent photographer, as a result of his experience, will be able to get consistently the best possible results only with those cameras possessing all the necessary refinements and wide ranges of speeds and lens apertures.

Before describing in the next chapter some typical stereo-cameras of various grades, it is proposed to show how satisfactory stereoscopic pictures can be obtained with ordinary single lens cameras. A number of alternative methods will be considered in turn, commencing with the simplest and proceeding to the more involved ones later.

Single Lens Stereoscopy, without Accessories.—Any camera, which will take an ordinary flat print type of photograph, is also capable of making equally good stereoscopic prints ; the better the camera, the higher will be the standard of the results, just as in flat photography.

With a single lens camera one is limited in the choice of subjects to those which show no movement (for at least 30 seconds), for it is necessary to move the camera and change the plate or film between the two exposures, essential for stereoscopic effects.

The camera is set up facing the subject, which may be any still object ; for example, a vase of flowers, group of statuary, a piece of machinery, a bird's nest, a still landscape, or a street scene. The subject is focussed up on the ground glass screen, which in this case should have a pair of intersecting pencil lines at its centre, and the photograph taken as usual. Next, the camera is shifted sideways bodily by about 2½ inches; this can be done by moving it along a board, stand, or table, or by moving the tripod legs so that the camera is shifted by this amount; it is a good plan in the latter case to have a plumb-bob hanging from the centre of the tripod top, and to measure the shift at the point of the bob; in each position the camera ought to be level, as shown by the bubble. The camera is directed to the same view as before—and it is here that the intersecting lines on the ground glass screen help—and another photograph taken with the same stop and shutter setting. It is not absolutely necessary to direct the camera, it can be slid along sideways.

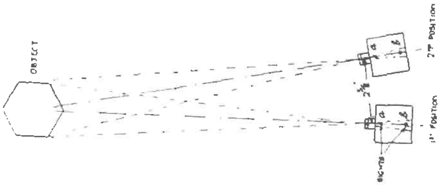


FIG. 17.—STEREOSCOPIC PHOTOGRAPHY OF STILL OBJECTS WITH SINGLE LENS CAMERA.

The prints from the two negatives will form a stereoscopic pair, which when viewed in a stereoscope give true relief effects. To obviate the necessity of re-focussing, or positioning the camera, in the second case, with the aid of the ground glass screen, two points, or sights on the camera body can be used instead; these sights are directed on the same object in each photograph. It is not difficult to obtain stereo-photographs of individuals with this method, although a little patience is necessary on the part of the subjects photographed.

Stereoscopy by Shifting the Subject.—In many cases, where the still object photographed is capable of being handled conveniently, the camera can be kept stationary, and the two views obtained by moving the subject bodily sideways (i.e., at right angles to the lens axis) by the usual amount ($2\frac{1}{2}$ inches for normal subjects). A sliding board on which the objects can be placed will be found an advantage for this type of work. If two marks be placed on the fixed guide of the sliding board, corresponding to the above separation, this will be found to facilitate the taking of the photographs. A plain background should be provided, and the illumination should be "parallel," i.e., not concentrated. Alternately the object may be rotated slightly, to give the two views.

Many subjects—for example, flowers, statuary, objects of interest in the home, stuffed birds and animals, curios and educational models—can be dealt with quite satisfactorily in this manner.

We shall refer to other methods in subsequent chapters.

The Sliding Lens Method.—It is possible to employ a half-plate ($6\frac{1}{2} \times 4\frac{3}{4}$ in.) stand camera to obtain stereoscopic pictures, if the lens is mounted in a special panel which is arranged so as to slide horizontally a total distance of $2\frac{1}{2}$ in. It is necessary to fit a central partition inside the camera, in order to prevent the light admitted during the exposure on one side from fogging the other part of the plate. In effect, we have two cameras formed inside the half-plate one, with a single lens which slides over to each of the component cameras in turn, and with a single large plate, on which both of the stereoscopic photographs are impressed. It is, of course, necessary to transpose the prints made from the negative in this case, or if glass transparencies are taken, to cut the glass and transpose the two sides. Stereoscopic pictures can also be made with a fixed lens half-plate camera by utilising alternately the two halves of the plate, and moving the camera sideways between the exposure; it is necessary to mask off the half of the plate not being exposed in each case. By selecting the left half of the plate for the right hand position, and vice-versa, transposing the final prints can be avoided.

The Use of a Sliding Camera or Board.—There are several methods of making a simple sliding device for shifting the camera between the exposures, when taking stereoscopic photographs. One method is to mount a flat board on the tripod top, as shown in Fig. 18 (*a*), and to provide two slots in another board, so that it can slide sideways by the required amount, and can be clamped in each position. The camera is mounted on a screw affixed to the upper board, and, therefore, moves with it. The amount of the separation of the lens positions can be varied in this case, and if a suitable scale is provided much useful work can be done.

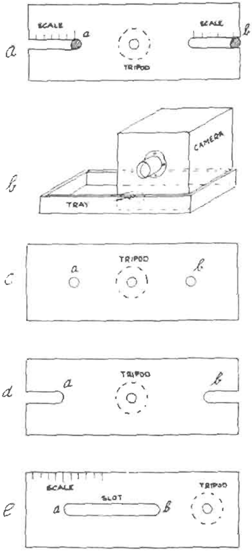


Fig. 18.—Illustrating Several Alternative Methods of Stereoscopy with a Single Lens Camera.

Alternatively the camera can be placed in a wooden tray, as shown in Fig. 18 (*b*), of the same fore-and-aft length, but 2½ in. or so wider than the base of the camera. The tray is mounted rigidly on the tripod head, and the camera is merely slid from one side to the other when making exposures; it is necessary to allow for a small angular movement of the tray when photographing near objects, but this is unnecessary for objects beyond about sixty to eighty times the focal length of the lens from the camera.

Another useful scheme is to mount a rigid board, a little larger in area than the camera base, on to the tripod head, and to drill two holes *a* and *b*, or make two slotted holes, as shown in Fig. 18 (*c*). The camera is located on the board by means of a pin screwed through the tripod screw hole, and is bodily lifted and transferred to the other hole, for the second photograph ; if the camera can also be clamped in each position it will avoid moving it accidentally when drawing the dark slide or making an exposure.

An offset slotted board, held at one end to the tripod head as shown in Fig. 18 (*d*), can also be used with a rigid design of tripod. All that is necessary in this case is to fix the camera at the inner end of the slot (nearer the tripod) for the first exposure, and to slide it to the appropriate mark on the slot scale for the second exposure. Other methods for sliding the camera will no doubt suggest themselves to the keen worker.

Swinging Devices for Single Lens Cameras.—An improvement on the foregoing devices, most of which necessitate unclamping, or removing the camera, before it can be shifted, is the single or double link method shown in Fig. 19. In each of these methods the camera is mounted on another board, plate, or arm, and is merely swung over on a pivoted link, or on two links, from the left to the right position. In Fig. 19 (*a*) the camera is clamped to a slotted metal link, which is pivoted to a board or table mounted on the tripod head. After the first exposure the camera is swung through 180°, by rotating the link over to its extreme position, and the

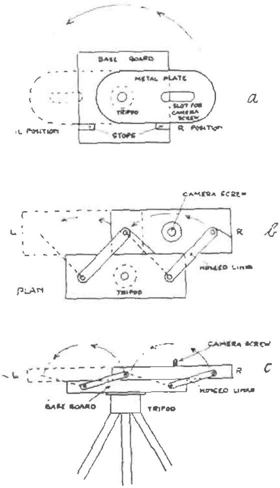


FIG. 19.—THE SWINGING CAMERA BASE (SINGLE LENS) METHOD.

camera unclamped and pointed in the proper direction; it is possible to vary the inter-lens distance in this case.

Fig. 19 (*b*) illustrates (in plan view) a much better method, in which a pair of hinged links are employed, so that the camera remains parallel in its two extreme positions, and no clamps or screws are required; by the provision of suitable adjusting stops on each side, the separation distance can be varied as required. It should be pointed out that in this method the camera moves in a horizontal plane from one position to the other. It is also possible to arrange for the camera to swing in a vertical plane, as shown in Fig. 19 (*c*), by substituting a pair (or two pairs) of vertical links for the horizontal ones previously described. Adjustable separation can readily be arranged by the provision of screw stops to limit the lowest position of the upper board, or by the simple expedient of inserting a piece of wood between the upper and lower members.

Single Lens, Single Exposure Methods.—Each of the methods previously described necessitates the making of two separate exposures, and in some cases the changing of the plate in between; it is also necessary to move the camera bodily from one position to the other. These methods are quite satisfactory for still subjects, and where the lapse of a short time interval does not matter. Attempts have been made, in the past, to employ a single lens camera, so as to obtain two photographs to form a stereo-pair with a single exposure only. The principle of most of these methods lies in the use of a single photographic plate, large enough to contain the two stereo-photographs at their proper separation, and the employment of a special optical attachment to the lens or camera front for giving two distinct views of the subject photographed, at the correct separation. It is well-known that half a photographic lens (i.e., divided or masked diametrically) will give a correct photographic image on the ground glass screen, but of reduced light intensity; this fact is made use of in one or two forms of stereoscopic adapters for single lens cameras.

A popular fitment of this type was the adapter invented many years since by Theodore Brown, and illustrated diagrammatically in Fig. 20. Here a pair of surface-silvered mirrors, *P*, *Q*, inclined at a very slight angle are attached to the tripod or camera body, so as to face the camera lens a short distance away from it. Imagine that in place of the mirrors *P*, *Q*, a plain mirror were substituted, then the ground glass screen *acb* of the camera would give an image of the distant view seen by reflection from this mirror. As, however, there are two plane mirrors, *P* and *Q*, two views of the distant scene or object, *AB*, photographed will be seen on the ground glass screen. Each of

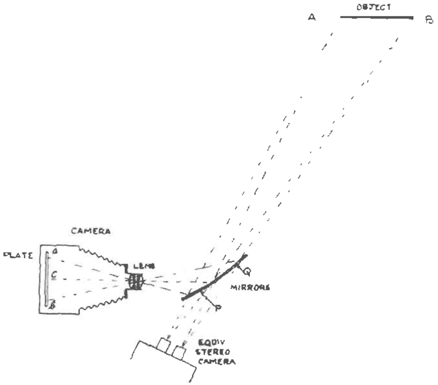


FIG. 20.—THE BROWN MIRROR DEVICE.

the views is identical with that which would be seen by the camera lens shown below so that a stereoscopic pair of pictures, *ac* and *bc*, is obtained in the camera, corresponding to the view-points of the equivalent two lens stereoscopic camera shown in the lowermost part of Fig. 20. By altering the relative inclination of the mirrors, the separation of the images can be varied; the nearer the obtuse angle between them approaches 180° the smaller will be the separation. It is not necessary in this case to transpose the prints, but owing to the reversal effect due to the reflections at *P* and *Q* there will be a reversal of the right and left sides of the pictures as viewed subsequently in the stereoscope; thus any words or printing photographed will read the reverse way. This defect is remediable by printing, in a parallel beam of light (as in a long box) the negatives through the glass (or film) side, or by making use of one of the transfer processes.

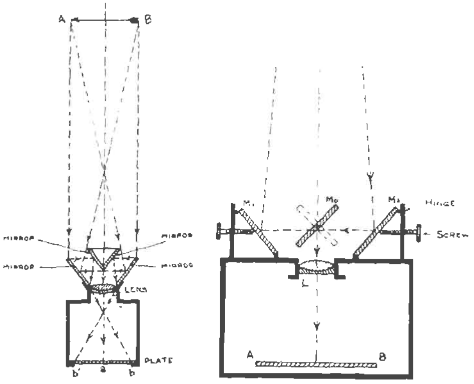


Fig. 21.   Fig. 22.

Fig. 21.—The Stereo Photoduplicon. Fig. 22.—Alternative Method using Adjustable Fixed Mirrors M_1 and M_2, and a Mirror M_0, Rotated between the Two Exposures.

Another method devised originally by the same inventor is that shown in Fig. 21, and known as the Stereo-Photoduplicon. In this case the camera lens receives two distinct pictures, by reflection from the surfaces of two pairs of mirrors. The writer hit upon this method before knowing of its previous discovery, when using a surface-silvered right-angled glass prism and two mirrors. In this case there are two reversals at the mirrors, so that the final prints are correct as regards right and left-handedness, but it is necessary to transpose the prints.

A disadvantage of these devices is the loss of light by reflection at the mirror surfaces, and the need for optical flatness of the mirrors themselves.

M. Dinesmann* has recently placed on the market an ingenious inexpensive arrangement of silver on glass mirrors, for obtaining with a single lens camera, and a single exposure a stereoscopic pair of photographs

Use of Two Cameras.—It is possible to obtain excellent stereoscopic results by using two cameras of identical construction and focal lengths, by mounting one rigidly on a tripod head table and allowing the other to be clamped in any position along a slot in the table.

Alternatively, the two cameras can be connected together at their bases, and their shutter releases also connected in such a manner that the one release operates both shutters. The two cameras should have lenses of identical aperture and focal length, and further, the shutters should work at the same speeds. This method can only be applied to small cameras, however, for it is otherwise impossible to obtain the correct separation between the lenses ($2\frac{1}{2}$ ins.). For this reason cameras taking plates or films of greater width than 2 to $2\frac{1}{4}$ inches are ruled out.

No doubt, by a careful examination and selection of the cameras from stock, two suitable ones might be found.

* *Photo Revue*, May 15, 1925.

CHAPTER V

THE SELECTION OF CAMERAS AND ACCESSORIES.

PARTICULARS are given in Chapter VI. of various stereoscopic cameras, now obtainable, and there it is pointed out that under favourable conditions the cheaper cameras give quite satisfactory results. In common, however, with ordinary cameras, in scope, application and results they are limited by their lenses and their general design. In the hands of a skilled worker, the more elaborate camera will enable a wider range of subjects to be photographed under more unfavourable conditions. Thus it will be possible to obtain well-defined stereograms of rapidly moving objects, to obtain better negatives in poorer light—due to faster and wider aperture lens—to photograph with the hand-held camera moving objects or poorly illuminated subjects for which a stand would be required with the less expensive cameras, to obtain better definition, more uniform illumination over the plate, and greater freedom from distortion. All of the foregoing factors count in the case of serious photography of difficult subjects.

Let us examine, briefly, the essentials of a first-class stereoscopic camera. The necessary features are (1) Rigidity. (2) Good Lenses. (3) Convenient Focussing. (4) Good Shutter or Shutters. (5) Lateral and Vertical Movements. (6) Convenient Film or Plate Holders. (7) Weather-proofedness. (8) Compactness. (9) Efficient and Convenient View Finder. (10) Provision for attachment of Accessories, if required.

Rigidity.—When the camera is extended ready for use, the lens panel must be quite rigid in relation to the body and plate or film holder. Otherwise any vibration, or even the act of releasing the shutter, will cause a movement of the image on the plate; when used on a stand in the open, with the wind blowing, it is essential to have both a rigid tripod and rigid lens front. It is in this respect that all-metal unit construction cameras, such as the Verascope, and Contessa-Nettel Stereco models score, for the lenses are securely attached to the rigid body of the cameras. The better makes of bellows cameras, however, will be found to possess rigid mechanism for extending the camera front, and for focussing.

When purchasing a new or second-hand camera, the rigidity of the lens panel and body should be tested, in the working position.

Lenses.—Sufficient has already been mentioned on the subject of lenses to indicate the necessity of the best lenses that circumstances will permit being used. The latest designs of the more expensive stereo-camera have excellent lenses, of apertures F/3.0 to F/4.5, well matched and giving good definition, little or no distortion, a flat field and even illumination over the whole plate. A special feature of such lenses is their ability to give good negatives under most adverse circumstances as regards the nature, the lighting and the movement, of the object photographed. Another advantage, more particularly where the small sizes of plates are used, for example the 45 × 107 mm. ones, lies in the fact that the negatives will stand a fair amount of enlargement and yet give good detail ; the writer has frequently made 12 × 12 inch enlargements from negatives, the image portions of which measured 1¾ inches square. A wide aperture lens also obviates the need of a tripod in the case of most ordinary subjects.

Focussing.—Although in the case of certain high grade cameras of the fixed focus, rigid box form, it is the rule to obtain sharp negatives of objects situated at distances beyond about 10 feet from the camera, yet there are occasions when the use of a focussing device enables special subjects to be photographed, and special conditions to be taken advantage of. In the case of fixed focus cameras such as the Verascope, supplementary lenses are obtainable for photographing objects at 9ft., 6ft. and 3 ft., or even at a few inches from the camera ; one has examined some excellent stereograms obtained with such lenses.

The advanced stereoscopic worker will, no doubt, favour the inclusion of a separate focussing adjustment, however. Of the available types there are (*a*) The sliding lens mount variety, in which the rotation of a milled head on one of the lens mounts works screw thread devices of quick pitch which move the lenses in and out. A scale is usually engraved on the periphery of the mount, and by a simple connecting-rod mechanism both mounts can be moved simultaneously as shown in *Fig. 23*. Some of the Ernemann cameras employ this method. (*b*) A type of lazy-tongs mechanism, such that the lens panel always moves parallel with the plane of the plate. Focussing is carried out by operating one of the lazy-tongs links in a lateral direction (to the axes of the lenses) by means of a screw and nut device. A scale of distances is provided. The Nettel Stereax* camera has this arrangement. (*c*) By the usual reflex camera mechanism, in which the front panel carrying the lenses is attached to two parallel brass racks, operated by a long pinion, or pair of pinions rotated by the hand focussing screw. These stereo-reflex cameras represent almost the last word in refinement, and are accordingly very attractive instruments to use. Typical examples of such cameras are the Ernemann Eastman Stereo Graflex, and the Mentor Stereo Reflex cameras.

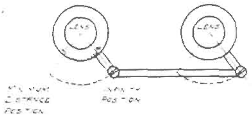


FIG. 23. SLIDING MOUNT FOCUSSING ARRANGEMENT.

There is also a camera, known as the *Heidoscope*, in which a separate lens of wide aperture is provided in conjunction with a mirror type focussing viewer. In this case the focussing lens aperture is F/3.0. By an ingenious adjustable device the view-finder can be used for direct or indirect viewing as desired.

Shutters.—It is important that efficient shutters should be fitted to stereoscopic cameras. The majority of modern cameras employ the sector or sliding plate type of shutter mechanism, but there are a few examples of focal plane cameras available. In the former case a similar type of shutter to that employed in ordinary cameras is used for each lens, and the two shutter releases and reset mechanism levers are so connected that they

* Vide Fig. 38.

work simultaneously. The shutters fitted are usually arranged to give time, bulb and instantaneous exposures; the latter range from one sec. to 1/100 sec. in some examples, from 1/5 sec. to 1/150 sec. in others, and in one or two expensive instruments up to 1/300 and 1/400 sec. exposures. These rated exposures are, of course, nominal ones; the actual ones are probably appreciably slower than these values. Some excellent results can, however, be obtained with the shorter speed settings; one has seen some splendid examples of stereograms, illustrating men jumping and diving, horses and dogs jumping, aeroplanes in flight and motor cars at speed. The sliding plate type of shutter is seldom found on the better types of camera, as, owing to its construction, and to the inertia of the relatively heavy parts, it cannot give the shorter exposures required. Here it should be mentioned that to obtain the best use from wide aperture or 'fast' lenses, it is essential to be able to give rapid exposures.

The focal plane shutter is undoubtedly the ideal for rapid photography, and in the smaller sizes of stereo-camera owing to the long width and small depth of the plates used, very rapid exposures can be obtained; in the case of one of the writer's stereo-cameras, the fastest exposure is rated at 1/2500 second; actually, of course, it is slower than this.

For the same exposure interval the focal plane shutter enables almost twice as much light to reach the plate; it is, therefore, much more efficient than the sector shutter.

One drawback of most focal plane shutters is their inability to give a slower 'instantaneous' speed than about 1/15 second. Thus the range 1 sec. to 1/10 sec., say, is not usually provided for, and one is forced to use the bulb or time exposure setting, namely, one release movement to open, and one to close; it is necessary to use smaller aperture settings of the iris diaphragms in such cases. The sector shutter undoubtedly scores in respect to the slower 'instantaneous' speeds, and in its ability always to give 'bulb' exposures.

As regards the operation of shutters, it is unfortunately a common fault of many cameras to place microscopic shutter release knobs or levers in inconvenient positions, so that there is a tendency to shake the camera in releasing the shutter. Personally, the use of an antinous release is preferred for hand work; the release of this can be arranged in any convenient position to suit the operator, and there is no tendency to rock the camera.

Lateral and Vertical Movements.– Although the majority of stereo-cameras are fitted with fixed lens panels, a few of the more expensive instruments are provided either with lateral or with vertical adjustments for the lens panel. In the former case the camera can be used for panoramic pictures. Thus, in the case of the Stereo-Deckrullo-Nettel 10 × 15 cm. camera, one of the stereo lenses is fitted with an eccentric convertible metal plate, for this purpose, whilst in another model of the same instrument one of the lenses is fixed on a metal plate so that it has the proper focal length for stereo work, and can be taken off the lens panel, and placed in the middle of a second lens panel, which can be fitted to the camera for panoramic picture photography.

The Mentor stereo camera has also a separate front panel provided for the same purpose.

As regards the rising front, this is frequently required for architectural studies, for the photography of tall buildings, trees and other objects; its use enables the photographer to obtain the required picture without tilting the camera, so that single picture distortion does not occur.* Obviously the lenses fitted should have a sufficient covering power, when the sliding front is in its extreme position.

Film and Plate Holders.—Where expense is not a primary consideration, the stereo-camera should be provided with plate-holders, or plate magazine, and a film-pack adapter. It is often necessary to carry several types of plate—slow, medium or rapid ordinary, orthochromatic, panchromatic or backed plates —so that the appropriate emulsion can be selected at the last moment to suit the light and other photographic conditions. The single plate holder enables this to be done conveniently.

The *plate changing magazine* carries twelve plates, and fits

* Vide also p. 157.

on the back of the camera similarly to a single slide. By the mere act of depressing a milled screw or knob, pulling out the magazine body-slide, just as one would remove the slide, or cover, of an ordinary single-plate holder before exposing the plate; and pushing the body-slide in again the top, or exposed plate is transferred to the bottom of the pack, whilst the second, or unexposed plate is brought to the top position. In this way twelve plates may be exposed and changed quickly, in turn Each plate is fitted to a thin metal sheath, provided with indentations or projections which preclude the possibility of wrong loading, in the dark room. The magazine has, of course, its own draw-slide—usually of sheet metal—for preventing light from reaching the plates when the magazine is removed from the camera. An indicator is also fitted, to show the number of the last plate exposed; this is a necessary fitting. A typical magazine is shown in position in *Fig.* 33. The advantage of the plate magazine is that it enables a number of plates to be carried integrally with the camera, and that rapid plate changing can be carried out; for tourist purposes, and where several photographs have to be taken rapidly, this is a marked advantage. On the other hand, its use adds to the weight of the camera, and single plates cannot be developed without the extra trouble and inconvenience of extracting them from estimated positions in the pack. The act of changing the plates also stirs up the air, and any dust which may happen to be in the camera interior. The plate-magazine is usually fitted to the 45 × 107 mm. size of camera, where the question of weight does not count to any appreciable extent.

The Film Pack Holder.—The film pack holder is a neat and convenient means of carrying a large number of films about, and for using them in batches of one dozen. The film pack adapter is a light metal holder, provided with an ordinary draw-slide, and a hinged back; the latter, enables the film pack—a rectangular packet of twelve films enclosed in a black, card box—to be inserted. There are twelve paper tags exposed after the pack is loaded, and the flat films are changed in turn by pulling in order each tag out as far as it will go, and then tearing it off. The tag nearest the camera is always pulled when changing a film. After the whole of the films have been exposed, they may be removed and developed singly or together as desired.

The film pack, owing to its lightness and convenience, affords a convenient method of carrying a large stock of films, as when touring countries where supplies are unobtainable. The user is limited to the common film emulsions and speeds in ordinary use, however. For the highest standard and range of general results, the dry plate is undoubtedly superior to the film.

Film Cameras.—Before concluding this section, reference should be made to the type of stereo-camera—of which the Jules Richard Homéos is a good example—which employs ordinary cinema film wound on spools. The latter measures only $6\frac{1}{2} \times 2\frac{1}{4} \times 2\frac{1}{4}$ inches, and is fitted with Zeiss F/4·5 lenses of fixed focus. A lever sets the shutter, which gives an accurate

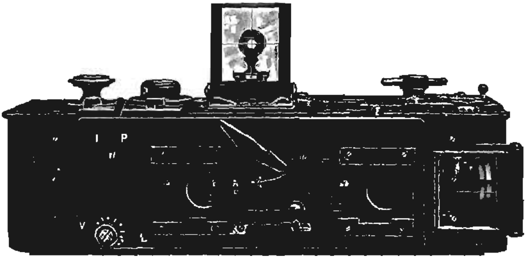


Fig. 24.—The Homéos Roll Film Stereo Camera.

range of exposures from 1/8 to 1/150 sec.; longer exposures may also be given by setting the shutter on "time." The Homéos camera takes daylight loading spools of standard cinematograph film; each spool carries a metre (just over a yard) corresponding to 26 pairs of stereoscopic pictures. The pictures of a pair are staggered relatively to each other, that is to say what would normally be the space between a pair is filled up with two pictures belonging to other pairs, so that no gaps are left, and no film space is wasted. During exposure the film is pressed into contact with a plate of glass, so that it is truly in the focal plane. The film winding key registers automatically the number of exposures. The positive films are printed on a strip of cinema positive film, a special printing machine, which automatically transposes the pictures, being employed. The stereoscope for viewing the pictures is shown in Fig. 25. By pulling a rod, each pair of pictures on the strip can be brought into position, and the whole 26 pairs viewed successively. The

FIG. 25.—HOMÉOS STEREOSCOPE AND SPOOL OF FILM.

advantage of this type of film stereo-camera is the small amount of storage space of the positives obtained, for a number of films can be wound on to one spool when not in use. The individual pictures measure about 1 inch deep by ¾ inch wide.

Finish and Bulk of Camera.—The stereo-camera should, in common with other types be finished externally so as to withstand the elements. The leather or exposed metal finishes are excellent; the all-metal types of box camera possess the advantage of being able to resist climatic effects in all countries, and the ravages of tropical insects. The folding camera protects the lenses and other parts, and occupies less space. Personally, leaving other considerations for the moment, we prefer the leather-covered metal case, folding type, of stereo-camera; when closed the hinged front protects the lenses, shutter and diaphragm apertures against both wet and dust. For tropical use, cameras containing wood or leather parts are unsuitable, the metal type being best.

View Finders.—The type and the position of the view-finder is of great importance in connection with stereo-cameras, as the latter are necessarily of small dimensions, and there is not much room available for fitments. There are two principal types of view-finder favoured—disregarding the reflex type, in which the full-sized picture is seen and focussed, to the moment of exposure—namely, the prismatic or inclined mirror, and the direct vision type. The first type enables the camera to be held at a lower level than the eyes, namely, at chest level; the point of view is, therefore, lower than the visual one; moreover, it is difficult in the smaller sizes of stereo-camera to pick up the details in the small viewer so far from the eye.

The second type is by far the most popular one, and rightly so, for one is able in many cases to obtain a large field of view, and to hold the camera much steadier. The square, concave lens view-finder, with its peep-sight to locate the object viewed, is the best known of these. A pair of straight lines at right-angles intersects the square lens, and enables the centre of the field of view to be ascertained.

This type usually folds down flat on to the top or side of the camera, the peep-hole bracket folding first and the lens afterwards; springs and hinges are fitted for this purpose.

The better position for the view-finder is probably on top of the camera and offset, so that the camera can be held central. In using view-finders of the direct-vision type it is important to check the correct position of the peep-sight or pointer relatively to the eye, as this distance governs the size of the field of view; by using a ground-glass screen the field of view of the view-finder may be checked. If too large in the latter, a mask may be pasted or otherwise mounted on the lens of the finder, or the peep-hole moved away from the lens; if too small, the peep-hole should be moved towards the lens.

In using a focussing-scale, it should be remembered that *the nearer the object to the camera, the smaller will be the true field of view* in the finder, so that the view-finder requires a correction. A good plan is to engrave with a diamond point another rectangle, on the lens face, corresponding with the nearest distance, as shown by the focussing scale, for use at shorter distances. Many close-up views have been spoilt, owing to the photographer omitting to remember that the view-finder gives too big a field of view under these conditions.

Another form of direct finder, possessing many advantages is that illustrated in Fig. 32 on the Ica Plaskop camera ; this has no lens, but in place a relatively large wire frame is provided with a central hole mount, and at the rear a Vee-notched bar. These two components fold down flat on the top of the camera. In one Ernemann focal-plane stereo-camera, there is an ingenious arrangement, whereby the front folding cover also constitutes a direct view-finder, there being a large square orifice in the cover, and a folding rear sight ; the square hole is covered with another folding plate when the camera is closed up.

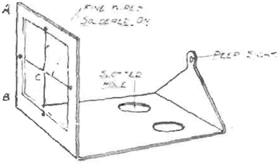


FIG. 26.—A HOME-MADE VIEWER.

Many stereo-cameras are fitted with two independent view-finders, one being a "brilliant" or prism finder and the other a direct one. In one example, on one of the writer's camera, there is a folding, inclined, mirror type viewer, and a direct one formed in the camera lens cover. It should be mentioned, in connection with view-finders, that it is a perfectly easy matter to make a direct viewer as outlined in Fig. 26, from a sheet of tin, or brass ; these should be blackened with a matt photographic paint afterwards. The correct angle of view of the finder can readily be ascertained, for the ratio of the distance CP (P being the peep-sight position) to the side AB, should be the same as the ratio of the lens focus to the smaller side of the plate.

$$\text{Thus } \frac{CP}{BA} = \frac{\text{lens focal length}}{\text{side of plate}}$$

This field of view is correct for the infinity setting of the camera.

Accessories.—It has been mentioned that the camera should be designed so that accessories may readily be fitted, if desired. The term accessories includes tripod attachment, screw nuts, self-photography devices such as the Richard Cunctator, and the Photoclip, levels, antinous or bulb releases, magnifiers, and colour screens and the like.

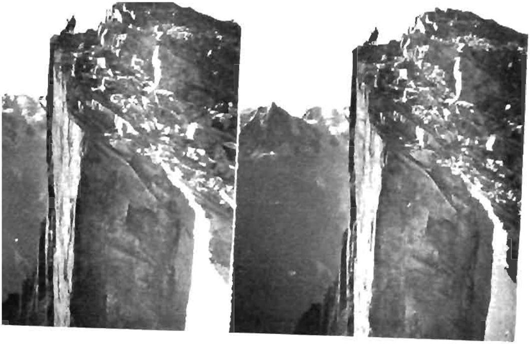
Colour Screens.—It is frequently necessary to employ colour screens when using panchromatic plates in order to obtain the true rendering of colour tones; further, in connection with the use of colour photography, such as the Autochrome process of Lumières, a special screen is required for each lens. Stereo-cameras must, therefore, be provided with some means for holding these screens either in front of or behind the lenses; a convenient method is to have the colour screens supplied in circular spring mounts and to fit these, by pushing over, to the backs of the lenses inside the camera; they are this protected by being inside the camera.

The writer has used the ordinary Wratten K.3 screens supplied in the form of gelatine strips, by shaping circular discs (placed between two pieces of paper when cutting with the scissors), to fit between the two lens components; one component must, of course, be unscrewed in order to insert the gelatine film. The advantage of this method lies in the important fact that in this position the foci of the lenses are not interfered with. If a glass screen be placed behind the lens, the effect will be to increase the effective focal length so that *when focussing scales are worked to, these will all be incorrect*, due to the refractive effect of the glass; it should be added that the usual colour screen consists of two discs of optically flat glass with the stained gelatine film cemented between them.

Focussing the Picture.—Although the focussing scale is the more convenient for small stereo-cameras, yet on many occasions, more particularly, with still-life objects, close-up views and for special purposes, it is necessary to use the method of focussing directly on the screen. It is very important in the case of the 45 × 107 mm. and 60 × 130 mm. sizes, to focus the small images very sharply, for the stereoscope viewer magnification is such that any very small out-of-focus effect is greatly magnified.

The first essential is a good piece of ground glass, of very fine

A CLOUD STEREOGRAM. *(C. Benham.)*



WIDE ANGLE STEREOGRAM. PART OF THE MONT BREVENT NEAR CHAMONIX. *(Col. L. E. W. van Albada.)*

grain; this may be made by the somewhat laborious process of rubbing an old negative down, on a piece of plate glass, using very fine emery or carborundum (the latter of the type known as *FFF* is suitable) or even knife-powder.

The writer prefers to use an ordinary lantern plate (i.e., transparency plate) which has been slightly fogged, developed and fixed. The slight amount of fogging gives minute grains of silver in the emulsion, and an excellent almost grain-less screen results; some photographers prefer perfectly plain glass.

The second essential is a focussing magnifier, for giving an enlarged image, which can be examined critically; most scientific instrument makers, and photographic firms, sell small magnifiers for this purpose: a magnification of between 2 and 4 is usually enough for most practical purposes.

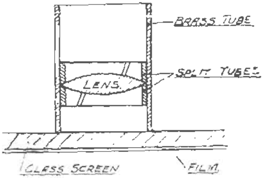


FIG. 27.—A HOME-MADE FOCUSSING MAGNIFIER.

A useful focussing magnifier may readily be made from a common double-convex single lens, and a piece of metal tubing as shown in Fig. 27. The lens is held by spring rings made either from split tubing or bent wire, and the edge is turned or filed down progressively until the image on the screen is sharply in focus at the normal distance of the eye for viewing. The interior of the tube should be finished matt-black. In an emergency a cardboard tube may be rigged up for the purpose.

The Scaleometer, pocket, measuring microscope, supplied by Messrs. Ottway & Co., of London, is also a most useful focussing magnifier. When focussing on the screen, it is a good rule to make the sharpest images, not those in the dead centre of the plate, but about half-way between the centre and the edge. Always focus with the full lens aperture on the most prominent object required, stopping down afterwards; the table of hyperfocal distances on page 64 will be found very useful.

Some photographers cement a microscope cover-glass to the ground-glass screen, in about the position previously recommended, and focus the 'aerial' image by means of a magnifying lens of low power (4 to 10).

CHAPTER VI

STEREOSCOPIC CAMERAS.

We have referred to the matter of the choice of stereoscopic cameras, and have mentioned the fact that these are no more expensive in first cost than single lens cameras, and that their working cost is no greater—in many cases where a single pair of prints or a transparency only is taken, materials are not a serious item. We shall commence this section with a short account of the simpler forms of camera on the market, and then proceed to the more expensive types, preceding our descriptions, however, with a few remarks upon camera sizes and choice of lenses.

Choice of Camera and Lens.—To those commencing stereoscopic photography, the question of the size of camera, type, and lens usually offers a certain amount of difficulty, and rightly so, for it is only by experience that one ultimately arrives at the ideal type of camera for one's work. It is a common experience, unfortunately, for the beginner to select an unsuitable type, when no outside advice is available. The first point to settle is, of course, the price which one can afford to pay, and in this respect the more ambitious, but impecunious stereoscopist has now the advantages of purchase of excellent cameras by extended payments.

The cheapest stereoscopic cameras at present are probably the 45×107 mm. ($1\frac{3}{4} \times 4\frac{1}{4}$ in.) all-metal types, of the transparency-positive kind. Second-hand cameras, in larger sizes, namely, up to $3\frac{1}{2} \times 3\frac{1}{4}$ in., can usually be obtained, quite inexpensively from the leading camera firms; they give very good results as a rule. Further, the second-hand lists issued periodically by such firms as Chas. Baker (High Holborn), The City Sale and Exchange (Fleet Street), W. Watsons (High Holborn), and Sands Hunter (Bedford Street), London, frequently contain references to stereoscopic camera fronts complete with shutters, and usually with lenses. The keen amateur will not find it difficult to build his own sterescopic camera, or to adapt the front to another camera.

The beginner is well advised to commence with a cheap type of camera, with which to obtain his experience, just as in ordinary photography one should commence with a Brownie, Klito, or similar inexpensive camera.

Those proceeding to specialise in this branch of photography, and who have the necessary experience and wherewithal to purchase, will find a range of excellent cameras from £8 or £10 up to £60 and above, fitted with various refinements, such as wide-angle lenses, wide-range sector or focal plane shutters, focussing mechanisms of the direct reading scale or reflex type, plate-changing magazines, autochrome screen attachments, rising fronts and other improvements.

As regards lenses, one should procure the best within one's means; the best results are obtained with the higher grades of lenses. Moreover, a good lens yields crisp, well-defined negatives which will give good enlargements, if required.

Transparency or Print?—There are two classes of stereoscopic workers, firstly, those who prefer to follow ordinary photographic practice and employ plates of normal size, from 2½ × 2½ in. to half-plate, or two lantern plates (3¼ × 3¼ in.), and to make prints for the final result, and secondly those who employ the smaller sizes of plate, namely, 45 × 107 mm. (1¾ × 4¼ in.), and 60 × 130 mm. (2⅜ × 5⅛ in.), and to make transparencies from their negatives, the former being, of course, positive prints on glass similar to lantern slides.

Each method has its merits. In the former case the ordinary simple photographic processes of single lens photography can be followed; moreover, the contact prints made can be used for presentations to one's friends, or for albums. The prints can also be hand-coloured, giving enhanced stereoscopic effect. In the latter case the transparency undoubtedly gives a much more brilliant result, due to the greater latitude of the plate's emulsion, as compared with bromides or P.O.P., so that more realistic results are obtained. The transparency sizes are usually too small for contact prints, to give sufficient detail, but on the other hand quite good enlargements can be made if the taking lenses are good ones. These smaller plates are less expensive to purchase, and they require a smaller quantity of developer: more plates or films can also be carried conveniently than in the case of the larger print-type stereo cameras.

The transparency camera is also much less bulky, and it can also be used as a viewing stereoscope, in most cases.

The only difficulty experienced with these small plates is that due to specks on the plate before the exposure is made; these become magnified considerably in the final result, and often resemble pieces of coal in relative size. Similarly, unless suitable precautions are taken, the negatives often exhibit a granular effect, which depreciates the final result. With suitable precautions, however, both of these difficulties can readily be obviated; the experienced photographer is seldom concerned with them.

Summing up the pros and cons, the print method of stereoscopy is the easier one, whilst the transparency method is cheaper, gives better stereoscopic results, but requires a higher degree of skill in manipulation.

The Choice of Lenses—The optical properties of the two lenses of a stereoscopic camera are probably the most important factors governing the final results obtained; poor lenses cannot be made to give consistently good results. The two important properties of lenses with which the stereoscopic worker is concerned are, firstly, the *Focal Length*, and secondly, the *Maximum Aperture of the Stop*.

It is important that the two lenses used in the camera should be properly "paired," that is, should have the same equivalent focal lengths, and the same working apertures for equal plate illumination. In this way the two images will be similar in brilliancy and in size.

Most reputable lens manufacturers will "pair" lenses for stereoscopic work, when the lenses are ordered, at a slight extra cost.

A good deal has been written concerning the most suitable focal lengths to employ, but in many cases the plate sizes for which the lenses are used have been overlooked.

The use of a *long focal length* of lens gives a better and more accurate rendering of perspective—more nearly that experienced by the human eye, but it reduces the effect of solidity and depth in the final stereoscopic result, unless the viewing stereoscope has long focus lenses also. Moreover, it is difficult to obtain much foreground (in focus) when distant objects have also to be included. The general pictorial effect obtained by lenses of relatively long focal length in respect to the size of the plate used is not so marked, but is more truthful than in the case of shorter foci lenses used on the same plate; the field of view is also smaller. When hill or mountain scenery is photographed with long focus lenses, the relative sizes of the images on the negative of far and intermediate objects is much greater—and hence more natural—then when short focus lenses are used; the latter cause a relative diminution in the size of distant objects and therefore result in a loss of proportion, the nearer objects appearing to be larger than they actually are.

