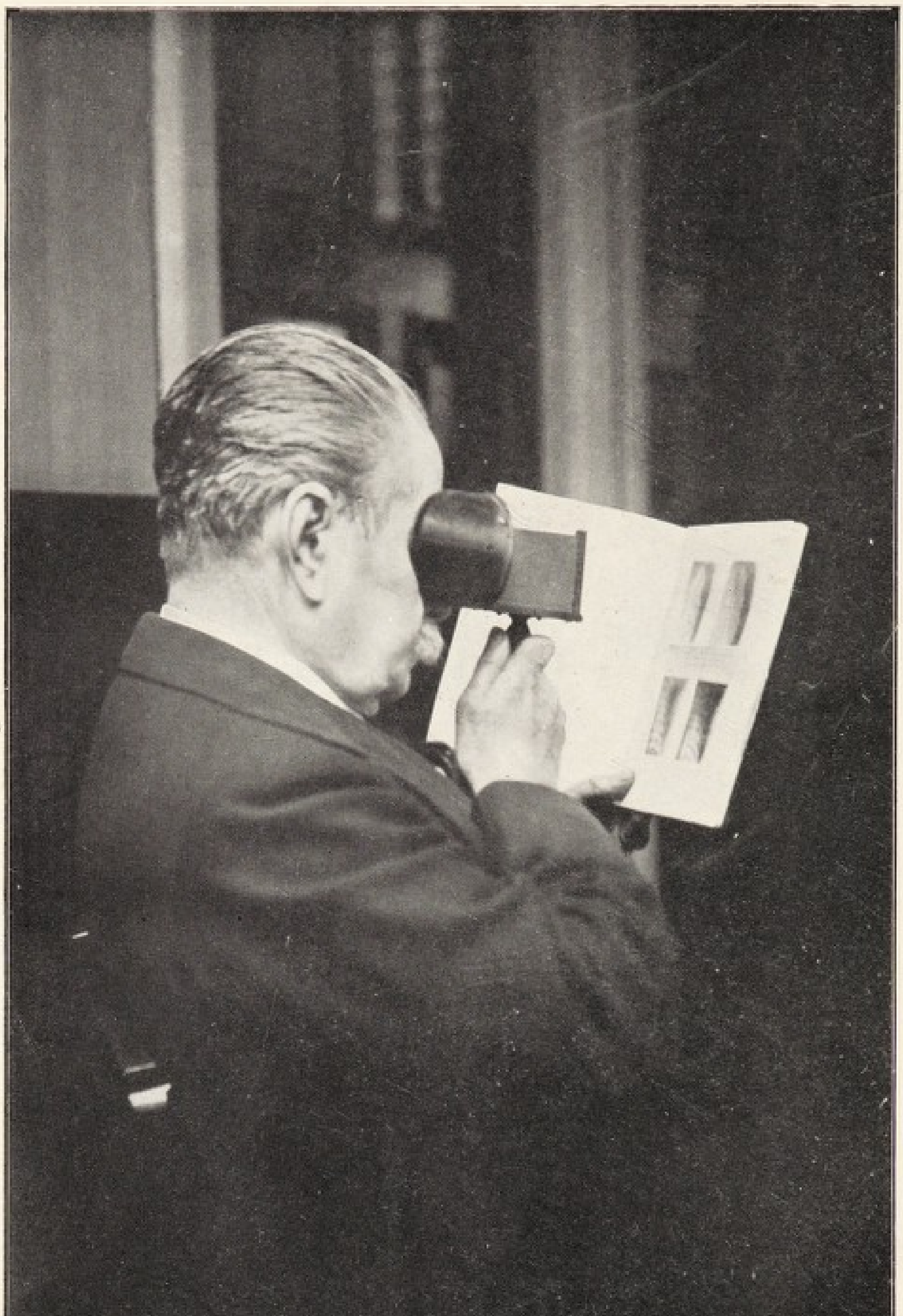
LOCALIZATION BY X RAYS AND STEREOSCOPY



A Convenient Procedure for Viewing the Stereoscopic Illustrations in this Volume.

The stereoscope employed is one commonly supplied by opticians with the end-piece sawn off. The focus is easily adjusted by arranging the distance at which the book is held from the observer.

Frontispiece.

LOCALIZATION

BY

X RAYS

AND STEREOSCOPY

BY

SIR JAMES MACKENZIE DAVIDSON

M.B., C.M. ABERD.

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WITH 35 STEREOSCOPIC ILLUSTRATIONS ON SPECIAL PLATES
AND OTHER FIGURES IN THE TEXT

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1916

PREFACE

It is nearly twenty years since the author first described, in the medical press, the system of exact localization by means of X rays which is mainly the theme of this volume. The present appalling war, with its enormous number of casualties, made it seem likely that a more detailed description of the method in book form would be of some service to those engaged in X-ray work among the wounded. No attempt has been made in these pages to cover the vast ground of X-ray work in general; the aim has been merely to bring together a number of practical points connected with the author's personal work. The system he advocates has stood the test of time, but it has also shown itself adaptable to the more rapid procedure which is demanded, and the simplifications which have been introduced into the original method will be found fully described in the body of this book.

The author would direct special attention to the final chapter, which deals with the precise localization of foreign bodies in eyeball and orbit, for he trusts that this application of X rays may be extended. As every ophthalmic surgeon knows, foreign bodies in the eyeball and orbit are ever with us. At present, owing to hand-grenade warfare, such cases are occurring in very large numbers, but in civil life, especially in engineering workshops and various industrial concerns, these cases are constantly met with; and very often it happens that the eye can be saved if—but only if—the exact position of the foreign body is known, so that it may be extracted without difficulty.

As far as possible, the practical and utilitarian aspect of the subject has been adhered to, and any theoretical considerations have been introduced only in so far as they have a direct bearing on the practical side of the work. Probably no one is quite satisfied with the result of his labours, and the author is fully aware of the many shortcomings of this little volume; at the same time, he hopes that it may prove of some use at the present juncture.

Special care has been given to the illustrations, the great majority of which are from the author's stereoscopic photographs. A book which advocated stereoscopy could hardly be otherwise illustrated than by stereoscopic methods; in fact, many of the illustrations in this book rely for their value entirely upon being viewed stereoscopically; otherwise they are meaningless. The author recommends the viewing procedure illustrated in the frontispiece. The instrument held in the hand consists of a stereoscope minus the ordinary projection for holding the print; it is cut off short at the end of the T-piece which separates the lenses, and will be found convenient and economical for use in the case of stereoscopic book illustrations, and, indeed, for ordinary prints and transparencies. It is supplied by Messrs. Hinton & Co., of 38, Bedford Street, Strand, London, W.C.

The author's thanks are due to Messrs. W. Watson & Sons, Ltd., for the loan of the plates on pages 23, 27, and 34; and to Mr. A. W. Bond for the illustration of the telephone attachment on page 57. He has also to thank Mr. Harry Cooper for his most valuable assistance in the preparation of this little book—indeed, without his aid and co-operation it might never have been completed.

March, 1916.

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(*From stereoscopic X-ray photographs.*)

LOCALIZATION BY X RAYS AND STEREOSCOPY

CHAPTER I

THE X-RAY TUBE

Introduction.—The importance of being able to ascertain the exact position of bullets and fragments of shell lodged in the tissues of the human body needs no insistence at the time of writing, when an appalling number of wounded are being returned from the seat of war. Not only are localization methods essential while war is actually in progress, but even after hostilities have ceased many cases are bound to arise in which fragments of metal, whose extraction was not at first thought necessary or desirable, will be found to give trouble and require to be localized. It would seem that, in this country at all events, while a great many of those occupied in X-ray practice can produce admirable photographs, they encounter considerable difficulty in localizing with sufficient exactness the position of the foreign body. It has occurred to the author, therefore, that having given many years of labour to this subject of localization, he may usefully offer to other workers in this same field some remarks on his methods and experiences.

It is assumed that the reader is familiar with the ordinary X-ray outfit and its working, and therefore a dissertation on this elementary part of the subject may be omitted entirely. There are several excellent manuals describing in detail the apparatus and technique, and it would be of little use to repeat, in a condensed form, what can be found so fully dealt with already in these publications. So far as this volume is concerned, the consideration will be limited mainly to the localization of foreign bodies by methods of precision, to stereoscopic X-ray work, and to the highly specialized subject of localization in the eyeball and orbit. Before entering upon a discussion of these subjects, however, it is necessary to pay some attention to the question of the X-ray tube in action (Fig. 1) and its properties, as this will be found to have a practical bearing upon the successful working of the localization methods to be considered presently.

The X-Ray Tube.—In the rapid advance of modern physics, many points have been elicited which are of extreme interest to those who have to handle the X-ray tube, but in these pages the characteristics of the rays and similar questions can only be discussed in their relation to practical X-ray work. It is necessary, however, to bear in mind the internal construction of the tube and its adaptation to the energies which it has to control. The cathode rays, taking origin at the concave cathode terminal, proceed in straight converging lines until they meet at a fine point, beyond which they slowly diverge (Fig. 2). The degree of convergence depends upon the curvature of the cathode from whence they take their departure. This radiation has only to impinge upon a target to produce X rays at the point of impact, and this target

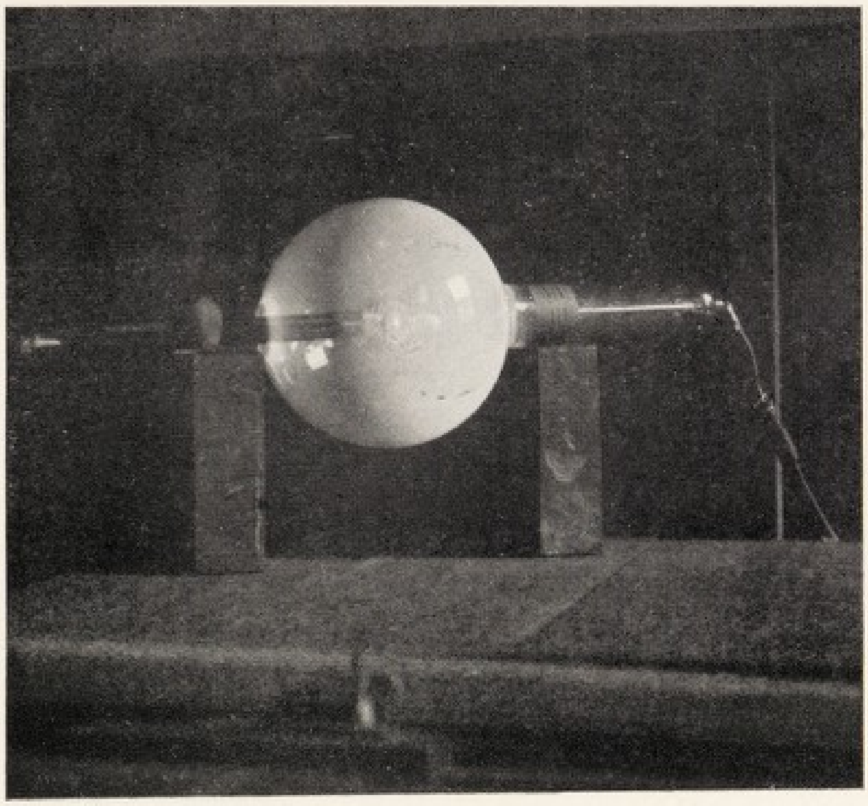


FIG. 1.—PHOTOGRAPH OF X-RAY TUBE IN ACTION.

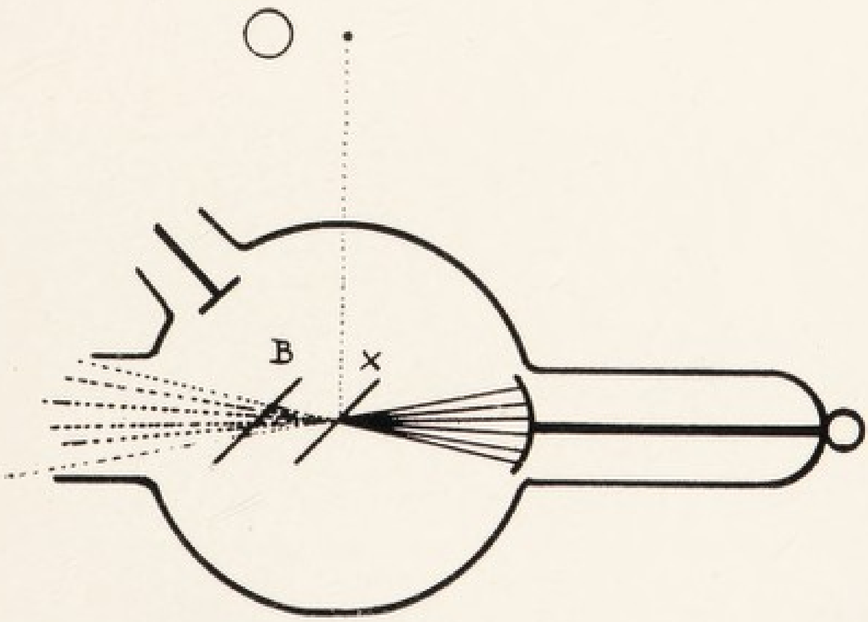
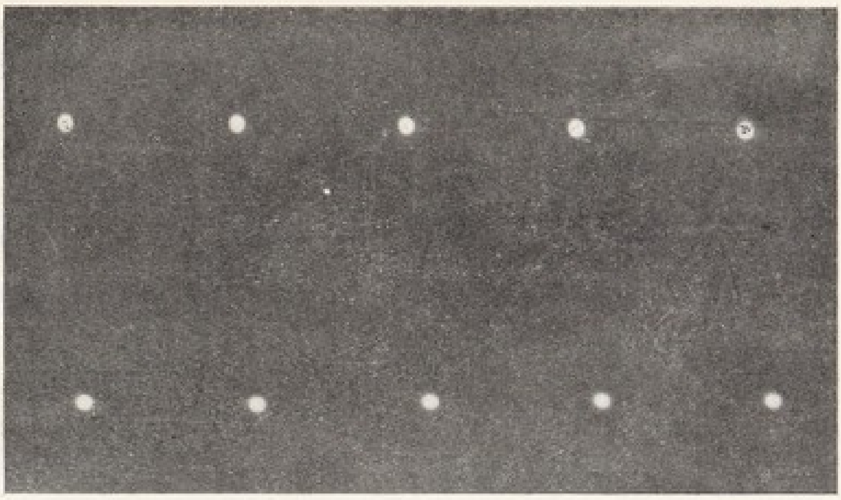


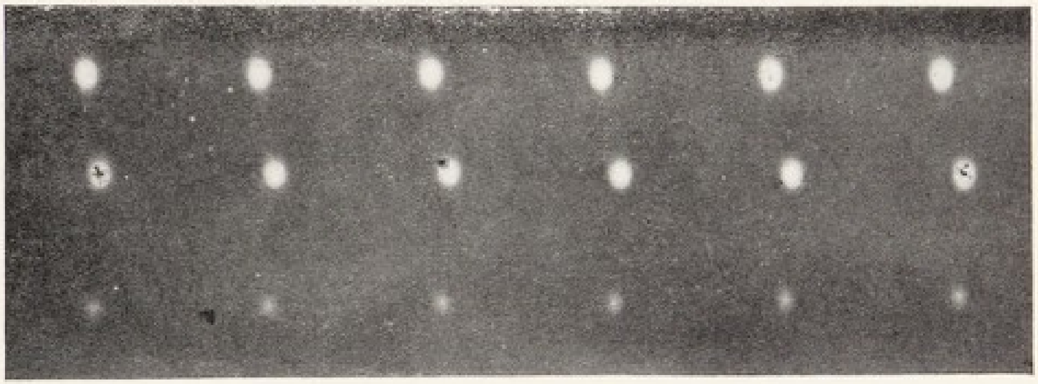
FIG. 2.