We have assumed the ordinary normal focus lens stereoscope in the above considerations, but if the stereograms are viewed with lenses of appropriate focal length the stereoscopic effect will be the same in all cases. Long focus lenses are, generally speaking, more difficult to work with, and more accurate focussing is required; usually, also, a smaller stop must be employed in order to obtain sufficient depth of definition.

Short focus lenses are undoubtedly easier to work with, as their "infinity" distances (i.e., the distances beyond which everything is equally in focus) are shorter, and the stereoscopic effect therefore better; distant objects photographed with such lenses tend to lose their appearance of magnitude. The following table gives the usual sizes of stereoscopic camera plates in present use, in both English and metric measure, and also the focal lengths of the lenses employed in modern cameras.

An examination of this table shows that the shortest focus lenses have a focal length about 25 per cent. greater than the small side of the plate, whilst the longest focus lenses have focal lengths about 50 to 75 per cent. longer than the small side of the plate.

A good average focal length to employ is one about 30 to 40 per cent. longer than the small side of the plate.

TABLE No. I.

STEREOSCOPIC CAMERA PLATE SIZES AND FOCAL LENGTHS.

Plate size in mm. Short Side.	Plate size in mm. Long Side.	Plate size in inches. Short Side	Plate size in inches. Long Side.	Focal Length. mm.	Focal Length. in. (Nearest)	Ratio Focal Length / Small side of Plate
45	107	1¾	4¼	55	2⅛	1.22
				60	2⅜	1.33
				65	2½	1.45
				75	3	1.55
60	130	2⅜	5⅛	90	3½	1.50
				100	3⅞	1.67
				120		
70	130	2¾	5⅛	90	3½	1.28
				120	4¾	1.71
90	180	3½	7⅛	120	3½	1.33
				130	5⅛	1.45
				140	5½	1.55
100	150	43⅞	5⅞	120	3½	1.20
				150	5⅞	1.50
				180	7⅛	1.80

In connection with the question of actual focal lengths, a very important point to remember is that the shorter the focus the greater the depth of focus, and the nearer the infinity point. For the fixed-focus type stereoscopic cameras, which are now popular in the 45 × 107 mm. sizes, the use of a short focus lens means that all objects beyond about 10 to 12 feet are always in focus, so that one difficulty experienced by the beginner, namely, the estimate of distances for setting the focussing scale, is removed.

The following table shows the approximate Infinity Distances for lenses of different focal lengths and apertures; the aperture used affects this distance, as will be observed from the values given; the larger the aperture the farther away the infinity distance, and *vice versa*. The values in the table have been computed from the following formula :—

$$D = \frac{100 \times f^2}{12 \times S} \text{ feet,}$$

where D is the hyperfocal (or infinity) distance in feet, f the lens focal length in inches, and S the aperture, or lens stop number. (A stop of $f/8$ is taken as giving $S=8$; $f/6{\cdot}3$ gives $S=6{\cdot}3$, and so on.)

TABLE No. 2.

SHOWING THE INFINITY (OR HYPERFOCAL) DISTANCES FOR DIFFERENT LENSES.

Focal Length of Lens in inches.	Apertures.					
	f/3	f/4.5	f/6.3	f/8	f/11	f/16
	Hyperfocal Distances in Feet.					
2.0	11	7½	5½	4¼	3	2
2.25	14	9½	7	5¼	3¾	2½
2.5	17	12	8½	6½	4¾	3¼
3.0	25	17	12	9½	6¾	4¾
3.5	34	23	16	13	9¼	6¾
4.0	44	30	21	17	12	8¼
4.5	56	38	27	21	15	10½
5.0	69	46	33	26	19	13
5.5	84	56	40	31	23	16
6.0	100	67	48	38	27	19
6.5	117	78	56	44	32	22
7.0	136	91	65	51	37	26

Most focussing types of camera are provided with a focussing scale ; for these the values given in Table 2 will be found very useful. Suppose, for example, it is desired to photograph an object 8½ feet away from a camera, fitted with 2½ in. lenses ; the table shows at once that in order to get the correct definition at 8½ feet, a lens stop of $f/6.3$ must be used, when everything between 8½ feet and infinity will be in focus, as well as objects 2 or 3 feet nearer the camera. For critical definition, for enlargement purposes, it is better to use the figure in the next column to the right for lens stops ($f/8$ in the present example). For focussing distances with a given lens and stop, the hyperfocal distance given in the table is the best average position to set the focussing scale to, in order to secure critical definition, and maximum depth of focus at this distance.

In the case of fixed focus cameras, the table shows the nearest distances at which it is advisable to photograph objects. Thus, in the case of a stereoscopic camera, fitted with fixed lenses of $2\frac{1}{4}$ in. focus and maximum lens apertures of *f*/8, it is inadvisable to attempt to photograph objects nearer than about 5 ft. : by stopping down to *f*/11 objects up to within 4 feet of the camera will be well defined. For transparencies which are magnified a good deal in the viewing stereoscope, and for enlargements, it is better to take the next figure on the left for the hyperfocal distance.

In works upon optics it is usually stated that if the lens scale be set at the hyperfocal distance, then all objects situated from *one-half* the hyperfocal distance to infinity will be in focus. Thus, in the case of a $3\frac{1}{2}$ in. focus lens with an aperture of *f*/6.3, the hyperfocal distance is 16 feet, and all objects between one-half of this distance, viz., 8 feet, and infinity should be in focus.

For stereoscopic work, having regard to the magnifications employed in viewing the results, we prefer to consider the next figure on the left, viz., 23 feet, and to assume that the above rule applies : thus, all objects between $12\frac{1}{2}$ feet and infinity are considered to be in focus : this rule works quite well in practice.

Two Lens Cameras—The simplest form of stereoscopic camera consists of a common camera body of rectangular section, fitted with a pair of lenses of equal focal lengths and working apertures, and provided with a partition in the centre of the body, to separate the two views. It is easy to understand that instead of using two similar single-lens cameras side-by-side, several of the common features of each can be combined. Thus a single body, shutter, plate-holder, focussing arrangement, scale view-finder and tripod screw can be employed, with the result that the camera is simplified. Except for the fact of the two lenses, the larger shutter, and the partition, the steresocopic camera construction is identical with that of the single lens one.

Shutters.—In the cheaper forms of stereoscopic camera, a simple metal box (usually of aluminium) is employed for the camera body, and the shutter arrangement consists of a single sliding plate device, which operates by moving inside the camera across the lenses. The speed is controlled by the tension of the spring on the shutter, and can sometimes be varied by means of a milled screw fitted for the purpose. A sliding plate is also used for the lens apertures; usually three pairs of holes of different sizes are arranged in this plate. This type of sliding plate shutter is usually arranged so as to give time exposures (but not often for "bulb" ones). It is simple, sturdy, and reliable.

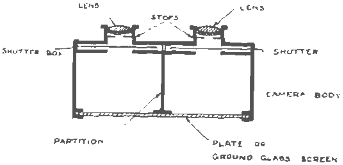


FIG. 28—ILLUSTRATING THE ARRANGEMENT OF A STEREOSCOPIC CAMERA.

The most popular type of camera shutter is the between-lens or sector type, similar to that commonly employed on ordinary cameras. Both of the shutter setting and shutter releasing levers are connected together in such a way that they operate together. The best sector shutters, in stereoscopic cameras, will give "instantaneous" speeds down to 1-400th second (nominal), in addition to "time" and "bulb" exposures.

The best shutter is, no doubt, the focal plane one, but this type is fitted only on a few of the more expensive stereoscopic cameras. It possesses the advantages of greater speed range (i.e., very much higher speeds), much greater shutter efficiency, and the very important property of equality of exposures. It is difficult with two separate sector shutters to obtain the same shutter speeds at each of their scale settings; if the actual speeds of the coupled shutters are not the same, the result will be unequal exposures in the two views.

The focal plane shutter in the ordinary way will give speeds down to 1-1000th second. In the case of the smallest (45 × 107 mm.) stereo cameras, owing to the relatively small width of the plate, and, therefore of travel of the focal plane shutter, very short exposures can be obtained. The self-capping focal plane shutter is preferable to the open slit type, since the shutter can be wound irrespective of whether the dark slide has been drawn or not. Most modern focal plane shutters are now of the self-capping type, although there are still one or two open slit types sold.

The focal plane type shutter is favoured in Germany, and is found on many cameras emanating from that country.

The focal plane shutter requires expert manipulation on account of its very wide range of speeds, and its high efficiency; it is, as we have mentioned before, much more difficult, relatively speaking, to obtain correct exposures under all conditions.

Typical Stereoscopic Cameras.—One of the reasons put forward for the lack of practical interest in stereoscopy is the expensive nature of the equipment, which places it beyond the reach of the ordinary individual. Whilst this has been true to

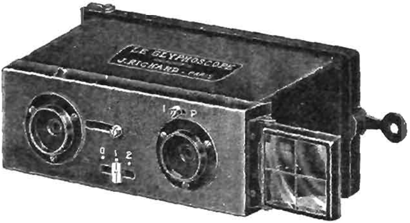


FIG. 29.—THE GLYPHOSCOPE CAMERA.

a certain degree, it should be pointed out that apart from the possibility of obtaining stereoscopic photographs with a single lens camera, and to which we have referred in Chapter IV. There are now on the English market several cheap but really efficient stereoscopic cameras, several of which are described in the following pages. We have been fortunate in being able to test a number of these instruments, and have been agreeably surprised at the results obtained. Given fair light conditions, and a steady hand, excellent stereoscopic pictures can be obtained with no very special knowledge of photography, and as easily as with a Kodak or similar hand camera. Fig. 29 shows the new Glyphoscope film-pack camera, recently introduced by Messrs. the City Sale and Exchange, the English agents for M. Jules Richard, of Paris. This camera, which resembles the well-known plate model, which costs only £3, is of the metal box form, provided with fixed focus single lenses of aperture f/12 and focal lengths about 2½ ins. With such short focus lenses, all objects beyond about 10 or 12 ft. are always in focus; for shorter distances than these a smaller stop, or the special 6ft., 3 ft., and 1½ ft. magnifiers supplied become a necessity. The film pack of 12 films fits neatly in the hinged metal holder at the back, the films measuring 45 by 107 mm.—a standard size. Three apertures or lens stops are provided, the adjustment for these being shown in the centre, and marked 0, 1, and 2 respectively. The simple sliding-type shutter used and which has one instantaneous speed, which we should judge to be about 1-25th second, and a time release, is set by means of the sliding

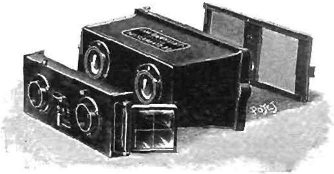


FIG. 30.
SHOWING METHOD OF USING CAMERA, WITH SHUTTER PORTION REMOVED, AS A STEREOSCOPIC VIEWER.

screw head shown to the right of the left-hand lens. The camera support consists of a smooth hole in the camera body, into which fits a vertical tapered peg camed on a ball-and-socket joint on the tripod—a common arrangement of this type of camera. The camera is held quite rigidly with this form of tripod head. An interesting and useful feature is that the camera can also be used as a stereoscope, or viewing apparatus, by simply detaching the front portion containing the shutter, and placing the holder (supplied), fitted with a ground glass, in place of the usual film pack, behind the transparency to be viewed. The ideal conditions of viewing the transparency with the same lenses as the negatives were obtained are thus realised.

The results of our tests with this camera showed very clearly that excellent pictures can be obtained with no more trouble than with ordinary single lens type cameras. Fig. 31 shows the Discope stereoscopic camera which is made in the 60 by 130 mm. size, giving negatives rather larger than in the preceding example, and possibly more suitable for single prints, and in which dust markings are less important. The body of the

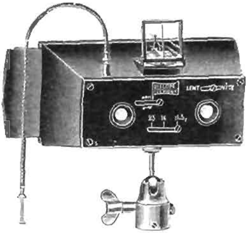


FIG. 31—THE DISCOPE CAMERA.

camera is made solidly in one piece in a composition which is unaffected by ordinary or tropical climatic conditions. It is provided with a bush for the tripod head, similarly to the Glyphoscope camera previously described. The camera is fitted with fixed focus achromatic lenses working at F/8, and is provided also with two other smaller stops. A metallic shutter of the sliding plate type is fitted, giving instantaneous exposures of 1-25th, 1-50th, and 1-100th sec., and also time exposures. A cable release is also provided.

The camera is provided with a direct vision view finder of ample proportions. The complete outfit of camera, screen and three single metal slides retails at £3 5s. There are canvas and leather cases supplied with the outfit. The overall dimensions are 6 by 3 by 4½ inches, and the weight 1 lb. 6 oz.

It may be added here that flat-film pack adapters and extra slides, as well as roll-film holders are obtainable at slight extra cost for use with the Discope camera described.

The new Ica Plaskop camera is very similar to that illustrated in Fig. 32, and is another example of an inexpensive apparatus capable of producing good stereo negatives. There are two 45 by 107 mm. models marketed, namely, the 603 type which measures 5.6 by 2.4 by 3.4 inches, and weighs 12 ozs., and which is fitted with two single achromatic lenses, and the 603/2 type of the same dimensions, weighing an ounce more, but fitted

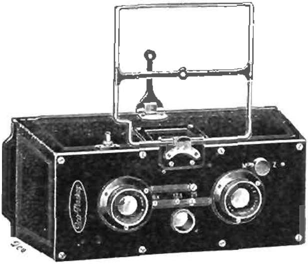


FIG. 32.—THE ICA PLASKOP CAMERA.

with two Ica "Novar" anastigmats of aperture F/6.8, and 6 cm. focal length. Both models are provided with a simple time and instantaneous shutter. The outfit includes six metal slides, and a direct vision view-finder is fitted to each model.

From the examples given, it will be evident that the amateur or beginner in stereoscopic photography need not be prevented from enjoying this fascinating branch, either on the score of first cost of apparatus or of materials; the small plates used are quite inexpensive, whilst the fact that only one positive print on glass, or transparency, need be made is also some compensation to those accustomed to making numerous prints from their negatives.

It is now proposed to describe one or two typical stereo-cameras now on the market, for the interest of those who desire to obtain the best results under all conditions, and to whom the first cost is not the sole consideration. In this matter it may be added that a relatively expensive camera is a good investment, for good second hand prices can always be realised, the depreciation being fairly small, under normal conditions. One of the best-known stereo-cameras in both this country * and in France is the Verascope, illustrated in Figs. 33 and 34. It is made in a number of different models, in the size 45 mm. by 107 mm., varying in details, lenses and other refinements. The No. 2 *bis.* model, is of all-metal construction, with fixed focus, rapid rectilinear lenses of apertures of F/8. The lenses are of short focus, so that all objects at and beyond about 9 ft. from the camera are in sharp focus; for shorter distances supplementary magnifiers are provided. In the hands of the novice and inexperienced the fixed focus all-metal stereo-camera provides a fool-proof arrangement, with which a high percentage of successful results is obtainable. A sliding plate type shutter giving slow, medium and fast "instantaneous" speeds, as well as time exposures, is fitted; it is set each time by sliding the small knob shown, in its slot to the left, and releasing a direct vision view-finder; and also a ground-glass reflector type (the viewing opening for which is shown in the middle of the upper side, and the small lens below the shutter reset knob).

The shutter release is by finger, or antinous release. This camera can be supplied either with magazine changing box, film pack adapter, or roll-film holder. The tripod upon which it is mounted, has a tapering socket which fits in a taper hole in the camera; it has also a ball-and-socket joint for tilting the camera in any position.

The Model 6 Verascope illustrated in Fig. 33 is a highly developed model, containing many refinements. It is made in the 45 × 107 mm. size, in metal construction, plated with oxidised silver. A range of lenses is available for selection; the model illustrated is fitted with Berthiot "Stellor" anastigmats F/4.5.

* We are indebted to Messrs. City Sale and Exchange, Ltd., London, for the particulars here given.

The shutter fitted is known as the "Chronomos," and gives instantaneous speeds from 1/8th sec. to 1/150th sec. and time; a table is provided showing actual and marked speeds. Diaphragm variations ranging from F/4.5 to F/16 are provided

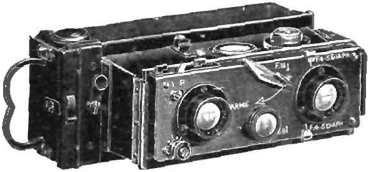


FIG. 33.—THE VERASCOPE NO. 6 MODEL.

This camera is fitted with a rising front which enables the lenses to be raised one-third of an inch above the normal level, or, by reversing the camera a falling front is obtained. Two circular

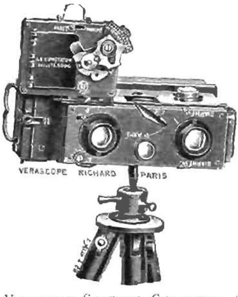


FIG. 34.—MODEL 7 VERASCOPE SHOWING CUNCTATOR (SELF-PORTRAITURE) DEVICE IN POSITION.

spirit levels are fitted for levelling purposes. Two view-finders are provided, namely, a direct vision one, and a brilliant box-form reflector type; the latter shows the image exactly as on the plate. The shutter is set by the swinging trigger shown between the two lenses ; it can be released either by finger or antinous release. This model can also be arranged for natural colour photography. Special Autochrome filters and plate carriers are supplied to suit the camera. A plate changing box is provided as standard, but single slides or film holders can be supplied. This model is admirably suited to tropical and touring purposes, as there are no parts made in organic materials. It is always ready for use and plates can be changed, by means of the magazine changing box, in a second or two. The results obtained with this camera, when used properly, are all that can be desired, whilst its manipulation is quite simple and fool-proof.

Another Verascope model is fitted with a high speed "Chronomos" shutter, giving instantaneous speeds ranging from 1/8th to 1/400th second. It is particularly suited to the

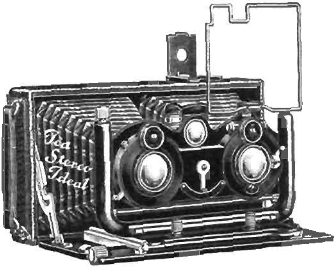


FIG. 35.—THE ICA STEREO IDEAL CAMERA.

photography of rapidly moving objects, e.g., horses galloping, athletic movements, locomotives and automobiles.

The No. 7 Model Verascope is a de luxe camera, fitted with self-portraiture and natural colour photography equipment; in general specification it resembles the No. 6 model, but F/4.5 lenses are fitted as standard. A 7 × 13 cm. Verascope model is also made by the firm of Jules Richard. This is, of course, a larger model, giving stereoscopic pictures 2¾ inches square. It is fitted with F/4.5 Zeiss Tessar or Voightlander lenses, provided with iris diaphragms, in place of the sliding diaphragms of the other models. Means are provided for focussing this model, as the foci of the lenses are longer, and the nearest "infinity" distance much greater than in the case of the other models. Fig. 36 illustrates the Ica Polyskop camera which is made in the 45 × 107 mm. size; it weighs, complete, 39 ozs. It is very complete in equipment, and its manipulation is a simple matter. Special features of this camera are the F/4.5 Zeiss Tessar lenses, which are fitted in a focussing device operated by a lever on the

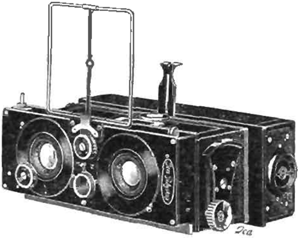


FIG. 36.—THE ICA POLYSKOP CAMERA.

top of the camera, Compur sector shutter giving speeds of 1 sec. to 1/250th sec., besides time and bulb, iris diaphragms both controlled by the single dial marked (Fig. 36), view-finder of the direct vision type, provided with centre lines, rising front, single slides and plate-changing box are provided. It is a very compact camera, well made and well finished. Metal construction is employed throughout, a leather type of covering giving the camera an attractive appearance.

The Mentor Stereo. Reflex Camera shown in Fig. 37 represents one of the "last words" in stereo-camera refinement. It is made in four different sizes, ranging from 45 × 107 mm. to 90 × 180 mm.; the three larger sizes may also be used for panoramic pictures, a special single lens panel being provided for this purpose. One of the pair of stereo-lenses may be used, or a special wide angle lens fitted. The camera opens to the infinity position, and the full-sized picture can be focussed on the ground-glass screen in the upper viewing hood right up to the moment of exposure. A focal plane shutter giving time, and instantaneous speeds up to 1/1000 sec., is fitted. The camera collapses and both hood and bellows fold up compactly into a rectangular shape.

The Ica Minimum Palmos camera employs 6 × 13 cm. plates. It is of the folding bellows type, with rigid struts at the corners

FIG. 37.—THE MENTOR STEREO REFLEX CAMERA.

of the lens panel when opened out for use. Focussing is by means of helical lens mounts, connected together by means of a rod; an engraved focussing scale is employed. A ground glass screen is also provided for stand focussing. The shutter fitted is a focal plane one, which is capable of giving instantaneous exposures from 1/30th to 1/1000 sec., time exposures can also be given, two pressures on the release being necessary, one to open and one to close. Carl Zeiss Tessar lenses of aperture F/4.5 are fitted; adjustable iris diaphragms interconnected by hinged rod are also provided. This model has a large folding type of direct vision view-finder, consisting of a large wire frame provided with a bar with central hole, and a rear-sight.

The Stereax camera (Contessa Nettel) is made in the 6 × 13 mm. size; a smaller model (Duchessa-Stereo), is made in the 45 × 107 mm. size. These cameras are provided with folding bellows, the lens panel being held out by a lazy-tongs movement. Focussing is done by means of a milled head which actuates a screw, moving one of the lazy-tongs members; the lens panel is maintained parallel to the plate all the time. A focal plane shutter is fitted giving time, and instantaneous exposures from 1/10th to 1/1200th second. The camera is fitted with F/4.5 Zeiss Tessar lenses,

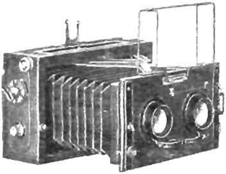


FIG. 38.—THE CONTESSA NETTEL STEREAX CAMERA.

adjustable, and coupled iris diaphragms being provided. Single metal plate cameras, plate magazines and film pack adapters are supplied. There is a direct vision large-sized wire view-finder. The whole camera is very compact when folded up.

Another modern stereo-camera, which possesses many refinements, is that known as the Heidoscope. It is a box-form camera

FIG. 39.—HEIDOSCOPE STEREO-REFLEX CAMERA.

fitted with a focussing arrangement for the lens, actuated by the milled head shown on the left. A special feature of this model is the reflex finder, having a separate lens of aperture F/2, which shows the full-sized picture on its ground glass screen. This image can be focussed and viewed from above, or at eye-level, a metallic mirror being provided for this purpose, together with a 2½ times magnifier. In this way, it is possible to observe the picture and to focus the two stereo-lenses right up to the moment of exposure. A Compur sector shutter giving speeds of 1 sec. to 1/200th sec., time and bulb exposures, is fitted; the speeds are set by means of the milled head shown on the right. There is a self-locking rising and falling front. This camera is made in the 45 × 107 mm., and 60 × 130 mm. sizes, and is fitted with Zeiss Tessar F/4.5 lenses.

Messrs. Goerz also make a Stereo Tenax camera, on the lines of their well-known, larger, single lens Tenax. It is a focussing, folding, leather bellows model, fitted with Goerz Dogmar F/4.5 lenses of $2\frac{3}{8}$ in. focus, and a sector-type shutter giving time and bulb exposures, and "instantaneous" exposures from 1 sec. to 1/150th sec. It measures $1\frac{1}{8}$ in. × $2\frac{3}{4}$ in. × $5\frac{1}{2}$ in., and weighs 18 ozs.

There are, of course, many other makes of stereo-cameras, chiefly of French and German origin, which space considerations preclude descriptions of here. From the typical examples given, however, a general idea of the design, accessories, fittings and operation will have been obtained.

CHAPTER VII

THE VIEWING OF STEREOGRAMS.

HAVING outlined the principles of binocular vision, let us now consider the practical applications of these to the taking and viewing of photographs in relief, confining our attention in the present instance to methods of viewing objects stereoscopically. It will be assumed that pairs of photographs, each taken with the appropriate lens of a stereoscopic camera, are available for the purpose. To recapitulate, each photograph of a stereoscopic pair is taken from a different view-point. For ordinary close range subjects, such as buildings, streets, portraits, and the like, it is usually only necessary to take two equal-sized photographs of the same objects, from two positions separated laterally by about $2\frac{1}{2}$ inches; it is sufficient merely to shift the camera laterally by this amount in the case of still objects photographed with a single lens camera, and to take another photograph under similar light and exposure conditions. Prints from the two negatives thus obtained will form a stereoscopic pair, which if viewed in a stereoscope or by one or other of the methods described next, and which require no stereoscope, will show the natural relief.

Stereoscopic Effects without Photographs or Stereoscopes.*—It is possible to experience stereoscopic, i.e. relief and perspective, effects without the aid of the camera, or stereoscope, as will readily be appreciated from the following simple test.

Draw two circles or black dots, about $\frac{1}{4}$ inch diameter at a horizontal distance apart of about 2 inches; it will render the test easier if these are drawn near the top edge of a sheet of white paper. If the eyes be focussed on these dots in the ordinary way, both will be seen distinctly, but if the paper be held at about 15 to 18 inches from the eyes and the dots be observed

* Several more advanced examples are given in Chapter XII.

with the eyes accommodated for a long range, or infinity, they will be found to merge into a single central dot: in most cases there is also a fainter or ghost image on each side. It is better to hold the paper in front of the eyes at the distance mentioned, and whilst still looking at a distant object to slowly move the paper upwards, and without altering the position of the eyes to look at the dots: they will appear to travel inwards and to merge. This experiment should be repeated with dots or circles at wider separations, up to that of the normal eye, namely,

FIG. 40.—ILLUSTRATING THE METHOD OF MERGING TWO DOTS.

about $2\frac{1}{2}$ inches, and also with a dot on one side and a circle on the other, or a short horizontal line on the one side and a vertical line of equal length on the other. It should be possible to merge the dot into the circle in the former case, and the two lines into the form of a cross in the latter case; dots of different colours may be blended in a similar manner.

Some persons are able to merge objects in this way without difficulty, and can view stereoscopic prints without the aid of a stereoscope. It is also possible by "crossing" the eyes, or squinting, to obtain a stereoscopic effect when viewing a "pair" of illustrations and without the aid of any viewing apparatus.

The reader should practice the dot-merging experiment, and then endeavour to view stereoscopic illustrations, such as those given in Chapter XII, and the test chart reproduced later.

The reader can also, knowing the principles involved, and which we have previously outlined sufficiently, make his own stereoscopic line and shaded illustrations, and with the exercise of a little ingenuity can build up, graphically, some remarkably interesting stereograms. To make clear the principle employed, Fig 41 has been prepared; it shows two control points, or foci, L and R, at $2\frac{5}{8}$ inches apart in this case, and each at $2\frac{1}{4}$ inches from the line XY. The images of any two objects (in this case circular rods, or circles), A and B, as viewed by lenses at L and R respectively are shown at a, b and a', b' respectively: these images correspond to those which would be thrown on a ground glass screen XY by lenses situated at L and R respectively, and each of focus $2\frac{1}{4}$ inches. By projecting these images below, as shown, a stereoscopic pair is obtained.

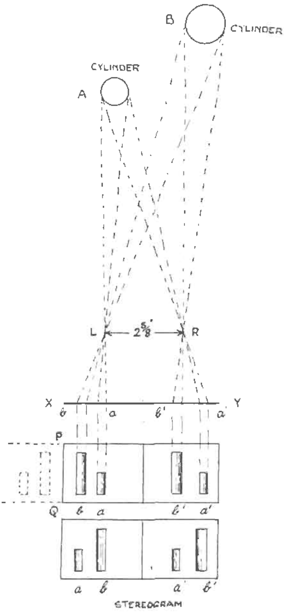


FIG. 41.—ILLUSTRATING METHOD OF CONSTRUCTING A STEREOGRAM. (reduced diagram).

It is necessary before attempting to view this result in the ordinary way to transpose the left and right hand diagrams, so that the left becomes the right and the rigbt the left; this is done because, similarly to what occurs when objects are photographed, the images are reversed in position. If the diagram is not reversed, but is viewed directly in a stereoscope, there occurs a curious optical illusion known as a *pseudoscopic* one, which is the reverse of stereoscopic relief; anyone who has looked at the negative of a small stereoscopic pair, such as those obtained on a 45 × 107 mm. plate, will appreciate the strange optical effect experienced.

It should be pointed out, also, that the above method reverses the relative positions of the objects *A* and *B*. Using the photographic analogy again, we are looking at what corresponds to the negative, and in order to obtain the correct relative positions of the images *a*, *b*, *a'*, *b'* we should have to do the equivalent of making a print; the print, in so far as it concerns the true relative positions of the objects photographed, is reverse from the negative. Thus to obtain the correct right and left hand images of Fig. 41 we must either apply our construction not to the real positions of *A* and *B*, but to their mirror, or looking glass, images, or alternatively to reverse, or use the looking-glass images of *a*, *b*, *a'*, and *b'*. It is not necessary to do this, however, for simple black-and-white diagrams, where reversal is of no consequence, since the stereoscopic effect is unaltered. In connection with this method of construction, the nearer the objects *A* and *B* and the bigger they are, the greater will be the relief effect experienced.

Another method of making stereograms of solid objects, and one which can be applied to many useful educational and instructive purposes, is to actually draw, to the correct scale, the object, firstly as seen with the right eye, say, and secondly as seen with

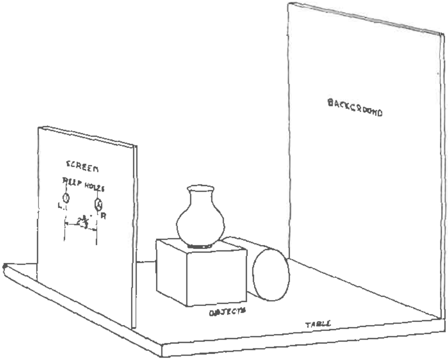


FIG. 42.—SHOWING METHOD OF DRAWING STEREOSCOPIC DIAGRAMS.

the left. The drawings may be done to any scale, but must both be equal in size, or reduced to equal-size, and to the ordinary stereoscopic print size (3 by 3 inch) if to be viewed in an ordinary stereoscope.

A simple piece of apparatus can be rigged up, as shown in Fig. 41 consisting of a vertical wooden board or cardboard screen, provided with two peep holes at the same horizontal distance apart as the eyes of the person making the drawings.

By the aid of suitable models, some useful stereograms can be prepared at little expense in the case of simple objects.

Stereograms by Translation or Rotation.—Stereograms may also be made by using one eye, and one peep-hole only, if the object, or group of objects be given a displacement sideways of, say, 2½ inches, or be rotated a little about a vertical axis. The same methods can also be used with a single lens camera.

Simple Viewing Devices.—The principle to be observed when viewing stereoscopic prints or illustrations is for the right eye to see only the print taken with the right-hand lens, and the left eye that with the left lens. Both views should appear superposed. Unless the observer is able to merge the views in the manner previously indicated, he will find it impossible to concentrate the attention of each eye on its respective illustration, so that some artificial aid becomes necessary.

One of the simplest methods of viewing a stereogram is that illustrated in Fig. 43 and consists of a vertical black screen *S* placed in front of the two views *A* and *B* of the stereogram, and moved backwards or forwards until it just about occupies the position indicated. It will be evident that the black screen *S* prevents the right eye from seeing the left view and the left eye from observing the right view. A little practice is required, as in the case of the merged dots (Fig. 40), and as before it is better to practise with stereoscopic prints of smaller lateral width and separation than the full-sized ones, and after sufficient control of the eye muscles has been acquired to gradually increase the width of the prints and also their separation until, in the latter case, the full 2½ inches has been obtained.

A convenient way to carry out this method, or rather to practise it, is to place the two reduced width stereoscopic prints against a book on a table and to bend a piece of tin or cardboard in the form of an angle so as to make the screen *S* (Fig. 43).

The eyes can be then arranged at the required level, near the edge of the table. After a certain amount of practice, the screen *S* can be dispensed with in many cases.

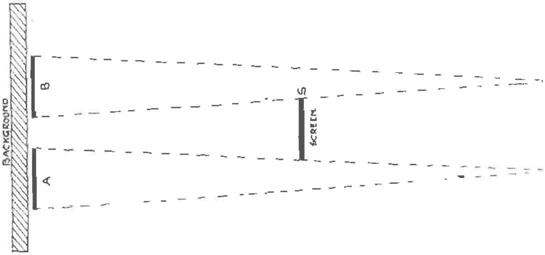


FIG. 43—A SIMPLE METHOD OF VIEWING STEREOGRAMS.

It is not difficult to those who have practised viewing print with the merged dot or the single screen method to view any stereoscopic pair by merely holding two adjacent fingers of the hand vertical and in front of the eyes at the distance (10 to 1 inches), giving non-interference between the eyes.

Elliott's Stereoscope.—An interesting viewing device, which dispensed with lenses, mirrors, or prisms, was invented by Elliott in 1834, and made some five years later. It required the use of transposed prints, that is, the left print was placed on the right hand side of the viewer, and *vice-versa*, and depended in its application, upon the crossing of the optical axes of the eyes at a point nearer to the eyes than the prints under view. Referring to Fig. 44, a box *K* was provided with two symmetrical viewing or peep-holes *a* and *b*, and another hole *C* in the centre of the opposite face. The left eye observed the left photographed view at *B* through the holes *b* and *c*, and in virtue of the position of these holes was unable to perceive the other right view *A*. Both views appeared superposed, or merged at *C*, due to the crossing of the optic axes at this point. Although it was not so convenient or so easy to use as the ordinary prism or lens type stereoscope, this lens-less viewer marked a distinct step in the progress of the subject.

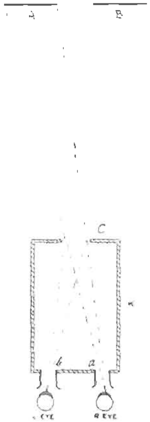


FIG. 44.
ELLIOTT'S STEREOSCOPE.

Wheatstone's Stereoscope.—The first successful stereoscope of practical utility was that invented by Prof. Wheatstone in 1838, and first exhibited at the British Association Meeting held in that year at Newcastle. It depended in principle on the viewing of the prints of a stereoscopic pair by reflection from two mirrors set at about 45° to the prints. Referring to Fig. 45 the left and right prints were placed as shown at *A* and *B*, and were viewed by the left and right eyes through holes *a* and *b* in a screen *S* and by reflection from mirrors M^1 and *M* respectively. Owing to the reflection process the prints were reversed, that is to say, although the combined effect was stereoscopic the view or object was reversed from left to right; thus any printing in the originals would read backwards, and right-handed persons would appear to be left-handed, exactly as if viewed through a looking-glass. The prints *A* and *B* were moved towards or away from their mirrors

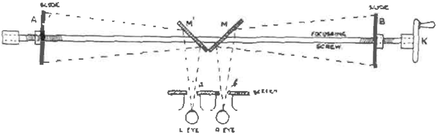


FIG. 45—SHOWING PRINCIPLE OF WHEATSTONE'S STEREOSCOPE.

by a right- and left-handed screw and wheel *K*. Although the Wheatstone stereoscope is still in use for viewing large photographs—one has seen some excellent full-sized radiographs of the human body*—it suffers from the above disadvantage, from bulkiness, loss of light, and for the most effective results requires surface silvered mirrors—otherwise double reflections are obtained from the front and back surfaces of the glass. This stereoscope was undoubtedly the first real advance made.

Brewster's Stereoscope.—The popular type of stereoscope in use to-day for viewing ordinary stereoscopic prints is due to Sir David Brewster, who applied the principle of optical refraction, in place of reflection, and thereby overcame the inherent disadvantages of the latter method. The Brewster stereoscope employs prisms, or lens sections, to enable each eye to see its appropriate view, and to merge the two views thus seen by both eyes.

Referring to Fig. 46 it will be seen that the effect of the left prism is to refract the light rays proceeding from the left view *AB* and to cause the left eye to appear to see this view, not in

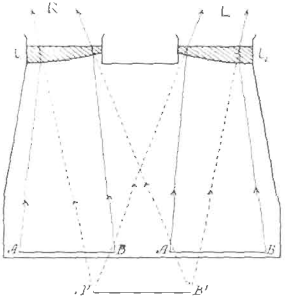


FIG. 46—ILLUSTRATING PRINCIPLE OF BREWSTER'S STEREOSCOPE.

its true position, but in a central one A^1B^1 between the two prints. Similarly, the right eye also appears to observe its right view *AB* in the same central position, the net result being the required merging of the separately seen views; thus the real conditions of stereoscopic viewing are fulfilled.

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* A complete instrument is shown in Fig. 127.

The prisms l_1 and l_2 employed are not plane, but curved or lenticular ones, and are usually made by taking a double convex lens of three or four inches diameter, and cutting square-shaped wedge-like pieces from near the edge. In this way it is possible to focus the prints viewed, as well as to obtain stereoscopic effects.

Most people are familar with the ordinary print viewing type of stereoscope, so popular many years ago, with its square lenticular prisms, mounted in a wooden frame, provided with a velvet-edged light-excluding hood and wooden guide for sliding the print-holder when focussing the photographs. A wooden partition was also provided to assist in preventing interference of the two views when observing same. This pattern was designed by Oliver Wendell Holmes, and originated in America. An example is shown in Fig. 47.

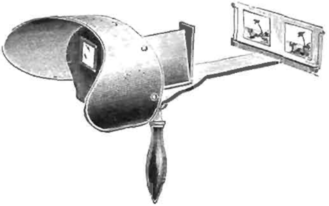
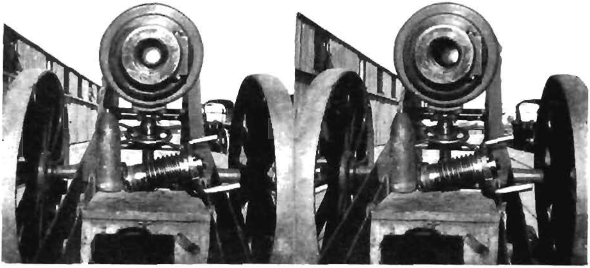


FIG. 47.—ORDINARY STEREOSCOPE.

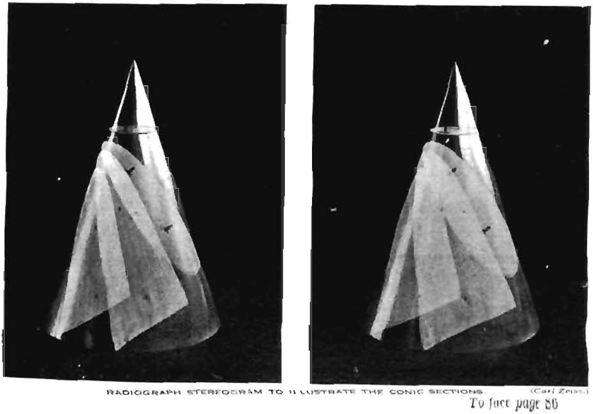
There is also another type of stereoscope which is somewhat on the lines of Wheatstone's, but two mirrors are used per picture, and both pictures face the observer. Here the double reversal gives the correct disposition of objects in the stereoscope.

Other Types or Print Viewers.—There is a number of alternative types of stereoscope for viewing prints, but all of these follow the same basic principle. They range from the small folding metal types provided with means to vary the distance between the viewing lenses (or inter-ocular adjustment, as it is termed), to the large outfits resembling retouching desks in appearance for viewing large sizes of stereoscopic photographs, and similar to

(Underwood Keystone Stereographs Ltd
LATE NORMAN NAVE AND ANCIENT CHOIR ELY CATHEDRAL



(Underwood Keystone Stereographs Ltd.)
AN OLD GUN, "LONG CECIL," USED DURING BOER WAR.



RADIOGRAPH STEREOGRAM TO ILLUSTRATE THE CONIC SECTIONS (Carl Zeiss.)

To face page 86

the aerial and topographical stereoscopes in present use. A neat portable stereoscope is that supplied with the Sunbeam Tours series of photographic reproductions of travel, zoological and similar subjects.

The Carl Zeiss Stereoscope.—This stereoscope, which is illustrated in Fig. 48 is an exceedingly well-designed and constructed apparatus, provided with all of the necessary adjustments. It contains an ocular or eyepiece unit, which can be slid bodily up and down the rod shown and clamped anywhere; rotation is prevented by a key in the body-sliding in a keyway

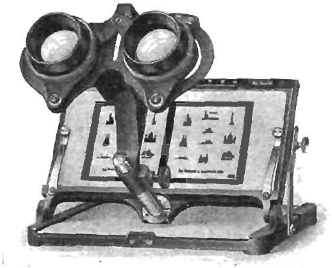


FIG. 48—THE ZEISS STEREOSCOPE, SHOWN IN INCLINED POSITION.

cut in the rod. The simple ocular viewing lenses are of 15 mm. focus, but two better achromatic lenses of 10 mm. focus can be supplied. The print or transparency holder accommodates pictures of 6 by 9 cm., and can be tilted (with the eyepiece rod) to any desired angle relative to its base, and clamped in this position. The lens holders are provided with interocular adjustment, operated by the simple method of rotating a large milled head on one or other of the lens holders; both of the latter are connected together in such a way that they move outwardly or inwardly by the same amount, i.e., symmetrically. A pointer and scale enables the ocular distance to be set, so that for any future occasion the correct separation may be noted.

The stage carrying the photographs is accessible from all three sides; clips are provided to hold the prints or transparencies. When viewing the latter, equality of illumination (from behind, of course) is given by means of a frosted class screen immediately behind the slide carrier, and also by the aid of an opal glass reflector in the horizontal base of the apparatus. A scale is provided at the top of the view-holder, graduated in metric measure. The 10 cm. focal length eyepiece lenses are preferable when viewing photographs obtained with ordinary modern hand cameras, since the latter have lenses of about this focal length. It is a basic fact in stereoscopy that stereoscopic prints should be viewed with lenses of the same foci as those employed in the photographing camera. For this reason, those cameras which by a simple conversion (*e.g.*, removing the shutter unit) enable them to be used as viewing stereoscopes, give better results than when the results are viewed with stereoscopes of different foci.

In passing, it should be mentioned that the Zeiss stereoscopes are supplied in wooden cases, complete with sets of stereoscopic photographs. The latter include some most original and unique subjects.

Box Type Stereoscopes.—A popular type of stereoscope is the enclosed, or box form, provided for transparencies. The earlier models could be used also for prints, a hinged lid, containing a reflecting mirror, being provided for illuminating the photographs.

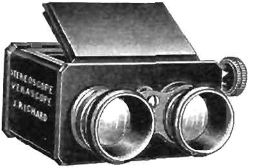


Fig. 49.—Box Stereoscope with Mirror Top.

The ordinary box viewer, illustrated in Figs. 49 and 50, is fitted with fixed viewing lenses, provided with a common rack-and-pinion focussing device operated by the milled screw shown on the left. The more expensive instruments have interocular adjustment also. The glass transparency—which is simply a lantern-slide type of print on glass, viewed by transmitted light—is inserted through a slot in the side (shown just below the focussing screw in

Fig. 50), a clip being provided to prevent its falling out whilst being viewed. A ground-glass screen behind the slide, and just out of focus in respect to the viewing lenses, gives the necessary diffused and even illumination of the transparency. The slide is viewed by facing any suitable source of illumination, so that the ground-glass screen is illuminated directly.

FIG. 50—ORDINARY BOX FORM STEREOSCOPE.

This form of viewer is probably the best of any, as it enables a far better range of tones, and a considerable increase in brilliancy to be obtained.

Collapsible Stereoscopes.—Figs. 51 and 52 illustrate two types of collapsible metallic stereoscopes, for pocket requirements; each can be folded up when not in use. The former stereoscope has a sliding arrangement for focussing; the pictures are inserted

FIG. 51.—FOLDING FOCUSSING STEREOSCOPE.

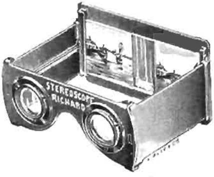


FIG. 52.—FOLDING FIXED FOCUS STEREOSCOPE.

horizontally. The latter is a fixed focus device, in which the slides are inserted vertically from the top. There is a number of such devices in existence, but the two shown are modern examples supplied by Messrs. The City Sale and Exchange.

The Pulfrich Reflecting Stereoscope.—The reflecting stereoscope of Dr. C. Pulfrich, made by the firm of Carl Zeiss, Jena, and supplied here by Messrs. Atha and Co., London, possesses many advantages for viewing large prints, over the original Wheatstone stereoscope. In the first place the prints employed can be contact ones from the negative, and do not require reversal as with the Wheatstone instrument. Secondly, the prints can be illuminated evenly from one source of light, in the front; and thirdly, the whole apparatus is portable and can be assembled from its components, on the containing box.

The principle of the stereoscope will be apparent from Fig. 53. Here the pictures forming the stereo pair are shown at P_2 and P_4

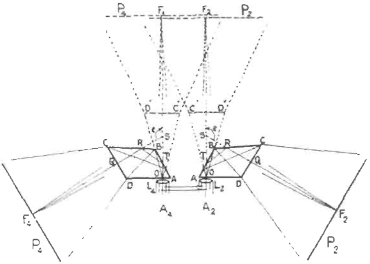


FIG. 53.—ILLUSTRATING PRINCIPLE OF THE PULFRICH-ZEISS LARGE PRINT STEREOSCOPE.

situated in the focal planes of lenses L_2 and L_4. On each side behind the lenses are two glass prisms A B C D, which enable the pictures P_2 and P_4 to be observed by two internal reflections, from the faces AB and BC in each case. This double reflection does not cause image reversal as in the case of a single reflection. The effect apparent to the eyes placed at A_2 and A_4 is that indicated by the dotted lines above; the pictures actually at P_2 and P_4 in the stereoscope appear in the dotted positions P_2 and P_4. The distance between the upper far points F_2 and F_4 is equal to the distance between the lens centres, i.e., to the lens separation. The amount of angular deviation of the rays due to the two mirrors is about 120°. In order to view the pictures with lenses of approximately the same focal lengths as those employed in taking the pictures, the stereoscope is also provided with a revolving eye piece consisting of three lenses of respective focal lengths 100, 150 and 200 mm., and one empty ring for taking a lens of some other focal length. This stereoscope is particularly suitable for large prints of pictorial views, portraiture, still objects, X-ray photo-

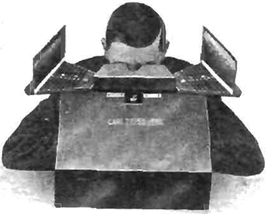


FIG 54.—SHOWING THE PULFRICH-ZEISS STEREOSCOPE IN USE.

graphs, aerial and land survey photographs. The original set includes fifteen mounted stereo pairs of photographic prints, principally of examples illustrating the application of stereo-photogrammetry.

FIG. 55.
REVERSING PRISM STEREOSCOPE.

Stereoscopes with Reversing Prisms.—It has already been shown that the positive prints from a stereoscopic negative require transposing, in order to correct for the lens reversal effect. In the case of transparencies this is done in the special printing frames provided for the purpose, or by cutting the positives, transposing, and mounting on a glass slide similarly to a lantern slide.

When coloured transparencies, such as Lumière autochromes, are used, no printing is required, as the positive is made by a reversal process on the negative direct. The only method of transposing these coloured views hitherto available was by cutting, transposing and mounting up again—they cannot be transposed in the ordinary way, since there is no equivalent printing process.

A stereoscope (Fig. 55), now available, is provided with prismatic viewing lenses, which reverse, by an optical method, the two views, so that the correct disposition of the two views is obtained without cutting the glass slide. The apparatus is also applicable to ordinary transparency slides, and saves a good deal of trouble in the printing and mounting.

Automatic Stereoscopes.—The ordinary hand type of stereoscope described has been elaborated in many ways, so as to enable a series of views to be seen one after the other, without having to insert them separately. These automatic stereoscopes have reached a very high standard of perfection, thanks to the ingenuity of Jules Richard and others, and have become a drawing-room innovation to a small extent in this country but more so on the Continent. The first automatic devices, many of which are still in active use, consisted of long endless chain pairs, provided with wooden or metal carriers for the prints (mounted on cards) or slides. By rotating a handle on one side of the containing cabinet, the slide was changed. In the case of prints, these were viewed at the top of the travel of the vertically arranged chains; when the handle was given a turn, the card was released from its vertical position against a retaining clip, and allowed to drop into a horizontal position on the viewing side, thus leaving the next print ready in its vertical position. This method, it will be seen, is very similar to the box magazine camera plate-changing mechanism.

Fig. 56 illustrates the American cabinet-form stereoscope, but in this case modified by Jules Richard. In the ordinary chain-operated stereoscopes the space necessary for the changing of the view necessitates the use of lenses of fairly long foci, which is a disadvantage. In the model shown the turning of a handle on the machine drops the chain down below the line of vision, and then rotates it, bringing the next view up at the correct angle for viewing. As the views do not rotate in front of the lenses there is no disturbing movement to tire the eyes. It also allows the use of short focus lenses, so that large images are obtained. The chains hold fifty pictures, which are easily removed and new ones inserted. The machine has an adjustable focus, and there is also a device, operated by pulling a ring, for moving the lenses over so that the title of the picture may be seen.

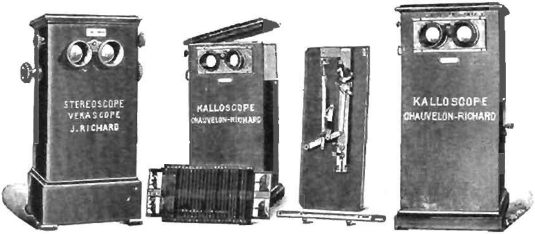


FIG. 56—THE AMERICAN TYPE CABINET STEREOSCOPES

The Taxiphote Stereoscope.—The Taxiphote is an instrument which has been specially designed for viewing, classifying, storing, and projecting stereoscopic transparencies made with the stereoscopic cameras.

It takes the form of an elegant cabinet, the base of which contains a series of small drawers for storing the transparencies. Each drawer accommodates four Ambroine boxes which take the glass transparencies, each in a separate groove. At the top of the instrument is the optical arrangement, consisting of a pair of eye-pieces containing special lenses, which give definition, coupled with true perspective, and natural relief, and also a mechanical device to hold the series of transparencies which is to be viewed.

The eye-pieces are provided with rack-and-pinion focussing, so that the pictures can be brought into sharp focus by merely turning a milled head. The distance between the eye-pieces can also be adjusted. By one simple movement any transparency can be brought into position for viewing without disturbing the order or touching the transparencies with the fingers.

The Taxiphote raises the required plates from a grooved box, places it opposite the eye-pieces, and then replaces it into the box again without changing its order. These boxes with twenty-five grooves can be used equally well for the negatives as for the positives.

In its base are twelve boxes, each with twenty-five grooves, thus giving a storage capacity of three hundred views. These boxes can be changed instantaneously. One of the boxes is placed on a platform, a lever pressed with a very simple movement, and the required plate is in position before the eye-pieces of the stereoscope.

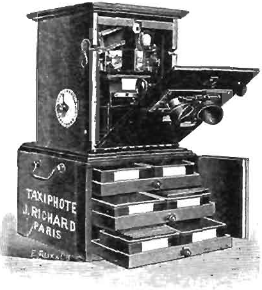


FIG. 57—THE TAXIPHOTE AUTOMATIC STEREOGRAM VIEWING DEVICE.

One of the advantages of this apparatus is that the central clear band of the positive between the two views may be used for writing the title of the picture with ordinary ink on the gelatine. This is very simple, as the space is considerable, and one writes in the ordinary way. By simply lowering a small handle the picture is covered and the title appears.

It frequently happens that the distance between the eyes is more, or less, than the normal distance of 65 millimetres adopted for the space between the eye-pieces of the stereoscope. In order to obtain a perfect centre for the eyes and the eye-pieces of the Taxiphote, a simple adjustment for altering the distance between the two eye-pieces from 45 to 75 millimetres is fitted.

This range meets all cases. A dial with suitable divisions enables the observer to find at once the most convenient position.

Stereoscopic transparencies for use in the stereoscope require no cover glasses or binding. The Taxiphote keeps the transparencies in convenient order, ready for inspection at a moment's notice, and free from dust and the danger of breakage. If desired, the Taxiphote can be supplied with special reversing prisms which obviate the necessity for transposing. This is particularly convenient to those using the Lumière autochrome process. The Taxiphote is made in a variety of woods and different styles of design and finish.

The instrument is supplied in various sizes to take transparencies of the following sizes: 45 × 107 mm., 6 × 13 cm., 7 × 13 cm., 10 × 15 cm. (postcard size), $8\frac{1}{2}$ × 17 cm., and $6\frac{3}{4}$ × $3\frac{1}{4}$ in. (English standard size).

The Taxiphote can also be used for the projection of transparencies on a screen, up to a very large size, for private entertainments, or for use in small halls for lectures, etc.; it can be successfully used for the production of bromide enlargements or enlarged glass transparencies.

Test Charts for Stereoscopic Vision.—The degree of stereoscopic vision possessed varies in different individuals; some persons can merge stereo-pairs of photographs without the aid of stereoscopes, whilst others are able only with difficulty to attain stereoscopic vision of photographs. The inter-ocular separation distance also varies with different people, so that the *ordinary fixed lens type stereoscope sometimes fails to merge the* objects viewed. A further failing frequently met with is that of focal and anastigmatical differences between the two eyes of an individual. It is for these reasons that the best stereoscopes are fitted with interocular adjusting lenses, each lens having a separate focussing device.

When there is any doubt as to the quality of stereoscopic vision possessed by any person recourse should be had to a standard test chart of the type indicated in Fig. 58. This chart was devised originally for the purpose of ensuring that observers using the Zeiss stereo-telemeter and stereo-comparator were capable of detecting the smallest differences in the relative distances of objects, and to obtain quantitative evidence, i.e., expressed in figures of the exact degree of stereoscopic vision possessed.

Referring to Fig. 58, if this stereoscopic pair of silhouette objects be viewed in a stereoscope, they will be found to lie in different planes; indeed, the stereoscopic effect is somewhat remarkable with normal vision. Referring to Diagram (1), the circle is nearest in distance and the centre dot farthest, the square and triangle being intermediate. In Diagram (2) a planetary system is seen in relief against a starry background.

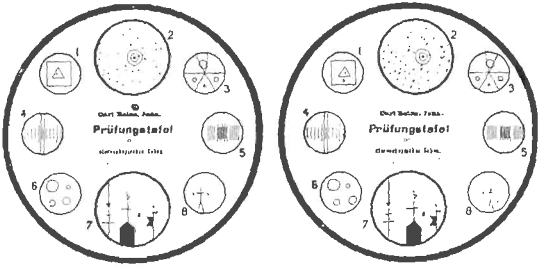


FIG. 58—THE ZEISS TEST CHART FOR STEREOSCOPIC VISION TESTS.

In (3) there is seen a circular ring looped on two wires converging (in perspective) to an apex near the observer. The vertical lines in (4) and (5) are at different distances from each other, some appearing to stand out in relief. In (6) the smallest circle is the nearest to the eye, whilst the circle immediately beneath it is the farthest away, the lower left circle being next in order of distance. Diagram (7) is a fine test of stereo-vision. A good observer should be able to see no less than eight objects, each in a different plane to the other; the vertical arrow is nearest and the peculiar double loop (figure eight) sign in the upper middle the farthest. In (8) the steeple outline stands well back relatively to the outer circle and the dots also appear to lie in different planes.

VIEWING OF STEREOGRAMS

If the printing in the centre of the largest and blackest circle (enclosing the other diagrams) be examined carefully, the words will be found to lie in different planes. Thus the word " Zeiss " is well in front of " Carl " and " Jena," but all three are well behind the word " Prüfungstafel." Also, some of the letters of the latter word are in different planes, but it is difficult in the present reproduction of the original test diagram to detect this, owing to a slight blurring of the printed letters. In the original transparency (of similar size) this relief effect can readily be discerned by persons of normal vision.

A later test chart produced by Dr. C. Pulfrich, of Jena, for Carl Zeiss, contains ten numbered silhouettes, representing ships, steeples, airships, etc., each of which has about it four stereoscopic measurement marks, namely, a line, cross, triangle, and balloon. Each of these marks is usually in a different plane relatively to the silhouette object, and the test is to set down for each of the ten silhouette objects the relative positions of the four measurement marks. A tabular statement is then made, commencing with the easiest silhouette. The number of the silhouette at which the observer first shows signs of uncertainty in his statements is taken as standard for computing his power of stereoscopic vision. It should be mentioned that the four stereoscopic measurement marks above referred to are the same as those used in the Zeiss stereoscopic measuring instruments.

CHAPTER VIII

PHOTOGRAPHIC PROCESSES AND NOTES.

Developers.—It is not possible, nor is it desirable, in a book of the present nature to enter very fully into the subject of photographic materials, since many excellent handbooks and treatises on the subject exist. A few notes will, however, be given on the subject from the point of view of stereoscopic pictures.

For photographic prints, intended for stereograms, any good negative developer may be used for the exposed plates, but the photographer should aim at softness and detail, when selecting a developer. If he has obtained satisfactory results with ordinary single lens camera negatives, he will be well advised to continue to use the same developer and methods. The well-tried pyro-soda, and metol-hydrokinone developers may be recommended for plate development, when prints are to be taken for stereoscopic pictures; with ordinary care, and attention to development time-temperature factors, excellent results may be obtained.

Small Plates and Graininess.—In the case of negatives from which transparencies are to be made for stereoscopic viewing, greater care is necessary in the selection and use of the developer. This is more particularly so, when the smaller sizes of plate, namely, the 45 × 107 mm., and 60 × 130 mm. types, are employed, for the transparencies are viewed at much higher magnification in the stereoscope. Any graininess, defects, lack of detail or excessive contrast is amplified to a disagreeable extent, as a rule.

It is therefore essential in the first place to avoid any developer which is like to cause "grain," or contrast. It is a well-known fact that the size of grain, the latter of which, incidentally is due to silver deposit, increases with the time of development, for a given temperature and concentration of developer, and is more pronounced with some, than with other developers.

Although a few professional photographers employ pyro-soda developers for these small sizes of plate, and are able to obtain good results, general opinion appears to show that pyro-soda is apt to cause undue 'graininess.' This fact is due, no doubt, to the almost general tendency on the part of the amateur to under-expose his plates, and then to over-develop in the endeavour to obtain sufficient density. In such cases it is wiser to avoid using pyro-soda or pyro-ammonia.

Graininess depends also upon the type of plate employed, that is to say, upon the emulsion. Fast plates always show more graininess than slow plates. For this reason it is inadvisable to employ the high speed plates (of 450 H. and D. and over) for the 45 × 107 mm. and 60 × 130 mm. cameras: the grain effect of such plates is apt to become inconvenient. The slower the plate which can be used satisfactorily, the better; the slow process plates are very suitable for still object photography.

Developers which experience has proved to give consistently reliable results, with good soft tones and detail, include metol-borax, metol-hydrokinone, azol, Rytol, eikonogen, metol, amidol, and paramidophenol.

The metol-borax developer recommended by Messrs. Wellington and Ward, the well-known plate manufacturers, we have found to give excellent results, with a somewhat remarkable clearness and freedom from grain, fog or stain; the negatives are well-graded, not too contrasty and full of detail. The following is the Wellington formula:

Metol-Borax Developer.

Metol	20 grains or	1 gramme
Hydrokinone	50 ,,	2.5 grammes
Sodium Sulphite (cryst.) ..	200 ,,	10 ,,
Borax (powdered)	200 ,,	10 ,,
Water (hot)	20 ounces	500 c c.

The chemicals should be dissolved in the order given, allowing each to be in complete solution before adding the next. The developer keeps almost indefinitely in a well-stoppered bottle.

The development time is about 5 mins. at 60° Fah., 4 mins. at 65° Fah. and 3 mins. at 70° Fah. It is not advisable to use this developer below 60° Fah., as the hydrokinone rapidly loses its developing power with further decrease of temperature.

In developing stereoscopic plates, the time, or factorial method of development is strongly recommended. Whether the exposure be correct or otherwise the best results for stereoscopic viewing are given by correct development times. In certain special cases, as for example with night and flashlight photographs, a certain latitude is allowable, or a prolonged development with a weakened developer can be given.

The following is a good all-round one-solution metol-hydrokinone developer which we have found to give most satisfactory results :

Metol Hydrokinone (Wellington)

Metol	20 grains or	1 gramme
Hydrokinone	60 ,,	3 grammes
Sodium Sulphate (cryst.) ..	700 ,,	35 ,,
Sodium Carbonate (cryst.)	700 ,,	35 ,,
Potassium Bromide ..	6 ,,	0.3 ,,
Water to	20 ounces	500 c.c.'s

This solution *must be diluted with an equal quantity of water* for use as a developer. The chemicals should be dissolved in the order named, allowing each one to be in complete solution before adding the next. This developer keeps almost indefinitely in well-stoppered bottles. The same remarks apply as regards the lowest temperature of development as in the case of the metol-borax developer. The development times are about one minute longer in each case, than those previously given.

We give below, a well tested formula for a pyro-soda developer, which has the advantage of long keeping qualities ; oxidation of the pyrogallic acid is prevented by the potassium metabisulphite. This developer, in the case of negatives intended for prints, gives well-graded, finely detailed results of very high quality.

Pyro Soda (B.J. Non-Staining Developer)

The following two solutions are made up in separate bottles.

Solution A.

Pyrogallic Acid	1 oz. or	50 grammes
Sodium Sulphite (cryst.) ..	8 ozs. or	400 ,,

Potassium Metabisulphite ..	4 ozs. or 200 grammes
Water	60 ozs. or 3000 c.c.'s
Solution B.	
Sodium Carbonate (cryst.)	12 ozs. or 600 grammes
Water	60 ozs. or 3000 c.c.'s

For use take 1 part A, 1 part B. and 2 parts of water.

The sodium sulphite and the potassium metabisulphite should be mixed together dry and then put together into hot water; the solution should be boiled, and the pyro. then added.

This developer will produce negatives free from stain in from 4 to 6 minutes at 60° Fah.

The Tabloid Rytol developer of Messrs. Burroughs Wellcome when used with their Tabloid Restrainer gives good fine-grain negatives, and also transparencies. The standard formulæ recommended by the plate manufacturers should be used in the case of the other developers previously mentioned; some good reliable formulæ are given in the British Journal Photographic Almanac.

Development.—In the case of stereoscopic plates, it is necessary to take particular care in the development process, in order to obtain the best negatives for the stereograms. Over-development is to be preferred to under-development, but the grain growth with the time of development should be borne in mind, and development should not be carried too far. Under-development usually results in loss of detail, and flatness; the latter is not necessarily a drawback as we have shown. It should be remembered that if development is correctly timed, even although the negative may appear thin, it will still give a good stereogram; it yields much better stereos than from dense negatives.

When developing, one should aim at getting as much detail as possible in the shadows before the high-lights become too dense.

Transparencies.—Most of the leading plate manufacturers now supply transparency plates in the stereoscopic sizes, and each recommends in the pamphlets enclosed with their plates the particular developer suited to the plates in question. Transparencies, that is to say, positive prints on glass, similar to lantern slides undoubtedly give much more realistic and brilliant effects for stereoscopic pictures than any type of print. Not only is there a very much fuller range of tones, but, owing to the fact that these slides are viewed by transmitted, instead of reflected light (as in the case of prints) there are no surface markings or reflections.

A wide range of tones is possible with the lantern type of plate used for transparencies, by employing suitable exposures, developers and development times. The tones range from a black or warm-black to browns and rich sepias.

For the blacker tones, the usual amidol or hydrokinone lantern plate developer should be used.

For warmer blacks, the metol-hydrokinone developer previously given will give satisfaction.

For brown sepia tones it is usual to increase the exposure and modify the developer, by adding more of one of the solutions constituting it. The plate manufacturers instructions should be followed in all cases.

A very convenient plate for transparencies, and one which will give a variety of tones ranging from a cold stone grey through browns and warm browns to warm sepias, simply by varying the time of exposure, during printing, is the Ilford Alpha plate. The manufacturers recommend a two-solution developer, containing hydrokinone and caustic potash. Equal proportions of the two solutions are used in all cases, and only the exposure is varied in order to vary the tone of the transparency, although there is also a certain amount of latitude in the development period. It is a particularly easy plate to work with and the latitude results obtained are excellent. Any mistake in the exposure of the transparency plate does not mean a scrapped plate as in the case of certain other lantern plates, but merely a change in tone.

Messrs. Wellington and Ward supply lantern plates for stereoscopic work, in two types, namely the ordinary lantern plate to be used in the dark-room, and the slower S.C.P. lantern plate which can be handled in subdued artificial light. Both grades will give a range of tones with suitable developers, exposures and development. Ammonium bromide and ammonium carbonate are used in the developers intended for the warmer tones.

Prints for Stereoscopic Pictures.—Stereoscopic prints are not viewed at such high magnifications as the smaller plates previously mentioned, and are usually direct contact prints from negatives of about 2½ to 2¾ inches wide. For clear detail and brilliance, the highly glazed bromide or P.O.P. print as such cannot be excelled; it is possible, also to vary the tones considerably.

Many workers prefer to use the fine surface matt bromides, self-toning P.O.P.'s, or platinotypes, in order to avoid the reflections of the glazed papers. We have seen some good hand-coloured fine matt bromide stereoscopic pictures.

It is a mistake, however, to use any printing paper which has anything in the nature of a grain or surface texture, as the presence of any surface marking is detrimental to the results seen in the stereoscope, since these are magnified and the markings of the two pictures tend to over-lap and depreciate from the detail and stereoscopic effect.

Varnishing Transparencies.—It is very necessary to protect the film of the transparency, as otherwise it quickly becomes scratched or marked, in ordinary use, and the general cleanliness and pictorial beauty of the stereoscopic picture is lost.

Varnishes for transparencies are of two types, namely, the Hot and Cold varieties, depending upon whether the plate has to be heated or not. The former kind are considered to give the more lasting effects.

Good hot varnishes can be purchased from most photographic chemists.

The following is a recipe for a satisfactory cold varnish:

Dissolve $\frac{1}{10}$ ounce of *celluloid* shavings in 5 ounces of *amyl acetate*; the solution should have a syrupy consistency. It is flowed over, or applied to the plate with a camel hair brush.

An excellent varnish, which is much used for *colour plates*, consists of 1 ounce of *gum dammar* dissolved in 5 ounces of *benzole* (pure). It is applied by flowing over the surface of the plate, and then draining.

This varnish adds greatly to the transparency and quality of colour plates, and ensures their permanence. Other varnishes are apt to destroy the colours, in time.

Transparencies.—It will, perhaps, assist if we consider for a moment the sequence of operations in printing a transparency; afterwards the case of the photographic print will be dealt with.

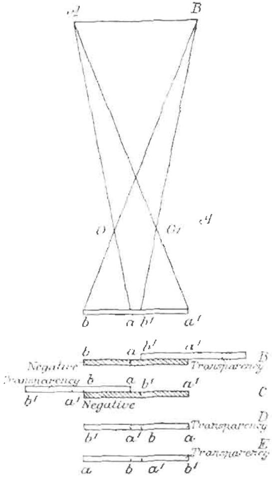


FIG. 59.

Referring to Fig. 59 AB represents the object photographed, whilst O and O' represent the lenses of the stereoscopic camera, and ba and $b'a'$ the left and right-hand images on the plate (negative). It is important to note that the images are reversed in the negative, both as regards right and left-handedness, and as regards top and bottom. A little reflection will show that if the eyes replace the lenses O and O' respectively, the images of AB will be seen in the order—reading from left to right—$ab\ a'b'$;

we have, therefore, to obtain the same sequence of images on the positive plate, or transparency.

This is secured by placing the film side of one end of the positive in contact with the film of the *opposite* end of the negative as shown at *B* (Fig. 59). Next the positive is slid along so that the other side is in contact with the other end of the negative as shown at *C* (Fig. 59). In each case an exposure is made of the portions of the positive plate and negative in contact, but with the other portion of the positive masked from the light. Thus in *B* (Fig. 59) the portion *b'a'* of the plate would be printed, the rest being masked, whilst at C (Fig. 59) the portion *ab* would next be printed, whilst the already exposed portion *b'a'* would be masked, or protected from the light.

Upon developing the doubly exposed positive, the result obtained is a positive print, or transparency as shown at *D* (Fig. 59). Since the images are upside down, due to reversal in the camera, it is only necessary to reverse the plate endwise (e.g. by rotating about *a*, at *D*, Fig. 59) in order to obtain the correct position for viewing in the stereoscope as shown at *E* (Fig. 59).

Although the sequence of operations described may sound a little complicated, yet it is quite straightforward in practice with

FIG. 60.—TRANSPOSING FRAME FOR PRINTING POSITIVES.

the aid of a special transposing frame supplied for the purpose. This frame (Fig. 60) consists of a light-tight flat frame or box, of length equal to about one-and-a-half times the length of the negative, but of the same width. The centre one-third is cut away to form a square hole or mask, the size of the finished picture. This square is usually about 2 mm. or so smaller each way than the negative width, in order to cut off the bad edges of the negative. The frame is provided with a light-tight hinged lid, having a central spring to hold the positive plate and the negative in contact.

The method of using the transposing frame consists in first placing the negative, film side upwards in the frame, and at one end of the frame. The positive plate is then placed film side downwards (i.e., in contact with the negative film), but at the opposite end of the frame, similar to position *B* (Fig. 59). The lid is secured, and the printing exposure made, after which the frame is removed to the darkroom, the lid opened and the negative slid along to the opposite end of the frame, and the positive plate to its opposite end, similar to position *C* (Fig. 59).

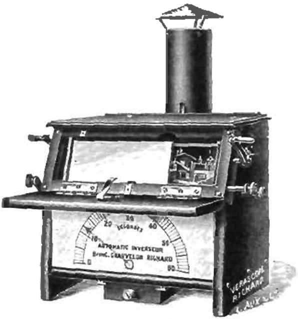


FIG. 61.—AUTOMATIC INVERSEUR SHOWING NEGATIVE AND PLATE IN POSITION.

Another exposure of equal duration, at an equal distance from the source of illumination is then made, and the positive is developed in the usual manner. The developed, fixed and dried positive plate then gives a correct stereoscopic pair of pictures.

An automatc inverter printing device has been marketed by Messrs. Jule Richard, of Paris* , which enables the printing of transparencies to be carried out quickly, and easily. Fig. 61 illustrates this "Automatic Inverseur," as it is termed. The

* English agents, Messrs. City, Sale and Exchange, London.

stereoscopic negative is laid on the inclined bed of the machine and is there held firmly by a strong clip. The positive plate is then laid on a metal carrier to the left-hand of the printing bed. It then falls automatically into the position for the first exposure. After this, the act of pulling out the knob, shown on the right, to its full extent, causes the positive to be carried over to the other side of the bed, and on pushing the knob back again it is placed in the correct position for the second exposure. The actual exposure is made by turning a second knob, shown on the right (at the back), which lowers a ruby screen placed in front of the light source; the latter may be either an electric bulb or a gas burner. The act of lowering this screen starts the seconds hand of a clock for timing the exposure, the yellow dial of which is illuminated by the light source; the clock hand returns to zero after each exposure has been made; the yellow clock dial serves also as a dark room lamp for the development of the positive plates.

Transposing by Cutting the Negative.—There is another method of printing transparencies from the negatives which does not require the use of a special transposing frame, and duplicate exposures. This method which was at one time fairly popular, consists in cutting the glass of the negative, so as to divide the latter into three portions, namely two squares and a central blank film portion separating the two negative pictures. The left-hand negative is then transferred to the right, and the right-hand negative to the left. The blank central strip can then be used as a distance piece in order to get the proper separation. A better plan is to scrap this distance piece and to use a special recessed printing frame sold for the purpose of printing direct from cut and transposed negatives. The same method applies, of course to prints.

Transposing Prints.—The process of mounting the prints made from a stereoscopic negative is much simpler than in the case of transparencies. All that is necessary is to make a contact print from the two-picture negative, to divide, by cutting the two pictures on the print and to interchange them, i.e., to make the left the right and the right the left, and mount up in the usual way. The reason for this process will be clear from Fig. 62, in which *F* represents the same negative as in Fig. 62 *A*; the photographic printing paper is shown just above, ready for the contact print. The relative positions of the images obtained when the contact print is reversed in position (to correct for the camera inversion of top to bottom) is as shown at *G*. If now the print be cut in two, and the left-hand image *a'b'*, moved to the right, and the right-hand image *ab* to the left, we have the correct disposition for viewing in the stereoscope, namely, *ab a'b'*.

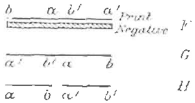


FIG. 62.

Mounts for Prints.—The standard cardboard mount for stereoscopic prints, has a matt or dull black surface, and measures 7 ins. by 3½ ins. The usual size of the individual pictures is rather smaller than lantern slide size, that is about 3 ins. by 3 ins.; this allows for trimming the edges. Any other size of print, within the limits of the mount may, of course, be used; a popular size is the 3 ins. square one, which allows undesirable edges to be cut off lantern plate size prints, and leaves room for the titles below; the separation, namely, 3 inches, is rather more than advisable, however.

Trimming and Mounting the Prints.—One of the most important factors in connection with stereoscopic prints, is that of the correct trimming and mounting. It is necessary, in order to obtain the proper relief effect to trim the prints so that the left-hand print shows more of the right-hand margin, and the right-hand print more of the left-hand margin. The reason for this will be clear if one remembers the window analogy, in which the two views of a stereogram are considered analogous to the two views seen by the two eyes, respectively when situated in a room at some distance behind an open window. Thus the left eye will see more of the right-hand portion of the view, and the right eye more of the left view; this can easily be verified by closing the right and left eye, in turn.

Although it is possible to estimate, mathematically, the correct marginal widths in each case, it is easier, in practice, to tentatively trim the two prints, judging the results by placing them at the correct separation on a black mount, but without pasting down. The prints can then be shifted apart, or orientated, and the respective margins trimmed by the trial and error method, until the correct result is obtained; the positions of the edges of the prints can then be marked with a fine pencil on the mount, before pasting down. A wrongly trimmed stereogram will show overlapping non-stereoscopic marginal portions. The use of a self-transposing frame automatically locates the prints and gives both the correct marginal portions, orientation and separation.

The two prints should be so mounted that the corresponding points are at 2½ to 2¾ ins. apart, and at the same horizontal level. The height of the prints is immaterial, and does not affect the stereoscopic result; the stereoscope lenses should, of course, have a sufficient field of view to cover the whole area of the picture; otherwise the eyes must be removed relatively to the stereoscope lenses.

A useful accessory for triming and mounting prints is a sheet of glass, cut so as to form a "cutting plate" of the size of the complete stereogram. If vertical and horizontal scratches be made across each picture position, so that their intersection gives the centres of each, these lines will be found useful in positioning the prints for mounting. A single square of glass is also useful for trimming single prints. In the former case the horizontal line is used for obtaining the correct level of corresponding points and the vertical line for lining up verticals, such as trees or buildings in the pictures; a series of horizontal lines may be drawn, with advantage.

Commercial Reproduction of Stereographic Prints.—It is important to observe that a good deal of the value and interest of the stereoscopic effect may be lost if the pictures are not reproduced properly. It is for this reason that many of the earlier half-tone reproductions lost their value, and stereoscopic photography its public interest. There is nothing worse for stereoscopic pictures than the coarse dots of the half-tone screen, as seen under the relatively high magnification of the stereoscope viewing lenses.

The photogravure process of reproduction is certainly to be preferred to the half-tone one, owing to its absence of screen effects, but there must be no noticeable granular appearance to depreciate from the details of the pictures. One has noted a similar result to the rough surface effects of matt photographic prints in the case of certain photogravures.

Undoubtedly the best method as regards uniform excellence of the results is that of employing actual photographic prints, and for this reason the leading firms now specialise in this kind of stereogram. The surface of the print should be glossy, and free from markings of any kind.

A recent German invention for obviating the usual drawbacks of the photo-mechanical printing process consists of employing a different kind of screen for each separate picture of a pair, so that the different grainings will fail to combine in the stereoscopic picture, which will therefore appear as uniform as if made without a screen or exhibited without enlargement. The result will be obtained if, for instance, one screen is ruled with vertical and horizontal lines and the other with diagonal ones ; or one screen may be ruled and the other granulated. In either case the screen effects, it is claimed, will neutralise one another and produce a grainless and pleasing picture.

The Illumination of Still Objects. Portraiture.—The lighting of still objects for stereoscopic photographs plays a very important part in connection with the final results obtained. We have shown that light and shade are of great assistance in the stereoscopic rendering of objects observed, and have noted that when a round object is illuminated strongly from the front, or two sides at once, there is marked loss of stereoscopic effect, whereas directional lighting with its shadows and half-tones produces that graduation of tones which the eyes instinctively associate with relief and solidity. It is important, therefore, when arranging still objects for stereoscopic photography, that the illumination is principally from one direction, and further that it is not too intense, but diffused. Too intense an illumination gives black and white effects with a loss of half-tones, and therefore of details and relief. Fig. 63 illustrates a well-tried method of lighting still objects for stereoscopic work, in which the object *A*, to be photographed, is placed at some distance from the screen *S*, the colour of which is chosen to suit the subject ; for example, a black screen for white objects such as light flowers or statuary. The camera is placed at *C*. The object *A* is illuminated from the window *W*, a semi-transparent screen being placed at *B*, so as to give a diffusion of light, whilst the two beams through the unobstructed portions give a stronger lighting in two adjacent directions. The side of the object *A* remote from the window should not be too dark, however; if necessary a light screen or reflector may be placed in the position shown by the dotted lines at *F*.

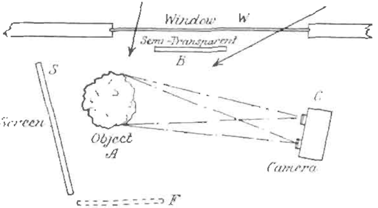


FIG. 63.—ILLUSTRATING METHOD OF LIGHTING INDOOR SUBJECTS.

In connection with the principles of illumination, it may be stated that the lighting should generally be so arranged that there are well-graded half-tones in the photograph. For this reason front lighting is to be avoided. Side lighting with a strong but diffused light gives the best results. Care should be taken to avoid too dense shadows or tones, for in such cases that part of the profile of the subject which is situated on the darker side may become lost; this frequently happens in the case of amateur photographs of flowers, or persons, taken indoors. In such cases better results may be obtained by a partial illumination of the shadows, by means of a light-coloured reflector placed on the darker side of the object, so as to reflect part of the direct light on to the darker side.

When an object is to be photographed outdoors, it is best to avoid top-lighting, and to so arrange the object that one side is partly shaded so as to enhance the gradations of the light, or to obtain the half-tones. For some purposes the object may be placed in the angle formed by two walls, the lighting then being from one side; it may be necessary to shade the object.

When photographing persons outdoors, the head should be arranged against a darker background, not against the sky or a lighter background; in the latter case the detail is to a large extent lost. The camera should never face the sun, nor should it back the latter, for then the subject is directly lighted, and the shadow details and half-tones are lost. The camera should be so arranged as to have the sun on one side or the other, preferably at a little greater angle than a right-angle to the optical axes of the lenses.