[*To face p.* 2.

PLATE II.

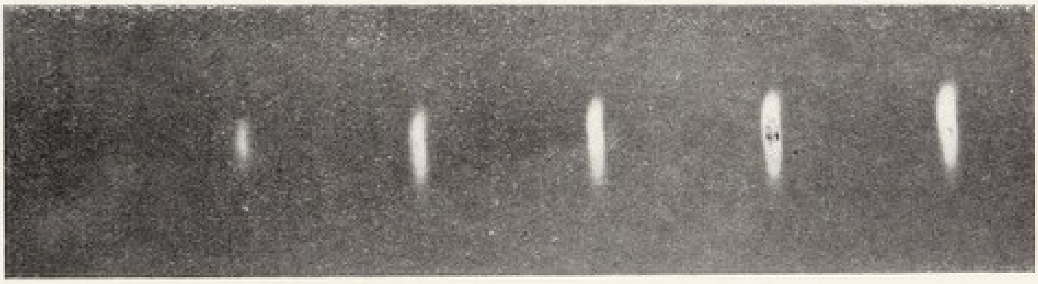


Pinhole Photograph of an X-Ray Tube having a Very Fine Focus, in which the Target receives the Cathodal Stream at a Very Narrow Point.

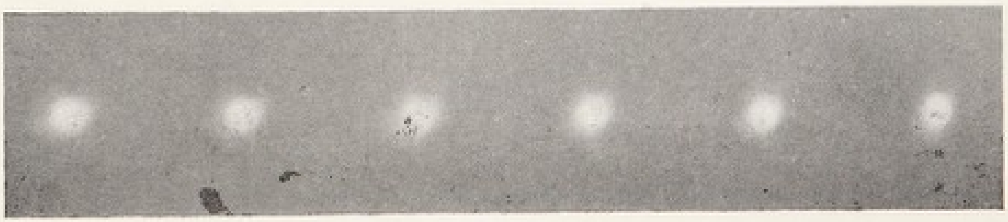


Pinhole Photograph of a Tube of Larger Focus.

The lowest row of pinholes represents a voltage in the primary of 4, the middle row of 8, the top row of 12 volts.



Pinhole Photograph, taken Obliquely, of the X-Ray Producing Surface on the Target of a Badly Focussed Tube.



Pinhole Photograph of a Badly Focussed Tube.

Fig. 3.

[*To face p.* 2.

is so placed as to meet the cathode rays somewhere near their focus. It seldom happens, however, that a tube is constructed in which the target—*i.e.*, the anode or anticathode—is arranged to meet the cathode stream exactly at its narrowest point. The tube-makers soon discovered that if the anode were placed in that position (Fig. 2, position marked *x*), the intensity of the cathode-ray impact, when strong currents were used, would be so destructive as speedily to fuse the target. The anode, therefore, was placed only approximately at the cathode focus, with the result that the photographic definition obtained with different tubes varied considerably according to the position of the anode in relation to the cathode beam. The series of pinhole photographs (Fig. 3, *a*, *b*, *c*, *d*), taken many years ago by means of a special arrangement devised by the author, are of interest in this connection, and a note upon their meaning and method of production will be found below the illustrations.

The Cathode Focus.—In view of the resulting difference in photographic definition, it became a matter of extreme importance, when selecting a tube, to discover the exact relation of the anode to the cathode focus. Some years ago a method enabling one to detect immediately which was the best focussed of a batch of tubes was devised by the author. This method consists of placing a very fine wire cross close to the tube, one of the wires being parallel to the plane of the anode or target of the tube, and slightly in advance of it as in Fig. 4. The tube is then excited, and the observer, taking a screen, views this shadow of the cross from a distance of 10 or 12 inches. If the X rays come from a fine point on the anode, he will be able to see the shadow of the cross with the upright and horizontal wires fairly equal in sharpness; but if it should happen that a large surface instead of a point is producing the rays, then, although the wire which lies in the plane of the anode will be seen with great clearness, the horizontal wire will be blurred out into a ribbon, or possibly rendered almost invisible (Fig. 5).

The explanation of this phenomenon is quite simple. A line is visible by reason of the sharpness of its margins, and with a shadow caused by a large surface viewed end on, so to speak, the wire which is parallel to the plane of the anode will have the overlapping shadows from the extreme points, top and bottom, of the surface producing the shadow superimposed in the direction of its length. On the other hand, the wire at right angles to the plane of the anode will have its shadow produced also at right angles to its length, and therefore, under the conditions already stated, will be blurred out into the pattern of the ribbon. By taking care always to place the cross at the same distance from the anode in the position indicated, and making the screen inspection at the same distance from the wires, the shadow thus yielded should enable one very quickly to select the tube having the finest focus.

Another method to the same end, with a result perhaps not quite so obvious, is to replace the cross wire with a plate of lead in which a very fine pinhole aperture has been made with a needle. If this pinhole occupies the middle position between the anode and the screen (or a photographic plate protected in its envelope in the usual way), one will be able to obtain a pinhole image the actual size of the X-ray producing surface on the anode. The annexed figures show,

PLATE III.

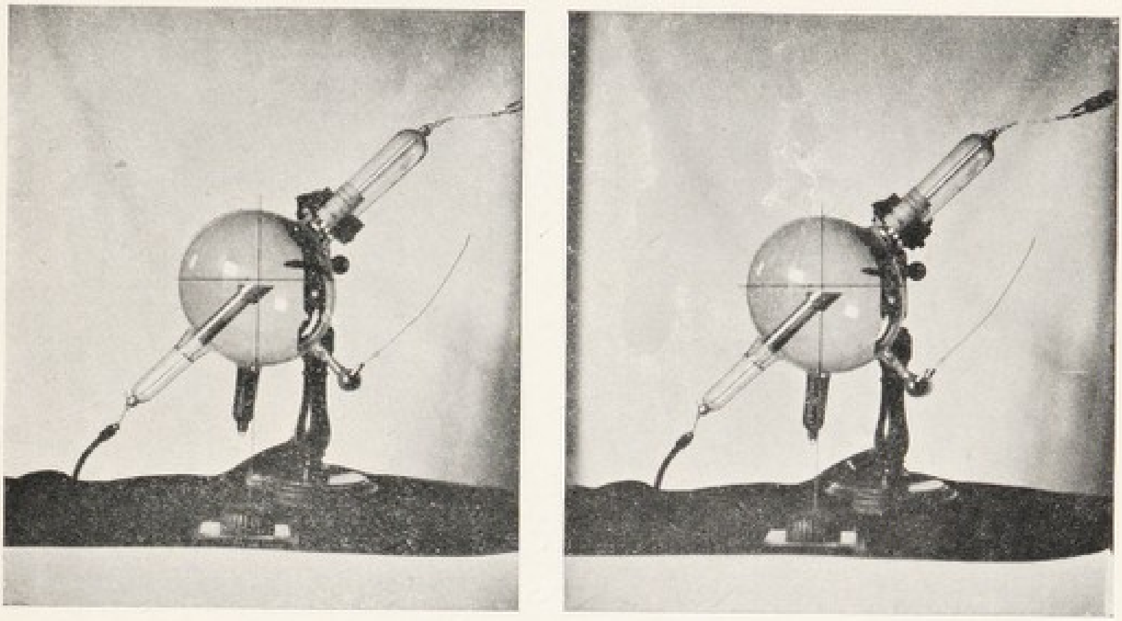


FIG. 4.—STEREOSCOPIC VIEW OF X-RAY TUBE WITH WIRE CROSS IN POSITION.

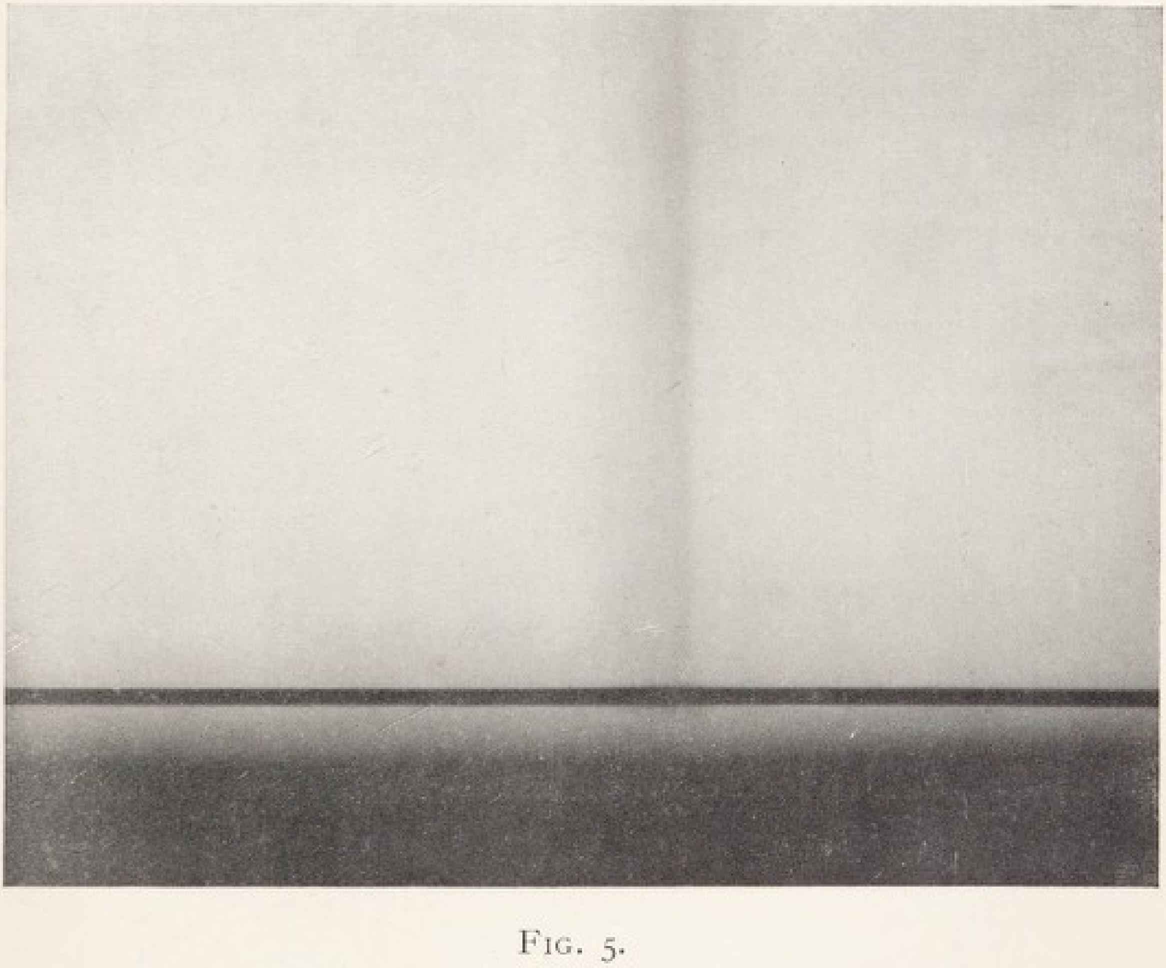


FIG. 5.

The wire parallel to the target of the tube is shown fairly sharp. The other wire is scarcely visible, owing to the diffusion of the shadow.

[*To face p.* 4.

PLATE IV.

FIG. 6.—PINHOLE PHOTOGRAPH OF SPOT ON TARGET WHERE THE X RAYS ORIGINATE —FRONT VIEW.

FIG. 7.—END-ON VIEW OF X-RAY PRODUCING SURFACE ON ANODE OR TARGET OF A TUBE.

[*To face p.* 4

in the one case (Fig. 6), the view of the anode taken directly from the front, and in the other (Fig. 7), the vertical longitudinal section or side or profile view of the anode. This method furnishes a very exact means of measuring the size of the area from which X rays are generated in any given tube. Many years ago the author constructed a tube having a small piece of *osmium* as a target at the exact focus, and this, being very infusible, gave splendid results and resisted puncture from very strong currents, but, for some unknown reason, the difficulty of maintaining a steady vacuum proved insuperable. In modern tubes fitted with tungsten targets this difficulty does not seem to arise.

So much, then, for what is meant by the fine focus of a tube. The production of "soft" and "hard" X rays—*i.e.*, of low and of high penetrating power respectively—is fully discussed in most of the text-books, and need only be mentioned in passing. The author has always adhered to the plan of having an adjustable alternative spark-gap on the terminals of his coil to test the hardness of the tube. On each terminal there is fixed an aluminium ball, 1 cm. in diameter, which is the arrangement he saw employed by Professor Röntgen himself when visiting him at Würzburg, in Bavaria, in 1896, the year after his discovery of X rays.