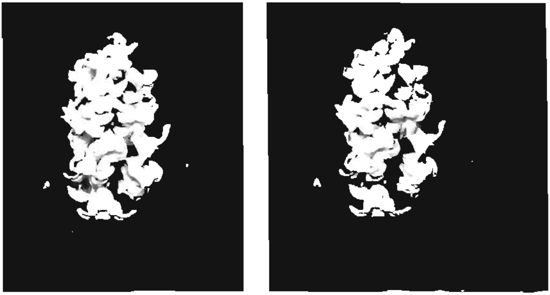
Flower Photography.—The subject of floral photography is an attractive one to the stereoscopist, for some excellent results are obtainable by the observation of a few simple rules. For this work it is essential to employ a focussing type of camera—the fixed focus type is unsuitable. The larger sizes of stereo camera enable contact prints of medium size to be obtained; if these prints are hand-coloured the resulting stereogram will be realistic and attractive. Better still is it to employ medium sizes of autochrome colour plates, in order to obtain colour transparencies which do not show appreciable grain effects in the stereoscope. The 3 × 3 ins. size of (individual) picture is well suited to this purpose. The camera lenses should be of wide aperture, in order to obtain short exposures, and also for putting the background out of focus so as to centre the interest upon the sharply focussed floral subject. Short exposures may be necessary when working out of doors, as there is frequently a breeze blowing, and therefore a risk of movement of the subject.

Correct focussing, exposure and lighting are the three principal factors concerned in successful floral stereo-photography.

A rigid tripod and bulb or antinous release should be employed.

As regards plates, it is necessary, in order to obtain the true tone values, to use panchromatic plates and a suitable correcting screen to give true colour values. This increases the exposure from 3 to 5 times, according to the screen used. If the exposure is too long for moving subjects on dull days, the colour screen should not be used. The ordinary orthochromatic plate will give partial correction of colour values.

PLATE No. [illegible]



FLOWER STEREOSCOPIC PHOTOGRAPHS

XAMPLE OF STEREOGRAM OBTAINED BY SLIGHTLY ROTATING THE SUBJECT BETWEEN THE TWO EXPOSURES MADE WITH A SINGLE LENS CAMERA.

The most effective lighting for indoor work is a combination of frontal and side lighting, somewhat on the lines illustrated in Fig. 63. The light should be *diffused*, not direct; above all, avoid strong sunlight with its hard tone effects, and lack of half-tones. The background should be selected to suit the predominating tones of the flowers. Thus for white flowers a dark matt surface cloth is suitable. For medium tones, a black, or even a white background can be employed. For dark flowers a drab or light coloured background is necessary.

In no case should the background be obtrusive; the chief interest should always be in the flowers themselves.

When arranging floral subjects avoid, as far as possible, overcrowding, but aim rather at the most artistic setting of a single blossom or spray. A good deal of time should be spent in focussing the subject; the screen image is the best guide to correct arrangement.

Do not employ too striking a design or pattern of vase, or holder, as this may detract from interest in the subject itself.

The development of the plate should be a slow one, more especially if the plate is a little over-exposed—and for this work it is better to err on the side of over-exposure.

Tank development is probably the most effective for floral subjects, as this method enables soft tones to be obtained.

Lighting of Outdoor Subjects.—A good proportion of stereoscopic pictures are spoilt through bad lighting. The most common mistake made is that of photographing a scene or group in strong sunlight. The result on the transparencies or prints is a black and white, contrasty effect. In the stereoscope, not only is there a marked loss of detail, solidity and relief, but what is worse, the picture appears to depict a snow scene; this effect has caused much criticism of amateur stereograms. The best plan is therefore *to avoid*, as far as possible, *strong sunlight, or light and shade effects.* The best illumination for stereoscopic work is diffused or dull light. A cloudy sky, or a dull grey day, will give much better tones and graduations than a bright sunny day, and the best stereoscopic pictures have been obtained under such conditions. Frequently, the flat print or transparency, obtained on dull days, will give a much better result in the stereoscope than the brilliant one full of detail.

In some cases, it is, of course, necessary for the purposes of the picture, to depict sunlight effects; for example in street impressions, water reflections, sunlight glades, and similar subjects. In these cases great care is necessary not only in the arrangement or composition, but in the exposure, choice of developer and development method, in order to obtain the desired results.

Colour Photography.—The effects observed in the stereoscope are very considerably enhanced if seen in their natural colours. In the case of prints this is not difficult, for with a little skill, and artistic taste, the prints can be hand tinted satisfactorily.

In the case of transparencies this is hardly possible, more particularly in the smaller sizes, and recourse must be had to the existing colour plate processes. Of the different colour plates on the market, the most popular is no doubt the Lumière type, but the Paget, Sanger-Shepherd, Agfa Farben, Hicro and Kodochrome methods have been applied satisfactorily in the case of lantern and larger sizes of plates. It is only possible here to give a very brief outline of the two former processes; the reader who is interested in colour photography should consult the Photo Miniature publication No. 147, "Practical Instructions in Colour Photography." Dr. Lindsay Johnson's "Photography in Colours," E. J. Wall's "Practical Colour Photography," and similar works. It may be as well to mention that neither the Lumière nor the Paget processes is really satisfactory for the 45 × 107 or 60 × 130 mm. sizes of plate, owing to the magnification of the starch grains in the former case, and the cross-hatching of the screen in the latter method. For larger plates these processes give very good results; we have examined a large number of 3 × 3 ins. stereograms made by the Lumière process and have been impressed by the excellent colour renderings.

Subjects for Colour Work.—A good deal depends upon the selection of the colours of the subject, in stereoscopic work. Most beginners attempt to crowd as much colour contrast as possible into their pictures, by choosing as many vivid colours as they can find. No doubt the inspiration is to take full advantage of the colour rendering properties of the plates. There are two golden rules in the selection of subjects for stereoscopic colour transparencies, as follows:

(1) Avoid many-coloured details, but aim at masses of colour, for the small sizes of plate will not render fine multi-colour detail satisfactorily on account of grain size and distribution. For this reason it is better to photograph a bed of flowers of one colour, say a mass of blue-bells in a green bank, than a bed of flowers of various colours. The rule then, is to aim at patches of colour which will give images of appreciable dimensions on the ground-glass screen.

(2) Select the subjects with colours which will harmonize in the final picture, just as one would choose the colourings of the furnishings of a living room to blend—not to irritate by their clashings or contrast.

The Lumière Plate.—This most commonly used colour plate was first placed on the market by Mm. Lumière, of Lyons, France. The plate is coated uniformly with a mixture of very fine starch grains, the individual grains being dyed with the three primary colours, namely, red, green and blue-violet. The coating therefore consists of a multitude of microscopic grains of the primary colours all mixed together. The sensitive emulsion is then coated on this layer of mixed colour grains. The plate is placed in the camera with the glass side towards the lens, so as to interpose the colour grain layer between the sensitive emulsion and the lens; this is contrary to the usual practice of placing the film side towards the lens. It is necessary to use a special colour filter or screen in front of, or behind, the lens, for the plate is naturally more sensitive to the blue-violet rays and therefore needs correction by the filter.

When an exposure is made the individual coloured grains forming the plate coating, in front of the emulsion, only allow light of the same colour as themselves to pass, and therefore the resulting negative *will reveal in its uncovered or clear parts only the colours which have not been allowed to pass*, i.e., in the unaffected part of the plate. The result is a picture in the opposite, or *complementary* colours to the real ones, so that it is necessary to reverse, or change the dark into light, and the light into dark parts in order to obtain the correct, instead of the complementary colours. Thus the blue portions in the developed plate will become yellow, and the green portions pink, when the plate is reversed. Reversal of the plate is carried out, immersing it, after ordinary development with *meloquinone** or Rytol, in a solution made up of potassium permanganate and sulphuric acid in the following proportions: Potass. permang. 35 grains, sulphuric acid (concentrated) 3 fluid drams, water 40 ounces. It is better to make up separate solutions of the first two, for keeping. After immersion in the reversal solution the plate is re-developed in the first kind of developer. The usual development period with Lumière plates is about 2½ to 3 minutes. Over-development should be avoided, as it causes a thin transparency.

Owing to the fact that the plate is sensitive to all colours it must be developed in the dark, although a very faint green safelight can be obtained and used (with discretion).

The British Journal Photographic Almanac, issued yearly, gives the complete formulæ and instructions for the developers used with Lumière colour plates. Messrs. Burroughs, Wellcome Ltd. have also devised a very satisfactory process of developing and reversing these colour plates, involving the use of tabloid Rytol developer and a tabloid reversing compound. They also supply a tabloid colour plate intensifier, namely a silver intensifier for increasing the brilliance of the colours.

The secret of successful colour plate results is undoubtedly that of correct exposure; under or over-exposure both give poor results. The Lumière plate is from 60 to 100 times *slower* than *the ordinary monochrome plates, and therefore the exposures are* correspondingly longer. It is practically impossible to avoid stand, or time exposure, although in recent times special hyper-sensitizers have been found which will greatly increase the speed of the plate; these are not yet within the province of the amateur, however.

Messrs. Lumière recommend as a basis of exposure, to give 1 second exposure, at mid-day, in mid-summer sunshine, at F/8 aperture. For smaller stops, of course, a longer exposure is required. Actually, it is found necessary to give a somewhat

* This developer is on the market, and is recommended for autochrome plates.

longer exposure than that corresponding to the aperture. Thus, whereas in going from one stop (e.g., F/8) to the next (e.g. F/11) instead of doubling the exposure as is usual with the ordinary plates, the exposure is 2½ times greater, with autochromes. It is advisable to use the special colour plate exposure meters, such as the "Bee" meter. The "Wellcome" photographic exposure calculator, handbook and diary, which is published yearly, gives complete instructions for ascertaining Lumière plate exposures under all conditions.

The autochrome plate owing to its thin film dries very quickly —usually in about one hour. After drying, the transparency should be varnished, both for protection and also to enhance its brilliancy. A good varnish should not contain alcohol. One which can be recommended contains 1 oz. gum dammar in 5 to 10 ozs. benzole. The same varnish as used for ordinary transparences is also applicable to colour plates. After varnishing, the transparency must be cut and transposed for stereoscopic viewing. It is usual to bind the two cut pictures either with ordinary lantern slide spot binding, or with a special metal frame and mask sold for the purpose. A sheet of thin clear glass should be used for binding.

Autochromes of the type described can be copied by the contact printing method, but the results are not always satisfactory.

The Paget Process.—This consists in using a colour screen made up of a multitude of regular cross-hatched small colour patches, in contact with the plate during exposure. A positive, or transparency, is obtained by contact printing from the negative. The positive is then bound in contact with a similar colour-patch screen to the original taking screen. Any number of positives can therefore be taken from one negative, but a separate colour screen is required for each colour transparency.

The Paget process, on account of the monotonous regularity of the cross-hatched colour patches, does not lend itself to use in the smaller sizes of stereoscopic plate. In the case of the Lumière plate the colour patches are irregular, and therefore less objectionable.

Special processes are now available for instantaneous colour photography by the Lumière and other methods.

CHAPTER IX

STEREOSCOPIC PHOTOGRAPHY OF SMALL OBJECTS.

THE correct rendering, in the stereoscope, of small objects, calls for much skill, and a sound knowledge of the principles involved. Many, who attempt, with the aid of an ordinary bellows type camera to obtain enlarged, or natural stereoscopic views of small objects such as botanic specimens, insects, and mineral specimens, are often disappointed with the results, owing to their omission to apply the correct principles.*

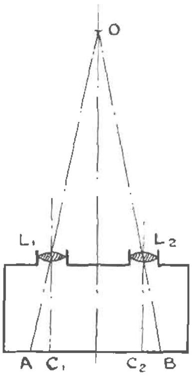


FIG. 64

The usual type of fixed focus stereoscopic camera will not be found suitable for photographing objects within a foot or two of the camera, although certain makers usually supply supplementary magnifying lenses which are attached to the ordinary lens mounts. It is necessary to have a bellows, or extending type of camera for this work; a single lens camera will do quite well, if a sliding base-board is provided for obtaining the respective photographs from the different view-points.

When the object to be photographed is very near to the camera, namely, from 4 to 14 inches or so, it will be found (Fig. 64) that the two images are displaced from the centre of each picture. Thus, in Fig. 64 the images *A*, *B* of an object at *O*, near the stereoscopic camera are displaced, respectively to the left and to

* An excellent series of articles, by the Rev. H. C. Browne, appeared in *The British Journal of Photography*, in 1922 (Jan. and Feb.).

the right, of the central positions C_1 and C_2. The result is that when the prints, or positives, are made from the negative, owing to the transposing which is necessary, the decentering of the corresponding points of the two images *A* and *B* takes place in the opposite direction, with the result that the separation of the images becomes less than the normal separation of the eyes, and

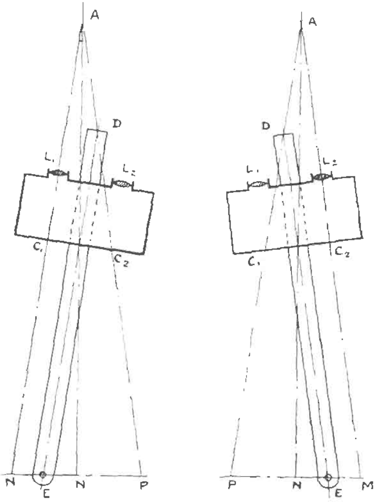


FIG. 65.—PRINCIPLE OF TILTING TABLE.

it becomes difficult, if not impossible to fuse the two images in the stereoscope. This defect becomes more and more accentuated the nearer the object to the camera lenses.

In order to overcome this difficulty the camera may be mounted upon a base-board which can slide along a rigid rod *DE* (Fig. 65) which is capable of rotating through a given angular range about a pin *E* at one end. A little consideration of the two diagrams will show that by tilting the rod DE, firstly to the left through an angle θ, such that it is the angle subtended at the point A, by the base MN equal to the normal eye separation (i.e. the distance C_1C_2), and then to the right through an equal angle, the images of the point A will fall on the centres C_2 and C_1, as shown. The correct separation of the images is thus obtained on both negative and print.

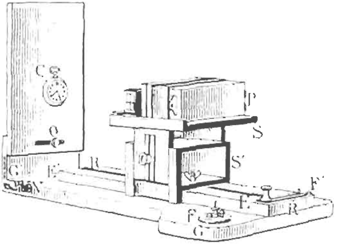


FIG. 66.—SPECIAL BENCH FOR STEREO PHOTOGRAPHY OF SMALL OBJECTS.

M. Colardeau has devised a special apparatus, or photographic bench* for the purpose of photographing small objects, which utilizes a similar principle. It consists of a flat board (Figs. 66 and 67) $R'E'$ RE provided with a slot, along which the camera

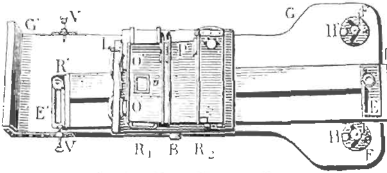


FIG. 67.—PLAN VIEW OF BENCH.

table can slide. The board can rotate between the adjustable stops V about the screw E. At one end C, is fitted the screen to which the object to be photographed is attached.

* Manufactured by Jules Richard, Paris.

In order to employ the ordinary fixed focus Verascope type of stereo-camera, a series of lengthening pieces, or adapters are provided for inserting between the usual slide position and the slide, or plate magazine; this gives the necessary camera extensions when photographing near objects. The extending piece is inserted in place of the dark slide on the camera, and the dark slide is placed at the other side of this piece, in suitable guides. Focussing is carried out by sliding the camera to and fro until the image is sufficiently sharp. Fig. 68 shows the general

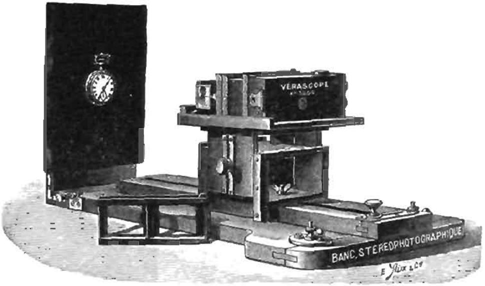


FIG. 68.—SPECIAL BENCH FOR STEREO PHOTOGRAPHY OF SMALL OBJECTS, WITH CAMERA IN POSITION.

appearance of the stereophotographic bench, and indicates the adjustments of the camera table. A set of converging and also of diverging lenses is provided, each mounted in a metal holder.

Some Theoretical Considerations.—It is possible, by utilizing the ordinary rules of optics, and by combining these with the conditions which have been laid down regarding the lens separation, distances of objects and image, and the focal lengths of the camera and viewing lenses, to obtain a number of simple formulæ expressing the relationship between these quantities. The practical photographer will find these formulæ very helpful in connection with the selection of object position and lens separation.

Let n = image magnification required

$$\left(= \frac{\text{image width}}{\text{object width}} = \frac{\text{image distance}}{\text{object distance}} \right)$$

d = distance of image observed in stereoscope, from the lenses.

F = focal length of viewing lenses.

f = focal length of camera lenses.

Y = lens separation distance or shift of single camera lens between two exposures.

The relation between F, d and the n can readily be shown to be as follows:

$$n = \frac{F}{d + F} \qquad \ldots \ldots \ldots \ldots \quad (1)$$

The print width we have seen is $\frac{1}{n}$ times the lens separation

so that *Print Width* $= \frac{1}{n} \cdot Y$

$$= \frac{F \cdot Y}{d + F} \qquad \ldots \ldots \ldots \ldots \quad (2)$$

The Focal Length of the camera lenses:

$$f = \frac{d \cdot F}{d + (n + 1) F} \qquad \ldots \ldots \ldots \ldots \quad (3)$$

Also we have already shown that $Y = \frac{65}{n}$ millimetres.

Further, in order that the prints may be made by direct contact from the negative, the following relation must hold:

$$\text{Scale of Photograph} = \frac{\text{length of image on negative}}{\text{length of original object}}$$

$$= \frac{nF}{d + F}$$

Also Object Width $= \frac{Y \cdot d}{F \cdot n}$

Practical Considerations.—When considering the question of viewing distance, for the stereoscopic images or actual objects, it should be remembered that there is a minimum distance from the eyes at which objects can just be discerned distinctly; within this distance vision is indistinct. For the average person, this *distance of distinct vision* is about 10 inches (this distance is usually taken as a standard one. Both real and stereoscopic views should therefore be seen at not less than this distance.

In connection with the practical side of stereoscopy of small objects, experience has shown that very satisfactory results are obtained with stereo cameras having a focal length of 2 to 3 inches, and arrangements for extending the bellows to 3 to 4 inches.

As we have previously mentioned, it is possible in fixed focus cameras to fit adapter pieces, or frames, so as to increase the distance between the lenses and the plate, for obtaining magnified images.

The viewing stereoscope should be fitted with eyepieces of about 3½ to 4 ins. focal length, and be provided with a focussing movement, giving from 2¾ to 4 ins. from the print or plate. A normal separation of 2½ ins. should be arranged between the lenses. The total width of each print should not exceed 3 to 3¼ ins.; this estimated width should be strictly adhered to in mounting the prints or transparencies.

The *plane of the object upon which to focus* for the best results is an important consideration*. The plane of the object may be fixed, for photographic purposes by two small plumb-bobs on cords, or pendulums suspended in the given focussing plane, or alternatively by means of two vertical knitting needles fixed to supports: these will also serve to fix the width of the object as seen on the focussing screen.

In order to obtain the best relief effects it is recommended that *one third of the depth of the object* photographed be arranged in front *of the vertical plane, and two-thirds behind*. In some cases, of course, there may be one particular portion of the object which is of special interest, so that the focussing plane will be fixed by this consideration.

It is necessary to use a small lens stop, or aperture, for close objects, in order to avoid recording on the photographic plate points of the object which the eye would not see from the given point of view.

If a single lens camera be used, any of the devices for moving the camera parallel to its first position, described in Chapter IV, can

* Vide "Stereoscopic Photography of Small Objects," Rev. H. C. Browne, *British Journal of Photography*, 1922.

be employed, but it is necessary to provide means for varying the separation distance on either side of the normal value ($2\frac{1}{2}$ ins.). As a makeshift the camera can be placed on a flat piece of board, to which a suitable sheet of drawing paper is attached. A line parallel with the principle plane of the object is drawn on the paper, whilst two lines are next made at right angles to the first line, corresponding to the positions of the slides of the camera in the two separated positions.

Identifying the Stereo Pictures.—It is important to be able to *identify the individual pictures* of a stereo pair, since in many cases a visual inspection does not indicate which is the right-, and which the left-hand print. In some cases, of course, bearing in mind the fact that the left eye sees more of the left side, and the right eye more of the right side of the subject, it is possible to pick out the correct prints.

Before mounting stereoscopic prints it is a good plan to place them on a flat surface, horizontal or inclined, and to interchange or adjust their positions until the proper stereoscopic effect is obtained. The positions should be marked, and the prints mounted in accordance.

When photographing still objects, it is useful to place a small card with the letter *R* by the side of the object, to be photographed with the camera in the right-hand position, and a letter *L* for the left-hand camera position.

Very often, however, the negative will show the distinctive outline of the slide mask ; the latter is usually different in shape at one end, so that the proper picture of a stereo pair can be recognised, when a stereo camera is used. A slight notch in the stereo camera mask, at *one end* can also be used as an indicator.

CHAPTER X

THE WIDE ANGLE STEREOGRAM.

One drawback of the ordinary stereoscopic camera is that the angles of view of the lenses are considerably less than that of the human eyes, so that one only obtains the impression of viewing, in the stereoscope, a portion of the real field of view. This matter may be stated from another viewpoint, namely, by imagining ourselves standing still in a room and looking through a window at the landscape outside. When we shut our right eye we can imagine the image of the landscape formed in our left eye to be projected on the window-pane and exactly copied with a pencil, and similarly with the image formed in our right eye when the left one is shut. Thus two drawings appear side by side. If now the landscape disappeared, we should see it unchanged in its former place because the two drawings would produce exactly the same images on the retinæ as the landscape itself.

There is no reason, if we leave out of consideration the question of accommodation, why we should not approach the window so closely that we have a field of view possibly as wide as the natural field of view of the eye, reaching up to 120° or more. In stereophotography we must ensure that the pictures become identical with the drawings on the window-pane. This is very easy if we employ a stereo-camera, the lenses of which have the same focal length as the distance of the eyes from the window-pane, provided that their lateral separation is equal to the interocular distance, and that they are free from distortion, because the imaginary drawings on the window-pane are free from it.

It is often argued that photographs must not be taken with too large an angle of view because of the effect of exaggerated perspective and also because the principal object is not brought into such prominence with regard to the background and surroundings. This may be quite true in the case of single photographs, but in the case of stereo-pictures the argument does not hold.

One practical advantage of short-focus lenses, apart from their greater definition of depth, is that they are much smaller and lighter and so allow the cameras to be more compact and lighter.

The ordinary photographic lens used in stereo-cameras has an angular field of view of about 60°, so that it does not correspond in angular field to the eye range. Similarly most lenses of viewing stereoscopes give a greater angular field than 60°, nor are they connected, optically, for wider angles.

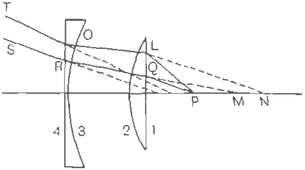
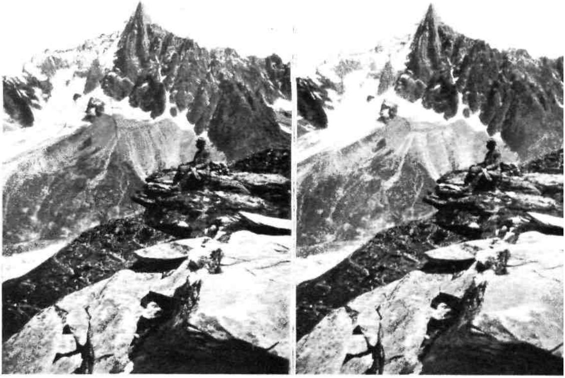


Fig. 69.

Col. L. E. W. van Albada, of Amsterdam, who has given a good deal of thought and study to this problem, has been successful in producing a wide angle stereoscope lens system* of 90° effective angle, and which is corrected for distortion and chromatic aberration, by means of the lens system shown in Fig. 70. The lens system illustrated in Fig. 69 represents an approximation to the previous design, and serves to indicate how the final design was arrived at.

Suppose we have a lens system as shown in Fig. 69. A point P on the axis is taken so that a ray, or narrow parallel pencil of rays, going from P to Q appears, after refraction at the flat

* *A Wide Angle Stereoscope and a Wide Angle View Finder.* Trans. Optical Society, vol. 25, No. 5, 1923–4.



AIGUILLE DE DRU, NEAR CHAMONIX.

(Col. L. E. W. van Alba

PARK ZORGVLISH—THE HAGUE.

TWO WIDE-ANGLE STEREOGRAMS.

surface 1, to come from a point M. If M is in the centre of curvature of the spherical surface 2, the ray QR will not be refracted when it emerges from the first lens into the air, nor when it enters the second lens, provided the spherical surface 3 has the same centre of curvature M. Thus the ray, on reaching the second flat surface 4 at the point R, is refracted in a direction parallel to PQ. Thus the system is similar in action to a glass-plate.

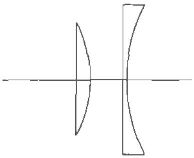


FIG. 70.

Moreover, when both lenses are made from the same kind of glass, there is no chromatic aberration, as the prisms at Q and R have the same angle but turned in opposite directions, nor is there any appreciable astigmatism because the rays pass normally across the spherical surfaces. The system has, however, a certain magnifying power, for the radius of curvature of surface 2 is smaller than that of surface 3. This system would be an ideal one if *all* rays emerging from P were refracted by the plane surface in directions which, when continued backwards, passed through M, but this is not the case. Thus a ray PL will, after refraction by the first lens, appear to come from a point N *farther* away than M and will consequently meet the spherical surface 3 at a point *nearer* to the axis than would be necessary to correct the deviation caused by the first lens. The consequence of this is that the angle between RS and OT is not so large as that between PQ and PL, so that the deviation of the pencils of rays towards the edge is somewhat under-corrected and towards the axis a little over-corrected.

There are various ways of obtaining better correction. One of these is to reverse the negative lens, increase its radius of curvature, and bring it nearer to the positive lens, as shown in Fig. 70. In this way we get a system which is practically corrected for distortion over a diagonal field of from 75° to 80° and shows but little chromatism. If a so-called achromatic positive lens is used, instead of the single lens, the correction for distortion may practically be carried up to 85° and 90°, while the system becomes almost entirely free from colour.

The correction for distortion, the flatness of field, its angle, and the definition of this lens system can best be appreciated by comparing the two photographs shown in Figs. 71 and 72 respectively. The former is a photograph taken of a rectangularly ruled test chart with an ordinary achromatic stereoscope lens, with the stop behind lens; the few central squares only are true in shape. Fig. 72 shows the same test chart photographed with Col. van Albada's wide angle stereoscope lens, with the lens stop behind lens; it will be seen that there is freedom from distortion over an angle of 90° to 100°, in all.

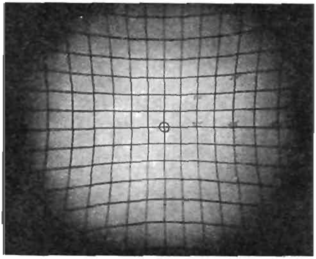


FIG. 71.—SHOWING DISTORTION OF ORDINARY STEREOSCOPE ACHROMATIC LENS (WITH STOP BEHIND).

Focal Length.—As regards the focal length of these lenses, although it is desirable to make this as short as possible, a limit is fixed by the eyes themselves—which form part of the optical system—at about 2½ inches.

Though the curvature of field of the system is very small, we have to place the picture far enough inside the focus on the principle axis to enable the margins to be seen distinctly, so that for example, at a focal length of 2¾ inches, the real distance of the picture is reduced to $2\frac{1}{2}$ inches. A system with a focal length of $2\frac{3}{4}$ inches allows a diagonal view of 85° to be seen at a distance of $2\frac{1}{2}$ inches without displacing the centre of rotation of the eye (which is placed as close as possible to the lens) away from the axis of the system. When using the system as a key-hole, that is, moving the centre of rotation of the eye a little away from the axis and looking slantingly through the centre of the lens, a field of view of more than 100° can be obtained.

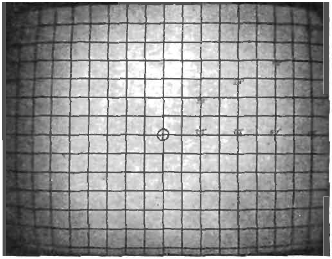


FIG. 72.—DISTORTION OF THE WIDE ANGLE STEREOSCOPE LENS (WITH STOP BEHIND).

As these lenses are designed to give the widest possible view, it is evident that they must be used centrally, that is, their distance apart in the stereoscope must be equal to the observer's interocular distance and the eyes must be placed as close as possible to the lenses. The distance from the lenses to the picture accords with the emmetropic eye. Small hypermetropic and myopic deviations can be corrected by changing the distance to the picture; other anomalies can only be corrected by spectacles.

We have been able, through the courtesy of Col. van Albada and Messrs. H. van Winhoop and G. P. Duuring, to examine a number of wide angle stereograms of mountain scenery, railway bridges and other subjects, and can personally vouch for their excellence, and also for the distinct advantage of the wide angle over the normal stereoscopic picture. Two or three of these are reproduced in the present volume.

CHAPTER XI

PSEUDO-STEREOSCOPIC RESULTS.

False Stereograms.—Many people unacquainted with the subject, imagine that if a pair of identical photographs be mounted at the correct inter-ocular distance apart, namely 2½ ins., that a stereoscopic result will be obtained, when the combination is viewed in a stereoscope. This is of course quite incorrect, since as we have shown, the two pictures forming the pair must be taken from different viewpoints, and are therefore dissimilar. In the past, unscrupulous or ignorant people have mounted identical photographs on stereoscopic mounts and offered them for sale; this fact had something to do with the fall in popularity of stereoscopy some years ago. If the two prints of a stereoscopic negative are improperly trimmed, or are mounted out of parallelism, the stereoscopic result frequently will not be realised.

Similarly, if two similar points on the pictures are mounted at the correct distance apart, viz. 2½ inches, but if either are orientated so that horizontal lines become inclined it will be difficult to merge the views and a false stereogram may result. Further, if two prints from a stereoscopic negative be properly trimmed and mounted parallel but at too great distance apart (namely, over 3¼ inches between corresponding points), the ordinary person will be unable to merge the two views and no stereoscopic effect will be obtained.

Latitude in Photographic Density.—The above are examples of false stereograms. On the other hand, there is a certain amount of latitude as regards the density of the photographs, and in respect to the relative densities of the pair, provided that they are correctly mounted. Weak negatives usually give quite good stereoscopic results, and if one picture is printed a little darker than the other, the stereoscopic effect will not be appreciably affected. There is a certain latitude, also, in the mounting distance; a good observer is able to merge views mounted with corresponding points at distances of from $1\frac{1}{2}$ to $3\frac{1}{4}$ inches.

Pseudo-Stereograms.—There is another type of false-stereogram which one frequently experiences, namely, in the case of the incorrect transposition of the two stereoscopic pictures, so that the left eye sees the right picture in the stereoscope, and the right eye, the left. One occasionally comes across cases of stereoscopic prints which have not been transposed before mounting, so that when viewed in the stereoscope, the true effect is not obtained. Stereoscopic camera pictures which are incorrectly mounted in this way are termed *pseudo-stereograms*.

The simplest example is that of a stereoscopic negative. If this be viewed in the stereoscope, by transmitted light (the Verascope, 45 × 107 mm. and 60 × 130 mm. sizes lend themselves very well to this experiment) a peculiar effect is experienced. There is a complete reversal of perspective; objects which were nearest the camera appear to be farthest away, and vice-versa. If the subject photographed is composed of a number of separate objects at different distances, the relative positions of these will appear totally different. In the case of the negative, however, the reversal of densities, rather detracts from the experiencing of the full pseudoscopic effects.

The reason for these pseudoscopic results can best be explained by reference to a simple case, namely, that of the parallactic displacement of the images forming a stereoscopic pair. If, for example, we take the two dots, *A A* at 70 mm. apart, say, as references, and two other dots *B B* at a greater distance apart, say 75 mm. then, as we have previously seen, if these be viewed in a stereoscope the dot *B* will appear to stand behind *A*. Similarly if two dots *C C* be introduced in the stereogram, such that the distance *CC* is, say, 65 mm., then the dot *C* will appear in front of *A*, and *B*. Referring to Fig. 74 (*A*) if, now we transpose the left hand diagram, so that it becomes the right-hand one, and the right-hand diagram becomes the left as shown in Fig. 74 (*B*) and this new arrangement be viewed in the stereoscope, the relative positions of the dots will appear to be reversed. Examination of the "true" and "pseudo" diagrams at once

FIG 74.—ILLUSTRATING THE PRINCIPLE OF PSEUDOSCOPY.

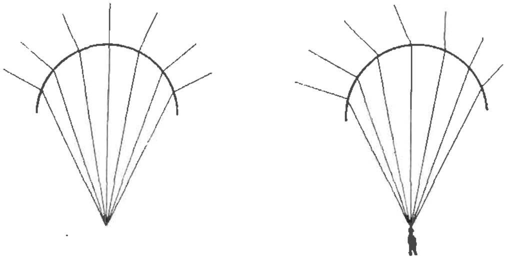


FIG 75.—ILLUSTRATING THE RAINBOW FORMATION PRINCIPLE.

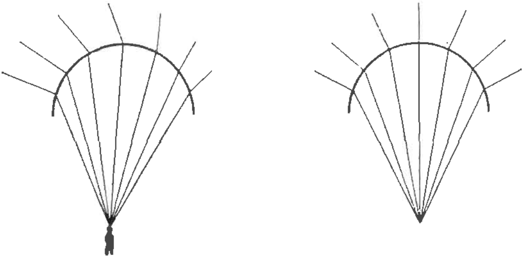


FIG. 76.—A PSEUDOSCOPIC RAINBOW DIAGRAM.

shows that in the second case the parallactic displacements of the images forming the pair have been altered, so that the distances between the images *B B* is now 65 mm., and between *C C* 75 mm.

The same general explanation applies to all pseudoscopic photographs, and it is not difficult, therefore, to understand the reasons for the results observed.

Figs. 75 and 76 illustrate examples of true and pseudoscopic results, the latter being obtained by interchanging the right and left diagrams in the true stereoscopic pairs. Line diagrams are admirably adapted to pseudoscopic results. In the case of Fig. 75 it will be observed that the straight lines in the upper portion appear to come from the observer's direction to the circle, whereas when the left and right diagrams are transposed they appear to recede from the circle. Fig. 77 illustrates the reversal of reference planes by transposition of the left and right hand views.

As a concluding example of pseudoscopy we shall consider the case of a pyramid on a square base, viewed in the first instance from above. The pyramid may be imagined to be formed of metal wires, so as to form a skeleton or frame.

If the eyes are situated at *L* and *R* (Fig. 78) it will be evident that the left eye will see the image of the apex *P*, of the Pyramid, in the position P_1, when projected on the base, whilst the right eye will see it at P_2. The two views, corresponding to the left and right eyes will therefore be as shown in Fig. 80 *A*, and if this diagram be viewed in a stereoscope the wire-frame pyramid will be seen in relief, standing on its base, with *the apex P nearest the eyes.*

If, next, we transpose the two images in Fig. 80 *A*, we shall obtain the disposition shown in Fig. 80 *B*; the distances between corresponding lines or points on the base are, of course, kept constant in each case. Viewed in the stereoscope the result is that of a wire-frame pyramid *with its base nearest and the apex farthest away.*

A little consideration will show that this is exactly the disposition of the left and right eye images of the inverted wire pyramid observed from above, as shown in Fig. 79. The left

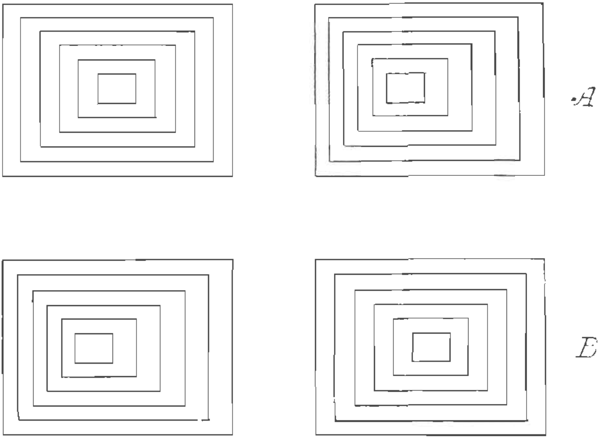


FIG. 77.—EXAMPLES OF STEREOSCOPIC AND PSEUDOSCOPIC DIAGRAMS. IN *A* THE SMALLER PLANES APPROACH, WHILST IN *B* THEY RECEDE.

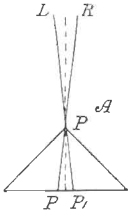


FIG. 78.

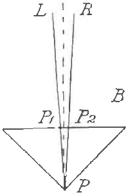


FIG. 79.

and right eyes at L and R, will see the apex of P in the positions P_1 and P_2 respectively in this case.

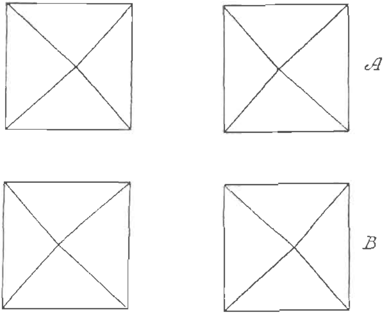


FIG. 80.—(*A*) PYRAMID WITH APEX ABOVE BASE.
(*B*) PYRAMID WITH APEX BELOW BASE.

Correction of Pseudoscopic Results. In the chapter on mounting and transposing stereoscopic transparencies it is shown that unless the negative is cut and the two halves interchanged, it is necessary to employ a double printing operation using a special transposing printing frame. There is, however, on the market a special form of stereoscope containing an optical arrangement which automatically inverts or transposes the pictures printed by direct single contact, thus simplifying the photographic process considerably.

This apparatus is particularly suitable for viewing autochromes with it, no cutting and transposing of the two coloured positives being necessary. Fig 55 illustrates a stereoscope, fitted with reversing prisms, made by M. Jules Richard for the above purposes.

Application to Radiography.—In the case of X-ray stereograms the objects in the interior of the body, or object, photographed are seen as shadows in different planes, and the position of any given object can at once be ascertained in relation to that of others ; this method, as is shown in Chapter XVII, is employed for locating the position of foreign bodies in the human system, or of defects in solid materials. If the two views of an X-ray stereogram be interchanged and viewed in a stereoscope, the result will usually prove of much interest and value, for with the reversal of the different planes, a fresh disposition of the objects occurs. In many cases advantage is taken of this fact when making X-ray stereograms of the human body for the purpose of locating foreign objects such as bullets, or pieces of metal. If the object happens to be on the opposite side of the body to which the photograph is taken, then the pseudoscopic view will reverse matters and show it nearer to the observer's eyes. In the majority of cases, where radiographs of solid objects are made, the positions of the particular objects of interest are not known with certainty, so that the pseudoscopic method provides a useful alternative method of examination; frequently it obviates the necessity for repeating the X-ray photography in cases of uncertainty of the position of the object of interest.

Pseudo-Stereoscopic Effects.—One frequently hears it mentioned that it is unnecessary to employ photographs forming a true stereoscopic pair, as an ordinary single photograph can be made to give relief effects. The latter part of the statement is correct to a degree, for there are devices available which certainly enable single flat prints to show a partial relief effect. On the other hand, the usual result obtained resembles that of a series of flat objects, which might be compared to photographs pasted on thin sheets, cut around in silhouette, and placed in different planes, somewhat like stage scenery. If a good print be viewed through a large convex lens, or if it be seen by reflection from a concave mirror, it will show a certain amount of relief of the stage scenery type. A convex mirror device known as the "Reflectoscope," now on the market, greatly improves the viewing of single photographs and gives a partial

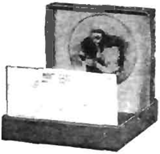


FIG. 81.—THE REFLECTOSCOPE VIEWING DEVICE.

stereoscopic impression. Both mirror and lens suffer from aberration or distortional effects, however.