The Coolidge Tube.—A considerable departure from standard X-ray tube construction has lately been forthcoming in the shape of the new tube invented by Mr. W. D. Coolidge, of Schenectady, U.S.A., which promises to be of great utility. It possesses two good recommendations: in the first place, the tube itself acts as an electric valve, preventing any reversed current from passing through it; and, in the second place, the quality or penetrative power of the rays can be controlled immediately at will by an easily adjusted resistance. In the ordinary tube the cathode rays are produced by the high-voltage current direct from the induction coil or other transformer; in the Coolidge tube, on the other hand, the cathode consists of a fine coil of tungsten wire, which is raised to a varying degree of heat, and gives off electrons in a volume proportionate to the amount of incandescence induced within it. These electrons, on being set free, become the carriers of the ordinary electrical impulse from the induction coil. Very heavy currents can be passed through this tube, and an intense X-ray output is the result. It is obvious that the battery which heats the little coil constituting the cathode must be insulated when this tube is worked, as it is directly connected with the negative terminal of the induction coil. For therapeutic purposes, the control of the quality of the X rays seems to be a specially useful feature, and the constancy of the tube makes it still more likely to be of service in treatment. It is very important to have a resistance with a fine adjustment for the battery current through the tungsten cathode, and it is also advisable to have an ampèremeter with a very open scale, so as to admit of fine variations in the amount of current passing through the small tungsten coil of wire. The current required to heat this coil seems to vary from 3½ to 5 ampères.

CHAPTER II

SECONDARY RAYS AND X-RAY PROTECTION

Secondary Rays from the Glass.—In addition to the characteristic beam issuing from the tube, other X rays are generated of which it is very important that the worker should be cognizant. In the present-day X-ray tube the area of the glass bulb is very large, and it is apt to be forgotten, even by those who have paid great attention to the physical side of the subject, that parts of this large glass surface are giving off radiation in considerable quantities. These rays from the glass of the tube are not only capable of partially fogging the X-ray image proper, but also, in the author's belief, they may cause serious burning and damage to the tissues of the worker, unless he has been forearmed against a danger so easily overlooked.

An experiment which anyone can perform for himself will demonstrate the existence of the secondary or indirect rays coming from the fluorescent green glass of the X-ray tube. If a piece cut off a solid lead rod, about 1 inch in thickness, be suspended close to the glass of the X-ray tube, directly in front of the anode (Fig. 8), and the tube be excited, a screen held at some distance away will have a shadow of the lead cast upon it, for lead to this amount will allow no X rays of any sort or kind to pass through. Nevertheless, actually within the shadow cast by the lead, the screen will not be entirely in darkness, and if a piece of netting be held slightly in front of a photographic plate, in a line with the lead cylinder, but separated from it by a short distance, a distinct shadow of the mesh will be recorded upon the plate within the eclipsed area (Fig. 9). The intervention of the lead cylinder in the path of the direct beam of the primary rays from the anode is thus shown not to cancel the X-ray photographic effect. The effect on the plate is the result of the action of those rays which come from the glass of the tube at such an angle as to escape the mass of lead.

In order to demonstrate that this phenomenon is actually due to the rays from the glass, a single strip of lead, very thick and solid, and curved so as to keep in contact with the glass surface of the tube, may be placed across the tube opposite the anode so as to divide the fluorescing glass surface into halves. The arrangement is shown in Fig. 10. If, then, a thin piece of metal, such as a knitting-needle, be placed in front of the photographic plate, within the shadow of the lead strip, it will be found that a double image of this metal is obtained when the photograph is developed (Fig. 11). The reason for this double image is that, the glass having been divided by means of the lead strip, each half of the glass, by virtue of the secondary rays issuing from it, produces its separate image. The phenomenon is demonstrated even more strikingly if, instead of the single strip of lead, a cross of lead be placed in contact with the glass surface, the intersection being opposite the anode. On suspending a small metallic object slightly in front of the photographic plate, within the shadow of the centre of the cross, there will be revealed on development of the plate four small images of this object (Fig. 12),

PLATE V.

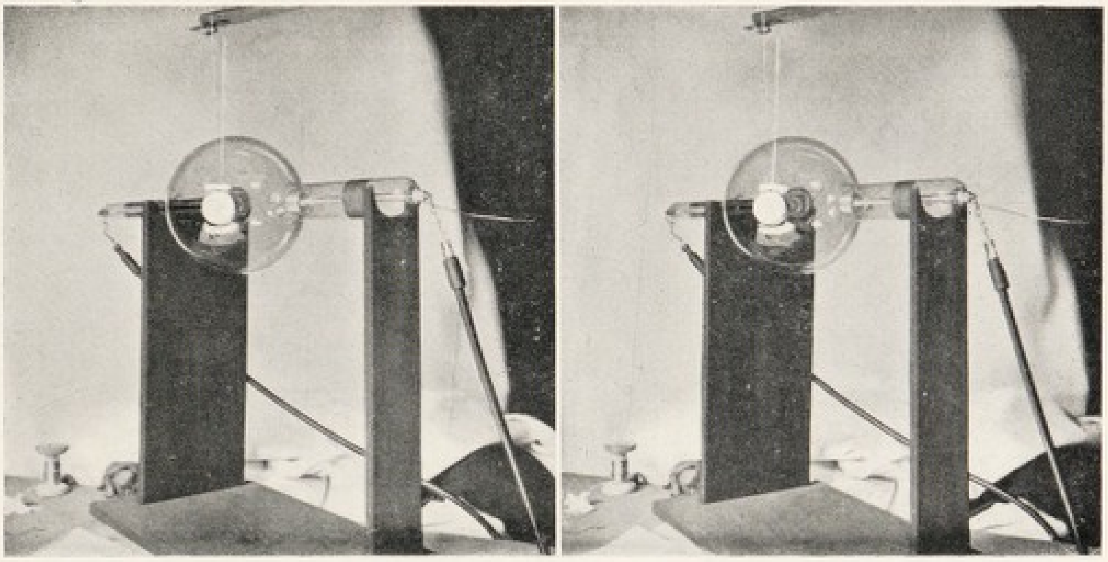


FIG. 8.—A MASS OF LEAD SUSPENDED OUTSIDE THE TUBE IN FRONT OF THE TARGET, TO DEMONSTRATE EXISTENCE OF SECONDARY RAYS FROM THE GLASS.

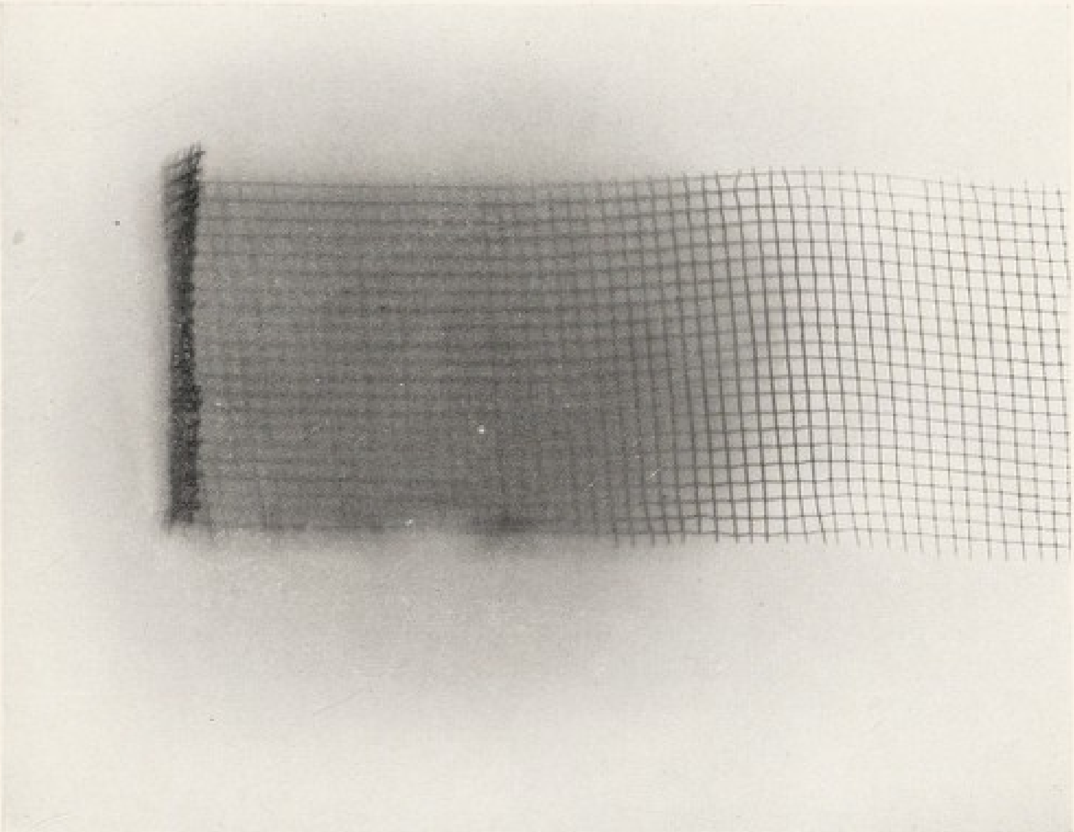


FIG. 9.—SHARP SHADOW OF NET PRODUCED BY DIRECT X RAYS; BLURRED SHADOW PRODUCED BY SECONDARY RAYS FROM GLASS.

[*To face p.* 8.

PLATE VI.

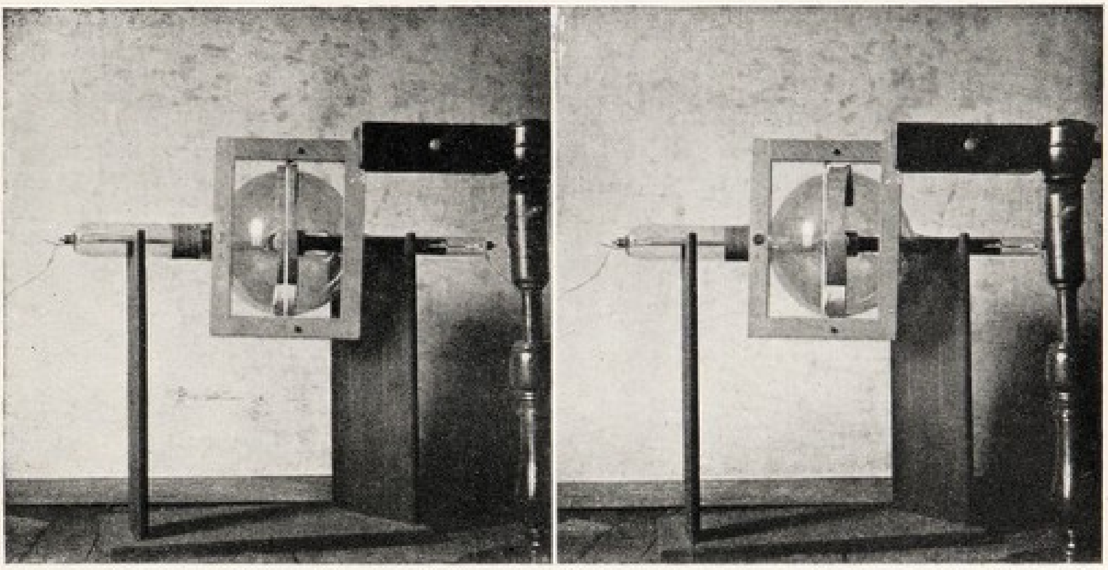


FIG. 10.—FLUORESCING GLASS SURFACE OF TUBE BISECTED BY STRIP OF LEAD, WITH KNITTING-NEEDLE IN FRONT IN POSITION FOR BEING PHOTOGRAPHED.

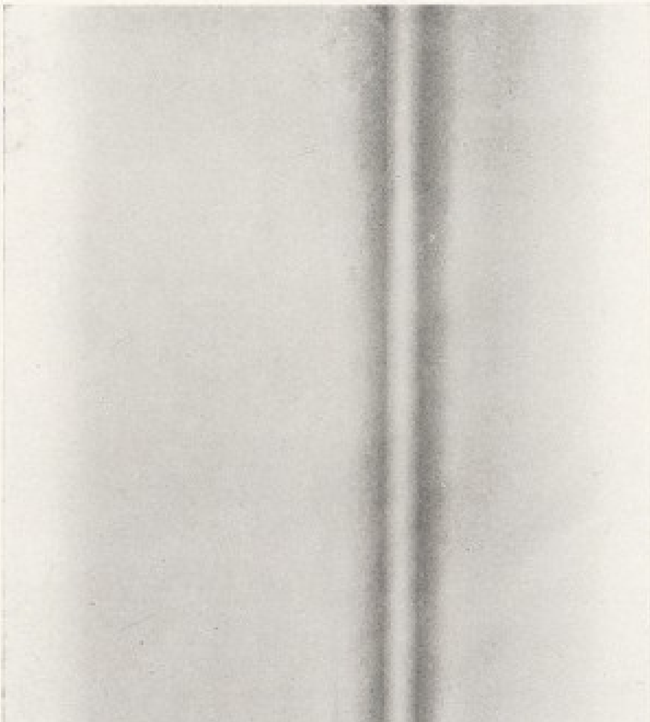


FIG. 11.—DOUBLE IMAGE OF KNITTING-NEEDLE OBTAINED WITH TUBE-SURFACE BISECTED.

[*To face p. 8.*

showing that each quadrant of the bare green fluorescing glass of the bulb has produced its own picture. It follows from all this that, in order to have the maximum value, any diaphragms which are used should be placed in close contact with the glass of the tube, or, alternatively, a tubular form may be employed, the screen, of course, being of lead. The difference in definition obtainable in such a test subject as the mesh of a piece of netting is discernible

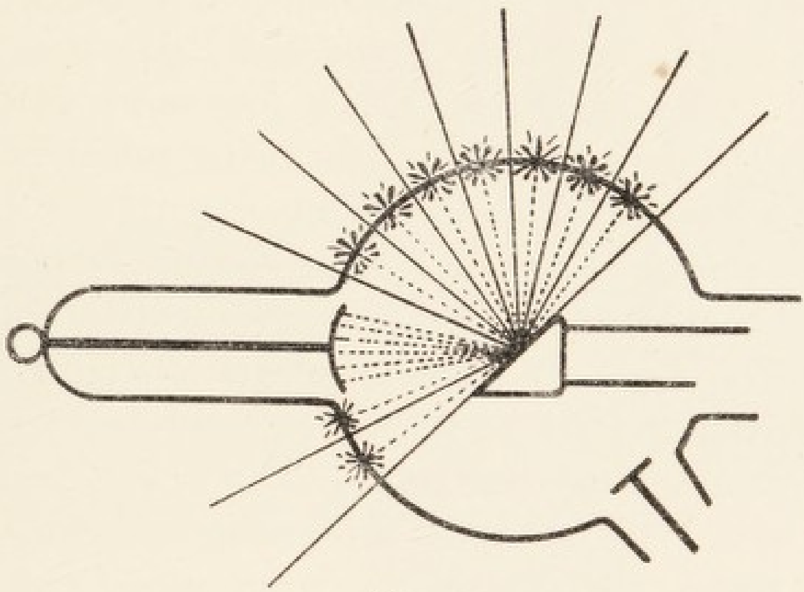


FIG. 15.

on a comparison of Figs. 13 and 14, the first having been taken with a tubular stop, and the second without.