A number of such devices have appeared from time to time, of which mention need only be made of the "Verant," and "Stereofactor." The former, which was devised by Dr. von Rohr, enabled relief effects to be obtained with a single photograph where placed in a special optical device and viewed with one eye; another of this type of viewer enabled two identical prints to be viewed, one with each eye. In the "Stereofactor" device two

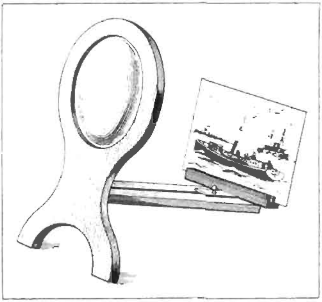


FIG. 82.—CONVEX LENS VIEWING DEVICE.

exactly similar non-stereoscopic prints were placed side by side and viewed in a stereoscope resembling the ordinary type, but having a special holder for allowing the prints to be inclined to each other at an angle of 140°.

No really satisfactory explanation of these pseudo effects appears to have been put forward, but in the case of the convex lens and the concave mirror, it has been suggested that there is an overlapping of the different rays due to aberrations. The fact should not be overlooked, also, that each of these devices causes the rays of light from the picture to be received a little differently by each eye in a somewhat similar way, but to a lesser extent, to the rays from a stereo-pair, viewed in a stereoscope.

PSEUDO-STEREOGRAMS

Those who have viewed single prints with any of the devices mentioned, and have also observed stereoscopic pairs in the stereoscope will agree that there is no comparison between the results, the latter being infinitely better in relief, solidity and perspective. A curious effect, which may be mentioned before concluding this section, is that which was pointed out by an *English Mechanic* reader,* some time ago, namely, the apparent relief effect obtained by observing a flat picture of correct perspective with one eye, using an open tube, or one hand, as a spy-glass to ward off light other than that proceeding from the picture. Many artists are in the habit of examining pictures in a similar way in order to obtain a more realistic impression.

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* Letter 102. Feb. 15th, 1924.

CHAPTER XII

MISCELLANEOUS APPLICATIONS AND CURIOSITIES.

APART from the applications of the principles of stereoscopy dealt with in the preceding sections, there is a number of miscellaneous uses, each possessing features of some particular interest. The stereoscopic principle has been applied, not only to microscopy, astronomy and land surveying from the ground and from the air, but also to optical instruments, including binoculars and range-finders. It is proposed to consider the latter class of instruments in a brief account; the former class is too well known to merit much attention here.

Stereoscopic Range-Finder.—The stereoscopic range-finder has been developed in Germany and elsewhere to a high degree

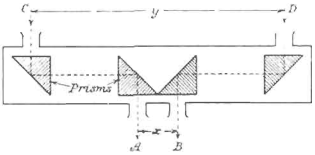


FIG. 83.—PRINCIPLE OF STEREOSCOPIC RANGE FINDER.

of accuracy, notably by Dr. C. Pulfrich.* The principle of this instrument depends, as we have stated elsewhere, upon increasing by optical means, the ocular base, that is to say, the distance between the view-points.

A simple method of increasing the ocular base is that indicated in Fig. 83, and in which the two normal eyes situated at A and B

* *Neue Stereoskopische Methoden und Apparate*, and *Stereoskopische Sehen und Messen*. Dr. C. Pulfrich, Berlin, 1909.

as shown, are able to experience a sensation of augmented relief, equivalent to that of an ocular separation y. The maximum range of natural stereoscopic vision, a subject which is discussed in Chapter II, can be extended by introducing a telescopic system of magnification, whereby the limiting angle of resolution of natural vision, which is, roughly speaking, about 30″ of arc, becomes reduced to a fraction of its value. If, for example, the magnification of the telescopic system is 10 times, then the equivalent limiting angle of resolution will be 3″ of arc.

In general, for a magnification m times, the limiting angle of resolution is $\frac{1}{m}$ times its natural vision value. Similarly, if the ocular base be increased by optical, or other artificial means, n times, then the maximum range of stereoscopic vision is increased to $m \times n$ times the natural vision value. The product $m.n$ is sometimes termed the *stereo power*, or *total relief* of the system.

As an example, let us suppose that by means of prisms the ocular base of 65 mm. is increased to 650 mm., and that a telescopic magnification system of $\times$ 15 is employed, then the value of $n = \frac{650}{65} = 10$, and the product $m \times n = 10 \times 15 = 150$.

The stereo power of the system is therefore 150.

It should be noted that if only the base (n) is varied without magnification, the effect experienced will be to bring distant objects proportionately nearer, but, as we have stated previously, will give the same angular subtension, and therefore the effect seen will be that of a model of the object situated at a nearer distance $\left(\frac{1}{n} \text{ of the actual distance} \right)$.

Increasing the magnification (m) without altering the ocular base, will give the effect of objects at $\frac{1}{m}$ of their actual distance, so that an increased stereoscopic effect will be experienced. In applying these principles to the range-finder, it will become evident that a scale of some kind is required in order to read off the distances of objects viewed. This scale usually takes the place of a graticule, i.e., black line scales on glass transparencies, placed in the focal planes of the eyepieces so that when a distant scene is viewed, there is also seen a scale of distances standing out in relief, as shown in Plate 9. It is then easy to ascertain the distance readings on this suspended scale, in space, opposite the object seen in relief; the range, or distance away is then known.

A little consideration will show that it is not difficult to construct a scale in the form of a stereogram, in which the individual markings or graduations will, in the stereoscope, appear to stretch out into space. It is only necessary to displace the individual marks of one scale to the right or left, in order to obtain any degree of advance or recession, as we have explained in Chapter II.

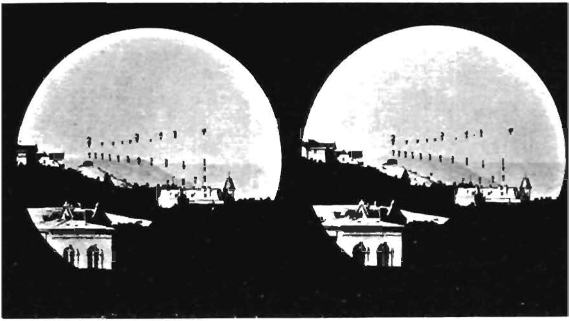
It is necessary to provide erecting prisms so that erect, instead of inverted, images are seen. In some cases a wandering point is fitted to the range-finder, the graticules having a single graduation only.

It may be added that it is easily possible in the case of those stereoscopic range-finders which employ separate graticules, the graduations of which appear in relief, to so arrange the vertical heights or lengths of the graduations, that each represents the actual height or size of the object seen in the same plane as the graduation. In this manner, the size as well as the distance of an object could be measured.

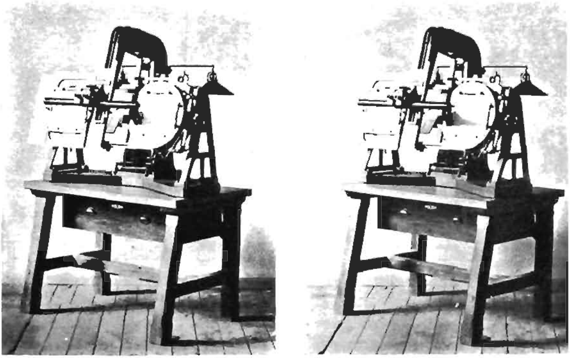
The stereoscopic range-finder has been shown to be, in the hands of a good observer, practically as accurate as the best forms of coincident type instruments, and to be more rapid and simple in use. It is necessary, however, to obtain observers possessing good stereoscopic vision; test charts of the type illustrated in Fig. 58 are used to ascertain the stereoscopic quality of observers.

The Stereo-Micrometer.—The stereoscopic principle has been applied to an instrument known as the stereo-micrometer, which has been employed for measuring the heights of hills and mountains, and distances of different objects seen in the stereogram from the camera. It has also been used for measuring the heights of mountains on the moon, and the depths of lunar craters.

Referring to Fig. 84, which represents a pair of pictures, AB, and $A'B'$, respectively, forming a stereogram, if two pointers, which are identical in size and shape, be placed at O and O_1,



ILLUSTRATING METHOD OF STEREOSCOPIC RANGE FINDING



(Carl Zeiss)

THE PULFRICH STEREO COMPARATOR.

respectively, in the plane of the photographs so that their images, as seen in the stereoscope, superimpose, or merge, they will appear as a single image. If, however, one of the pointers be moved to one side, the degree of superposition of the images will be changed, and in consequence the distance of the pointer from the observer will appear to alter. If a graduated scale is provided to indicate the position of the displaced pointer, it can be used to measure the distances of the objects with which the displaced pointer coincided from the observer. It will be realised that this is but a mechanical application of the well-known *method of parallactic displacement*, described elsewhere in this book. Re-stated this method is based upon the fact that if one point of a stereoscopic pair be displaced, relatively to a fixed, or reference point in the same diagram or picture, and in a direction towards its corresponding point in the other picture, it will appear, in the stereoscope, to stand out in front of the reference point; if displaced

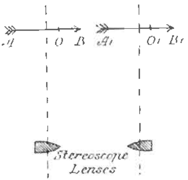


FIG. 84.

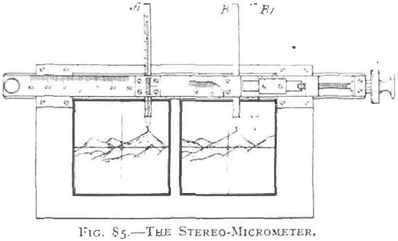


FIG. 85.—THE STEREO-MICROMETER.

away from the corresponding point it will appear to recede behind the reference point. The amount of displacement determines the apparent distance of advance, or recession.

In the Zeiss stereo-micrometer illustrated in Fig. 85, the image of the movable pointer *B* can be displaced so as to appear at any distance away from the observer, by means of the screw adjustment *S*; the amount of the displacement is read off the flat and divided head calibrated scales shown, and the distances corresponding to the displacement are then known.

Binocular Telescopes.—The principle of the extended base has been applied also to binocular telescopes. Here the eyepieces

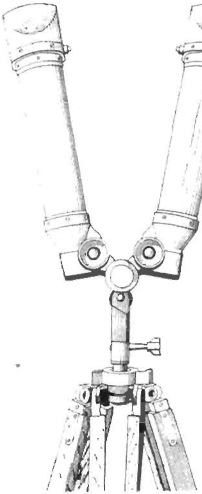


FIG. 86.—BINOCULAR TELESCOPE.

are arranged at the normal separation distance of the eyes, whilst the objectives are placed much farther apart. This enables the observer to obtain a much greater sense of solidity and depth in the case of distant objects.

Fig. 86 illustrates the Krauss prism binocular telescope mounted upon its tripod. The two eyepieces can be seen near the lower ends of the telescope tubes, the objectives being mounted at the upper ends. The telescope tubes are arranged to pivot, or swing, about their eyepieces, so that the two objectives can be separated by any distance within the limits assigned. In the present case the separation of the objectives can be varied from about normal up to 28 inches when the tubes are swung into the horizontal positions. The enhanced stereoscopic vision is of great value in observing distant objects, for it enables differences of depth to be perceived with precision.

When mounted on a stand the instrument can be swung into any position relatively to the hinge connecting the two telescopes and the vertical axis of the combined telescopes. For the latter purpose the stockhead is provided with a tangent screw. The two telescopes can be turned about the hinge into a horizontal position on a level with the eyes of the observer. In this position the stereoscopic effect reaches its greatest value. On the other hand, the two telescopes may be turned in scissor fashion vertically up above the head of the observer, in which case the stereoscopic effect has its least value, but in this position of the telescope arms the observer can conceal himself behind an obstacle and observe from behind the shelter so afforded, since the objectives alone reach above the obstacle; this constitutes a kind of periscope arrangement.

The two eyepieces have movable eyecups with diopter scales, by means of which they may be adjusted to suit the ophthalmic anomalies of the eyes.

In passing it should be pointed out that the ordinary prismatic binoculars having the objectives farther apart than the eyepieces will give an enhanced stereoscopic effect at their magnification distances.

Stereo Prism Binocular.—Fig. 87 illustrates the Ross stereo prism binocular, which embodies the principle previously outlined. It will be observed that the objectives have a greater separation than the eyepieces; with these binoculars a better stereoscopic effect is obtained at the shorter ranges than with the monocular telescope, or with binoculars having the usual inter-ocular separation for the objectives. The instrument illustrated gives a magnification of 9 diameters, and has the exceptionally wide field of view of 70°; the usual value is 40° to 50°. It

FIG. 87.—THE ROSS STEREO PRISM BINOCULAR.

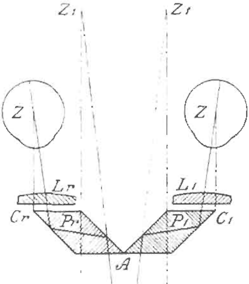


FIG. 88.—PRINCIPLE OF BINOCULAR MAGNIFIER.

has a stereoscopic power of 18. and light transmitting power of 16.

Binocular Magnifiers.—An interesting device for examining small objects under a low power magnification, has been placed on the market by Messrs. Zeiss. The principle is illustrated in Fig. 88. It will be observed that the object *F* is observed by the two eyes, *Z*, *Z* through the prisms *Pr* and *Pl*, and magnifying lenses *Cr* and *Cl*, respectively. The optical effect of this prism-lens system is indicated by the full and dotted lines. The eyes appear to observe the object as if they were at *Z'*, *Z'* respectively, i.e., with *a reduced ocular separation*. The prisms are designed on the rhomboid reflecting principle.

The binocular magnifier is a marked advantage over the single magnifier, since it enables many of the details of objects examined to be observed, which otherwise would be lost, and further gives a good stereoscopic impression. These magnifiers, which are supplied with ear attachments similar to ordinary spectacles, and

FIG. 89.—THE BAKER BINOCULAR MAGNIFIER.

also with a spring retaining band for the head, are used in natural history, medicine, geology, engineering, craftsmanship, and for other purposes. They have a magnification of 0.75 up to 3 times; the former reduction is for objects situated in a cavity. A reflecting mirror attachment, and a small electric lamp illuminator fixed between the prisms can be supplied with this instrument.

The Pinhole Camera.—It is necessary in the case of stereoscopic photographs not only to aim at obtaining as much detail as possible, but to secure sharp definition of all details. A stereogram having part of the picture out of focus, loses a good deal of its interest, except, perhaps in the case of animal and plant studies, and in portraiture, where the background is purposely placed out of focus.

There is, however, good scope for the utilizing of pinhole camera type of picture in stereoscopic work, on account of the range of definition, the softness of detail and the general pleasing nature of the tones and atmosphere of the pictures.

It is well known that if the lens of an ordinary camera be replaced by a light-tight fitted diaphragm of thin metal, having a tiny round hole, this latter will function as a lens of small aperture. The usual size of aperture is that obtained with a No. 10 needle.

A simple type of stereoscopic camera can be made with two such perforated diaphragms placed at $2\frac{1}{2}$ ins. apart; it is necessary to have a central partition inside the box in order to prevent the stray light from one pinhole affecting the plate of the other. The distance of the pinhole from the plate should be about equal to the side, or diagonal of the single picture part of the plate, e.g., in the case of stereograms of 3×3 ins., the pinhole should be about 3 to 4 inches from the plate.

The use of this type of camera is confined to still subjects, owing to the length of exposure necessary on account of the small aperture. The exposure varies from about 5 seconds in mid-summer to 45 or 50 seconds in mid-winter, at mid-day in each case. Pinhole camera subjects include architecture, statuary, mountain scenery, snow-scenes on still days.

Hand-Drawn Stereograms.*—A variety of fascinating stereograms can be made with pen and ink, if the underlying principles are understood. It is necessary to be acquainted, firstly, with the fact that parallactic displacement of one of the images of a pair to the left or right will cause the image to move backwards or forwards, when the pair is viewed in a stereoscope, and secondly with the principles of geometrical perspective. The individual diagrams must also be drawn very accurately in bold black ink lines of uniform thickness. The simplest example to begin with, is perhaps that of a receding square, as seen with the right and left eye, respectively. Referring to Fig. 90, which is not intended

* Vide also "Stereoscopy without a Camera," (C. E. Benham). *English Mechanics*, May 15 and May 22, 1925.

as a stereogram but to illustrate the method of construction, the two station points (*SP*) are drawn at $2\frac{1}{2}$ ins. apart, whilst the two points of sight (*PS*) are arranged horizontally at $2\frac{3}{4}$ ins. The two front edges of the squares are on the picture plane, and are equal in length; this equality gives the reference plane. The method of construction for the receding edges will be clear from the diagram; it should be noted that no measuring point is necessary for the right-hand diagram.

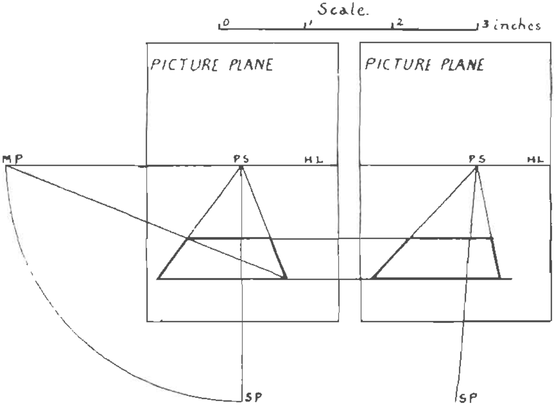


FIG. 90.—SHOWING METHOD OF STEREOSCOPIC DRAWING.
P.S. = POINT OF SIGHT. H.L. = HORIZON. M.P. = MEASURING POINT.
S.P. = STATION POINT.

If it is required to show a cube, all that is necessary is to construct squares having as upper sides, the front edges of the receding squares shown.

The important points to remember are that the corresponding points, in the two pictures must not exceed about $2\frac{3}{4}$ ins. apart, or be less than about $2\frac{1}{4}$ ins., and that the diagrams should not exceed 3 ins. in height. This condition is realized by making the SP separation $2\frac{1}{2}$ ins., and the PS distance $2\frac{3}{4}$ ins., in the example shown.

An elaboration of this method gives the result shown in Fig. 91 illustrating the law of inverse squares; as seen in the steroscope this example stands out in good relief.

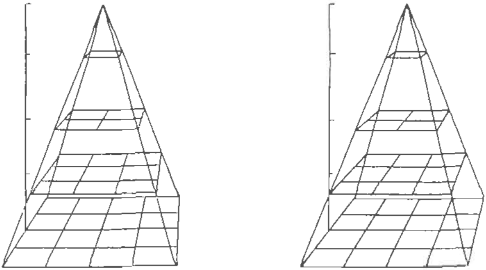


FIG. 91.—STEREOGRAM TO ILLUSTRATE THE LAW OF INVERSE SQUARES.

Hand-drawn diagrams can be made to any scale, but should be so reduced and arranged that the separation of the corresponding points is $2\frac{1}{2}$ ins.

Many other interesting examples, such as crystals, intersecting planes, perspective views and similar subjects will no doubt suggest themselves.

Compass Diagrams.—An interesting diagram may be constructed with a pair of ink compasses, by utilizing the method of displaced centres of the arcs in one of the two diagrams forming the stereo pair. An example is given in Fig. 95, in which the arc radii are equal but the centres of these arcs are displaced outwards slightly in the right-hand diagram, from their positions on the circumference of the circle in the left-hand diagram.

Other Diagrams.—The number of line diagrams forming stereoscopic pairs, which can be drawn is limitless, for once the principles of perspective and parallactic displacement have been mastered a very wide field is open to the stereoscopist. We have seen some remarkable hand-drawn anaglyphs (which are virtually,

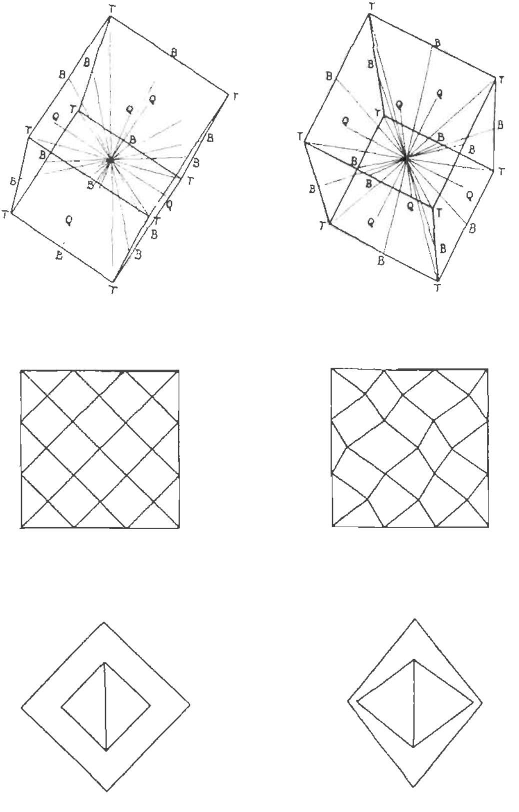


FIG. 92.—SOME INTERESTING EXAMPLES OF LINE STEREOGRAMS.

nearly superposed stereo pairs of diagrams) made in this manner, and illustrating crystal systems, geometry in three dimensions, intersections of solids and similar items of fascinating interest. A few simple stereo line diagrams are reproduced in Figs. 92, and 93. An examination and measurement of the relative positions of corresponding points in these diagrams will prove helpful to those readers who wish to make their own diagrams.

In connection with the rainbow diagram shown in Fig. 75, it will be observed that there are two identical arcs of circles but that the point of view of the observer in the right diagram is displaced to the left. The terminals of the incident (parallel) rays coming from the sun form a concentric circular arc in the left figure, but in the case of the right one form an eccentric arc with its centre to the left of the circular arc or " bow." In the stereoscope the diagrams show how all the angles from the bow are equal ; no attempt has been made to show the real angles of reflection, however.

Photo-Stereo Synthesis.—A method, devised by the Brothers Lumière, (and described in a reprinted paper in the *British Journal of Photography*, Feb. 25, 1921) for showing portraits in relief, consists in obtaining a number of transparencies representing successive planes of the subject, and mounting these one behind the other at intervals proportional to their separation in the subject, and to their scale of reproduction. When this set of transparencies is suitably illuminated by a strong transmitted light, and is viewed from the front, a striking impression of solidity is experienced. The method involves the taking of a number of photographs, each with the lens in a slightly different position, so as to focus successively on the selected reference planes through the subject. It is necessarily more complicated and expensive than the ordinary anaglyph or stereogram.

Apparatus for Drawing Stereograms.—It is not difficult to devise an apparatus of the compound pendulum type which will actually draw, or trace out pairs of curves forming stereoscopic pairs. The principle employed consists in providing two pens or tracing pencils, one of which is given a small difference of phase, so as to obtain the necessary parallactic displacement.

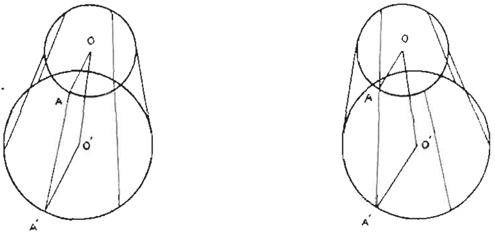


FIG. 93.—ANOTHER EXAMPLE OF LINE STEREOGRAM.

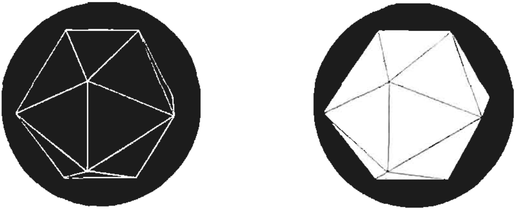


FIG. 94.—STEREOGRAM OF CRYSTAL SHOWING IRIDESCENT EFFECT.

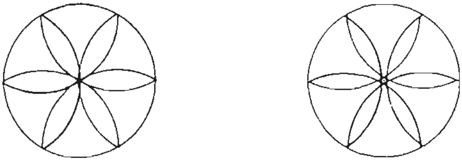


FIG. 95.—PEN BOW DIAGRAMS.

In this way some very beautiful and complicated curves can be constructed automatically, which when viewed in the stereoscope stand out in relief, with their loops, cusps, and other convolutions appearing in different planes, exactly as though constructed of thin wire.

Fig. 96 illustrates a twin-pendulum apparatus * for drawing stereograms; it belongs to the twin-elliptic class. By means of this simple device a harmonic displacement in a lateral direction may readily be obtained. For this purpose it is only necessary to

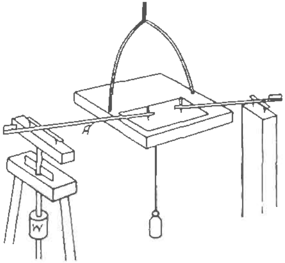
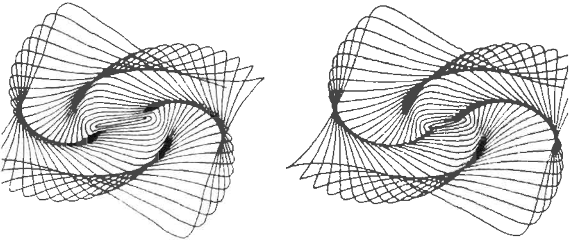
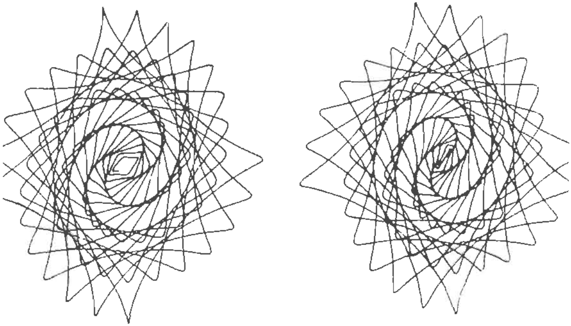


Fig. 96.—Twin Elliptic Pendulum Apparatus.

use two pens working simultaneously, one of which is given a slight lateral oscillation in tune with the pendulum as a whole. By such means no vertical displacement is introduced. It is clear that, taking the simplest case of an ellipse, the lateral oscillation of one pen with each sweep of the ellipse will merely cause one of the two ellipses to be wider than the other, exactly as a phase alteration does in the rectilineal harmonograph, as already explained. Here again the principle so obviously operative in the case of a simple ellipse must also hold good for any of the more complex twin-elliptic figures, as they are all compounded elliptical movement.

* "Stereoscopic Twin-Elliptic Pendulum Curves." C. E. Benham. *English Mechanics*, Mar. 20, 1925.





FIGS. 97 AND 98.

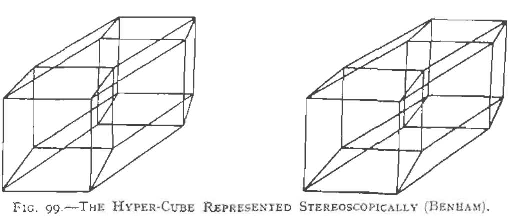


FIG. 99.—THE HYPER-CUBE REPRESENTED STEREOSCOPICALLY (BENHAM).

The practical method of obtaining these effects consists in having one pen-lever supported on a fixed base while the other rests on the head of a pendulum rod tuned to the period of the main pendulum, and introducing, as it swings on a knife-edge, a harmonic lateral displacement, which should not exceed a quarter of an inch, so that very slight oscillation of the laterally swinging rod is necessary.

Fig. 96 shows at a glance the general construction of the apparatus. The pendulum rod bearing the pen-lever *A* is on a knife-edge and gives the pen a slight lateral motion, each oscillation being accomplished in the period of one orbit of the main pendulum. The tuning for this is easily effected by sliding the movable weight *W* along the rod until its period is found to harmonise with that of the main pendulum. Absolute harmony is not essential, or even desirable, but there should be sufficiently close coincidence to present no appreciable variation of phase for at least two oscillations.

It is of course necessary that the two pens should be in the line of lateral movement, and they should be from $2\frac{1}{2}$ to $2\frac{3}{4}$ ins. apart, the proper stereoscopic distance.

To ensure that the two pens start together a loose sheet of paper may be interposed between the pens and the actual sheet used for the stereogram. After the pendulum has been started the loose sheet may be gently but quickly drawn away. The loose sheet should have a horizontal line ruled across it as a guide for the correct placing of the pens at the outset.

The tendency at first is to introduce too much displacement. A quarter of an inch is the maximum allowable, otherwise separations beyond the limits of stereoscopic accommodation would be introduced.

The results, though of no practical or commercial value, are of such varied beauty and fascinating interest that they will repay any worker with the twin-elliptic pendulum for the very small trouble of fixing the attachment described. Two examples are shown in Figs. 97 and 98. The chief difficulty is perhaps in ensuring that the two pens give an exactly equal line, but it is here assumed that the experimenter knows how to make and manipulate the glass pens generally used in harmonograph work. With a little practice these are readily made. The glass tubing, having been heated in a flame and drawn to a fine point, is quickly sealed at the tip in the flame and then ground down on a fine hone with water until the aperture is just reached, after which the " shoulders " of the point are gently ground off on the hone.

The Hyper-Cube in Stereoscopic Representation.*—Fig. 99 *is intended to represent the parallel case in four dimensions* of the cube in three dimensions. Regarding the latter as two parallel squares joined by lines, the former may be said to represent two cubes joined. By means of the stereoscope the theoretical representation of the hyper-cube can be traced. Two separated cubes must be perspectively drawn as they would appear to the right and left eye, respectively. Lines must then be drawn connecting corresponding corners. Just as the cube has eight terminal points, so the hyper-cube has sixteen, four being within the figure. The illustration is, of course conjectural but may be regarded as the shape in three dimensions of the hyper-cube as seen by a being with four-dimensional sight or sense.

Correction of Distortion by the Stereoscope.—One of the most interesting facts concerning stereoscopic photography is that the stereoscope corrects automatically the distortion produced in the individual photographs forming the stereo. pair. Thus if a pair of photographs be taken, with a stereo camera, of a tall *building, nearby, each individual picture will appear to be hopelessly* distorted and out of proportion. As a single photograph it will convey a somewhat exaggerated and even ridiculous impression of little value as a record. Viewed in the stereoscope with lenses of appropriate focal length all sense of distortion is at once lost, *and the building appears in solidity* and *perspective*, just as it does to the eyes. The stereoscope thus provides a means of correction to the single pictures forming the pair. Another familiar example is that of a sitter's feet which appear out of all proportion to the rest of the body. If a stereo pair of such pictures be viewed in the stereoscope, the abnormality at once

* " The Hyper-Cube Stereoscopically Represented," C. Benham. *English Mechanics*, Sept. 4, 1925.

disappears and a perfectly natural view of the subject is obtained. Some typical examples are given on Plate No. 10.

The reason for this is that although each lens of the camera gives a distorted view, yet similar views are actually impressed on the retinae of the eyes, but owing to the binocular merging, a true impression is obtained. The eyes and stereoscope both view the different features of the picture in their true planes, and thus obtain the correct impressions.

Many beginners and amateurs who make a point of focussing their pictures beforehand, on the ground-glass screen, have been misled into believing that the distorted individual pictures on the screen will result in an exaggerated stereoscopic result; this is of course, quite erroneous. Many an apparently hopeless single view of a tower, spire or lofty building may prove an admirable *stereoscopic subject.*

Inaccessible Subjects and Distant Views.—In a previous chapter we have referred to the method of employing a greater separation between the taking lenses, in the case of distant views, and have given a formula to estimate the base-length, or separation.

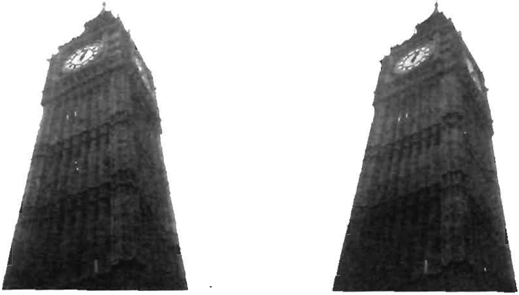
This method of extended bases, or "giant's views" has a number of interesting applications in practice; a few examples are dealt with in the present volume. Provided that there *are no moving objects in the scene*, and that there is *no foreground appearing*, some excellent results may be obtained, giving perfect relief to distant objects.

The method is of particular value in the stereoscopic photography of mountain scenery (Plate 3), distant towns and landscapes.

Thus a distant town, hill or mountain, which to the eye, on account of its distance, fails to excite a sense of relief, may, by a *suitable extension of the base-length or distance between the two* lens positions, reveal a marked degree of solidity and perspective in the stereoscope.

Cloud Photography.—The same method has been applied to the stereoscopic photography of cloud masses. In this case, if the *clouds* are moving steadily, a single lens camera placed at one definite spot may be used; with a little experience the

FOCUS OF STEREO CAMERA LENS [illegible] MM



BIG BEN (LENS FOCUS = 80 MM.)

WESTMINSTER CATHEDRAL (LENS FOCUS = 80 MM.)

ILLUSTRATING DISTORTION CORRECTION IN THE STEREOSCOPE.

To face page 158.

correct interval between the exposures for good relief may be ascertained. It should be remembered that for the best contrasts panchromatic plates and deep yellow, or contrast filters should be used, preferably Wratten K.3. or K.4. screens. The method of exaggerated perspective by employing the extended base has been much employed in aerial photography for showing up clearly small variations in height of buildings and ground undulations, trenches and earthworks. Examples of such stereograms are given in Plate 18. In astronomical stereo photography, advantage also is taken of the principle of extended bases in order to show celestial objects in relief; further reference is made to this point in another chapter.

Geological Photographs. An interesting account is given in a paper on *Stereoscopic Photography in Geological Field Work*, by F. E. Wright, *of the Geophysical Laboratory of the Carnegie* Institution of Washington, in the Journal of the Washington Academy of Sciences. In it he gives the details of a mathematical and experimental investigation of the recognition and representation of depth (the different distances and objects in the line of vision), and comes to the following conclusions: In geological field work, stereoscopic photographs taken with an ordinary camera are of value to the geologist. Details which may have escaped notice are indicated more emphatically than in a single photograph. No special apparatus is required. It is advisable to take the two photographs, one after the other, the distance between the two cameras stations to be from 1 to 5 per cent. of the distance of the object, the camera in each position to be pointed at the object and the line joining the camera stations to be approximately normal to the lines of sight to the object. The stereoscopic effect can be enhanced if enlarged prints are made and a lens stereoscope of the ordinary type is used in the examination of the prints.

Stereoscopic Apparatus for Motion Study.—It is now possible to examine inexpensive stereogram sets, arranged in the form of cinematograph films, of various subjects, by means of a French device known as the "Magster" (an abbreviation for Magazine Stereographique). This apparatus, which is illustrated in Fig. 100, shows the exact details of each of a series of pictures taken from life by means of a stereoscopic cinematograph camera, and depicting the various actions of a technical expert or a specialist. On the film is found the exact or relative time taken, together with speed or direction, and particulars relating to the method employed by an expert worker to obtain the maximum output. By observing such a film with a wide angle

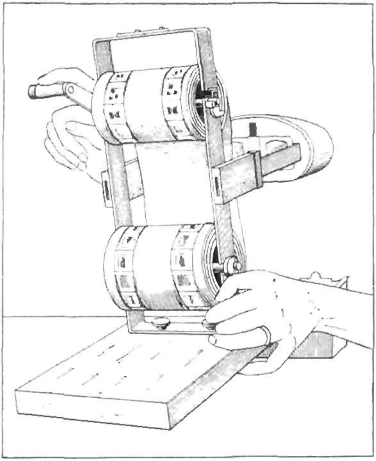


FIG. 100.—THE MAGSTER MOTION STUDY APPARATUS.

stereoscope it is possible to compare a dozen pictures at the same time without turning the handle. Thus one is able to give an account of the factors which contribute to professional ability (slow or rapid movements, muscular contraction, automatic repetition of the actions, etc.). At the side of each picture the apprentice or engineer is able to discover the reason for, and the proof of, the characteristics which it contains, and the need, scope and importance that it suggests for the practical routine, so as to increase production by diminishing the fatigue of the individual. Thus the "Magster," by a process as ingenious as it is simple, places the result of industrial importance before the foreman, apprentice, engineer, or professor. This apparatus is of particular interest to welfare workers, and those engaged in problems relating to motion study and industrial fatigue.

Stereoscopic Effect by Direct Vision.—Dr. Estanave, of Marseilles, has produced a special plate which gives a stereoscopic effect of relief by direct vision, on the single picture. The theory of the effect may be explained as follows: If two photo-

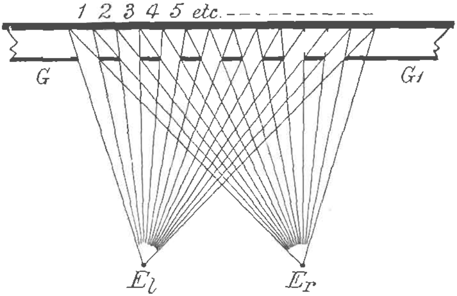


FIG. 101.—ILLUSTRATING THE PRINCIPLE OF THE AUTOSTEREOSCOPIC PLATE.

graphs of a stereoscopic picture be cut into thin sections each one of which is numbered 1, 2, 3, etc., the even sections being placed on the left image, and the odd sections on the right, two images are obtained which give a stereoscopic effect, provided that the sections are sufficiently thin. Suppose now a third image in which the odd sections of the left are placed side by side with the even sections of the right, then the sections will be in correct numerical order, the narrow sections of one of the stereoscopic pictures alternating with those of the other. All that is necessary to complete the stereoscopic effect is to place a grill of fine parallel bands before the pictures. Thus the eye at *El* sees the odd while the eye at *Er* sees the even sections.

The "autostereoscopic" plate has a grill of fine bands printed or traced on the glass side of the plate In order to obtain a composite picture an ordinary stereoscopic negative is obtained, each image is projected on to the special plate, which is placed so that the glass side is in front. The light rays are automatically filtered by the grill. Development is carried out in the usual manner, hydroquinone being specially recommended on account of bringing out the lines into relief, as the image is composed of banded sections. A photograph is thus obtained which can be enlarged and the transparency gives an impression of relief.

CHAPTER XIII

ANAGLYPHS.

AN *Anaglyph* is type of stereoscopic picture, in which each of the two pictures forming the stereoscopic pair is printed in red, and in green respectively, and are superposed, with one of their pairs of corresponding points coincident. The result obtained is a blurred combination of the red and green pictures, with certain parts on the edges showing either red or green. If we arrange that the right hand picture of the stereoscopic pair be printed in red, and the left in green, then, on looking at the combination through two pieces of stained celluloid film, placed in such a way that the right eyes looks through the green screen and the left eye through the red one, then *each eye will only be able to see the picture taken from its own viewpoint ;* the result will be a stereoscopic rendering of the picture.

The above explanation will be clearer, perhaps, if it is stated that if a red picture is viewed through a red screen, it will not be visible—it will, in fact, disappear. It can only be seen through a coloured screen of a complementary, i.e., a green colour. The invention of the Anaglyph was due to M. d' Almeida and Ducos of Hauson.

Advantages of the Anaglyph Method.—Unlike the ordinary stereograms, the anaglyph takes up only about the space of a single picture, so that for reproduction purposes a good deal of space is thus saved. Moreover there is practically no limit to the size of the picture by the Anaglyph method, whereas the size of the stereogram is strictly limited by the separation of the prints, i.e., to widths of 2½ to 3 inches. The anaglyph method has been much used in France, by periodicals, e.g., *L'Illustration*, for the purpose of showing pictures in relief, in the case of different publications. In this country the *Illustrated London News*, has created a good deal of interest in stereoscopy, by the excellent

Anaglyphs which have been published as a regular feature, these pictures are very much more realistic and of much greater interest than the best single pictures.

With each issue of the paper mentioned, containing anaglyphs, a pair of red and green spectacles, or viewing mask is given. These masks can be purchased separately. The anaglyphic method is also used in connection with aerial survey work, an account of this application being given in Chapter XVIII.

Anaglyphs have an interesting, and very useful application in connection with the stereoscopic representation of geometrical figures, crystal formations and other complicated three-dimensional figures. M. H. Vuibert, in his book *Les Anaglyphes Géométriques* gives many excellent examples of the application of this method to the study of various solids, including the conic sections, celestial spheres, figures in cubes, crystals with different formations or facets, projections of solids and intersections of planes, solid sections, the illustration of refraction in a solid, perspective view of a windmill and similar examples. The diagrams are very well executed and on a large scale, suitable for observing with the viewing mask supplied. The examples given in this book represent the result of a considerable amount of accurate and painstaking work on the author's part.

Limitations.—Those who have viewed ordinary print or transparency stereoscopic pictures will agree that they are superior to the anaglyph in stereoscopic rendering. The majority of anaglyphs give the relief impression of a series of thin cardboard models of the different objects placed in different planes; in other words they appear to lack roundness, but show distance.

There is also an appreciable loss of light through the viewing mask screens, due to absorption; this necessitates a stronger viewing light. Further, if light-tones, or white objects figure in the pictures, the red and the green inks or dyes have a disagreeable habit of appearing to wander on to the whiter portions. Anaglyphs can only be shown in monochrome, whereas stereograms lend themselves in many cases to colour reproduction. For this reason line anaglyphs are not quite satisfactory, as a rule. The process of making anaglyphs is more complicated, and liable to errors, than that of obtaining stereograms, from the amateur's point of view. Its real domain lies in press publication and commercial reproduction work, and for magazine, periodical or catalogue illustration purposes.

Production of Anaglyphs. The following notes are given for the benefit of those who desire to make anaglyphs from ordinary stereoscopic negatives.

A method which gives good results employs the Pinatype process,* in which positives are made on transparency plates which are sensitised in ammonium bichromate and exposed to light through their backs. The gelatine is thereby hardened, in the well-known manner, proportionally to the amount of light which has passed through; thus the darkest parts of the negative will allow the least light to pass, and the gelatine will be left in its soft condition; where the negative is thin, or light, the greatest hardening occurs. The plates are then stained with special dyes, the Pinatype Complementary Red *D* being used for the left hand picture, and Pinatype Complementary Green *D*, for the right one.†

The dyes are absorbed most by the softer portions of the gelatine, and least by the harder parts. Further if such a dye-soaked gelatine film plate be squeezed in contact with a piece of gelatine coated paper, it will give an excellent positive impression. Each of the red and green positives is impressed on the paper, in turn, and in its correct relative position. The gelatine coated paper is best prepared by fixing out gaslight or bromide paper and hardening in a 5 per cent. formalin solution; it is better to employ a matt surface. Negatives are developed in the usual way, with a hydrokinone, or amidol developer, for preference (pyro-soda has a tanning effect), and after thorough washing are placed in the following solution for a few minutes :—

Ammonium bichromate........	10 grammes
Ammonia Solution (0.880)......	100 c.c.
Distilled Water	500 c.c.

The plates are then dried in the dark, and afterwards exposed to light through the glass side, when the gelatine is affected in the manner previously stated.

* A full account is given in *English Mechanics* for December 25, 1925. "Anaglyphs with a Hand Camera." R. A. Fairthorne.

† Due to the prints being reversed in the process, and having to be transposed.

The original right-hand image of the negative is printed in green, and the left, in red, due to the reversal of the prints in the printing process. The standard viewing mask has a green screen for the right eye, and a red one for the left eye. The finished anaglyph has a green edge, or rim on its right side and a red rim on its left side.

Anaglyphs can also be made by the carbon,* or double transfer photographic process. In this case, as in trichrome work, the carbon prints are mounted on temporary supports of waxed transparent celluloid. When the print has been transferred to its final paper, the surface is cleansed of wax with benzine, and the second print superposed on it, a little out of register, in the manner described hereafter. The tissues recommended are the Autotype Co's "Trichrome Red," and either their "Bright Green No. 158," or "Viridian Green": the latter gives rather better results.

General Notes.—It is very important to remember that the anaglyph process requires the best photographic negatives. Sharpness of detail must be the first consideration; any blurred, or out-of-focus portions of the pictures will not merge satisfactorily in the final result, and will detract from the general interest in the picture. For this reason it is better to stop down until all of the objects to be seen in relief are in sharp focus.

It is also advisable in selecting subjects for anaglyphs to aim at strong foregrounds, and marked solidity and distance effects. If distant landscapes or objects are to be shown, select some object of appreciable solidity, or relief, in the foreground to form a kind of stereoscopic datum or reference.

In arranging the two coloured prints on the gelatine paper, or by any other suitable process, it is necessary to so place the second block or dyed bichromated gelatine plate on the distant points of the first image coincide with distant point of the image of the printing plate; in this way the *stereoscopic image stands out of the picture.* If the *near points* are arranged to coincide, *the image will stand away.*

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* Vide, "Anaglyphs," by H.E.D., *English Mechanics*, Mar. 13, 1925.

In cases in which the distant points are not shown, as with near objects, the following relations will be found useful :—

Let d = distance in inches to the right of the corresponding red point, which a point on the green print has to be placed, to make the corresponding stereo image *stand out* D inches *in front* of the paper.

X = distance of observer's eyes from the anaglyph.

O = Ocular separation (2.5 inches).

$$\text{Then } d = \frac{O \times D}{(X - D)} = \frac{2.5 \times D}{(X - D)} \text{ inches.}$$

If d^1 = distance in inches of a point on the green print to the left of the corresponding red print, required to make the corresponding stereo image *stand back* D inches *behind* the paper.

$$\text{Then } d^1 = \frac{O \times D}{(X + D)} = \frac{2.5 \times D}{(X + D)} \text{ inches.}$$

CHAPTER XIV

THE EDUCATIONAL VALUE OF THE STEREOSCOPE.

MOST people associate the use of the stereoscope and the pairs of stereoscopic pictures (known as *stereograms* or *stereographs*) with the portrayment in natural relief of topical subjects only; for example, interesting landscapes, buildings, street scenes, topical events and travel scenes. There is, however, a very much deeper and wider application of the stereoscope which is now becoming recognised, and which undoubtedly has a great future before it, namely, its use for instructional and educational purposes.

Hitherto, with a few notable exceptions, it has been the custom to teach technical, medical and other students, pupils and ordinary school children by means of lantern diagrams and photographic illustrations in the form of flat prints. For ordinary flat or two-dimensional diagrams and illustrations this method is fairly satisfactory, but when it becomes necessary for the lecturer, or teacher, to explain solid objects, and those situated at different distances from the observer's camera, or eyes, it becomes increasingly difficult to convey the proper impression. As an example, suppose that the teacher of solid geometry wishes to demonstrate the properties of a line, curve or solid in space, in relation to its three co-ordinate planes, he can only do so with the aid of a two-dimensional (or flat) diagram, either in perspective view, or in projection on the planes of reference. Frequently, the student is quite unable to form a mental picture of the object under review and thus finds the subject a difficult one to grasp. Give him a stereoscope and stereogram of the object, however, and he is at once enabled to observe the actual object in *three dimensions*, as if he were holding a model in his hand, and examining it. There is the further advantage, also, that with suitable stereograms, several objects, curves and reference planes can be observed, suspended, as it were, in space, the eyes being able to see all around, in a manner which is impossible even with the actual models themselves.

We have taken a rather advanced example of the educational value of the stereoscope, in order to render clearer our explanations of its more elementary uses. A little consideration will show that if stereoscopy is of value to the ordinary technical student it is also of greater value to the elementary school pupil, who has

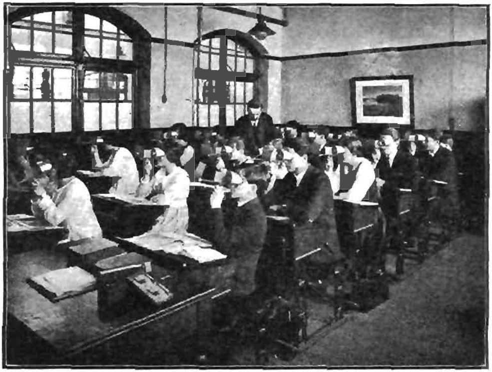


FIG. 102.—THE GEOGRAPHICAL CLASS ROOM, LATYMER SCHOOL, EDMONTON. ILLUSTRATING THE USE OF THE STEREOSCOPE IN EDUCATION.

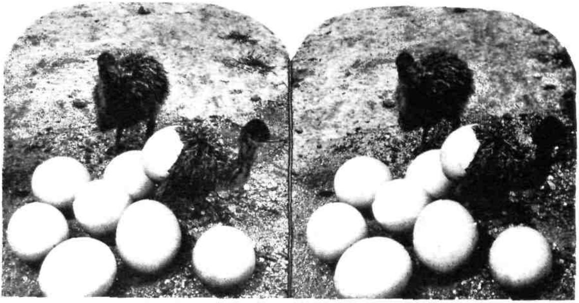
not attained the same standard of mental training, imagination and perception as the former.

Elementary School Education.—The teacher frequently finds it difficult, more particularly when giving instruction in subjects such as geography, natural history and travel, to create the correct impressions of the objects or features described, in his hearers' minds. The pupil being, as a rule, quite ignorant in the first place of the appearance, size and details, can only be instructed by means of models, diagrams and flat pictures. These are, of course, quite helpful, but many objects cannot be thus represented, on account of expense considerations, whilst in the case of pictorial illustration, as we have previously emphasised, the flat picture lacks solidity, relief or perspective, and is a poor substitute for the real three-dimensional impression.

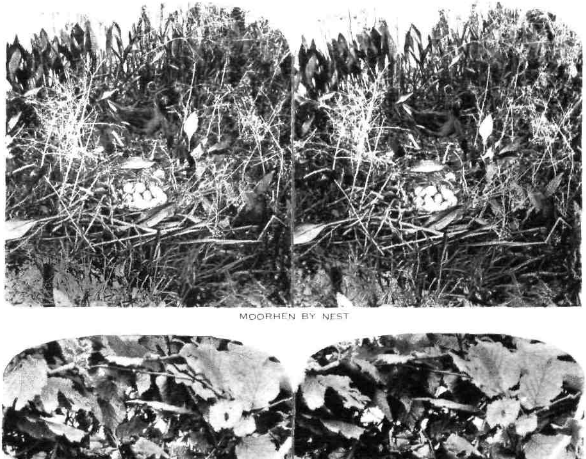
It is now possible, thanks to the perseverance and forethought of one or two commercial bodies, to obtain excellent stereograms of a very wide range of educational subjects, carefully selected for the purpose. Thus, Messrs. Underwood-Keystone Stereographs, Ltd., of New Oxford-street, London, have a selection of over half a million stereograms, of high photographic quality, taken in all parts of the world, and of a very wide range of educational and general subjects. These stereograms consist of a pair of actual photographic prints (taken with a stereo camera) mounted on the standard card mount, on the back of which are full descriptions of the objects shown. In many schools it is now the rule to supply each scholar with a robust pattern stereoscope and the necessary stereograms of the lesson subject so that he or she can obtain an excellent mental concept of the subject taught.

The firm mentioned above have issued a comprehensive list of school subjects and prices (the sets being quite inexpensive) which they supply.

Stereoscopic Aid to Geometry Teaching.—As far as plane or two-dimensional geometry is concerned there is no need, of course, for the use of stereoscopy in depicting the geometrical diagrams. In the case, however, of solid geometry the stereoscopic method of illustrating diagrams will be found extremely valuable. Nothing is more disconcerting to the student than a mass of intersecting lines, intended to represent planes with different inclinations, when studying rectilinear solid geometry. In the stereoscope method, however, the various planes stand out in their natural positions, exactly as if they were made of thin glass sheets with wire framings, and one is thus able to see through the nearer planes and obtain a very clear impression of the whole disposition, or arrangement. The stereoscopic method has the advantage over actual models that everything can be seen at once, and objects can be shown suspended in space,



OSTRICH EMERGING FROM EGG



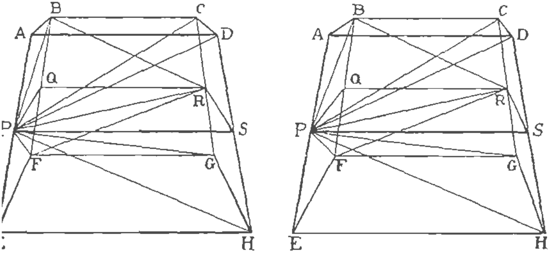
MOORHEN BY NEST

HAWFINCH AND NEST. *(Underwood-Keystone Stereographs Ltd.)*

SOME EXAMPLES OF NATURAL HISTORY STEREOGRAMS.

with their reference, or co-ordinate planes in the back—or side—ground; with models this can only be achieved with the aid of supports; and the latter are apt to detract attention from the intended objects. Figs. 103 and 104 illustrate two typical *geometrical stereograms.*

Fig. 103 shows a typical example of a geometrical stereogram and illustrates the prismoid. If these diagrams are examined in a stereoscope it will be observed that the lines PA, PB, PC, PD, PR, PF, PG and PH all radiate in different directions from P,

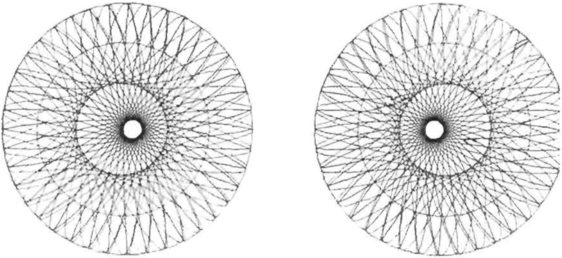


(Underwood-Keystone Stereographs, Ltd.)

FIG. 103.—A GEOMETRICAL STEREOGRAM.

and in different planes. The effect observed is that of a wire frame made in the form of a prismoid, with a central horizontal plane PQRS, and radiating diagonals from P and R.

Every solid geometry diagram may be shown in this manner. In particular the conic sections can be well illustrated. Messrs. Carl Zeiss, in their standard series, show an X-ray type of stereogram of a cone, built up of different parts in such a way that these latter represent sections cut by planes parallel to the base, inclined to the base, parallel to the height and the sloping edge, thus giving the conic section curves known as the circle, the ellipse, the hyperbola, and the parabola, respectively. The half-tone illustration in Plate No. 6 is a reproduction of this stereogram. Stereograms have been made of most of the known solid shapes. Apart from the above examples mention may be made of the use of stereograms in depicting complex curves, spirals and looped figures in space. Some examples of the twin-elliptic pendulum curves are given in Figs. 97 and 98. As a final example we shall refer to Sir George Greenhill's stereoscopic diagrams illustrating the *elliptic integral* curves which are associated with mathematical problems involved in the motion of the spinning top, and gyroscope, a catenary on a sphere, and in algebraic formulae. Fig. 104 illustrates one of the elliptic integral curves



(Underwood Keystone Stereographs, Ltd.)

FIG. 104.—THE ELLIPTIC INTEGRAL CURVE.

referred to. This set of twenty-four stereograms of mathematical figures and their algebraic formulae has been prepared by Sir George Greenhill and T. T. Dewar, and is published by Messrs. Underwood-Keystone Stereographs, Ltd. The curves illustrated were drawn very accurately on a large scale and afterwards reduced to the stereogram size.

Abel's theory of the pseudo-elliptic integral is utilised when the integral is of the third kind, by making its elliptic parameter a simple aliquot part of a period. The solution of the mechanical problem can then be made algebraical, and the curves drawn with ease and accuracy, and made into stereograms. The analysis is explained in " The Applications of the Elliptic Function," 1892, and in articles in the Proceedings of the London Mathematical Society, 1895, 6 and 7 and Phil. Trans., 1904.

The preparation of the stereograms in question involved a very large amount of labour, in connection with the solutions of the equations required in the calculation of the crossing points of the curves, to serve as standard points of the diagram between which the curved lines were drawn in stereoscopic representation. The curves of this series include the algebraical spherical catenaries in various numbers of festoons and loops, the gyroscopic curves (including the rosette gyroscope curve), the geodesics on oblate and prolate spheroids, catenaries on vertical cone, and vertical paraboloid, and revolving spherical catenaries. These stereograms give an excellent space-position effect and show very clearly the true shapes of the curves in three dimensions.

Stereoscopy and the Teaching of Optics.—The elementary student of optics usually experiences a difficulty in following the usual diagrams representing the paths of rays of light in three dimensions. For example in the case of simple lenses, the usual diagrams frequently appear as a mass of super-imposed lines representing the light rays. In the stereoscopic method, however, every line appears in its correct position and the general paths of the rays appear perfectly easy to follow. The diagrams illustrating the errors of lenses, notably spherical aberrations and astigmatism, are always difficult for the student to grasp, as these attempt to represent in a single plane (two dimensions) three-dimensional phenomena; the stereogram at once simplifies the picture and a correct mental impression is at once obtained.

Another frequent stumbling block with students is that of the polarisation of light; the latter is essentially a three dimensional phenomenon. The usual ether wave theory pre-supposes light vibrations to occur in all directions normal to its path as shown in Fig. 105, in which the point *O* is intended to represent the "cross-section," as it were, of a ray of light. The arrowed lines Oa, Ob, Oc, etc., then show how the ether particles are assumed to vibrate. It is quite easy to illustrate this particular property, but when one attempts to show the modes of vibration of the ether when a ray of light is polarised, it is more difficult, more particularly when the optical properties of crystals and planes at different angles are considered. It is here that the stereoscope affords a valuable help to the student, for it at once enables him to follow every phase, in space, of the ether vibrations and light ray changes of path. In this connection an interesting series of stereograms

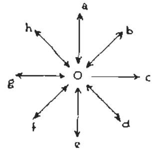


FIG. 105.—ILLUSTRATING THE ETHER VIBRATIONS PERPENDICULAR TO THE DIRECTION OF A RAY OF LIGHT.

FIG. 106.

FIG. 107.

FIG. 106 AND 107.—ILLUSTRATING PRINCIPLE THAT LIGHT VIBRATIONS ARE MOVEMENTS IN ALL DIRECTIONS AT RIGHT ANGLES TO THE LINE OF PROPAGATION.

FIG. 107.—SHOWS A SERIES OF 4 SUCH ETHER PARTICLES VIBRATING IN 4 DIFFERENT PLANES, EACH AT RIGHT ANGLES TO THE DIRECTION OF PROPAGATION.

has been prepared by C. E. Benham, of 28, Wellesley Road, Colchester, and is on the market. The set comprises ten stereoscopic diagrams, in which the light rays and the outlines are shown by white lines on a black background. This method enables a very strong and clear stereoscopic effect to be obtained, for the black background gives an excellent contrast. The first five stereograms illustrate the principles of the light vibrations, amplitudes and wave-lengths in three dimensional space ; they show at a glance the planes and directions of vibrations of the particles. The other five stereograms show, in a beautifully clear manner, the polarisation of light by reflection and refraction, as viewed in space, and the principle of double refraction by a rhomb of Iceland Spar. The effect of crossed Nicol prisms and

FIG. 108.—NICOL PRISM.

A rhomb of Iceland spar divided diagonally and then cemented with Canada balsam. The ray entering at the upper surface is doubly refracted, and the "ordinary" ray is "totally reflected" by the layer of Canada balsam. The "extraordinary" ray emerges as a single ray of plane polarised light.

FIG. 109.—CROSSED NICOLS AND INTERFERENCE.

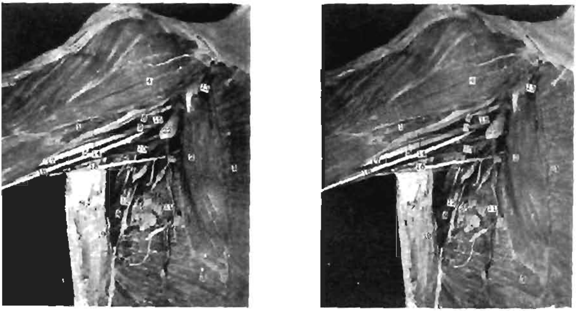
Between the crossed Nicols is a plate of selenite, the planes of which are shown by cross lines. Ray from first Nicol has its plane resolved into two by the selenite, and these two are again resolved by the second Nicol. Owing to the unequal retardation of the 2 rays in the selenite, interference may occur when the two are reduced to the same plane by the second Nicol. Interference of any given wave length suppresses corresponding colour sensation, and tinges the surviving light with the complementary colour.

a plate of selenite, upon the light ray, and its ether vibrations, is very clearly shown in another of these highly instructive stereograms. Explanatory notes and a printed pamphlet are included in the set of stereograms described. Sufficient has been said, we think, to indicate the great utility of the stereoscopic method of presenting optical diagrams and illustrations to emphasise this method. It may, however, be added that in connection with the study of crystallography and atomic or stereo chemistry, the use of the stereogram will prove of great value to the student, and others interested. It is not sufficient for the lecturer to show models during his lectures; these are frequently forgotten by the student, for later when at his private studies he is unable to remember the complex solidities and perspectives. If, however, he has a few stereograms available he can at any time study these and refresh his memory.

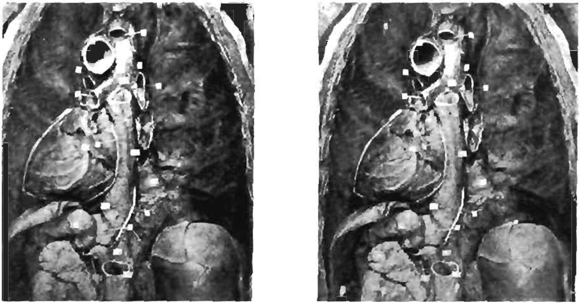
Stereoscopy and Anatomy.—A very comprehensive series of stereoscopic photographs illustrating the complete dissection of the entire body systematically (by Messrs. Underwood-Keystone Stereographs, Ltd.) has for some time been on the market; it is known as the Edinburgh Series. The stereograms, which are excellent, both photographically and stereoscopically, were prepared, in the first place, under the authority of the University of Edinburgh by Prof. D. J. Cunningham, assisted by Drs. D. Waterson (Senior Demonstrator of Anatomy), Prof. M. H. Cryner (Philadelphic General Hospital Visiting Surgeon), and Dr. F. E. Neres (Chief of Clinic, Manhattan Eye, Ear, Nose and Throat Hospital). Two of these are reproduced on Plate 12.

The present revised edition represents a big advance in demonstration methods, on account of the clearness and detail of the stereograms. The authors availed themselves of the method of preparation and preservation of the anatomical specimens by the use of formalin; this is especially important in respect to the *viscera*, both solid and hollow, situated in the cavities of the body; but it also applies to many other structures, so that the position and relation of many blood vessels, nerves, layers of fascia and other structures are well preserved for illustration purposes. The dissections, from which the stereoscopic photographs were made, were undertaken by recognised authorities in anatomy.

The collection in question consists of ten different sections, each containing from 10 to 36 separate stereograms. The section



WALLS OF AXILLA



(Underwood Keystone Stereographs Ltd.)

BACK—THORACIC ORGANS IN SITU FROM BEHIND

ANATOMICAL STEREOGRAMS SHOWING THE HUMAN BODY DISSECTED subjects include the following: Cranio-Cerebral Topography. Central Nervous System, General Nervous System, Thorax, Heart and Pericardium, Head and Neck, Mediastina, Upper Limb, Abdomen, Inguinal Region, Lumbar Region, Viscera, Perineum, Pelvis, Lower Limb, Internal Anatomy of the Face, the Nasal Chamber, Frontal Sinus, and Normal Anatomy of Temporal Bone and Internal Ear. Each of the stereograms is mounted on a card of about three times the normal picture height, the upper part containing a good deal of descriptive text to facilitate ready reference from one to the other; no difficulty is experienced in following the description whilst using the stereoscope. The complete set consists of 324 stereograms. There is also a series of 36 views entitled Appendectomy (Operative Surgery), in which the progressive surgical operations are depicted section by section. There is little doubt that these realistic records of anatomy are a most valuable aid both to the student and practitioner, and as a permanent reference means. We shall refer later to another branch of anatomical application of stereocopy, namely that of the X-rays.

CHAPTER XV

STEREOSCOPY AND MICROSCOPY.

APPLICATION of stereoscopic principles plays a most important part in the microscopic examination and photography of minute objects; there is strong evidence to show that in the near future it will become of increasing importance now that its advantages are realized.

Binocular Vision and Stereoscopy.—Many microscopes are fitted with two viewing eyepieces instead of the usual single eyepiece (or monocular), principally for the purpose of enabling both eyes to be used at the same time. It is a common experience that after from 10 to 15 minutes examination through a monocular type microscope, the eye becomes fatigued and perception of microscopic detail is impaired; it is therefore necessary to rest the eye for a time before proceeding. A further drawback in connection with the use of one eye is the loss of visual intensity, which necessitates the employment of a stronger illumination than is advisable, or required with two eyes. The binocular microscope not only prevents fatigue of the eyes, but enables better perception to be obtained.

The binocular microscope, or attachment to an ordinary microscope does not always give stereoscopic vision, some of the models having been designed for the purpose above mentioned. On the other hand most modern binocular microscopes, will, (sometimes with the aid of suitable stops or diaphragms) show very good stereoscopic effects.

Principles to be Observed.—The principle to be observed here, for stereoscopic vision is that the light rays from the right-hand side of the object under observation must be viewed with the right eye, the left-hand rays being cut-off, or excluded; similarly the left-hand side-light rays should be seen only with the left eye

The *inter-ocular distance* (between the eyepieces) should be made variable to suit the eye-separation of the observer. Most manufacturers allow a variation of 55 to 75 mm.; the normal inter-ocular distance is in microscopy 65 mm.

The binocular system should, of course, give *an erect image*. For this reason it is necessary to include in the ordinary optical system (which normally gives an inverted image), an erecting system. The latter is usually a combination of prisms interposed in the path of the rays, and which by utilizing the principle of reflection reverses the position of the image. The Porro erecting

FIG. 110.—THE PORRO ERECTING PRISM (BAKER).

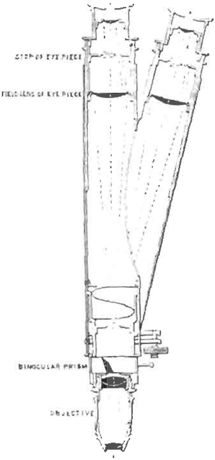


FIG. 111.—THE SWIFT-STEPHENSON ERECTING SYSTEM.

prism is one of the best known erecting systems. This is illustrated diagrammatically in Fig. 110, from which the paths of the light rays can readily be traced. It will be observed that each ray undergoes four internal reflections, in all, and lies in two planes at right-angles. Another efficient erecting system is the Stephenson (manufactured by J. Swift and Son, Ltd). This system is considered much better for prolonged observational work; further, it enables the body of the microscope to be set at an angle relatively to the object.

Types of Binocular Microscope.—There are three principal types of binocular microscope, or attachments in common use, namely: (1) The Binocular Prism, placed between the objective and the eyepiece, and close to the former (2) The Binocular Eyepiece Attachment containing a prism arrangement to split up the objective beam into two portions; and (3) The Binocular Microscope consisting of two separate microscope tubes, each with its own eyepiece and objective, inclined to one another.

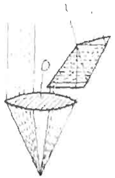


FIG. 112.—THE WENHAM BINOCULAR PRISM.

The earliest form of binocular prism employed for the purpose was the Wenham (Fig. 112). This prism was placed behind the object glass and split up the light beam into two halves, one of which went through the prism to one of the observer's eyes, whilst the other half passed direct to the other eye. This type possessed the disadvantages of reduced *resolving* power, low power, and unequal illumination of the two images. The use of *revolving* nosepieces was impossible, and the instrument involved the use of long tubes.

Amongst other types of binocular coming under the first heading may be mentioned the Powell and Lealand, and the more recent Beck instruments. In these, the light beam from the objective is not divided into two halves, but the entire beam is filtered into two portions so that some light from each portion goes to each eye. Fig. 113 represents the early Powell and Lealand arrangement. Here, the whole of the beam from the object glass *O* is incident on the prism *I*. Part of the light is transmitted through this prism, this beam being refracted and displaced to the left. The rest of the light is reflected to a second prism 2, whence it is again (internally) reflected into the second tube and eyepiece; the two beams are at an angle the one with the other.

Whilst this arrangement gives good resolution, it does not give equal illumination in the eyepieces, the light received by the one eye being a small fraction of the light received by the other, due to a differential absorption in the two beams.

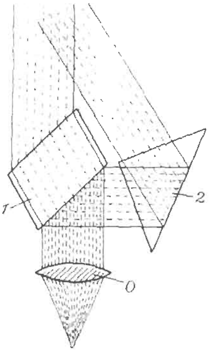


FIG. 113.—ILLUSTRATING PRINCIPLE OF EARLY POWELL AND LEALAND BINOCULAR.

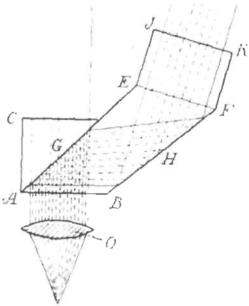


FIG. 114.—THE BECK OPTICAL ARRANGEMENT.

The principle of the Beck binocular arrangement is illustrated in Figs. 114 and 115. In this case the main beam from the objective *O*, is partly transmitted through the prism *AGC*, so as to form the left image, and partly through the two prisms *AEFB* and *EJKF* to form the right image. The surface of the prism *EA* is semi-silvered so that it allows part of the incident light to pass through it into the prism *AGC*, and part to be reflected to the surface *BF*, as shown by the dotted lines, whence this beam is again reflected through the compensating prism *EJKF* into the right tube and eyepiece. In this way the full sized beam is utilized, to form each image and no loss of resolution occurs;

further, the intensities of the two beams can be made identical, by regulating the amount of silver deposited on the surface *AE*. The prism *EJKF* is introduced into the optical path of the right beam in order to compensate for the lengthening of focus due to its having been reflected twice (at *AG* and *BH*); the effect of interposing a parallel plate of glass in a converging light beam is to shorten its path; this effect is obtained by the prism *EJKF*.

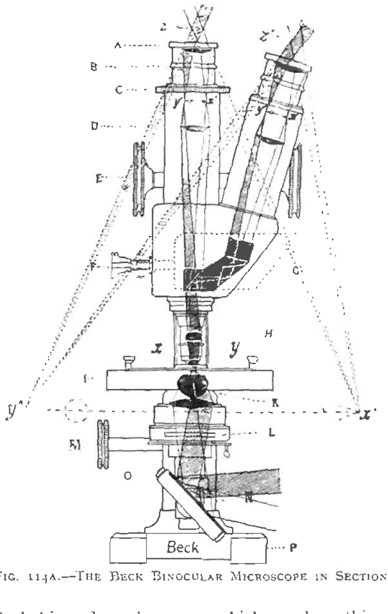


FIG. 114A.—THE BECK BINOCULAR MICROSCOPE IN SECTION.

The Beck binocular microscope which employs this arrangement, is shown in section in Fig. 114A; from this diagram the paths of the two beams can be followed, and also the images formed by the lenses can be seen. Thus the object on the stage is shown at *xy*, the image formed by the object glass is shown at *x'y'*, whilst the virtual image formed by the eyepiece is indicated at *x''y''*.

The Beck binocular can also be used as a monocular, by substituting a single eyepiece tube for the binocular tube. The binocular microscope is capable of being used for both high and low power work; this is a great advantage. Fig. 115 illustrates the complete microscope.

Messrs. Zeiss supply a binocular tube attachment for microscopes, known as the "Bitumi," which can be substituted for the single eyepiece without adaption. The tube length is, however, extended from 160 to 230 mm.; to rectify the resulting adjustment alteration an achromatic lens is fitted in the lower portion of the Bitumi Attachment.

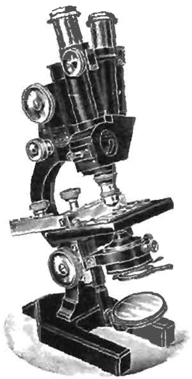


FIG. 115.—THE BECK BINOCULAR MICROSCOPE.

How the Stereoscopic Effect is Obtained.—It may, at first, appear a little difficult to understand how a single beam from the objective *O* (Fig. 116) can be made to give a stereoscopic effect, since the two light beams (direct and reflected) include light from all parts of the objective *O*. Let us state at the outset that the effect obtained is truly stereoscopic, but that in order to realise this, it is necessary to exclude from the right eye most of the light proceeding from the left side of the object viewed, and from the left eye most of the light from the right side. This is accomplished in most binocular microscopes of the general type described, by inserting *D*-shaped diaphragms in the part of the two beams, known as the Ramsden circles, where the images of the object glass aperture are formed. At these places *y* '*z*' it is possible to divide, or cut off the light in just the same manner as shown in Fig, 114A, i.e., as if it were at the back of the object glass. The *D*-shaped diaphragms placed in the Ramsden circles can therefore easily be arranged to cut off portions of the beam so as to satisfy the stereoscopic conditions previously stated. Actually, there is a practical objection to this procedure, due to the fact that the eyes cannot be placed sufficiently close to the eyepieces. To overcome this the eyepieces are given a slightly incorrect ocular displacement, so that the pupils of the observer's eyes cut off the edges of the Ramsden discs, by a backward or forward movement of the head; care must be taken in this operation, or the wrong portions of the Ramsden discs may be cut off and a pseudoscopic image obtained.

The Zeiss Bitumi Binocular Attachment.—When the eyepieces have been properly adjusted to the correct inter-ocular distances, it will be found that the images fuse together to give the stereoscopic effect. This fusion process may be assisted by looking for a moment into the distance; this has the effect of dispelling the accommodation of the eyes for near vision.

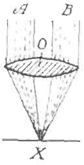


FIG. 116.—SHOWING HOW A SINGLE OBJECTIVE *O* CAN GIVE TWO DIFFERENT BEAMS *A* AND *B* SHOWING TWO VIEWS OF AN OBJECT AT *X*.

The rays of light, proceeding from the objective into the main tube are deflected by the prisms into the two eyepiece tubes. In order to secure a full stereoscopic effect with the Bitumi attachment, either eyepiece is fitted with an eye-lens cover fitted with a half-or *D*-stop. The two stops are placed so that the straight parts of the *D*, are inside; if placed with the rounded parts inside a pseudoscopic effect occurs.

When objects are viewed in a bright field, or under magnifications exceeding 300 diameters *the stereoscopic effect may be enhanced* by *placing a two-hole diaphragm under the condenser* upon the iris carrier. The usual single pencil is thus replaced by two pencils inclined at an angle to the axis, the image as seen by one eye being formed by one pencil, and that seen by the other eye by the other pencil. The stop should be so arranged in position, that when the iris carrier is swung back into its correct position above the mirror the two holes will be accurately on the left and right. The image will then be distinctly stereoscopic even with immersion lenses of 2 mm. and shorter foci, provided, of course, that the object is capable of being observed stereoscopically. The Bitumi attachment is supplied for use with achromatic and apochromatic objectives, and for magnifications from 100 to 1350.

Unequal Illumination.—The partition of the pencil of rays from the objective is usually effected with the aid of a translucent film of silver on one of the inclined surfaces of the prism. Occasionally the two fields of view appear of unequal brightness, or colour. This does not interfere with binocular observation, nor does it impair the stereoscopic effect, since it does not impede the binocular fusion of the two images. It is a common experience that two stereoscopic prints, forming a pair, may be of different densities without affecting the stereoscopic effect observed; the same applies to the binocular microscope.

The Stephenson Binocular. Messrs. James Swift and Son make a very convenient form of binocular microscope of the Stephenson type. This was designed for delicate and critical dissection, marine and other biological studies, and for the selection and arrangement of diatoms, scales, etc. It employs the Stephenson erecting prism system previously referred to. Sufficient focussing adjustment is provided to allow of the use of a 5-inch objective. An understage fitting of universal size is provided to carry an iris diaphragm and the illuminating apparatus. The binocular draw-tubes have an arrangement for adjusting them to the correct interocular distance. Arm-rests (shown in Fig. 117) are provided. The sloping binocular tubes enable a most convenient and comfortable position to be obtained, for viewing the microscopic objects. The same firm also make a high power binocular which possesses several advantages, namely equal illumination in both tubes, the same resolution as in a monocular, short tube length (without the use of correcting negative lenses), and instant conversion to a monocular instrument, by means of a sliding device operated by a knob, whereby the entire binocular optical system is pushed to one side out of the path of the rays, thus leaving the vertical tube free and unobstructed for monocular work. Interocular variation of 56 to 68 mm. is provided for in this model.

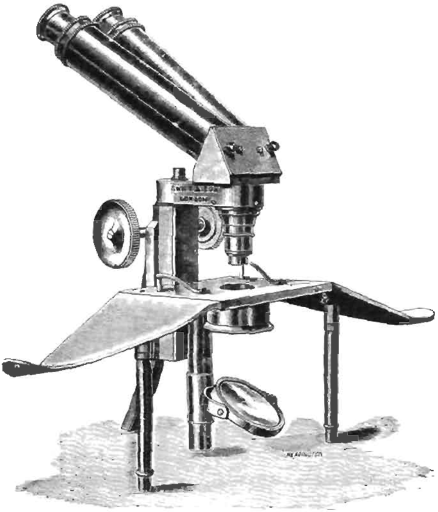


FIG. 117.—THE SWIFT BINOCULAR MICROSCOPE.

Fig. 118 illustrates the Watson-Conrady "Bicor" type binocular body which employs an optical arrangement consisting of a system due to Abbé, which divides the light coming from the objective, the dividing lens being placed close to the objective as in the Wenham system. The lateral prism is provided with a glass extension of such length as to cause the two separated beams to focus at the same distance from the objective.

Provision is made for the withdrawal of the prisms from the field so as to obtain a monocular arrangement. The binocular body is effective for all objectives from 1-inch to $\frac{1}{12}$-inch oil immersion, and the full resolving power of the objective is obtained. The images in the two tubes are of equal brilliancy.

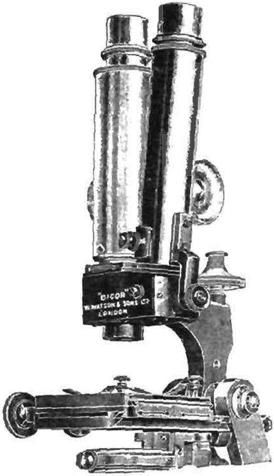


FIG. 118.—THE WATSON-CONRADY "BICOR" MICROSCOPE.

The Greenhough Binocular.—This consists of two complete microscopes, each with its own objective and eyepiece, mounted side by side, with their axes inclined (usually at $7\frac{1}{2}$ degrees), inwardly towards the objectives. Each eye, therefore, looks through its own microscope, and sees its own side and front of the object viewed, so that a good stereoscopic effect is obtained. This type of binocular (Fig. 119) which is made by most of the leading microscopical apparatus firms (*e.g.* Watson, Baker, Zeiss and others), is employed for dissection and low power work, for example, the examination of insects, crystals, textiles, and other similar objects. It is usually mounted on a metal fork stand or on the end of a sliding arm, for traversing a given area; an example of the latter is illustrated in Fig. 120. The instrument in question can be used with low power objectives up to about 25 mm. It consists of two microscopes placed side by side, and in each is incorporated a Porro erecting prism, which enables the object viewed to be observed in an erect position. It is usual to provide lateral adjustment for the prism boxes in order to accommodate different ocular separations. The low power instrument is also provided with a long range of coarse adjustment to enable thick objects to be examined; a large stage is also provided, with a diaphragm below, to give black and white backgrounds.

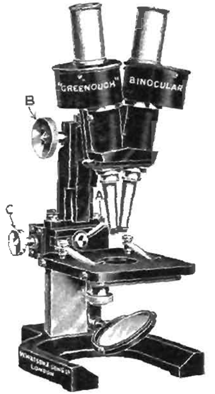


FIG. 119.—THE WATSON-GREENHOUGH MICROSCOPE.