Nature of the Secondary Rays.—Without entering upon the speculations which open out as a result of these proofs of the existence of secondary rays from the glass, it is interesting to note in passing that the secondary X-ray beam produced at the glass surface is probably complex in its constitution (Fig. 15). Thus it includes, in the first place, the secondary rays proper, the origin of which is due to the impact of the reflected cathode rays from the anode, these latter being what Professor Silvanus Thompson suggests should be called the paracathodic rays; and, in the second place, secondary X rays are probably produced also by the passage of the primary X rays through the glass. These secondary rays from the glass are much more richly produced in a "hard" tube, and some comparative measurements made by means of the electroscope showed that with a "hard" tube emitting very penetrating rays, if the action of the primary rays was taken as one, that of the secondary rays might be taken as one-half; whereas with a "soft" tube, giving rays of a low order of penetrability, the primary rays again being taken as one, the secondary rays would be one-seventh. Enough has been said to show that these secondary rays are of great importance, and certainly worthy of the attention of those who command the resources of a physical laboratory. Their further study may throw light upon many obscure problems in X-ray practice, and it would be at least interesting to employ a tube in which these secondary rays alone could be employed for experimental purposes, with a view to their use in therapeutics should this seem to be advantageous.

Protective Devices.—The question of protection follows naturally upon the foregoing, seeing that the secondary or indirect rays given off from the glass may be, if not the primary factor, certainly largely contributory to the superficial skin burns found among X-ray operators. It is worthy of note in this connection that, with a tube so high or "hard" as to give no fluorescence on the screen, Freund of Vienna found that the radiant effect was such as to cause the epilation of the exposed part, and also that,

PLATE VII.

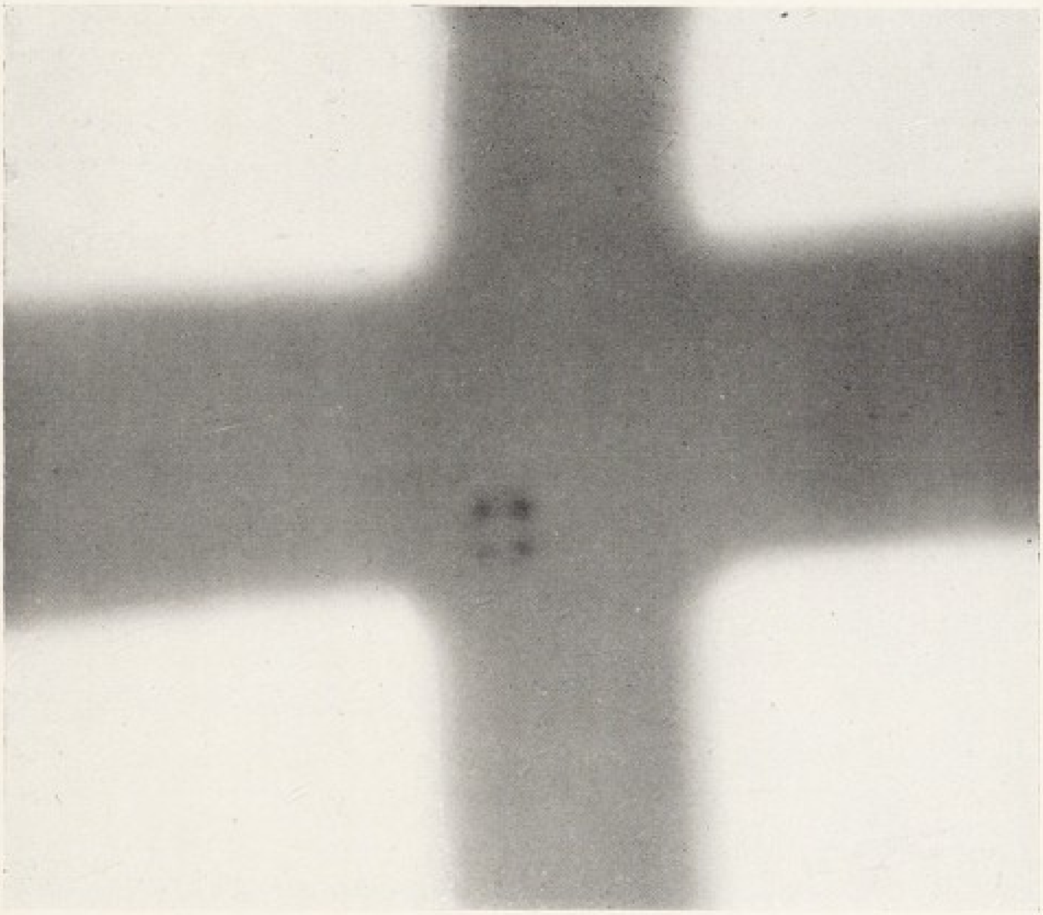


FIG. 12.—FOUR IMAGES OF A METALLIC OBJECT SEEN WITHIN THE INTERSECTION OF A CROSS OF LEAD WHICH HAD BEEN PLACED IN FRONT OF THE TUBE.

[*To face p.* 10.

with a tube having the current passed in the reverse direction, so as to produce only very weak primary rays, similarly radical results were obtained. The physiological action of these secondary rays is proved beyond doubt, and is certainly considerable in view of their ready absorption by the skin. Those X-ray workers who have suffered from dermatitis on the hands have found that the part of the skin covered by the coat cuff invariably has escaped the trouble. Seeing that the cloth offers no obstruction to the primary rays, it seems evident that the secondary rays have a great deal to do with causing the lesions.

It is well understood by this time that those engaged in X-ray work must employ adequate means of protection, although it may be doubted whether, in view of the large numbers of X-ray outfits which are now being sent forth, and placed in the control of operators whose experience has necessarily been brief, and who have to work under conditions of great pressure, the rigid necessity of abundant protection is fully appreciated. The lower the atomic weight of a substance, the more easily is it penetrated by X rays, and therefore lead, being one of the heaviest and also one of the most economical of metals, is most serviceable for protective purposes. Many years ago the author buried an X-ray tube in a large box filled with red lead, for it so happens that the oxides of metals which themselves are good conductors are excellent insulators. Wires were attached to this buried tube in the usual way, and it was excited in a completely dark room. A fluorescent screen was moved about around the box in all directions, and not the slightest evidence of the passage of any X rays was forthcoming. Then, from a point approximately opposite the anode, the red lead was gradually scooped aside until a faint glimmer of fluorescence revealed itself on the screen. In the case of the tube with which the experiment was made, it was found that a thickness of red lead, equal to at least half an inch, was required to stop the rays from passing through. As the red lead was a fine and heavy powder, most unsuitable for practicable use, a wooden box, large enough to contain the tube, was coated on its inner side with a putty made up of red lead and the white lead of the shops. This was put on in a thick layer all round the box, and a hole was cut in the lid, against which the anterior part of the tube was secured by elastic bands. This white and red lead hardened into a solid mass, which kept radiation under control, cutting off all the rays save those which were allowed to come through the aperture in the lid of the box. A box of this kind, naturally, was heavy, but there is no way of obviating this disadvantage in view of the fact that it is only heavy substances which suffice to cut off the unwanted rays.

Screens, Gloves, etc.—At the present time some such protection is supplied by the tube-makers. It consists of a combination of lead and rubber, which, if of sufficient thickness, acts as quite a good means of protection. Another plan which is very serviceable is to surround the X-ray table with screens of lead of considerable thickness, such as is used for roofing houses, this lead being sandwiched between sheets of wood. The worker can stand behind these screens, should it be necessary to use the tube in an insufficiently protected condition. The screens can be fixed on a narrow stand, with "domes of silence" or castors, which enable them to be moved to any required position. Gloves made of dense material are provided for the hands, which must at times come within the direct beam, and another measure of protection is to glaze the fluorescent screen. This should be done with very dense lead glass, which allows the useful visible rays to pass through unimpeded, but cuts off a considerable amount of the dangerous radiation. Should prolonged screen examination be necessary for any reason, the author would suggest having a fine plane glass mirror on a stand so adjusted as to enable the worker to watch the reflection of the fluorescent screen while he himself is standing, effectively protected, behind one of the big lead barriers just described.

By this method of reflection, also, an ordinary photographic camera can be made to record the image produced by the fluorescent screen. As the rays are of a yellowish-green tint on the best screens (those of barium platinocyanide), it is advisable to use panchromatic plates for the purpose; a screen of tungstate of lime or of barium potassium cyanide will fluoresce blue, and be photographically more speedy. In this way a 15 by 12 inch screen could be photographed down to lantern-slide size direct, but the exposure, judging from some brief experiments, would be too lengthy to make the method of much practical value.

CHAPTER III

X-RAY STEREOSCOPY

The Misleading Single Picture.—It has been stated already that X rays travel in straight lines from their point of origin on the anode to their destination, be it photographic plate or fluorescent screen. An X-ray photograph, therefore, is simply a shadowgraph of an interposed object, differing from the shadowgraph produced by light in that it reveals the interior of the object as well as its outline. From a single X-ray silhouette the relative position of the objects giving rise to the shadows of varying density can only be guessed, and very erroneous impressions may result. An example of the range of error which is possible is given in the annexed illustration (Fig. 16), in which the shadow cast by a pair of scissors is shown to be capable of more than one interpretation. On looking at the right-hand picture, the nature of the object could not be understood, but the stereoscopic view shows immediately the fact that it is a pair of scissors, and its position.

The application of the stereoscopic method to X-ray work was recognized by the author as a vital necessity very shortly after the discovery of X rays was announced.[1] Those who are interested in the

[1] J. Mackenzie Davidson: "Remarks on the Value of Stereoscopic Photography and Skiagraphy," *British Medical Journal*, December 3, 1898.

principles underlying stereoscopy (which, briefly stated, is the direct perception of the relative distances of near objects) may be referred to the work of Wheatstone, who was the first to put forward the hypothesis that the perception of depth was due to the difference between the two retinal images.[1] Another and rather later pioneer is Brewster,[2] and the writings of both these workers, although dating back for considerably more than half a century, deserve the most careful study if the stereoscopic theory is to be thoroughly grasped. A more modern exposition of the principles of binocular vision is that of le Conte.[3]

Preliminary Arrangements.—In order to produce X-ray photographs stereoscopically, it is essential either to have the X-ray tube held in a tube-holder which admits of displacement in a definite direction, or, what is more usual, to place the tube in some form of protective box which can be made to slide from one position to another. It is much more convenient to work with a tube beneath the couch upon which the patient is lying than to work with a tube placed above the couch, but some workers prefer the latter arrangement. Most couches are so constructed that the tube can slide backwards and forwards from head to foot parallel to the length of the couch, and also crosswise from side to side at right angles to the length. With these two movements, it is obvious that the tube can be brought to any desired position in relation to the

[1] *The Scientific Papers of Sir C. Wheatstone.* Reprinted from the Philosophical Transactions of 1838. Published by the Physical Society of London, 1879.

[2] *Stereoscopy: its History, Theory, and Construction.* By Sir David Brewster. (John Murray, 1856.)

[3] *Sight.* By Joseph le Conte, LL.D. International Scientific Series, vol. xxxiii. (Kegan Paul, Trench, and Co., 1895.)

couch above. The arrangements by which these movements are effected naturally vary considerably in detail as between one couch and another, and in a later chapter a very simple and portable construction will be described. In the meantime it is sufficient to say that, given this arrangement of a mobile tube-box, some means must be furnished for determining the position of the vertical ray coming from the anode of the tube. Once the position of that vertical ray is ascertained, it is definitely recorded by means of a plumb-bob attached to an adjustable horizontal arm above the couch, this arm jutting from a vertical support which is fastened to the tube-box below, and moves with it.

The Vertical Ray.—The position of this vertical ray can be determined by any one of several simple ways. One of the most convenient is to use a small celluloid box in which, immediately beneath the lid or top, two fine needles or wires are fixed at right angles to each other. From the intersection of these wires is suspended into the interior of the box a small metal plumb-bob. In order to make the plumb-bob cease its oscillations quickly, it may be immersed in a thickish fluid, such as thick paraffin. Instead of the ordinary lid, a small fluorescent screen is used to cover the box, and is thus in immediate contact with the cross wires below. When this arrangement is placed upon the couch, and the tube is excited in a darkened room, the shadow of the small plumb-bob and of the cross wires will be visible on the screen, and the box can be readily moved to such a position that the shadow of the plumb-bob is directly below the point where the wires intersect. It is obvious that the anode from whence come the rays producing this

PLATE IX.