The low power model can be obtained with a number of alternative arrangements of stands and holder arms for the purpoas of adjusting the instrument to any position over aquariums, parts of plants, portions of mineral specimens and similar subjects. A dissecting stage can be obtained either for use with direct incident, or with transmitted illumination. Several firms supply special object holders for entomological work. The Heller object holder consists of a rectangular base having a universal jointed arm, provided with an annular cork mount, capable of rotation and sliding motion. The object to be viewed is mounted on a pin, and the latter is stuck into the cork; the base accommodates a removable opal plate glass, furnishing a light background to the objects under examination.

In connection with the focussing of the Greenhough type of microscope, this is usually accomplished by moving the complete unit up and down with a rack and pinion movement (see Fig. 119). No fine adjustment is usually provided for the low-powered binocular models when the low magnifications are employed. The binoculars described can be obtained for magnifications up to about 200, from about 7.

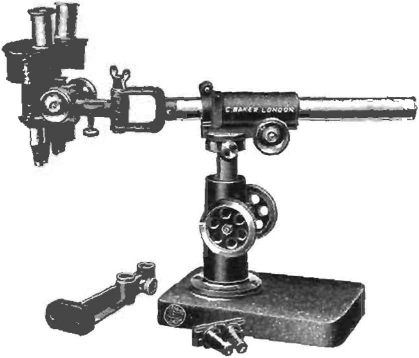


FIG. 120.—THE BAKER-GREENHOUGH BINOCULAR ON SPECIAL STAND FOR LOW POWER EXAMINATION OF LARGE OBJECTS.

Use of the Greenough Binocular.—When using this instrument, the drums containing the Porro prisms should be rotated on their axes, in order to adjust the distance between the objectives to suit the separation distance of the observer's eyes; the usual range of movement provided is from 55 mm. to 75 mm. Disparity in the brightness of the two component images as well as small differences in the corrections of the observer's eyes do not appreciably affect the stereoscopic impression, but if there is a serious difference between the two eyes, a suitable power spectacle lens may be slipped over one of the eyepieces when working without spectacles.

Photomicrographic Camera.—A special design of camera is supplied by Messrs. C. Baker, for use with the Greenough binocular microscope. This camera, which is illustrated in Fig. 121 accommodates two lantern size plates ($3\frac{1}{4} \times 3\frac{1}{4}$-in.), and is mounted on a rigid steel upright and cast iron base. The front is fitted with a shutter and light-tight connections, which can be removed and replaced with a lengthening piece for direct photography without the microscope or eyepieces. A focussing screen and dark slides are also supplied. With this camera

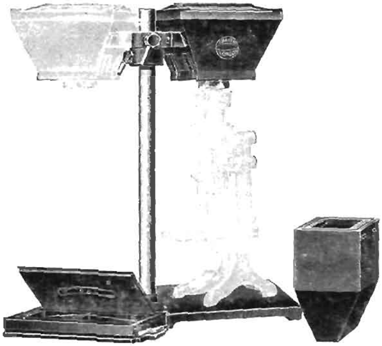


FIG. 121.—PHOTOMICROGRAPHIC CAMERA ATTACHMENT.

attachment stereograms of a wide variety of subjects can be obtained. This camera has been used for examination of paper and linen fibres, sugar, leather, rubber, type, precious stones, sands, timber, seeds, stamps and coins. It has also been widely used in biological, pathological, bacteriological, chemical and entomological research work.

Stereo-Photomicrographs with the Single Microscope.—It is not very generally known, that it is possible to obtain excellent stereograms with a monocular, or single microscope, in a somewhat similar manner to those obtained with an ordinary single lens photographic camera. In the present case, however, instead of shifting the camera between the exposures, the object is moved, or tilted under the objective, in order to obtain two views, one on either side of it. In another method, which has given very good results, a diaphragm is fitted near the objective, provided with an eccentric aperture, and is rotated so as to place the aperture first to the one side, and secondly to the other of the objective.

Mr. Taverner, F.R.M.S.,* has obtained many excellent stereo-photomicrographs with this arrangement, of his own conception, illustrated in Fig. 122 *b*, and consisting of an eccentrically placed aperture in an objective diaphragm. Fig. 122 *a* represents an alternative arrangement which is inferior, however to that shown in (*b*). The two photomicrographs obtained are taken firstly with the aperture on the one side, and then, by a 180° rotation of the diaphragm, with it on the opposite side of the optical axis of the objective; it is essential that the inner edge of the aperture does not extend as far as the optical axis.

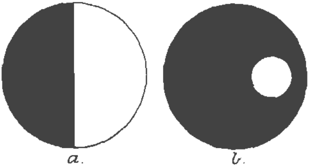


FIG. 122.

The amount of eccentricity of the aperture determines the degree of stereoscopic relief observed in the results. It is easily possible to obtain exaggerated relief, by increasing the eccentricity beyond the normal amount.† Further by reducing the size of the aperture, for the higher magnifications a greater depth of definition is obtained. With low powers, when using a small aperture for deep subjects, the inner edge of the

*Described in the Journal of the Royal Microscopical Society. 1906, p. 260 *et seq.*, also in the Quekett Journal, April, 1906.

†See Plate 13

aperture is beyond the optic axis, but for higher powers such as a 12 mm. objective, with large back lens, an aperture of 10 mm. is used, de-centred only 0·5 mm. We have inspected a large number of beautiful stereograms obtained by the above method, and with magnifications of about 10 up to 2000, of various subjects of interest, including foraminefera, orbulina, water-mites, mycetozoa, radiolaria, portions of insects, and similar subjects. The stereoscopic effect was excellent in each case, and a totally different impression was obtained of the shapes of the objects observed, than in the case of ordinary photomicrographs. One can sum up these impressions by remarking that so interesting is the stereoscopic view that one usually devotes from five to ten times the amount of time to observing it.

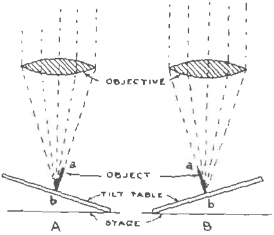
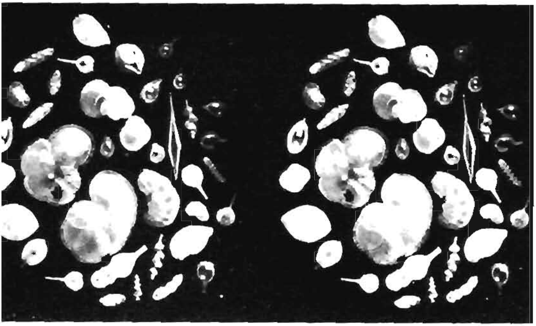


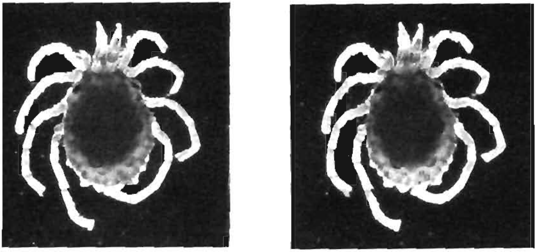
FIG. 123.

Reference has already been made to another method of obtaining the two distinct views of an object, to form the stereoscopic pair, namely by tilting the object stage first to one side and then to the other through a small angle (10 to 15 degrees).

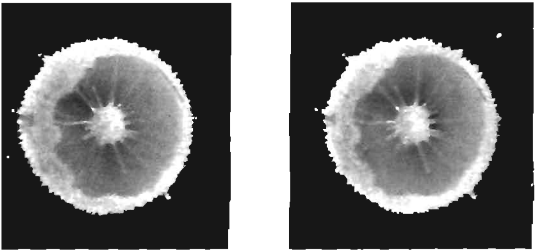
The diagrams given in Fig. 123 show that the tilting process enables more of each side of the object *a b* (assumed in this case to be a simple partition) to be seen in each respective position; it is also easy to see that if the partition *ab* is replaced by any other solid object, the same effect will be obtained, namely, that in each of the tilted positions more of one side will be seen than of the other, and a stereoscopic pair obtained.



FORAMINIFERA × 25 (TIMOR SEA) (Taverner.)



WATER MITE "PSEUDOSPERCHON." (Taverner.)



RADIOLARIA × 100. (Taverner.)

SOME TYPICAL STEREO PHOTOMICROGRAPHS

Care must be observed that in tilting the object, the focus is not altered, sensibly, for any re-focussing may alter the scale of one print relatively to the other, and a non-stereoscopic effect will be obtained. It is probably better to slide the object along through a small distance, between the two exposures, on the microscope stage, in order to obtain the necessary separation of view-points. The amount of separation will depend upon the magnification of the object, and can best be gauged after a few experiments.

Fig. 124 illustrates a stereoscopic photomicrographic attachment designed by Prof. H Jackson, and constructed by Messrs. James Swift & Son, Ltd., of London. It consists of a short fitting which screws between the nosepiece of the microscope and the objective. A slot is cut in this fitting into which drops a blackened brass slide so that it covers exactly one half of the back combination of the objective. If a negative be taken through one half of the lens and then another be taken after removing the metal slide and re-inserting it so that it covers the other half of the back combination, the prints from these two negatives will form a stereoscopic pair. The best results, it is stated, are obtained with objectives varying from 4-in. to 1-in. focus. Further, the addition of an iris diaphragm increases the apparent depth of focus of the objective. This method does not yield such good results, nor permit of the control of the eccentric aperture method perviously described.

FIG. 124.—STEREOSCOPIC PHOTOMICROGRAPH ATTACHMENT.

Stereo-Microradiography. M. Pierre Goby* has applied stereoscopic principles to the X-ray photography of microscopic objects, so that the internal structures are revealed in all their detail. By means of a simple attachment he is able to obtain the two views of very small objects, and to photograph them, so as to obtain the stereograms.

**Une Application Nouvelle des Rayons X, La Microradiographie*, C. R. de l'Acad. des Sciences, Mar. 3, 1913, and *Applications Nouvelles et Perfectionnements de la Microradiographie*, Compte Rendu, July 30, 1923.

CHAPTER XVI

THE APPLICATION OF STEREOSCOPY TO ASTRONOMY.

THE (stereoscopic) principle may be used to make pictures of celestial bodies, in three dimensions, which, because of their distance, are actually seen *in plano*. A stereoscopic combination is usually produced by shifting the camera through a suitable distance between the taking of the pictures, but the same effect is produced by keeping the camera fixed and displacing the object so that it presents a slightly different outline and a slightly different view of its features at the two exposures. The second is the method that must be adopted for making stereoscopic pictures of celestial bodies, since the available base line is, in general too small for the first. Any real displacement of a point or feature on one of the photographs relative to its position on the other, will cause it to stand out in relief or appear in recession; therefore, by contrary reasoning, such appearances will indicate change of position or motion, and in this way stereoscopy is found to be an aid to astronomical research.

Lunar Stereograms.—The Lunar libration will supply the necessary displacement between the exposures in the case of the Moon, and photographs taken of our satellite at the same phase, but in different libration, combine to make a picture of a solid globe which it cannot be doubted is a true representation of the Moon as it would be seen at close range.

Stereoscopic photographs of the Moon were obtained by Thomas de la Rue between 1857 and 1860, which certainly gave a most truthful impression of its solidity. The photographs forming the stereoscopic pair represented a displacement of about 20,000 miles—that is to say, they represented the respective views of each eye of an imaginary giant whose eyes were 20,000 miles apart. These photographs were obtained by taking advantage of the *libration*, or swinging motion, of the Moon. At these periods the Moon exposes more of its face, so that the eye (or telescope) sees a little "round the corner." Thus, by choosing suitable times of the year for procuring the photographs, which are identical in other respects except for the above-mentioned difference, a stereoscopic pair of photographs may be obtained, such that, when viewed in the ordinary stereoscopic viewer, give the moon a solid appearance.

The Frontispiece is a reproduction, in the form of a pair of stereoscopic illustrations, of part of the moon's surface. In order to obtain the required separation between the two images of the moon, that is, to obtain two different views of the moon, each looking a little further around one side than the other, it was necessary to wait for a period of nearly four years between the taking of the two photographs. One was taken with the Coudé equatorial, in Paris, on February 3, 1896, and the other on April 20, 1900, at 6 h. 15 m. 30 s. and 8 h. 18 m. 3 s., respectively. If these photographs are viewed with the ordinary print-viewing type of stereoscope, the solidity effect will be quite apparent. If anything, the stereoscopic effect is rather exaggerated, for the moon appears somewhat ellipsoidal. This is due to too much separation between the images, and is similar to the effects obtained by ordinary stereoscopic cameras when used to photograph objects very near to themselves. Thus, a large sphere taken at close range will appear in the stereoscope as ellipsoidal, with the longer axis in the direction of the optical axis of the viewing lenses. Plate 4 illustrates this effect.

Messrs. Keystone-Underwood supply one or two excellent lunar stereograms in the form of mounted photographs; the stereoscopic effect and the detail is exceedingly good in the originals. Messrs. Zeiss also include several astronomical subjects in their standard series of stereograms.

Solar Effects.—The suggestion has been made that photographs of the Sun's corona, taken from widely different stations during a Solar eclipse, might combine stereoscopically and give valuable information as to its true form, but this has been met with the objection that since this corona may presumably change its form in the interval between the taking of the photographs the result might be misleading.

Comets.—Similar objection has been made to stereoscopic pictures of comets. The change of position of a comet with reference to the background of fixed stars gives an excellent stereoscopic effect, the filmy tail covering the trails seen behind it stands out towards the observer with the utmost realism, and a short note* by Dr. Max Wolf on some photographs of Monet-Perrine (1902 b) may be read with advantage. He found that it was necessary to choose with care the interval of time between the exposures, which naturally depends on the rate of movement of the comet, in order to obtain the best stereoscopic result. In the particular case under consideration 10 minutes was found quite suitable. Some years later, however, Prof. Barnard approached the matter from a more critical point of view. He took a series of photographs of Morehouse's comet (1908 *c*) with the 10-inch Bruce lens belonging to the Yerkes Observatory and combined them to make stereoscopic pictures, the interval between the components of the pair being an hour and a half, more or less. He says† "One of the most remarkable of these combinations is that of 1908, October 15. On this date there was a sudden twist or break in the tail, which formed irregular cloud-like masses that moved out from the comet along the general directions of the tail. In the stereoscope these two pictures produce an exquisite object suspended in front of the stars. Apparently it is easy to see which are the farther and which the nearer parts of the comet, etc., etc. But how much of this perspective is real? I believe that there is little of it that can be true. In the first place, these masses were receding from the comet and changing their actual forms and especially their position-angles, so that a pseudo-stereoscopic effect would be produced, and what is really the nearer portion of the comet may appear to be a distant part."

This dictum should be remembered in examining such photographs, but Prof. Barnard goes on to say that though the appearance may be partly false, there is certainly no other method that can show how a comet really looks in space, and for this reason

* *Monthly Notices, Roy. Astron. Soc.*, *63*, 35

† Ibid., *69*, 625.

MOORHOUSE'S COMET. PHOTOGRAPHED AT YERKES OBSERVATORY.

THE FULL MOON. *(Underwood and Keystone Stereographs Ltd.)*

EXAMPLES OF ASTRONOMICAL STEREOGRAMS.

it must be helpful. A reproduction of a stereogram of the series from photographs taken on November 16, 1908, is given in Plate 14.

Star Photographs.—The principle of the method of preparing stereoscopic star charts may best be illustrated by means of the fictitious example of the Constellation Orion, shown in Fig. 125. *In this case the correct disposition of the stars in this constellation*

ORION. ORION.

FIG. 125.—THE CONSTELLATION OF ORION IN CONJECTURAL RELIEF.

is shown in one diagram, whilst in the other certain of the stars have been displaced laterally to the right, or to the left, by small amounts, in a similar manner to the example discussed on page 19, so as to obtain the stereoscopic effect of certain of the stars *standing in relief or in recession.*

Mention may be made here of other attempts to show the stars in perspective or as they would be seen at their relative distances so far as these are known. This has been done for a limited number of stars by making a model to scale and photographing it stereoscopically. A more ambitious scheme by the late Mr. T. E. Heath, of Cardiff, consisted of a series of 26 stereoscopic star charts which covered the whole sky and contained all stars to the fifth magnitude, the stars being plotted as they would be seen by eyes 26 light years apart. The star discs were drawn to scale of magnitude, and the parallaxes used are those determined by various authorities or extracted from magnitude. The result viewed by a stereoscope is a pleasing picture in three dimensions, but can scarcely be considered an addition to astronomical knowledge.

Eclipse Stereograms.—It is not generally known that it is possible to produce stereoscopic effects from pairs of photographs of the moon, taken during an eclipse. In these cases the time intervals between the exposures of the photographs forming the stereoscopic pair is relatively short. Thus in the case of the eclipse photographs reproduced in Plate No. 15, the interval between the two upper views was only 25 minutes; in the case of the lower ones it was 35 minutes. These photographs were taken by the Rev. W. A. Ellison, of Armagh Observatory, on February 8, 1925. It will be noted that the variation in the shading, or half-tones contributes largely to the stereoscopic effects observed.

The Stereo Comparator.—We now pass from the formation of striking pictures to consider an instrument of a stereoscopic nature, which, with its development has become of much value in astronomical work. The advance of stellar photography made it desirable to have some means of comparing two plates of the same field beyond that of a mere glance, and about the year 1901 an instrument for this purpose known as the Stereo-Comparator,* designed by Dr. Pulfrich, was made by the firm of Zeiss, of Jena. This instrument is essentially a frame for holding two plates side by side. A movable viewing apparatus with two eyepieces, is arranged so that all parts of the plates may be examined and corresponding images are seen as in a stereoscope—one by one eye, the other by the other. Peculiar objects are detected at a glance by some difference of appearance or an actual physical sensation in the eyes. If the plates are adjusted so that the majority of the images on the plates combine stereoscopically, these, the majority, will appear as in a plane, but if the image of a star is missing on one plate, the appearance of the one image suggests that of an object close to the observer. If the image of an object on one of the plates is displaced, that of a planet might be by motion, this object again comes out of the infinity plane, and the stereo-comparator, whose original purpose was the detection of false images or differences of brightness, was found to be effective for discovering motion. Prof. Comas Sola, of Barcelona, stated† that on plates taken on July 12, 1912, and

* See Plate 9. † Comptes Rendus, 1915, Aug. 9.

PLATE No. 15

W. F. A. Ellison

ECLIPSE OF THE MOON STEREOGRAMS.

UPPER L.H. TAKEN AT 20H. 20M. 8.2.25 UPPER R.H. TAKEN AT 20H. 25M. 8.2.25
LOWER L.H. „ „ 21H. 15M. 8.2.25 LOWER R.H. „ „ 21H. 50M. 8.2.25

July 20, 1915, of the field about MESSIER 11, which contains thousands of stars, he could see at least 200 which stood out, thereby indicating groups and alignments of stars which *apparently had a common proper-motion.*

The Blink-Microscope.—For the purpose of determining the proper motions the previously mentioned instrument has been developed by the addition of the Blink-Microscope. It might perhaps be said that the principle has been altered, for with the Blink-microscope the effect is obtained through the quality known as persistence of vision rather than by stereoscopy. The Blink-Microscope has only one eyepiece. The plates placed in the holders side by side are viewed through two optical trains, of which the Blink eyepiece is common to both. By mechanical means the two plates are alternately hidden automatically at the rate of 3 or 4 blinks a second, and when the plates are adjusted two corresponding images of a stationary object appear as one, but if one of the contributing images is displaced, the "blinking" gives a jumping effect which is easily apparent. Two micrometers at right angles to each other supply a means of measuring the amount of displacement of the image, or, in other words, the Proper Motion of the Star. The Blink-microscope has been used with much effect for this purpose by Dr. Innes, Director of the Union Observatory, Johannesburg. The instrument in question is manufactured by the firm of Carl Zeiss, Jena.

CHAPTER XVII

STEREOSCOPY AND RADIOGRAPHY.

AN important application of the principles of stereoscopy has been opened up in X-ray work, in connection with the localisation of objects, or defects, in solid bodies. In particular the stereoscopic method of indicating the exact position within solid objects, of specific items has been much used both in material examinations, and in anatomical and surgical work.

It is not proposed to deal with the principles of radiography in this book, but rather to indicate the great assistance, in this work, which is possible from an application of the stereoscopic methods.

The X-Ray Tube.—For the reader to appreciate the later remarks, it is necessary to refer to the action of a simple X-ray tube. Fig. 126 illustrates a typical tube arrangement. It

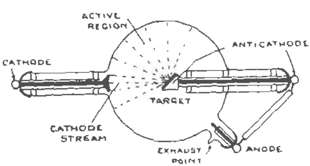


FIG. 126.—A TYPICAL X-RAY TUBE.

consists of an hermetically sealed glass bulb exhausted of air to a very high degree of vacuum.* The bulb contains three electrodes, as a rule, namely the *Anode, Cathode* and *Anticathode.* The cathode is connected to the negative terminal of a source of very high voltage, or potential, whilst the Anode and Anti-

* Usually to about ·0001 millimetres mercury column. (1 atmosphere = 760 mm. mercury.)

Cathode are joined up to the positive terminal. It is necessary to use an extremely high potential between the two terminals, usually from 100,000 to 350,000 volts; the current is however very small, measuring a few milliampères in most cases. The effect of applying such high voltages to the X-ray tube is to cause an emission of electrons from the Cathode, known as *Cathode Rays*. These electrons, or negatively charged electrical particles, strike the Anti-Cathode and are diverted. Without going into the electro-magnetic theory of the subject it may be stated that the act of the Cathode rays striking the Anti-Cathode results in the *creation of ether waves of short wave-length—much shorter than* the extreme ultra-violet rays—known as X-rays. These rays possess the remarkable quality of being able to penetrate opaque materials, such as timbers, metals, and organic bodies. The X-ray was first discovered, by Prof. W. K. Röntgen, in 1895.

X-rays are invisible to the human eye, but when they impinge upon special screens coated with substances like tungstate of calcium and barium platinocyanide, they cause the latter to fluoresce.

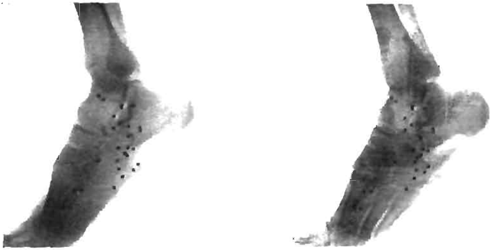
It has been found that X-rays penetrate the less dense materials the more readily, but the denser the material, the less the penetration. For this reason mercury and lead—both heavy metals—are practically opaque to X-rays. It will be seen therefore that if a suitable beam of X-rays is projected on to, say, the human body, the rays will readily pass through the fleshy and softer portions, but will not get past the heavier bones. Similarly, if there are any other solid bodies, e.g., portions of metal, such as shot, the rays will not pass these. If a suitable X-ray screen be held on the opposite side of the body, to the source of the X-rays the visible result, due to the fluorescent effect of the X-rays, mentioned previously, will be bright portions where the rays have passed through lighter matter, and darker portions (or shadows) where they have experienced heavier matter. In effect the X-ray picture formed on the screen (known as a *Radiograph*) is a shadow-picture in which the shadows depict the bones or foreign bodies in the system. Since X-rays possess the property of affecting photographic plates in a similar manner to light-rays, they can be made to photograph their results by the mere substitution of a suitable photographic plate for the fluorescent screen.

It is important, from the stereoscopic point of view to note that no photographic camera, or lens, is necessary for X-ray photographs, and that the necessary separation between the two photographs is obtained by moving either the subject or the X-ray tube through a distance of about 65 mm.

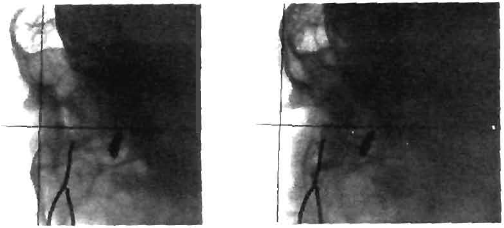
Application to Materials Inspection.*—The X-ray method of examination has been extensively used in connection with the inspection of timber for aircraft, welded metal fittings, steel and iron castings, and similar purposes. It is possible to indicate the existence of defects within solid bodies, by means of a single radiograph, but the location of the defect requires at least two photographs, or screen positions. If, however, the stereoscopic method of location be employed, the exact position of the defect, in relation to a fixed indicator or scale can at once be obtained. In order to obtain a stereoscopic radiograph it is necessary to move the X-ray tube through a distance equal to the interocular separation, or distance (i.e. 65 mm.) and to take radiographs in each position; the two form a stereoscopic pair. It is not difficult, if a fixed distance between the X-ray tube and the radiograph screen is adhered to, to construct a scale, or graticule, which can be superposed on the radiograph negative and printed on the photographs taken therefrom, and from which the exact distance of the defect or other internal object can be measured. A certain amount of useful information can, however, be gathered from a visual inspection of an X-ray stereogram, for the position of any internal object, or marking can be gauged in reference to the external surfaces of the body.

Thus, in the case of, say, a metal casting, the position of a blow-hole or slag inclusion can be located with sufficient accuracy from a visual examination of an X-ray stereogram. The structure of composite bodies such as moulded electrical parts with metal

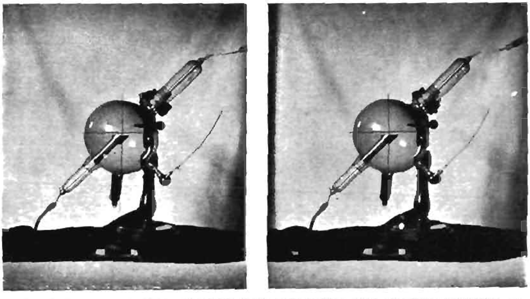
* A survey of the methods and apparatus is given in *X-Ray Examination of Materials*, A. W. Judge. (*Modern Motor Car Practice*, W. H. Berry. Henry Frowde, Hodder and Stoughton). A fuller account is given in *The Examination of Materials by X-Rays*. A general discussion, held by The Faraday and Röntgen Societies, April 29, 1919. Reprinted from the *Transactions of the Faraday Society*, vol. xv., Part 2, 1919 (13/6).



X RAY STEREOGRAM OF GUNSHOT WOUND IN THE FOOT. IN THE ORIGINAL PHOTOGRAPHS THE POSITION OCCUPIED BY EACH SHOT IN RELATION TO THE BONES CAN CLEARLY BE SEEN. (MACKENZIE DAVIDSON).



X-RAY STEREOGRAM OF PIECE OF EXPLOSIVE SHELL IN THE HUMAN EYE (MACKENZIE DAVIDSON)



STEREOGRAPHIC VIEW OF X-RAY TUBE WITH WIRE CROSS FOR LOCATION PURPOSES, IN POSITION (MACKENZIE DAVIDSON).

X-Ray Stereograms, *illustrating the use of the Stereoscopic* Method for Locating Foreign Bodies in the Human System.

To face page 202

portions, fuses, watches, cartridges, and similar objects can be revealed in a similar manner. Faults, such as blow-holes, or slag inclusions in welded joints are at once detected and located by the X-ray stereogram. The presence of hair-cracks in steel, of badly centred cores in golf-balls, interior faults in timber used in built-up aeroplane members and plywoods, reinforcement in concrete and numerous other examples could be cited as instances of the actual application of X-ray photographs to material inspection.

Uses in Anatomy.—It is in connection with anatomy that X-ray stereography has proved of most value, for with its aid, it has been possible to locate foreign bodies in the human system, so that in the subsequent surgical operations, the operators have known the precise positions of the objects to be removed. The method owes a good deal, in its development to the late Sir J. Mackenzie Davidson, who was the first to suggest the application of stereoscopy to X-ray work,* and who has successfully applied the methods in connection with the location and removal of bullets, shrapnel pieces, shot, needles, and similar foreign bodies from the body, and also to the removal of solid particles in the eyeball and orbit. He has left on record† an account of his methods and the results obtained; this should certainly be consulted by all who are interested in this branch of stereoscopy. The X-rays travel in straight lines from the tungsten target, and the radiograph is really a shadow photograph, in which the denser, or more solid objects in the path of the X-ray beam, form the denser shadows on the fluorescent screen or photographic plate.

The usual method of producing X-ray stereograms of any portion of the body, is to place the patient on a couch in a horizontal position, with the X-ray tube below, and the fluorescent screen, or the plate above (i.e., on top of the body). The X-ray tube is enclosed in a protective box, and the latter is provided with means for sliding it horizontally both longitudinally and

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* "Remarks on the Value of Stereoscopic Photography and Skiagraphy." J. Mackinzie Davidson. *Brit. Med. Journal*, Dec. 3, 1898.

† "Localization by X-Rays and Stereoscopy." Sir. J. Mackenzie Davidson, 1916. (H. K. Lewis & Co., Ltd., London.)

laterally in relation to the couch: these movements enable the necessary displacement between the two radiographs to be obtained. It is very important to be able to determine the position of the vertical ray from the tube, for the purpose of locating the position of the radiograph and of the objects shown. The usual method is to attach a vertical bracket to the sliding X-ray tube box, and to hang a plumb-bob from a horizontal arm attached to the vertical bracket; with the aid of a pair of cross-wires and a fluorescent screen, the point of the plumb-bob can readily be adjusted to coincide with the vertical X-ray. Once this adjustment is made the position of the vertical ray is known definitely, and the bob can be used to indicate the position of the ray in question. The subject to be photographed is placed on the couch, and the point of view having been decided upon, the tube-box beneath the couch is adjusted until the indicating plumb-bob is over the selected place on the body. The photographic plate, in its carrier or envelope is then placed on the body with its two opposite edges parallel with the longitudinal axis of the couch. Its position is recorded, for reference purposes, by means of a blue pencil run along adjacent sides. After the necessary exposure has been made, another plate is substituted for the first, in exactly the same position as the latter, and the X-ray tube is moved to one side, along either axis of the couch (depending upon the nature of the subject) through a distance of 65 mm. and a second exposure made. The plumb-bob indicator indicates the two positions of the X-ray tube.

The two plates, or their prints will then be found to form a stereoscopic pair, if properly mounted. The original type of Wheatstone stereoscope is well adapted to the viewing of these relatively large stereograms, and for this reason is still much used in medical work. The instrument is usually arranged to take the negatives in the vertical position from 15 × 12 in. downwards, and in the horizontal 12 × 10 in. downwards. Fig. 127 illustrates one of these stereoscopes, made by Messrs. Watsons, Kingsway, London.

For lecture demonstrations, or for the convenience of the surgeon who desires to refresh his memory while operating the stereograms may be reduced and made into lantern plate size transparencies; in the case the Wheatstone stereoscope is employed.

Other localization methods are also in use, which do not employ stereoscopic principles, but the latter give a useful check and a permanent record, of the cases treated.

In opthalmology, also, the stereoscopic method has proved very valuable in locating foreign bodies in the eye. In these

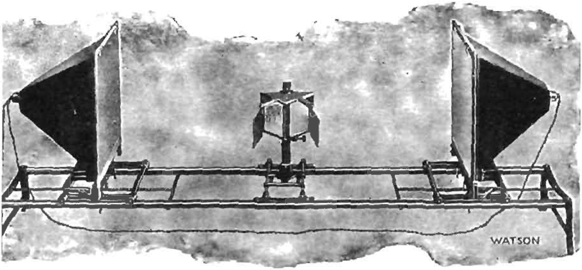


FIG. 127.—THE STEREOSCOPE USED FOR X-RAY WORK.

cases the highest precision is necessary, as the slightest deviation from accuracy may involve loss of vision. It is therefore essential that the head of the patient be kept quite rigid, and also that the eyeball under examination be prevented from the slightest movement. Dr. Mackenzie Davidson devised a headpiece, eye positioner, and X-ray indicating device for this purpose. The two X-ray photographs in Plate No. 16 show the stretched piano wires used for locating the axis of the X-rays, and also the wire loop used to keep the eye immobile; both of these serve to locate the foreign bodies in the eye. Confirmatory photographs may be taken, but with the X-ray tube fixed, and the eyeball rotated through a known angle, say at 45 degrees downwards and then horizontal. When the tracings from the displacement of the shadow of the foreign body are made, its depth having been previously ascertained by localization measurements, the degree of movement of the foreign body in relation to the centre of rotation of the eyeball is obtained (the centre of rotation being taken at 10 mm. in front of the retina).

The Pirie Stereoscope.—A special design of stereoscope has been evolved by Messrs. Watson and Sons (Electro-Medical) Ltd. for the examination of stereoscopic X-ray negatives. Instead of using reflecting mirrors as in the Brewster stereoscope, a double reflecting prism is employed. For convenience the prism is mounted in one of two metal tubes, fastened together by a connecting piece, the second tube being a plain one only, and serving to exclude extraneous objects from view. With this stereoscope it is very easy to observe stereoscopic effects. The

FIG. 128.—THE PIRIE STEREOSCOPE FOR X-RAY EXAMINATION.

negatives are taken in the usual manner, and are placed side by side, either in suitable boxes provided with electric light, or they can be rested on the framework of a suitable window. The distance at which the negatives are observed depends upon the distance between the centres of the negatives, that is to say, the size of plates. For instance, the best position to inspect a pair of 12 × 10 ins negatives placed as closely together as possible is about 42 inches; for smaller negatives it is necessary to come closer; for larger ones, farther. It is recommended that the negatives should be held on a level with the eyes, and slightly tilted towards one another. By concentrating the attention through the plain tube and centering the image on the corresponding side, a stereoscopic effect can at once be realised.

Stereoscopic Fluoroscopy.—It was suggested by Sir J. Mackenzie Davidson, and an apparatus for the purpose was produced and exhibited by him at the Charing Cross Hospital, and again at a *conversazione* of the Royal Society, that the stereoscopic image should be shown visually on the fluorescent screen. For this purpose it is necessary to have two X-ray tubes with ray-axes separated by about 2½ to 3 inches, placed side by side, so that the line connecting the points of X-ray production on the Anodes is horizontal. The fluorescent screen is placed behind the subject under examination, the tubes, being, of course, on the other side. It is necessary to provide an automatic switching device for illuminating each tube separately, and also a rotating sector shutter held in front of the eyes. In this way one eye sees only the X-ray image on the screen due to one particular tube; the other eye sees only the other image. If now the speeds of the shutter and switching device exceed about 10 alternations per minute, owing to the well known effect of persistence of vision, the impression upon each eye becomes continuous, and each eye therefore sees its own tube's image continuously. The two eyes, therefore, experience a true stereoscopic view of the X-ray image, similar to the cinematograph impression.

FIG. 129.
THE STEREO-FLUOROSCOPE.

Messrs. Watson & Sons now supply special stereo-fluoroscopes

FIG. 130.—METHOD OF STEREOSCOPICAL EXAMINATION OF PATIENT

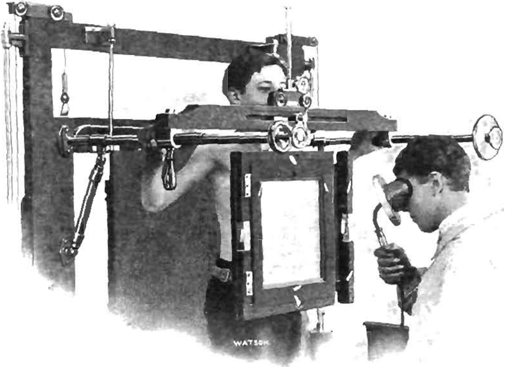
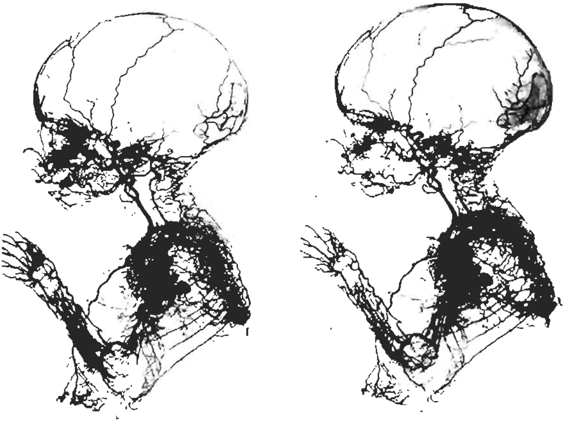


FIG. 131.—VERTICAL SCREEN METHOD OF STEREOSCOPIC EXAMINATION.



(J. F. Bergmann.)

STEREO-RADIOGRAPH OF HUMAN ARTERY SYSTEM.

To face page 208.

for this purpose. Fig. 129 illustrates one of the instruments in question. The handpiece of the stereo-fluoroscope contains an electrically driven interrupting disc, working on direct or alternating current supply with any ordinary induction coil or interrupterless transformer installation. The actual stereoscope itself consists of a small handpiece made of aluminium, from which the observer looks at the fluorescent screen. Two anticathodes (for two tubes are used) are placed at a separation as nearly as possible at 3 ins.; this involves the use of a Coolidge small diameter X-ray tube. Each tube is excited alternately, and a rotating shutter in front of the eyes is so arranged that the shadow cast by the tube on the left is viewed by the eye on the right, and *vice versa*. The illustrations, Figs. 130 and 131 show the apparatus in use for examination of horizontal and vertical subjects.

The excellent definition obtained by stereoscopic vision, and the fact of being able to observe living subjects internally, renders this method of observation a valuable one, for anatomical purposes.

X-Ray Stereograms.—Apart from the excellent stereograms reproduced in Dr. Davidson's book, previously mentioned, there is an exceedingly good set of stereograms of X-ray subjects in the form of ten pairs of photographic prints, each print measuring 3 ins. × 4 ins. by Prof. Hildebrand, Dr. Scholz and Dr. Wieting-Pascha, issued by J. F. Bergmann, of Wiesbaden. The first series appeared in 1903; it was revised in 1911. Some of these radiographs illustrate foreign bodies embedded in the hands, arms and legs, whilst others show very clearly the complete ramification of the arteries in the hands, body and face; the stereoscopic effect is excellent in the latter photographs, one of which is reproduced in Plate No. 17.

Mr. Colardeau in his book on Stereoscopy reproduces an anaglyph of a somewhat similar nature.

CHAPTER XVIII

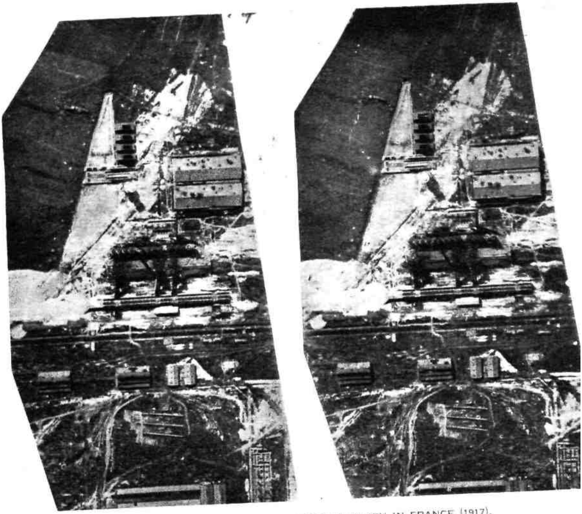
STEREOSCOPIC AERIAL PHOTOGRAPHY.

Exaggerated Stereograms.—Stereoscopic photography played an important part in the late war, and undoubtedly has an important future. It is a well-known fact that the stereoscopic effect of the eyes is greater the nearer the object is to it, and that this effect ceases when objects are sufficiently far away. Thus, if one looks at a hill or mountain, or at a group of buildings at a sufficient distance away, all stereoscopic effect is lost and flatness is the result.

Similarly, the Earth, as viewed from the air at a few thousand feet above its surface, appears monotonously flat and uninteresting. On the other hand, if objects of sufficient size on the earth are viewed obliquely from the air, their solidity is at once apparent and interesting. For this reason aerial photographs taken with the camera looking vertically downwards from a few thousand feet are mere "plans," and seldom reveal any contour effect. If, however, a pair of photographs be taken, such that there is a certain time interval between them, the aeroplane in the meantime flying steadily on the same path, then the two photographs can be made into a stereoscopic pair, and, when viewed in a stereoscopic viewing apparatus, at once bring out the solidity effect.