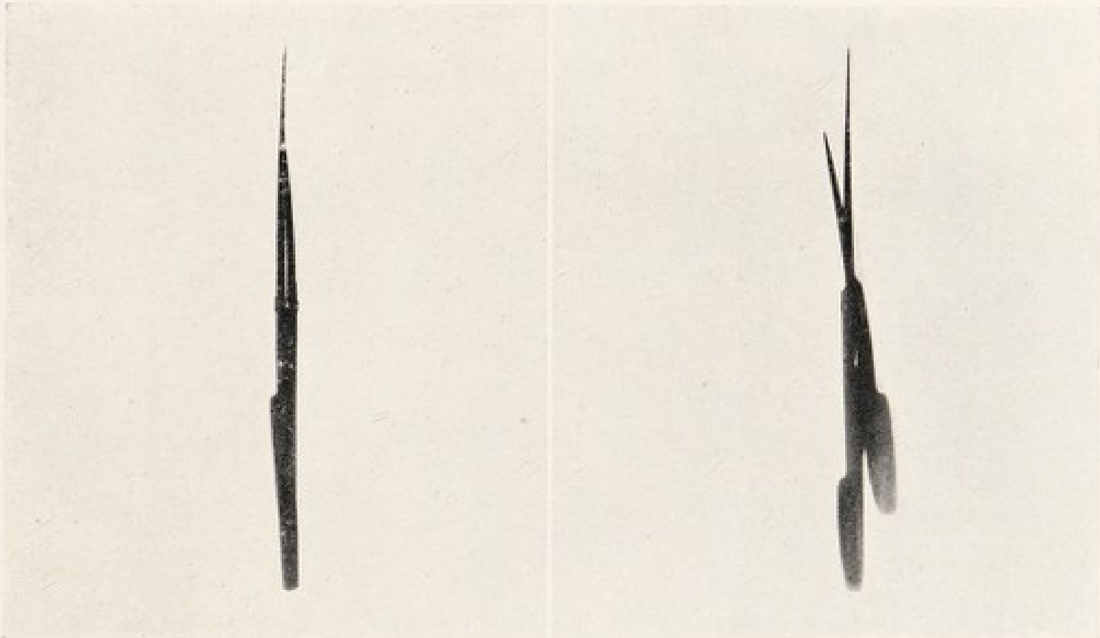


FIG. 16.—THE SHADOW CAST BY A PAIR OF SCISSORS, SHOWING HOW MISLEADING A NON-STEREOSCOPIC PICTURE MAY BE.

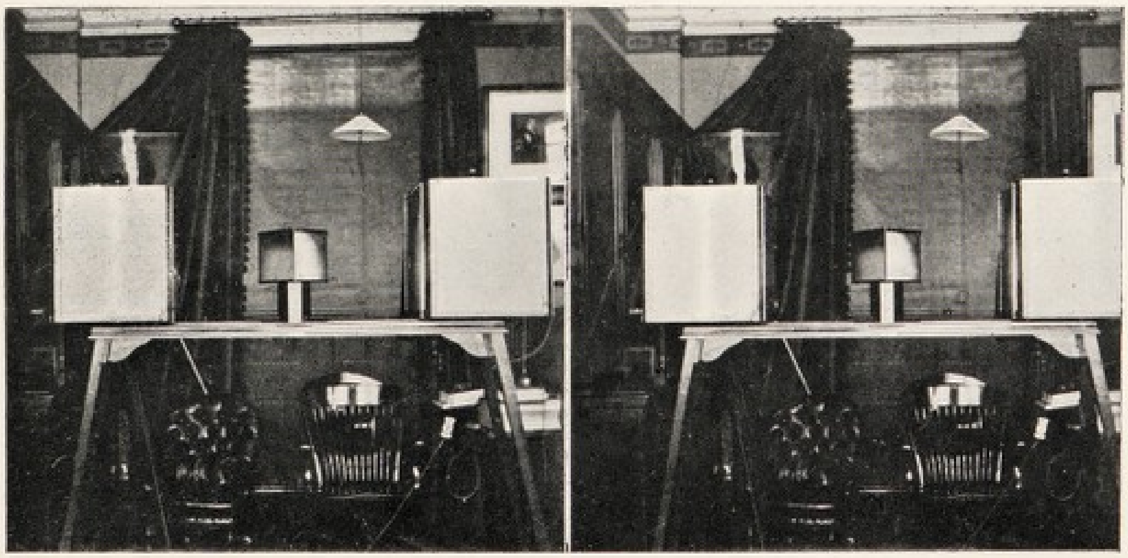


FIG. 17.—THE WHEATSTONE STEREOSCOPE.

To face p. 16.

shadow must be vertically below the cross wires, and it is only necessary then to adjust the arm attached to the perpendicular support so that the plumb-bob mentioned in the preceding paragraph as being suspended from this arm rests upon the point of intersection of these cross wires. Once fixed in this position, it follows that this indicator arrangement, which moves with the tube, will always denote the point vertically beneath which the anode is situated, no matter how much the tube may be moved up and down or from side to side of the couch. This plumb-bob arrangement, or some similar device, must always be employed if stereoscopic photographs are to be taken or any method of precise localization adopted.

The Two Exposures.—This preliminary condition having been fulfilled, the following simple method will at once enable a worker to produce two stereoscopic negatives. The subject to be photographed is placed upon the couch, and the point of view from which it is desired to take the photograph is decided upon. The tube-box beneath the couch is moved about, the indicator moving with it, until the plumb-bob suspended from the pointer rests upon the selected position. A photographic plate, contained in the usual carrier or paper envelope, is placed upon the subject in such a manner that two of its edges are parallel with the long axis of the couch. Its position, for reference purposes in view of the second exposure, is recorded by means of blue pencil simply run along two adjacent sides. The necessary exposure is then given, after which another plate is placed in exactly the position occupied by the first. The tube is displaced by 6 cm. (the interocular distance) to one side—the right or left—along either axis of the couch.

The nature of the subject will determine which movement out of the possible four shall be taken. The second exposure having been made, the two plates are developed, and the results viewed stereoscopically. To persons possessed of binocular vision, these two photographs, when viewed in a Wheatstone stereoscope, give an impression of striking relief. The image appears to have rotundity, and to be seen in three dimensions—namely, length, breadth, and thickness—instead of in the first two only, as with the single picture.

The Wheatstone Stereoscope.—The one essential in all stereoscopic procedures is that each eye shall see only its own image. The Wheatstone stereoscope (Fig. 17), already alluded to, is one of the simplest of viewing methods, consisting merely of two mirrors placed at right angles to each other, the apex being towards the observer. When, therefore, the observer approaches the line at which the two mirrors join, the right eye can only see the reflection of the photograph placed opposite the mirror to the right, and the left eye the reflection in the other mirror (Fig. 18). The two negatives are placed in the holder at equal distances from the centre of each mirror, and are illuminated by some suitable arrangement. If prints from the negatives are viewed, no special illumination is necessary, as these can be seen by ordinary reflected light. All that the observer has to do is to move the support of the mirrors backwards and forwards until he gets the single image in stereoscopic relief. The beginner will find it convenient to pull the mirror towards him until he sees the two photographs side by side and overlapping; then, by gradually pushing the mirrors away, keeping the middle line of his fore-

PLATE X.

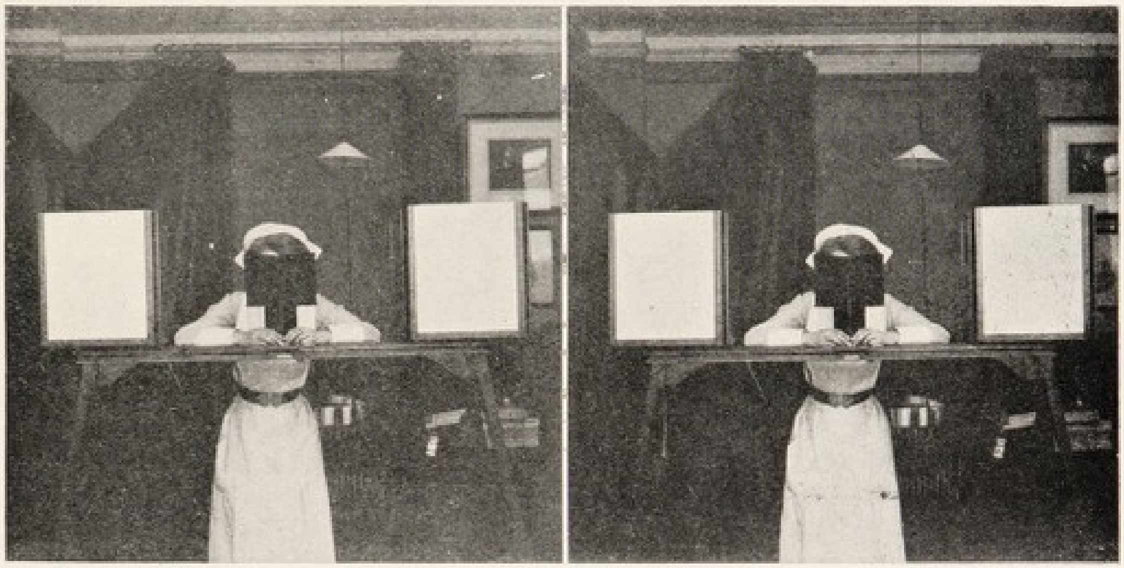


FIG. 18.—METHOD OF VIEWING WITH THE WHEATSTONE STEREOSCOPE.

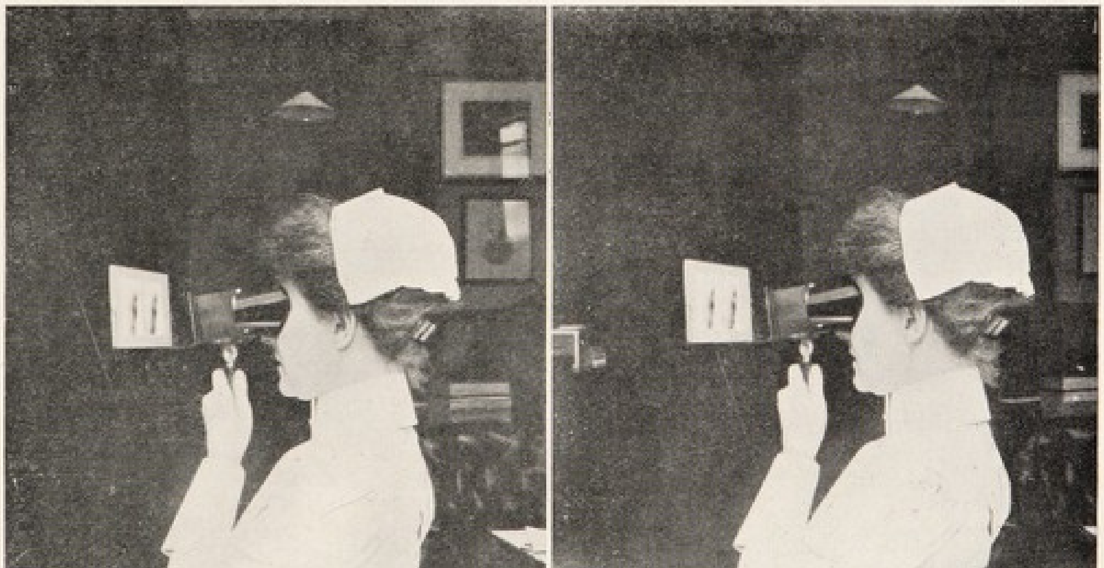


FIG. 19.—METHOD OF VIEWING WITH THE BREWSTER OR LENTICULAR STEREOSCOPE.

[*To face p.* 18.

head close to the apex, he will find that the images gradually approach each other, and finally fuse into one, whereupon this solid stereoscopic effect is immediately realized. After a short time the solidity of the image seems to grow upon the attention of the observer.

Another feature of the stereoscopic view which has a physiological interest, and in the case of surgical work a practical importance, is that by transposing the photographs (*i.e.*, taking the one on the right and placing it on the left, and *vice versa*) the point of view becomes reversed. Thus, if a hand be photographed stereoscopically, and the negatives be so placed that the observer seems to be looking on to the back of a right hand, the transposition of the two pictures in the way indicated will make it appear as though he were looking into the palm of a left. This, at first, may seem rather mysterious, but if Wheatstone's paper, to which reference has already been made, be consulted, the explanation of the phenomenon will be found to be quite simple.

Other Viewing Methods.—These two negatives, if they have been taken on large plates, can be reduced photographically to the usual size of two lantern plates, and the stereoscopic transparency thus produced may be viewed in the more generally known lenticular or Brewster stereoscope (Fig. 19). This is a considerable convenience in cases in which a surgeon, while operating, desires to refresh his memory by viewing the stereoscopic photograph of the case. If these reductions to lantern size are made on two separate lantern plates, it is possible to show them singly on the screen for teaching purposes, and at the same time, using a little holder with a ground-glass background, to vary the stereoscopic picture by transposition in the manner already described. When once a good stereoscopic X-ray photograph has been obtained, it becomes unnecessary to point out the realistic beauty of the picture or its enormous importance in medical and surgical work.

Stereoscopic Screen-Images.—Those who are familiar with stereoscopic X-ray photographs do not need to be reminded of the immense utility of any method which would render possible a stereoscopic image on the fluorescent screen. Several years ago the author produced an apparatus having this end in view, and it was shown at Charing Cross Hospital, and again at a conversazione of the Royal Society. The principles involved are quite simple, but the mechanical methods of carrying them out can be varied very greatly. The main condition is to have two X-ray tubes (or one specially constructed X-ray tube having two anodes) placed side by side, so that the line connecting the points of X-ray production on the anodes is horizontal. The screen has to be placed behind the object and in front of the tubes, and some mechanical arrangement must be devised whereby the tubes can be illuminated alternately. Synchronous with this alternate illumination there must be the action of a collapsing or rotating shutter, so as to insure that, when one tube casts a shadow on the screen, it shall be seen by only one eye of the observer; and when the second tube is illuminated, the first must be eclipsed, so that the shadow is visible only to the other eye. If this action is repeated at a rate of ten alternations per second, the impression made upon each eye becomes continuous, owing to the persistence of the retinal images. Thus, each eye sees its own image, and the combination gives a stereoscopic result. The advantage of this method is obvious, but there are many mechanical difficulties which make the carrying of it out and its maintenance in proper working order somewhat problematical. These difficulties have prevented the method from coming into general use up to the present time, but the author is convinced that, when these have been surmounted, it will prove eventually to be one of the most useful and reliable methods of medical and surgical X-ray investigation at command.

CHAPTER IV

RAPID X-RAY LOCALIZATION

A New X-Ray Couch.—Before entering in detail into the methods of localization recommended by the author, it will be convenient to describe a simple and portable X-ray couch which he has recently devised for the purpose of facilitating X-ray examination. The couch in question (Fig. 20) consists essentially of two ordinary hinged trestles upon which can be placed the standard Army stretcher. From one of the rests of the stretcher a couple of rails are made to connect with the opposite rest, and these rails are hinged at the points of union with the stretcher, and also in the middle, so that, when the stretcher and the tube-box are removed, the rails can be packed up into quite a small compass. On the rails there is placed a small board which runs along the whole length of the couch, and is moved and controlled by an upright arrangement which, with a windlass, makes movement easy along the rails placed lengthwise and from side to side of the couch. The tube-box, which is lined with lead rubber, is secured to U-shaped pillars by thumb-screws, so that its distance from the couch can be regulated by the simple movement up or down of these supports. From one side of the board which supports the tube-box there projects a stout V-shaped upright, having a horizontal hinged arm capable of an up-and-down movement. On the end of this

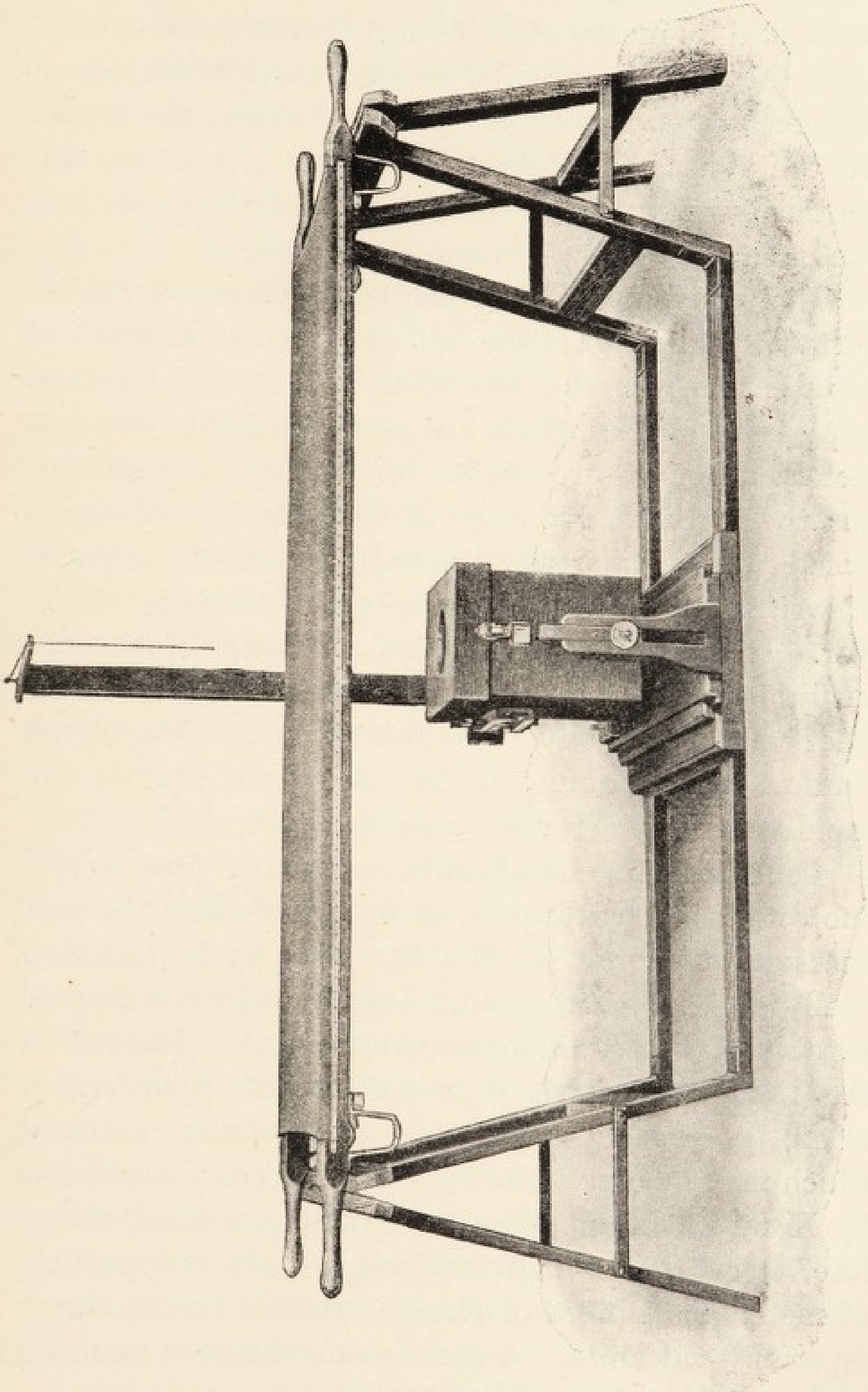


FIG. 20.

horizontal arm is a small piece of wood with cross wires, and by means of a slot and thumb-screw attachment this can be adjusted so that the intersection of the cross wires is secured vertically above the anode. On the top of this vertical support, if it is desired, another arm can be secured by a thumb-screw, and can be made to carry a small plumb-bob.

The convenience of this couch consists in its portability, its lightness, and the virtual absence of metal parts, thereby obviating the danger of those unpleasant shocks which are often administered when metallic couches are used. Its wooden construction has the further advantage of enabling it to be produced readily, whereas all metal work, at the moment of writing, is handicapped by the necessities of the war. If anything did require repairing, this could easily be done. The incorporation of the stretcher is of value, not only from the point of view of the comfort of the wounded, but also from that of the rapidity with which cases may be dealt with.

Conditions for Localization.—Turning now to the subject of the localization of foreign bodies, the first necessary condition is that the body to be localized shall be of sufficient atomic density to give a shadow capable of being differentiated from the shadows of the tissues in which it is embedded. Splinters of wood, portions of clothing, and similar material which may be carried into a wound, are not detectable by X rays. Localization is virtually confined, therefore, to cases in which the foreign body is a particle of metal, or a piece of glass or rubber tubing, more especially vulcanite. A great many different methods of localization have been brought forward, but for the time being we will content ourselves with describing the simplest of these and the most rapid, with a view to existing circumstances.

All methods of localization which make any pretence to precision must necessarily depend, in the first place, upon ascertaining the position of the vertical or normal ray; and, in the second place, upon the shifting of the shadow caused by the displacement of the tube to a known distance. This point has already been dealt with in a former chapter, and it is only repeated here in order that the reader may be reminded how crucial a point it is. The position of this vertical ray having been determined in the manner described on p. 16, and the plumb-bob or horizontal arm of the cross wires adjusted to it, the patient is placed upon the couch, the cross wires are so arranged as to be almost in contact with his skin, and the tube is excited in the dark-room. By means of the screen placed over the cross wires, it is then possible to see the relation which these wires bear to the position of the foreign body. The tube is moved about until the foreign body casts its shadow immediately beneath the wires, and this point is marked on the patient's skin. What we have now ascertained is that the foreign body is vertically below this point marked on the skin so long—but only so long—as the patient maintains that particular position, which must be carefully noted. All that remains to be done is to ascertain at what depth beneath this point the foreign body is lying.

Measurement on the Screen.—While the patient remains immobile, the tube-box should be adjusted—*i.e.*, moved higher or lower—so that the anode is exactly 50 cm. from the marked point on the skin. When this has been done, a small and very simple apparatus (Figs. 21 and 22) can be used to give immediately the depth of the bullet or other metal. The little instrument consists of a very thin piece of wood, having grooves to admit a sliding piece, and forming the framework of a couple of cross wires inserted at right angles to each other. The point of intersection of these wires is at the centre of a circle aperture, about the size of half a crown, which is cut in the wood. The whole arrangement should have an ample margin of lead rubber to protect the hands of the operator. A sliding piece, having another wire fixed across its U-shaped extremity, is then inserted into the larger piece of wood in such a manner that the wire it carries can be brought to rest immediately below, and in contact with, one of the stationary intersecting wires. This can also be withdrawn to the right of the operator, so that there may be a definite space between the stationary and the movable wire. A little ivory scale is attached to the projecting handle of the slide, and on this the extent of the displacement is read off.

If, now, the point where the wires intersect is adjusted so as to be exactly over the mark already made on the skin, one wire being parallel to the long axis of the couch, and the other at right angles to it, and a screen be placed over this little apparatus, the screen, when illuminated, will show—if the previous adjustments have not been disturbed—that the shadow of the foreign body is exactly vertically below the intersection of the cross wires. The tube-box is then displaced by 10 cm. to the left of the observer, whereupon it will be noted that the foreign body has been displaced on the screen to the observer's right, and now appears to be at some distance from the point

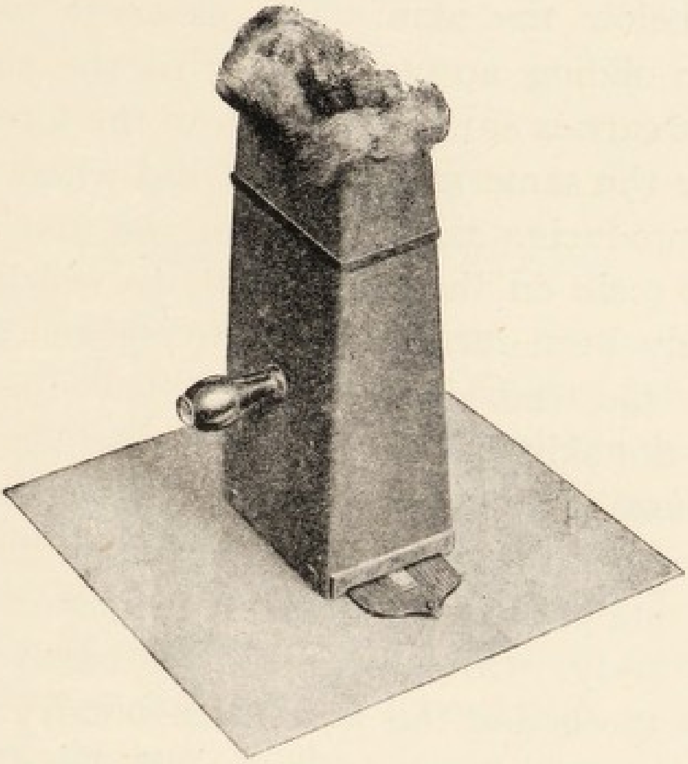


FIG. 21.

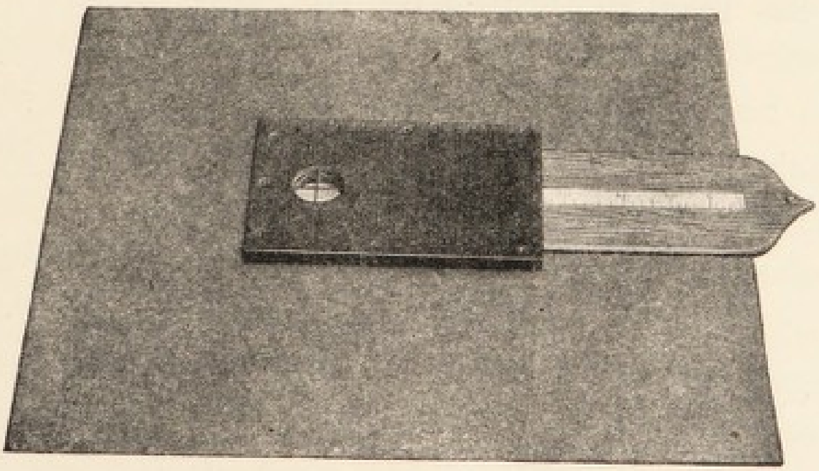


FIG. 22.

of intersection. The precise distance is in direct relation to the depth at which the foreign body is situated below the skin. The observer now withdraws the sliding arrangement until the shadow of the wire it carries cuts the shadow of the foreign body in exactly the same manner as it did when the axial ray was producing the shadow in the first instance. The little scale on the instrument, to which allusion has already been made, will then register the exact depth of the embedded metal below the marked point on the skin. It seems to the author that if a ready means of adjusting the distance of the tube to the marked point on the skin can be found, this method furnishes one of the very quickest means of localizing a foreign body. Obviously, it takes much longer to describe a method of this kind than to carry it out.

Methods analogous to this, all based on the principle of similar triangles, have been described recently by Dr. William Hampson and Captain Thurstan Holland, and tables prepared and supplied by them take the place of the direct reading scale which has been calibrated for this apparatus.

CHAPTER V

THE CROSS-THREAD METHOD

Precise Localization.—In the previous chapter, having in mind the necessity for dealing quickly with large numbers of cases, we discussed the most rapid methods of screen localization. Much more has to be said, however, if the principles involved in X-ray localization are to be grasped. The rapid methods may suffice in conditions of emergency, and for the more obvious cases, but the formulation of a precise localization method applicable to every condition demands certain scientific considerations, and, accordingly, we shall even have to go over more elaborately some of the ground already roughly covered in order to arrive at a complete understanding of the subject.

Cognizance must be taken, in the first place, of certain elementary facts in geometry. While the method of precision presently to be described can be carried out purely by mechanical measurements, without any knowledge of mathematical formulæ, it is, nevertheless, entirely dependent upon geometry; and in order to make it intelligible, it is well to refresh the memory as to certain geometrical propositions. We encounter a geometrical consideration at the outset, for the shadow cast by an X-ray tube is, in geometrical language, a central projection, and therefore shows the object on an enlarged scale. This is in contrast to parallel projection, which latter would give a shadow of the outline the exact size of the actual object. Fig. 23 illustrates what is meant by central and parallel projection.

On the question of localization we have first to remember that if two straight lines intersecting each other at right angles are drawn upon a plane surface, any point marked on that surface may have its position defined absolutely if its perpendicular distances from

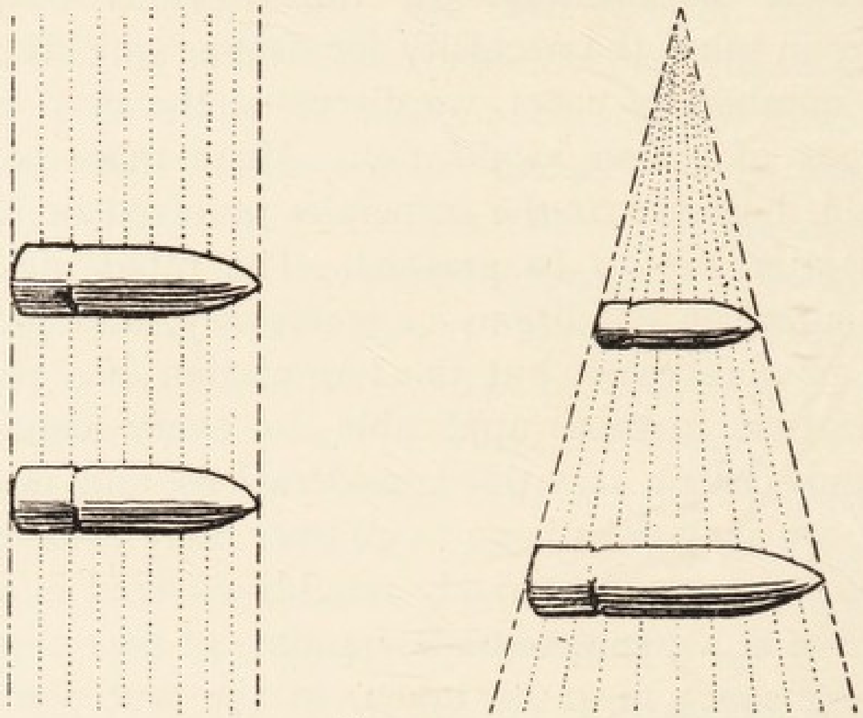


FIG. 23.

the two lines are stated. This method is the familiar one by which the position of points on temperature charts and recording barometric projections is determined. The base line is called the abscissa, or OX co-ordinate, and may be denoted by X; and the vertical line is called the ordinate, or OY co-ordinate, and may be denoted by Y.