Let us go a step further and take our pair of photographs at a greater time interval apart. We shall then obtain an exaggerated effect, such that buildings and chimney-stacks of, say, 20 to 60 ft. actual height, when viewed by means of the stereoscopic viewer, appear to be *some hundreds of feet high.* Apply this same method to the photography of trenches, dug-outs, camouflages, etc., and we have at once a most valuable means of detection of objects unnoticed by the eye or the ordinary single aerial photograph.

PLATE No. 18.



EXAGGERATED AERIAL STEREOGRAM TAKEN IN FRANCE (1917).

EXAGGERATED AERIAL STEREOGRAM OF ALBERT CATHEDRAL (1918).

AERIAL STEREOGRAMS, TO SHOW VERTICAL HEIGHTS, GREATLY MAGN

Estimation of Separation Distances and Intervals.—*Hitherto our remarks upon stereo aerial photography have been* of a general nature. It is now proposed to consider the question of the calculation of the positions from which the two aerial photographs should be taken, and the time intervals between the exposures made by an aerial camera, during flight.

In order to obtain the correct relief, the two photographs should be taken with a separation between the images of corresponding points equal to that of the eyes, namely $2\frac{1}{2}$-ins. (or 65 mm.). In practice this is accomplished by allowing the aeroplane to fly horizontally for a given interval between the first and second exposure, so that if a large plate had been used, two almost superposed photographs would have been obtained, separated, however by a distance of $2\frac{1}{2}$ ins.

If the separation of the eyes be denoted by d ins., the focal length of the camera lens by f ins., the altitude at which the photograph is taken by H feet, and the (required) distance between the exposures by D feet, then it is easy to show, by proportion that:—

$$\frac{d}{f} = \frac{D}{H}, \text{ whence } D = \frac{d \cdot H}{f} = \frac{2{\cdot}5\,H}{f}$$

Thus for an aerial camera of focal length, 25 inches, at a height of 5,000 feet, the distance between the exposures will be $\frac{2{\cdot}5 \times 5000}{25}$ that is 500 feet.

The *time interval* t seconds between the exposures, corresponding to the distance D, will depend upon the velocity V (m.p.h.) of the aeroplane.

$$t = \frac{D}{1{\cdot}466\,V} = \frac{d \cdot H}{1{\cdot}466\,V} \text{ seconds.}$$

(It should be noted that 1 m.p.h. = 1·466 feet per second).

In the above numerical example if the aeroplane is flying at 60 m.p.h. we have—

$$t = \frac{500}{1{\cdot}466 \times 60} = \frac{500}{88} = 5{\cdot}7 \text{ seconds.}$$

The stereoscope viewing lens should have the same focal length as that of the aerial camera for correct relief impressions, and the photographs thus obtained will then present the appearance of a *model* of the original view at a distance f (inches), and $\frac{f}{H}$ times the natural size.

If, as is frequently the case, exaggerated relief effects are required, the interval between the exposures as calculated above, should be increased to several times its value, according to the effect required. There is a fairly wide allowable latitude in the

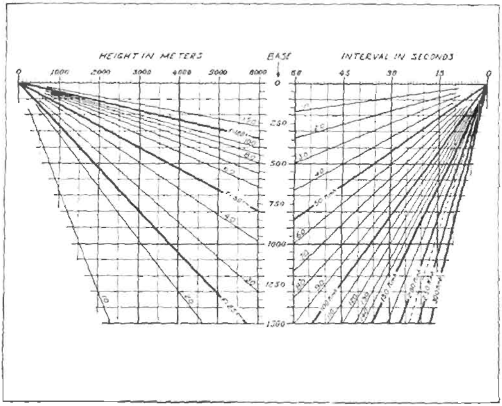


FIG. 132.—GRAPH FOR STEREOSCOPIC COMPUTATIONS IN AERIAL PHOTOGRAPHY.

selection of the time interval t, but as we have stated only the value estimated above corresponds to correct relief; the other values correspond to un-natural or distorted reliefs.

The aerial photographer cannot be worried with calculations in the air, and therefore must be provided with the necessary data on exposure intervals, heights and speeds, either in the form of tables, or more conveniently as a chart or slide-rule.

Fig. 132 is a reproduction of a suitable data chart* from which

* *Airplane Photography.* H. E. Ives. (J. B. Lippincott Co., London.)

the stereoscopic intervals can readily be deduced for any given combination of height, focal length and machine speed. The left-hand diagram shows how to find the stereoscopic base (*D metres*) *for any altitude and focal length*. *Having* found *D*, the time interval corresponding can be obtained by running along horizontally into the right-hand diagram until the line cuts the radiating speed line.

For example if the height and lens focal length are 3000 metres and 40 cm., respectively, the left-hand diagram intersection of these lines shows the stereoscopic base *D* to be 500 metres. If the aeroplane be assumed to fly at 100 kilometres per hour (=62 m.p.h.) then the right-hand diagram shows that the time interval between the two exposures will be 18 seconds.

In general, the *greater the height*, the *shorter the focal length* or the *slower the speed of the machine*, then the *longer* will be the time interval between the exposures.

The writer has produced a neat type of *aerial photography exposure indicator*, in the form of a rotating disc, whereby practically every possible information concerning exposure times, heights, speeds, focal-lengths and stereoscopic intervals can at once be read off.

It is interesting to note that if the minimum parallactic angle be taken as 20 seconds of arc, corresponding to $\frac{1}{10,000}$ of the distance from the eye to the object, then for stereograms taken with a lens of focus 25 cms., the maximum altitude *H* at which an object of height *h* on the ground can just be discerned, in correct relief is given by $H = \frac{10,000}{4} \times h = 2,500\ h$. Thus a building of 20 ft. height would just show in relief at $20 \times 2500 = 50,000$ ft. This relation is irrespective of focal length, as long as the conditions for correct relief and stereoscopic viewing are observed.

Aerial and Land Survey.—The method of oblique stereoscopic photography has also found a most useful application as a method of constructing maps from aerial photographs, the same method being applicable also to land surveying.

In this method, which has been worked out and applied with consummate skill and accuracy by Prof. Hugershoff and Dr. Cranz in Germany, a stereoscopic pair of aerial photographs are taken obliquely from a balloon, airship, aeroplane, or kite, two or more control points (i.e., *ground objects of known position*) being included. The photographs obtained are then placed in an apparatus known as a stereo-comparator, viewed, and measured up. Another more elaborate apparatus, known as a bildmetheodolite, enables the actual contour map to be drawn from the stereoscopic pair of prints, so that not only the plan view but the ground contours also are obtained.

This solution of a most difficult problem in aerial survey work, which problem is complicated by the distortional effects due to the unavoidable tilt of the aircraft and to photographic perspective, is probably the only practical and accurate one at present.

It is only possible in the present case to give a very brief outline of the methods employed for the construction of contour maps from aerial photographs, but at the end of this book a useful bibliography is included, reference to which will enable the reader to pursue this branch of stereoscopy more thoroughly. It should be mentioned in passing that the stereoscopic aerial survey method is based upon the same principles as that of land survey, but that the photographic apparatus is of course different. In both cases advantage is taken of the use of control points of known positions and distances apart; these positions are fixed by an independent land survey.

Ground Survey.—The powers of binocular vision—sometimes know as stereoscopy—are utilized for the measure of distance and bearing of objects appearing on two photographic plates, regarded as a stereoscopic pair. When two photos are taken of more or less the same landscape from the ends of a base of known length, these photos may be employed for mapping the portion of the landscape common to each. The process of measurement from stereoscopic pairs of photographs is known as stereophotogrammetry.

In ground survey, as distinct from work in the air, the photos are usually taken with their planes vertical and parallel to the vertical plane containing the "base." The procedure is illustrated in Fig. 133.

Let L_1 and L_2 be two positions of the lens of a camera, the focal length being f and the stereo base L_1L_2 being b. The plates are parallel to this base, so that $Y_1L_1C_1$ and $Y_2L_2C_2$, the optical axes, are horizontal, parallel and perpendicular to the base. Any object O in the field appears at I_1 on the left-hand plate and I_2 on the right hand plate.

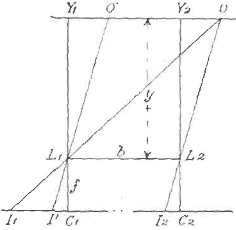


FIG. 133.

Draw $O^1L_1I^1$ parallel to OL_2I_2. C_1 and C_2 being the plate centres, it is easily seen that $I^1C_1 = I_2C_2$. Hence $I_1I^1 = I_1C_1 - I_2C_2$. The distance I_1I^1 is known as the parallactic displacement, which is designated as p.

Now let the perpendicular distance from O on the base L_1L_2 be y, so that $OL_1 : L_1I_1 = y : f$. But from the similar triangles OO^1L_1 and $I_1L_1I^1$, since $OO^1 = L_1L_2 = b$, we have—

$$b : I_1I^1 = OL_1 : L_1I_1 = y : f.$$

Hence

$$y = \frac{bf}{p} = \frac{\text{Base} \times \text{Focal length}}{\text{Parallactic Displacement}}.$$

Hence it follows that the base and focal length having been determined, the distance y of the object from the base can be found if the parallactic displacement is measured.

The parallactic displacement could be measured off the two plates by dividers; but the process would be slow. Deville in Canada suggested a modification of the Wheatstone Stereoscope, in which the images of marks were reflected on the two photos of a pair; each eye was thus enabled to see a mark in apparent coincidence with some point on the photo. When the two images of the same object were brought into stereoscopic combination, the images of the two marks were similarly fused; they thus appeared in coincidence with the stereoscopic object as a single mark, floating as it were in the spatial field.

In 1903, Pulfrich designed the stereo-comparator, in which the floating marks were etched on the diaphragms of the eyepieces of a binocular telescope and the movement of one photographic plate with respect to the other, in other words, the parallactic displacement, was measured rapidly on a micrometer.

The line I_1L_1,—or alternately the line I_2L_2,—gives the *direction of the point O. The direction of O and its distance from the base being both known, its position is thus fixed; and so for every other point which appears on both plates.*

Even with the stereo-comparator, the plotting of a map by this process would be excessively slow. Major Thompson, R.E., devised an apparatus to facilitate the plotting. To the stereo-comparator he attached a drawing board, over which there moved a bearing arm which gave immediately the direction of the point. The distance from the base, to the scale of the map, was set off by a transversal moving bodily up and down the board and reading against a scale which showed the distances corresponding to the parallactic displacements measured on the reading-drum of the comparator.

In passing it may be noted that the error Δy in distance corresponding to an error Δp in the displacement is given by

$$\Delta y = -\frac{y}{p}\Delta p = -\frac{y^2}{bf}\Delta p,$$

which shows that the error in distance due to parallactic error *increases as the square of the distance; the result follows the law of the first formula, since $\Delta p/f$ is equivalent to the $\Delta\beta$ which has been previously described as the differential parallax.*

The error due to incorrect measure of the parallax is only one of the instrumental errors which arise in practice. Thus errors of base measurement, of verticality and alignment of the plates and many others are involved; so that the total error in the estimation of distance possibly increases more rapidly than the square of the distance.

Modern Stereophotogrammetry.—The design of the stereo-plotter marked a distinct step in advance; but even with this instrument plotting of maps from pairs of photos taken on the ground was tedious and expensive, the operations being only automatic to a small degree. A young Austrian Lieutenant, von Orel by name, made great improvements in the design, rendering it almost entirely automatic. Utilizing the same principle of stereoscopic coincidence, he designed a machine to plot simultaneously both altitude and position of features. Moreover, of the two levers required for fixing position and the third lever for measuring height, it was possible to lock the latter at a given altitude; this reduced the degree of freedom of the two azimuthal levers, which were thus constrained to plot those points only which were situate at this altitude. The plotting pencil thus drew continuously on the drawing-board a contour of the terrain, that is to say, a line of given level. Without contours no modern topographical map would be complete. All later improvements in apparatus for stereophotogrammetry are merely developments from the design of von Orel.

Further improvements were introduced by the Zeiss firm, the object being to plot from plates which, though still vertical, were inclined to one another and to the base at varying angles and were taken at points of dissimilar altitude. The stereo-autograph, which is a sufficiently complicated machine, is now relegated to the duty of plotting from ground photos alone.

Plotting from Pairs of Air Photos.—The problem of the air photo is the general problem of photogrammetry. Aerial photos may be taken in any position, and at any angle. The inclination of the plane of the photo to the horizontal is known as the tilt; the angular movement around the optical axis of the lens is known as the swing. In all 9 quantities, called the *plate constants*, are required to fix definitely the position of a photographic plate in space at the moment of exposure. Of these, three are camera constants, that is to say, they are common to all photos taken with the same camera. Of the remaining six, three are linear and three angular. Before a map can be accurately drawn from two overlapping air photos, taken at any angles, we must know with fair approximation the 9 constants of each plate. It is not possible to obtain all these constants unless the position and altitude of at least three points which appear on the plate are known. This of course implies that it is not possible to construct a map from air photos without a considerable amount of preliminary survey on the ground: we must first survey a sufficient number of fixed points—control points they are generally named—so that at least three may appear on every plate. The methods, whether graphical, instrumental or mathematical, of determining the plate constants are complicated.

Flat Country.—Let it be noted that we are here speaking of very accurate mapping of country assumed hilly and we are speaking also of the general problem. If the country is flat or nearly so, the plate is exposed in a position very approximately *horizontal and the accuracy of the map is limited, the* problem is vastly simplified; moreover, by stringing together a certain number of photos to form a "mosaic," the number of the control points may be greatly reduced.

The Stereoscopic Solution.—The only strictly automatic instrumental means for solving the general problem at the moment are those which involve the *stereoscopic principle.* The most successful machines so far designed with this object incorporate an apparatus suggested by Porro, the Italian geodesist and optician, well known as a constructive genius. This apparatus, which is given the name *Photogoniometer*, consists of the half body of a camera in which a positive, illuminated from the front, is viewed backwards through the lens by means of a small telescope mounted as a theodolite. The positive is tilted so as to occupy the same position relative to the horizontal as it had at the instant of exposure and swing so that the principal plane—i.e., that plane through the lens and perpendicular to the plate which was vertical at exposure—is again set vertical in the photogoniometer. By viewing the positive through the lens the small theodolite gives the bearing with regard to the principal plane and the angular altitude of each point on the plate. The operation is thus the same as if a theodolite, placed at the position of exposure in the air, had measured the horizontal and vertical angles of the various features of the landscape in the field of view shown on the plate: the effect of tilting and swinging the plate in the photogoniometer is such as to render the angular measurements, horizontal and vertical, the same as if the view had been taken on a vertical plate. *A duplicated apparatus, containing two photogoniometers*, can thus bring each photo of a pair into the same condition as regards measurement as in the normal case previously considered above, that is to say, the case wherein both plates are vertical. Moreover, if the two principal planes are brought into

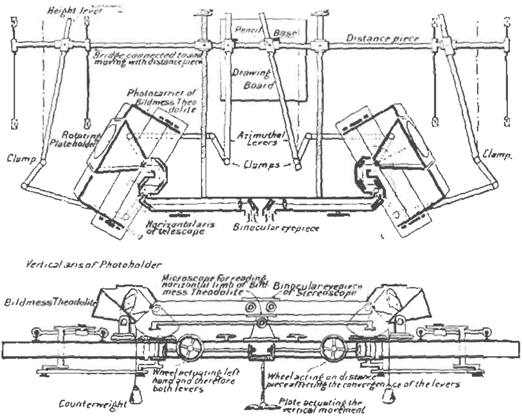


FIG. 131.—THE AUTOCARTOGRAPH OF HUGERSHOFF AND HEYDE, SHOWING THE OPTICAL AND MECHANICAL SYSTEMS

the same angular relation to one another as at exposure—a condition attained by rotating the photogoniometers bodily and horizontally round their lenses—both plates are now set relatively as they were when the views were taken, with the exception of one condition: we have not yet made an allowance for any difference of height there may have been in their respective air positions. The twin telescopes are connected with a stereoscopic system very similar to that of von Orel, linked with plotting levers of much the same nature as in the stereoautograph. For mechanical reasons the movements are not quite the same as those indicated but the principle of action is precisely similar.

The machine thus briefly described is the *Autocartograph* of

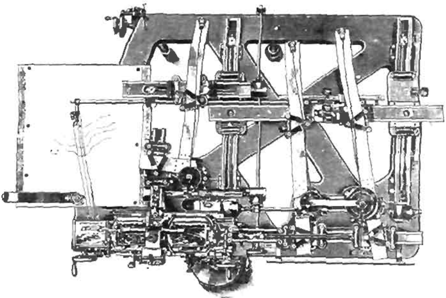


Fig. 135.—The Stereoautograph (Plan View)

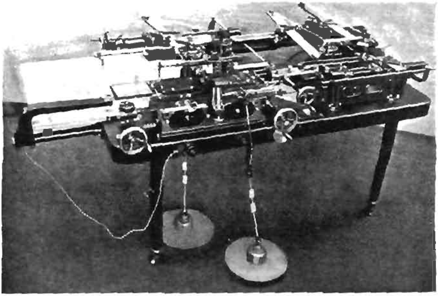


Fig. 136.—The Stereoautograph (Perspective View).

Hugershoff, Cranz & Heyde. This machine is primarily designed to take photographs tilted at 60°. With tilts so great as this the faintly seen backgrounds of the photos are of little use.

No adjustment is possible for difference of altitude of the photographic pair, but nevertheless the machine is a successful attempt at plotting position and altitude of features in the foreground of highly tilted air photos. Moreover—an important point—it can itself be used for determining the plate constants, provided that the positions and altitudes of three points in the common field are known.

The method of photogrammetry, apart altogether from the instrument, is open to two criticisms. If the ground is the least undulating there is always a certain amount of dead ground in the picture; that is to say, low land that is concealed by higher features in the foreground. Consequently, Hugershoff has to supplement his highly tilted photos by photo-topography, that is to say, by covering the ground with a series of horizontal plates. Since these cannot conveniently be exposed in the same light as the tilted photos, the air work is doubled. In the second place, stereophotogrammetry involves short air bases and, consequently, acute intersections.

Other Stereophotogrammetric Machines.—Another machine designed for this purpose is that of Bauersfeld-Zeiss; it is called the *Stereoplanograph*. This is an apparatus with several interesting features, though the fundamental principles remain the same as in the autocartograph, the Porro system being again utilized in a pair of photogoniometers. The machine is even more generalized than that of Hugershoff, for it permits of adjustment for varying altitude of the camera. The plates are set in the photogoniometers so as to be corrected for tilt and swing, but the photogoniometers themselves are not swung as in the Hugershoff machine.

An improvement in detail is introduced in the *floating marks*: these are designed to produce in themselves a stereoscopic effect which tends to stimulate the stereoscopic sense when objects are viewed in or near coincidence in the binocular field.

In stereoscopic apparatus in general, where the stereo-viewing system is movable, a curious phenomenon, known as the *somersaulting of the images*, is obviated by the introduction of special prisms in the path of the rays.

The stereoplanograph has a drawing-board and plotting

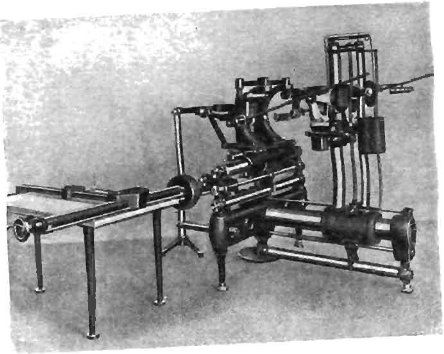


FIG. 137.—THE STEREOPLANIGRAPH (REAR VIEW).

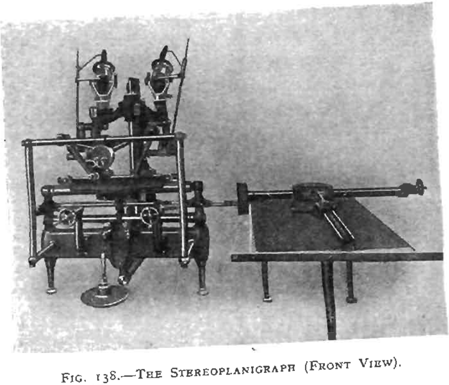


FIG. 138.—THE STEREOPLANIGRAPH (FRONT VIEW).

apparatus attached, whereby the motions of the instrument are reproduced on paper, universal-link chains being employed for the transmission. The motions are equivalent to the fixing of a point in the space by three co-ordinates, x, y and z, which, being interchangeable, render the instrument adaptable to plotting from photos which are taken at low as well as high tilts.

The machine is more compact and less ponderous than the autocartograph; but as more optical principles are invoked, it is certainly more complicated.

Another machine, simpler even than the autocartograph, has been invented by Wild in Switzerland.

The Convergence.—The maximum value of the convergence in the case of human vision is about 16°. The question at once arises: Does this limit hold also in case of the machines considered? Concerning this question, there is much difference of opinion. On the one hand, Comdt. Vavon, who is using the stereoautograph in France, is of opinion that for practical working the lower and upper limits of the convergence are 6° and 15°; according to him any greater angle than 15° involves excessive strain on the eyes. Other continental authorities put the upper limit of the working convergence at much higher figures.

It can be shown that, with increasing convergence, the portion of the field capable of stereoscopic fusion is narrowed. This latter point is of sufficient importance to warrant a short departure from the matter under present consideration.

The greater the convergence the greater the *curvature of the horopter*—a term which, whatever its original meaning, is applied here simply to the circle passing through the object and the two ends of the stereo base; otherwise it may be defined as the arc capable of the convergence or parallax. Again, the greater the curvature the smaller is the field within which objects on or near the horopter are at a given distance from the base, which, as previously seen, implies that they exhibit on the plates the same parallactic displacement.

Conversely, a stereo machine set for a given parallactic displacement should show in stereoscopic fusion all points in the field of view at the same distance from the stereo base. But if, as has been supposed, fusion is limited to points on the horopter, or very near it, the curvature of the latter necessarily narrows the field. Since experience appears to show that the field of fusion is actually limited when the convergence is large, the theory of the horopter would seem to be substantiated.

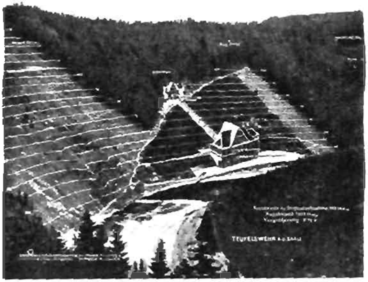


FIG. 139.—STEREOPHOTOGRAPHIC SURVEY FOR THE WISENTTAL WATER POWER PROJECT SHOWING PERSPECTIVE CONTOURS, FOREBAY, PENSTOCKS AND POWER STATION.

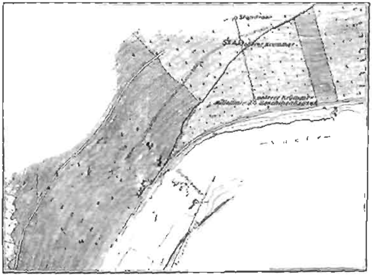


FIG. 140.—STEREOPHOTOGRAPHIC SURVEY OF WISENTTAL WATER POWER PROJECT. COMPLETE CONTOUR MAP MADE FROM STEREO-PHOTOGRAPHS.

It is worthy of note that in ground stereophotogrammetry the portion of the field in stereo combination for a given setting of the machine is confined to a horizontal band. The reason of this is that the lower parts of the field in general portray the terrain in the foreground while the most distant parts of the landscape are in general at the top of the picture.

The greater the convergence the less like one another will appear the images of the same object on the two plates. It seems then almost a foregone conclusion that the greater the convergence the greater must be the difficulty of fusing objects in general.

The Anaglyphic Method.—We now come to the anaglyphic method, whereby a plastic effect is obtained by projection. The method was applied to photographic survey by an Austrian protagonist, Scheimpflug, with whose collaboration an apparatus was designed by the Zeiss firm ; the latter, however, have never pushed its sale. During the war a similar apparatus, constructed by Gasser, became known under the name *Inag* (Intl. Aero-Geodetic Co.), which more recently has been taken up by von Bertrab. Nelles in Canada, apparently unaware of the previous work, hit upon the same idea in a form more directly applicable to aerial survey. Within the last year the British Air Survey Committee has arranged for the construction of similar apparatus, which it describes as the *Camera Plastica*.

In this method two positives, forming a stereoscopic pair, are projected simultaneously in coincidence on a drawing-board. Commonly one picture is projected through a glass screen coloured red and the other through a green glass. A circular blind, of which one half sector is cut away, is made to rotate in front of the coloured screens in such a manner that at one instant the red picture only is seen and at the next instant the green alone appears. If the photos have been taken over hilly country from an aeroplane, the effect is to throw on the drawing, viewed through hand-glasses, coloured respectively red and green, what appears to be a model of the country in relief. If the rotation of the blind is slow one gains a curious impression, as if the picture were in process of moulding.

A draughtsman may now sketch the country on the board, or a pantagraph may be used to transfer the picture to a drawing near by. The plastic effect of the combination of the two views enables the summit of a hill, for example, to be plotted in its true position; for, if the drawing-board is moved upwards by an amount which is the equivalent of the height of the hill, the summit of the latter becomes stationary and the moulding process, previously mentioned, ceases on the hill top. The position of the hill cannot only be shown, but the amount of upward movement of the drawing-board is a measure of its height. This is so because it is only when the board is in this certain position that true stereoscopic coincidence of the two projected images of the hill takes place.

Nistri in Italy has designed an apparatus to facilitate the plotting. In this apparatus the drawing-board is removed and placed alongside the main apparatus in which the combined picture is thrown on a screen. A pointer follows the line of coincidence, *i.e.*, the stationary line of the two projected images, which obviously corresponds to a contour level, and the motion of the pointer is transferred by a photographic attachment to the drawing. This method, which is a promising one, cannot conveniently be extended to oblique photographs, its present application being confined to photos taken with the optical axes approximately vertical.

In the case of the camera plastica, the positives in the projecting lanterns should be moved to and fro in order to obtain proper focus of features above a certain elevation. This movement of the positive is, unfortunately attended by transverse displacement of the images, so that difficulties are introduced.

For a given position of the drawing board, the stationary line previously mentioned is the line of points where the images are precisely coincident and therefore in focus. If a rotating blind is not used, reliance has to be placed on the estimation of correct focus alone. This is not so easy as it may appear: the positives have to be magnified, and magnification brings out the effect of engine vibration on the plates and the grain of the latter themselves. Even if the rotating blind is employed, movement in the vicinity of the stationary line is so minute that it is again difficult to draw the precise line of contour. Nevertheless, in spite of all the drawbacks mentioned, the method does provide an approximation to an accurately contoured topographical map.

CHAPTER XIX

THE PROJECTION OF STEREOSCOPIC PICTURES.

THE same principles of taking and viewing stereoscopic pictures apply also to the projection and viewing of transparencies in the form of lantern slides, or cinematograph films. The most important item to be observed is that each picture projected on the screen should be seen only with the eye corresponding to the lens of the camera with which the picture was taken; thus the right eye should only see the picture taken by the right lens of the stereoscopic picture, and the left eye, that with the left lens.

A certain amount of misconception appears to have arisen in connection with stereoscopic projections, many people believing that so long as there are two sets of pictures, each corresponding to the left or right view, then by projecting them simultaneously or alternately upon a screen, a stereoscopic effect will be obtained with the naked eye. This view is incorrect, although partial effects may sometimes be obtained in this manner.

The Anaglyph Method.—There are several possible methods for viewing either lanterns slides, or films, but the principle of these depends upon the use of some special means for observing the pictures in order to obtain the proper stereoscopic effect; the special means in question corresponds with the use of the stereoscope in viewing ordinary stereograms. In one method, red and green spectacles are worn by the audience, so that only the green or the red coloured picture projected on the screen can be seen, respectively, by the corresponding eye, as shown in Fig. 141. This method it will be noted is identical with that of the anaglyph described in Chapter XIII. Indeed it has been a common practice to project anaglyphs in the form of lantern slides, upon a white screen and to view them with the ordinary red and green masks. An extension of the same method to cinema films will enable an audience provided with these masks or spectacles, to obtain stereoscopic impressions on a big scale. *In this case there would* be two sets of negative films, one taken with the left, and the other with the right lens of a special two lens cinema camera. The positive film, say, *the left lens negative film* would be dyed or stained green, and the right one red. The projection apparatus would be arranged so that corresponding pairs of red and green picture were projected in an almost *super-imposed position as in the* anaglyph, whence they would be viewed by the red and green masks or spectacles.

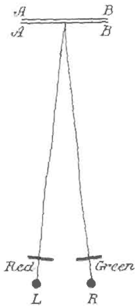


FIG. 141.—THE ANAGLYPH PRINCIPLE.

One drawback of this method is the loss of light on the screen due to the relatively dark colours employed.

Some demonstrations given in Paris,* utilized the anaglyph principle, in which the red and green images are almost superimposed upon the screen. For this purpose a single lantern *with a special attachment for obtaining the required superimposition* was employed. The lantern was fitted with two identical lenses which could be moved towards or away from one another as required. Two plano-convex lenses were arranged either close behind the common condenser (as in the Gaumont three-colour projector) or between the lantern stage and projection lenses. These glasses projected the light transmitted by the two halves of the condenser into the projection lenses. In order to make the construction clear it should be said that a segment was cut from each of the two plano-convex glasses so that these two glasses were close together with their straight joining edges midway in the optical system and in line with the space separating

* *Brit. Journ. of Photog.*, Mar. 14, 1924.

the two pictures of the stereoscopic pair. Two light-filters, red and green respectively, were fixed in front of the stereoscopic pictures, and, as usual, viewing pieces, for the use of the audience contained red and green filters, thus serving to fulfil the conditions requisite for obtaining the relief effect on the screen.

Another method which has been used in Paris music halls consists in projecting from the back of the stage by means of two projectors, one fitted with a red screen and the other with a green screen, arranged side by side, one about two or three feet from the other, two shadows of the subject on to the semi-transparent screen which closes the stage in front. When these shadows are viewed with the ordinary two-colour lorgnette the effect which is seen is a single shadow in front of the screen, advancing into the auditorium almost to the spectators as the separation of the two centres of projection is considerably greater than the separation of the eyes. Thus, any object thrown by the actor on the stage in the direction of the projectors appears to be thrown at a much greater speed in the direction of the spectators.

The anaglyph method of projection, on account of the cheapness of the viewing masks is certainly one of the most promising; those who have witnessed the cinematograph "plastigrams," will appreciate their value from the stereoscopic standpoint.

The Stereoscope Method.—It will be obvious that if stereoscopic pairs of pictures be projected upon a special screen, side-by-side, as in the ordinary stereogram, and if instead of the usual short focus lens type of stereoscope (which gives a magnified image), a special prism or mirror arrangement be employed to merge the two views as seen by the eyes, then a stereoscopic effect will be observed; one or two firms actually supply projectors for stereoscopic transparencies, both pictures being thrown upon a suitable screen. One simple arrangement for obtaining this effect is that illustrated in Fig. 142. Here a single prism of the shape shown is held to the right eye in the manner indicated, with the result that owing to two internal reflections the right hand picture A^1B^1 appears superimposed upon the left hand one, $A B$ at $C D$; this gives a stereoscopic impression. A pair of mirrors, similar to those shown in

Fig. 143 will give the same result. Indeed, this method is capable of several variations in application.

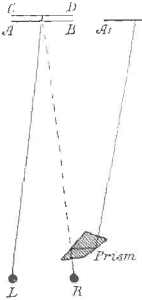


FIG. 142.

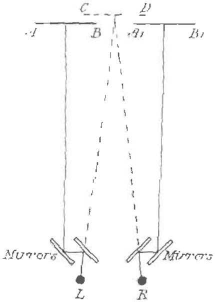


FIG. 143.

As in the previous case the use, by the audience, of special viewers is therefore essential. Fig. 144 illustrates the ordinary stereoscope viewer method of observing projected stereo pictures *A B* and *A*¹*B*¹. In this case the effect is that of a single picture in relief seen at *C D*.

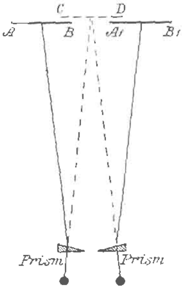


FIG. 144.

The Polarized Light Method.—An ingenious method due to J. Anderson, utilizes the well-known properties of polarized light for projection and viewing purposes. In this case two projecting lanterns are employed, one for each set of pictures. In each optical system of the lantern, is inserted in the light beam a Nicol prism plate of tourmaline ; this polarizer is often fixed between the condenser and projection lens. The important feature in fixing the Nicol polarizers is that the axes of the latter are arranged *at right angles*, so that the beam of light which emerges from the one lantern is polarized in a plane at right angles to the emergent beam from the other lantern. The optical axes of the two lanterns are arranged so as to meet on the screen, the result being that one picture consisting of erect images will be superimposed upon the other picture having its images at right angles, i.e., lying on their sides, due to the polarized light on the screen being at right angles. The result, as seen on the screen with the naked eye, will be a confused picture composed of two at right angles.

If now the observer views these superimposed pictures through a pair of analyser prisms, one in front of each eye, and so arranged that their planes are at right angles, each eye will see only the picture corresponding to that of its projecting lantern, so that a stereoscopic effect is observed. The viewing analysers usually consist of a number of thin glass plates mounted in the form of an opera glass; the refraction method of polarization is utilized in this case. It is essential in the application of the polarized light method that the screen upon which the images are projected should have a non-polarizing surface, otherwise the light will be depolarized by reflection; a metallic surface is suitable for a projection screen.

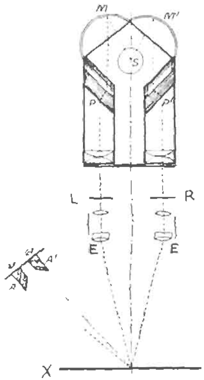


FIG. 145.—ILLUSTRATING THE POLARIZED LIGHT METHOD OF PROJECTION.

Fig. 145 shows a recent invention utilising the same principles. Here the source of illumination is at *S*. The rays of light are reflected from two reflectors *M* and M^1 through two piles of plates *P* and P^1, respectively in order to plane polarize the beams; the beam *P* is polarised at right angles to P^1. The left and right films are shown at *L* and *R*. These are projected by lenses *E*, *E* so as to converge on the screen *X*. The superimposed polarised pictures are then viewed by the eyes by means of analysing plates, or prisms at A^1 and *A*, in such a way that the former only sees the left, and the latter, the right picture.

Automatic Machines. In passing, mention should be made to the stereoscopic, or animated pictures still to be seen in penny-*in-the-slot machines. These consist of stereoscopic* pairs of pictures printed on leaves forming a kind of book. These leaves, by means of an automatic device operated by a handle, are caused to flick continuously in front of a pair of viewing lenses, i.e., an ordinary stereoscope, and an impression of moving pictures in relief is obtained, due to the persistence-of-vision effect.

The Eclipse Method.—*There is another type of stereo*-projector, the principle of which was first employed by J. Ch. D'Almeida, in 1858. The method employed consists in projecting, in rapid succession, the two stereoscopic pictures on a screen. For this purpose transparencies must be employed. If the pictures are projected with sufficient rapidity they will appear in continuous movement, instead of being intermittent, due to the well-known persistence-of-vision effect. If now a rotating sector (Fig. 146) be so arranged in front of the pictures that it rapidly covers and uncovers each picture in turn, and if, further, a similar revolving shutter be placed before the eyes of the person viewing the screen pictures, then if the latter shutter is properly synchronized with the first, each eye will see only the succession of images due to the corresponding side of the double film, and stereoscopic perception will be realised. The principal difficulty of this method, in practice, is in connection with the convenient arrangement and synchronism of the viewing shutter.

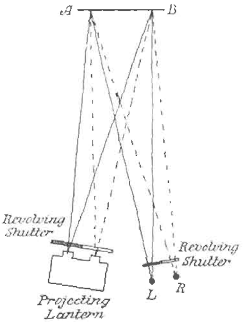


FIG. 146.—D'ALMEIDA'S ECLIPSE METHOD.

Fig. 147 illustrates an interesting method of projecting the alternate pictures, due to Mm. Dupuis and S. Schmidt. Here the pictures forming a stereoscopic pair are shown at I_1 and I_2.

There is a fixed inclined mirror M_1, placed so that the illuminating beam from the light source S will enable the image of I_1 to be projected by means of the lens O_1 on to the screen. There is

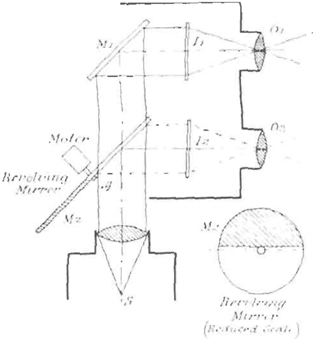


FIG. 147.—THE ROTATING MIRROR METHOD.

a second disc, M_2, inclined at the same angle (45°), which is arranged to rotate about a central inclined axis at A. The disc contains a mirror M_2, occupying one-half of the circumference,

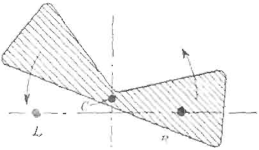


FIG. 148.—THE ROCKING SHUTTER FOR SYNCHRONIZING THE PICTURES.

and a cut-away portion. When the disc rotates, the mirror M_2 alternately illuminates the transparency I_2, and in doing so cuts off the light from M_1. In this way M_2 and M_1 are illuminated alternately and at such a rate that owing to the persistence of vision the eye appears to see a continuously changing picture. A conveniently arranged rocking shutter (Fig. 148) is arranged in a mask placed in front of the observer's eyes *L* and *R*, the shutter being operated by a small electromagnet with electric current supplied through a suitable pair of fine cables; the shutter rocks about the axis *C*. There is an interrupter in the projection disc apparatus which ensures the shutter working in synchronism with the rotating disc. In this way the left eye sees only the left moving picture image, and the right eye the right image.

Other Methods.—A very large number of attempts have been, and are still being made to solve, on a commercial scale, the difficulties of stereoscopic projection of cinema films. Numerous patents have been granted and many schemes have been tried. Most of the later schemes aim at dispensing with the need for special viewing apparatus so that the picture theatre audience can observe the films in a similar manner to ordinary single picture films; the same size and shape of screen is also desirable.

At the time of writing none of these schemes has proved itself practicable; many fail purely through lack of knowledge of the basic principles.

In another method for partial relief effects advantage is taken of the light and shade aids to stereoscopic vision, by taking alternate films with a shift of the lighting from side to side, so as to alter the lighting effect in consecutive pictures. In this case a single film only is used. In still another example a single film is exposed on the subject, and the positive film is treated chemically so as to cause the gelatine to assume a kind of contoured, or bas-relief appearance, somewhat similar to that of pyro-soda developed plates in the wet state.

Integral Photography.—An account was given in the *Photo-Revue* for May 15 and June 1st, 1925, of a development by M. Estanave from Lippmann's Auto-stereoscopic plate. The former has made a compound lens somewhat along the lines of an insect compound lens eye. The plate is placed in contact with the plane surface and the photograph taken in the ordinary way. It is stated that not only does a single image, in relief, appear when the negative or positive is placed behind the lens in its initial register, but by projecting light from the front a single image is seen on the screen. The *latest* "insect eye" of M. Estanave consists of 95 separate lenses, his first having 56. Examples of results obtained by this method were on view at the Provence Pavilion in the Exposition des Arts Decoratifs, in Paris, 1925.

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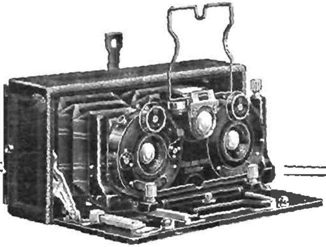

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