This, however, is a method applicable to only two dimensions on a plane surface, but our world is one of three dimensions—namely, length, breadth, and thickness. Points in space can have their position defined in the same manner by co-ordinates, providing there are three planes of reference, all at right angles to each other (Fig. 24). An illustration will help those unfamiliar with geometry to understand this statement. In the corner of a room we have an instance of two walls meeting at right angles to each other, and a floor which is at right angles to each of the two walls. The walls and the floor, therefore, furnish an example of three planes, all at right angles to each other. Any point in space may have its position defined by measuring its vertical distance from the one wall, which we may call *X*; its vertical distance from the other wall, which we may call *Y*; and then its vertical distance above the floor, which we may call *Z*. These distances are described as the co-ordinates of the point in question with reference to these three planes. Further, the position of this point with reference to any other point can be ascertained by measuring in a similar way the three co-ordinates of the other point, and making a simple subtraction.

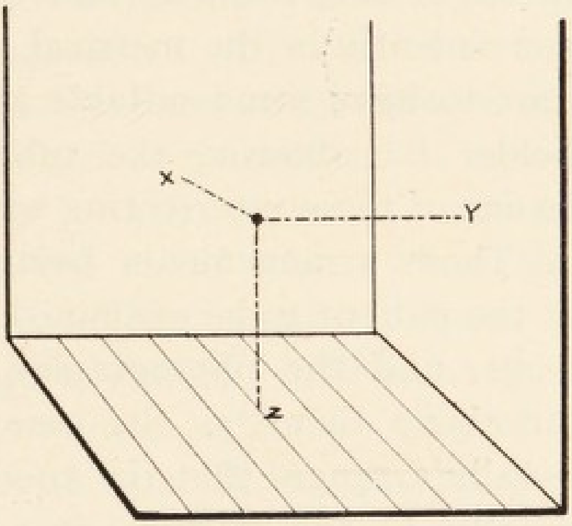


FIG. 24.

Applied Geometry.—We will proceed now to consider how this co-ordinated geometry in three dimensions may be applied to ascertaining with extreme accuracy the exact position, and, moreover, the exact size, of a foreign body in the tissues. If the principles of the method are thoroughly understood, the arrangements for their application can be varied in a number of ways.

It is necessary, in the first place, to have two intersecting wires stretched on a frame at right angles to each other. The point on the anode from which X rays take their origin must be placed, by an adjustment of the tube-holder, in a position vertically above or vertically below the point of intersection of these wires. The exact distance of this point on the anode must be ascertained, and will be expressed most conveniently in the metrical system. It is necessary, also, to have some suitable arrangement in the tube-holder for allowing the tube to be moved parallel to one of these intersecting wires.

These arrangements being carried out, the part of the patient to be examined is placed upon the cross wires, and the photographic plate below the wires (or above them, as the case may be). The author usually arranges that the anode of the tube be moved parallel to one of the wires a distance of 3 cm. to one side (say the right) of the vertical wire. The first photograph is then taken. The exposed plate having been removed and marked, another is put in its place, care being taken not to move the patient during this exchange. This is most conveniently done if the cross wires are arranged over a frame of stretched parchment such as is used for making drums; or, if the frame is placed above the patient, and the tube below the couch, then the plate can simply be laid on the frame, and changed without disturbing either the position of the patient or the wires. Before the second photograph is taken, the tube is displaced 6 cm. from the position it occupied during the first exposure, being now 3 cm. to the other side (the left) of the vertical. The second exposure is then made. Alternatively, the first exposure may be made with the central ray, the anode being vertical with the intersection, and the tube be moved 6 cm. to one side for the second exposure.

Interpreting the Negative.—When these plates are developed, the wires show as clearly defined white lines across each plate. Supposing, for simplicity, a round bullet be present in the tissues, its position in relation to the wires, even on the flat, will be found to be dissimilar in the two negatives. In order to determine the position of the bullet, and so interpret these negatives properly, the simplest method is to reconstruct geometrically the relations which existed between the tube and the cross wires when the photographs were taken. This, again, if one is familiar with the principles, can be carried out in a variety of ways, but the most satisfactory method is to have a small table with a thick plate-glass top, into the glass of which there has been cut with a diamond two lines at right angles to each other, intersecting in the middle of the plate (Fig. 25). The vertical support has a sliding T-piece, with three little notches 3 cm. apart. The middle notch is adjusted to be at right angles to the point where the two lines intersect. This can be made to slide up and down, and be fixed in any position, so that the exact distance between the middle notch and the glass plate can be arranged to be precisely the same as was the distance between the anode of the tube and the cross wires when the X-ray photographs were taken. As stretched threads can be made to represent the linear path of X rays, the paths of any of the rays with which one is dealing can be delineated by placing fine threads into each of the two notches, the threads being weighted at one end so as to be kept taut, while the other end is fixed to a fine needle. As some workers prefer to displace the tube to 10 cm. instead of 6, a small extension has been added to the T-piece. This

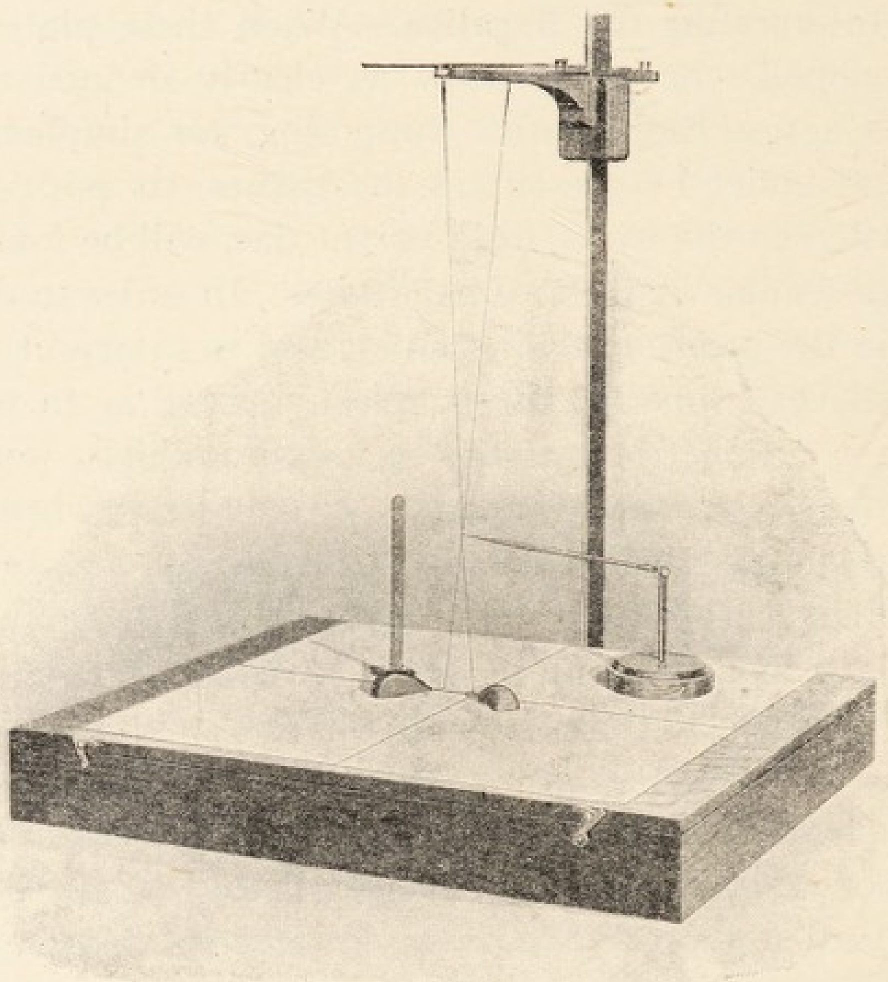


FIG. 25.

extension is shown in the illustration as a projecting piece beyond the portion where the cross threads are suspended. In the diagrammatic representation of the T-piece (Fig. 27), there is shown a horizontal scale which enables the operator to deal with any reasonable displacement he chooses to make.

The Cross-thread Method.—The cross wires are so close to the photographic plate that they suffer practically no displacement, but assuming that the bullet is at some depth from the surface of the skin which is resting upon the cross wires, this will show a certain amount of displacement, or, as it is called, parallax. If, however, upon some transparent material, like celluloid or tracing paper, two lines are drawn at right angles to each other, the image of these lines can be so placed over the negative that they and the shadow of the cross wires are brought into register, and while thus maintained, the shadow of the bullet can be marked or traced on the transparent material. The process is repeated for the other negative, using the same piece of celluloid or tracing paper.

Instead of the tracing being made directly, the same result may be obtained by drawing the cross lines on a sheet of paper or stiff cardboard, and the position of the bullet may be marked by means of compasses, the vertical distance of the two wires from the centre of the bullet being taken. Once this position has been obtained for the two negatives, it is placed upon the glass stage, and the cross lines are brought into exact register and fixed in that position.

It is important in this connection to point out that the wires upon which a patient is rested should be inked, so as to leave a mark of their position on the skin. Further, a mark must be made in one of the quadrants formed by the cross wires on the patient's skin, and on the same situation a small piece of lead wire should be placed, so as to enable the surgeon to learn in which of the quadrants the foreign body is situated. When the tracings from the negative are taken, it is very important to identify the position of the marked quadrant.

We now have a reproduction of the shadow pictures in the exact geometrical position in which they were produced. It is obvious that the shadow of the bullet which is more to the observer's left must have been produced by the tube when it was in the position more to the observer's right. Therefore, a thread can be placed in the appropriate notch, and the needle end attached to any position within the bullet shadow—*e.g.*, the centre. This being done, it follows that the bullet must have had its centre at some point along the line indicated by the thread. If, now, a second thread be placed in the other notch, separated 6 cm. from the first, it will represent the position of the anode when the second negative was made, and can be placed upon the centre of the corresponding shadow of the bullet. Here, again, the centre of the bullet must have been situated at some point along the course of the straight line indicated by the stretched thread, and the point where the two threads thus fixed cross each other must be the exact position of the centre of the bullet. Such is the essence of the theory of what is known as the cross-thread method of localization.

The Three Co-ordinates.—The question now remains as to the method of ascertaining the position of this crossing of the threads in relation to the patient's body. Here we must revert to what has already been said about the three co-ordinates in reference to the three planes. The distance of the intersection of the threads from the flat horizontal plane is first measured. This is the *Z* co-ordinate, and actually represents the exact depth of the centre of the bullet from the part of the patient's skin which rested upon the photographic plate. How shall this position on the patient's skin be determined ?

The position is ascertained in the following manner: The cross wires are to represent the basis of the vertical planes. For example, if one is inspecting the site upon which a building is to be erected, and the position

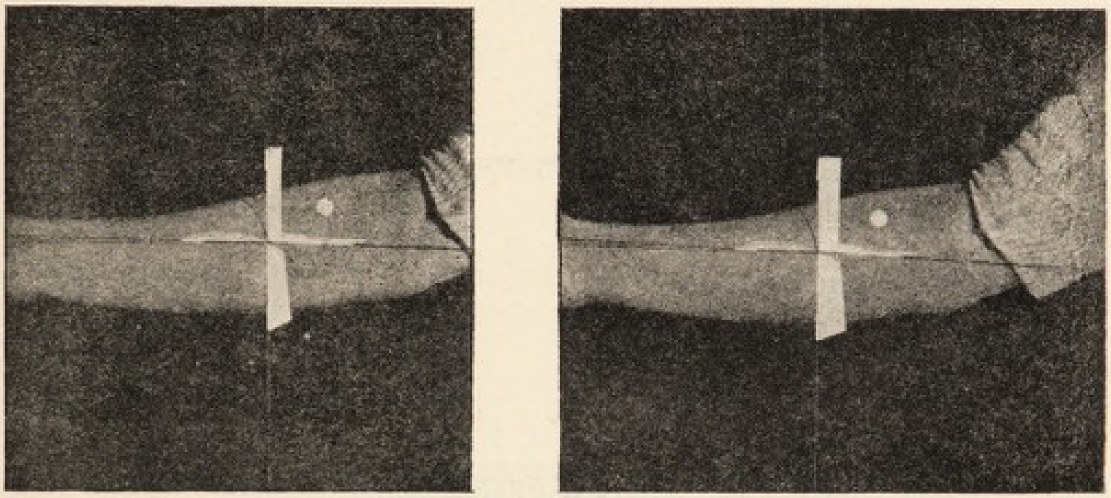


FIG. 26.

A "ghost," or double-exposure photograph, which, when viewed in the stereoscope, helps to visualize the fact that the mark of the cross wire on the patient's skin forms the base of planes. The position of the bullet is ascertained by the vertical distance from these planes, and from the skin of the arm on which the photographic plates rested.

of the walls is chalked out on the earth, one can quite well conceive the chalk lines as the base of a vertical plane, although the walls are not actually in existence. In the same manner, a vertical plane may be erected upon these wire shadows most conveniently by means of a centimetre measure mounted on a rectangular horizontal base. In this way the edge of the base can be brought into register with the line, and then the vertical distance from the face of this vertical plane to the point of intersection of the cross wires can be accurately measured.[1] By repeating the procedure

[1] *A Manual of X-Ray Technic*, by A. C. Christie (J. B. Lippincott). Description of alternative plan of marking a spot on tracing vertical below: first, where threads cross, and then measuring co-ordinate directly from the lines.

for the other planes, we arrive at the three co-ordinates, X, Y, and Z, of the point in question.

These data obtained, we go to the patient, and examining the marks made by the wires upon his skin, we learn in what quadrant the bullet is situated by means of the mark already mentioned. Were it not for some such means of identification, there might be disaster. If the patient had his hand or arm resting upon the plate, for example, the tube being above, then the mark of the cross wires on the palm when the back of the hand was inspected would be reversed in relation to the measurements already mentioned when the hand was turned over and an examination made of the palm. The two quadrants which were towards the inner side of the foreign body would now be turned towards the outer side. Although this is so very obvious, a lamentable error in this respect might readily occur if special precautions are not taken.

All that now remains to be done is to take the two co-ordinates, Y and X, and measure them on the skin from the respective planes. Premising that the hand, etc., is placed in such a position that the vertical direction can be ascertained—which is a very important consideration—the points where these co-ordinates meet fixes the point on the patient's skin below which vertically, at the distance Z, the centre of the bullet is situated. This distance is conveniently measured by a little surface gauge shown in the illustration with the pointer at the intersection of the cross wires.

At the risk of some recapitulation, the reader may be invited to study this procedure in a specific case as diagrammatically illustrated in Fig. 27, which represents the original diagrams produced when the author

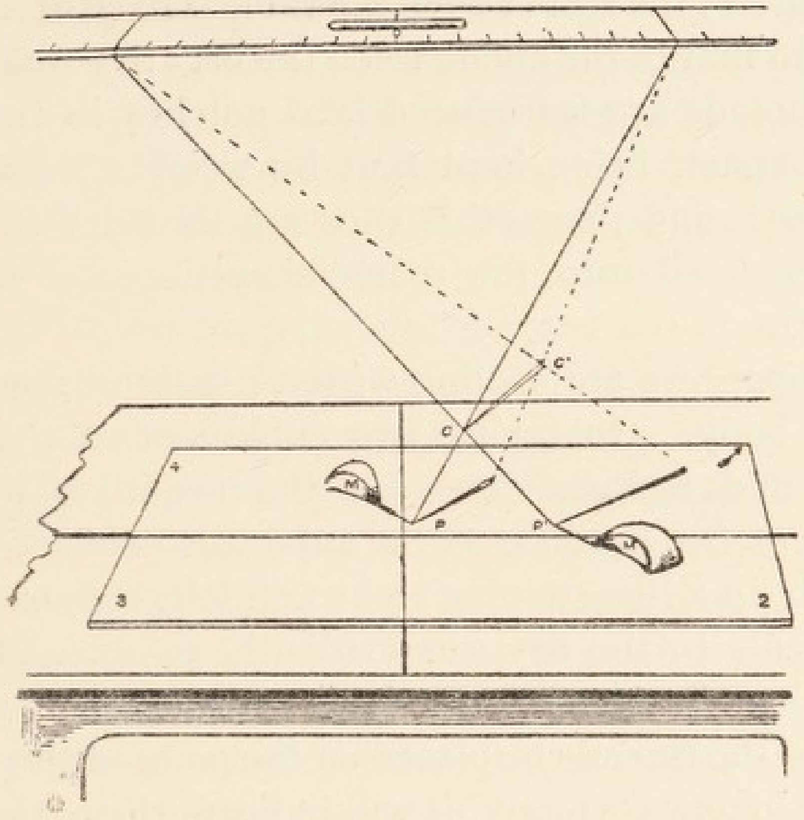


FIG. 27A.

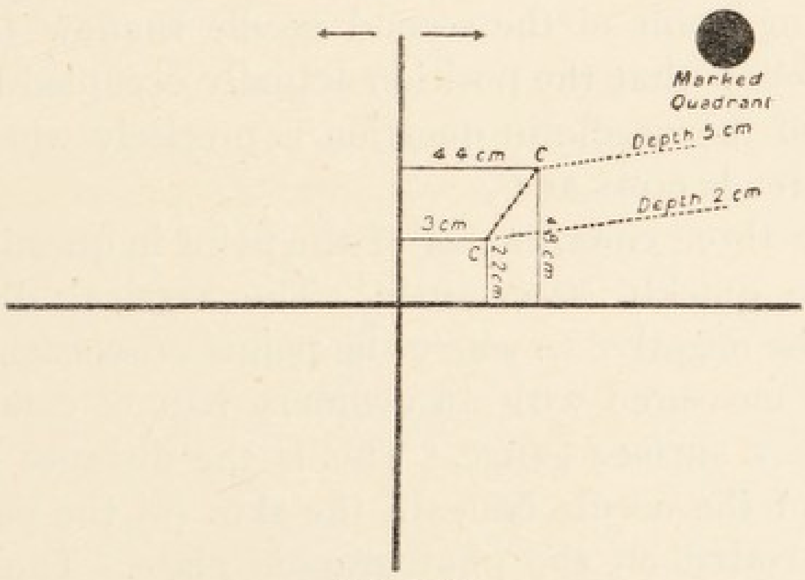


FIG. 27B.

first published his method in 1898. In Fig. 27A the negative is shown lying on the table with the glass side uppermost; the scale above the table is fixed at a height equal to that of the anode when the negative was taken. The threads are introduced into notches in the scale 6 cm. apart, being kept taut by weights, as already described, and their other ends are threaded into fine needles, fixed into the mouse-shaped pieces of lead (*M*, *M*).

Suppose we are dealing with a needle in some part of the body. On taking two exposures on the same plate, and looking down on the negative, we find images of two needles; as the tube was displaced horizontally in a line running right and left, the shadow of the needle to the left was evidently produced by the tube when displaced to the right, and *vice versa*. Thus, if one of the threads be placed on the point of the needle in one shadow correctly, it will indicate the path of the ray which produced the shadow of the needle-point (*P*); and if the other thread is placed on the corresponding point of the second needle shadow (P^1), it must follow that the position actually occupied by the point of the needle in question is precisely where the two threads cross at *C*.

The three co-ordinates of the point in question (*C*) can be quickly ascertained. The vertical distance from the negative to where the points cross each other is first measured with an ordinary pair of compasses or with a surface gauge. This is the distance of the point of the needle beneath the skin (of the patient) which rested on the photographic plate. The small arrow in Fig. 27A represents the marked quadrant, and 2, 3, and 4 mark the other corners of the negative.

We next measure the vertical distances from the two vertical planes represented by the shadows of the cross wires to the point where the threads cross. An upright square is placed with its edge coincident with the shadow of one of the wires, and the perpendicular distance is measured with compasses from it to the point where the threads intersect. We have now obtained our X, Y, and Z co-ordinates of the point of the needle, and we note the result down, as shown in Fig. 27B. The arrows here indicate the direction of the displacements of the tube. We then proceed in a similar manner to ascertain the position of the eye of the needle (C^1 in Fig. 27A), and the distance between C and C^1 gives the needle's direction and actual length.

From the measurements jotted down, as shown in Fig. 27B, we can mark a line on the patient's skin in the same plane as the needle, and give the surgeon the exact depth at which each of its extremities can be reached by a vertical puncture.

CHAPTER VI

PRECISE LOCALIZATION: FURTHER CONSIDERATIONS

Application to the Screen.—The method described in the previous chapter can be made purely a fluorescent screen method, and adopted without the necessity for employing a photographic plate at all. The foreign object or objects, however, must be clearly visible on the screen. The procedure is identical with the foregoing up to the point at which the photographic plate is introduced. Instead of the plate, attention must be turned to the screen, on which the intersecting lines must be clearly indicated, either by a mark on the glass itself, or by stretched opaque threads over a piece of tracing paper or film, which should be lightly attached to the glass covering of the screen by means of plaster at the corners. If the adjustments of the tube are made so that the vertical distances from the cross wires are all calculated, as already described, the shadow of the foreign body can be traced and the displacement carried out in the same manner as when using the plates. When the tube is excited, the screen should be moved about until the cross lines on the tracing paper come into exact register with the shadow caused by the cross wires which are on the patient's skin. In this position, with a pencil of a particular colour (red or black), the shape and position of the foreign bodies are outlined on the tracing-paper.

Then, the whole of the screening arrangement being kept securely in the same position, the tube is displaced by 6 cm. from the middle point along one of the cross wires. A displacement in the shadows of the foreign bodies is at once visible, and their new position is outlined by a pencil of a different colour (black or red). With an apparatus which will allow of the ready adjustment of the position of the tube, this work can be done in a few minutes, and the tracing so obtained can be placed upon the cross-thread localizer, and the exact position and size of the foreign bodies ascertained forthwith. If the principle of the method is thoroughly grasped, the apparatus and technique for carrying it out are matters for the individual worker to devise. This procedure, of course, saves time as well as plates, and, if the tracing be carefully done, the measurements are approximately exact.

A Stereoscopic Result.—Even if the photographic method be employed, an economy in plates can be effected by using only one plate for the two exposures. Two tracings, each corresponding to one of the exposures, can then be taken from this plate, and a diagrammatic stereoscopic picture can be made which will show the relative position of the foreign bodies to each other and to the cross wires. It is always important to remember that by this localization method the two images, whether from the photographs taken on two separate plates, or from the two tracings taken from the two exposures on a single plate, can be combined so as to form a stereoscopic result. The subject of X-ray stereoscopy has been dealt with in another chapter, but it is as well to mention here that this stereoscopic use of the results of the localization method is of considerable advantage to the surgeon, since not only does the localization method, pure and simple, give him material for exact measurements, but, if he possesses binocular vision, the stereoscopic relief will enable him to visualize the relative position of the cross wires and the bones of the patient to the foreign body. As the surgeon is more accustomed, naturally, to operate from anatomical relations than from vertical planes and co-ordinates, it is very fortunate that he can have this general stereoscopic view of the parts before and during operation, as well as the exact measurements, to guide him. It is possible, with the stereoscopic view, by placing a piece of wire of known length upon the patient's skin, to estimate more or less roughly the various distances of the foreign bodies from each other and from any of the points in the view.

The marking of the cross wires on the patient's skin can be conveniently done with nitrate of silver, and the point below which the foreign body is situated can also be marked with the same chemical. This has the advantage of marking the skin distinctly, and of not being readily obliterated by the necessary antiseptic washings and other procedures which are taken before the actual operation for the removal of the foreign body. An exception is to be noted in the case of iodine, which will obliterate the silver markings. It is important to take careful notes of the position of the patient's body when the photographic or screen examination is being made. In the leg, for example, the weight of the resting limb displaces the soft parts, and it is well, when the limb is in position, to mark with a surface gauge a horizontal line on the leg, and to note the vertical distance to the photographic plate, because the measurements one obtains give the distance below the skin when the leg is in that position. If the removal of the foreign body is to be carried out, the release of the limb from pressure would alter the distance between the point on the skin and the depth at which the foreign body is lying. It follows that any landmark placed upon the surface of the skin, such as lead wire or lead foil arrows, will permit of the measurements being made with reference to this fixed point, and in this way the trouble due to a difference of position is obviated, and the exact distance of the foreign body can be determined from any point on the patient's skin which the surgeon may select as the most convenient starting-place for operation. A little bismuth ointment on the skin is a convenient means of demonstrating stereoscopically the relation of the skin to the parts beneath.

Other Uses of the Method.—The method which has been described in a general way, and for one particular class of foreign bodies, is, of course, equally applicable to other classes. In the case of a needle, for example, the method will furnish information as to the exact position of either end of the needle, as well as its exact length, and the angle, often very oblique, at which it is situated. The method can also be used for ascertaining the exact size and position of any organ the shadow of which can be differentiated. For example, by means of tracings of the bones of the pelvis taken in the way described, and then tracings from the two negatives placed on the cross-thread localizer, the two needles carrying the threads being placed upon the corresponding points, the exact size of the pelvis can be ascertained. The results of such a method would be much more accurate for gynæcologists, not to speak of being obtained more simply, than any results based upon external measurements. The exact size of the heart could be demonstrated in the same manner.

Naturally, it involves some little practice and time for the mind to become familiar with the practical applications of the co-ordinates from known planes of reference, but it is well worth acquiring, for it places in the hands of the X-ray worker what practically amounts to an infallible method of getting all the necessary information as to the size and position of foreign bodies and their relations to the surface.

CHAPTER VII

LOCALIZATION OF FOREIGN BODIES IN EYEBALL AND ORBIT

Precision Essential.—The method of localization described in the preceding chapters can be applied in ophthalmology with very gratifying results. Precision in localization is important, whatever the part of the body with which one may be dealing, but it is essential in the case of so delicate a structure as the eyeball, where the slightest deviation from accuracy may involve the loss of vision. The principles concerned in the localization of foreign bodies in the eyeball and orbit are the same as those which have already been described, but if the method is to be carried out successfully, attention must first be paid to certain practical adjustments.

Arrangement of Patient.—The first point of importance is that the patient must be in a sitting posture, that the head must be kept rigid, and the eyeball under examination never allowed to move in the slightest degree while the photograph is being taken. This, like the method of more general application, can be carried out in a variety of ways. In the method which the author has adopted, an apparatus is employed which is known as the headpiece, and is clamped on to a table. The headpiece consists of a rigid frame of wood, with a space cut into it of sufficient size to admit a photographic half-plate. Across this space two intersecting wires (piano wires will serve) are stretched, one vertically, and the other horizontally. The patient, while sitting upright in a chair which can be raised and lowered like a piano stool, rests the temple of the side under examination against these cross wires, and the back of the head is supported by a piece of board fastened at right angles to one of the wires. On the opposite side of the head to that under examination, a second piece of board, with a thumb-screw sliding in a groove, serves to press and fix the head laterally against the two stretched wires, and the chin is supported on an adjustable projection. As an alternative method of producing steadiness, an adjustable horizontal bar can be used, which the patient may hold with his teeth. The arrangement, as just described, is illustrated in Fig. 28. There is no upholstery about this contrivance; it is all of wood, and admits of no shifting of the patient. The adjustment of the anode of the tube at right angles to the intersection of the piano wires is facilitated by fixing a rifle "sight" (Fig. 29) very correctly, so as to have its point at right angles on the same level as the point of intersection. To improve the definition of the tube a sheet of fairly thick lead rubber, with a hole about 3 cm. in diameter punched in its centre, can be suspended on a sliding bar in such a way that this stop can rest against the tube and be so adjusted as to admit a small cone of X rays through the aperture. This apron stop, being attached to a sliding bar, slides parallel to the movement of the tube, and can be easily adjusted when the tube is displaced. Although not absolutely essential, it greatly improves the definition of the photographs, as it cuts off all the scattered radiation from the glass.

PLATE XI.

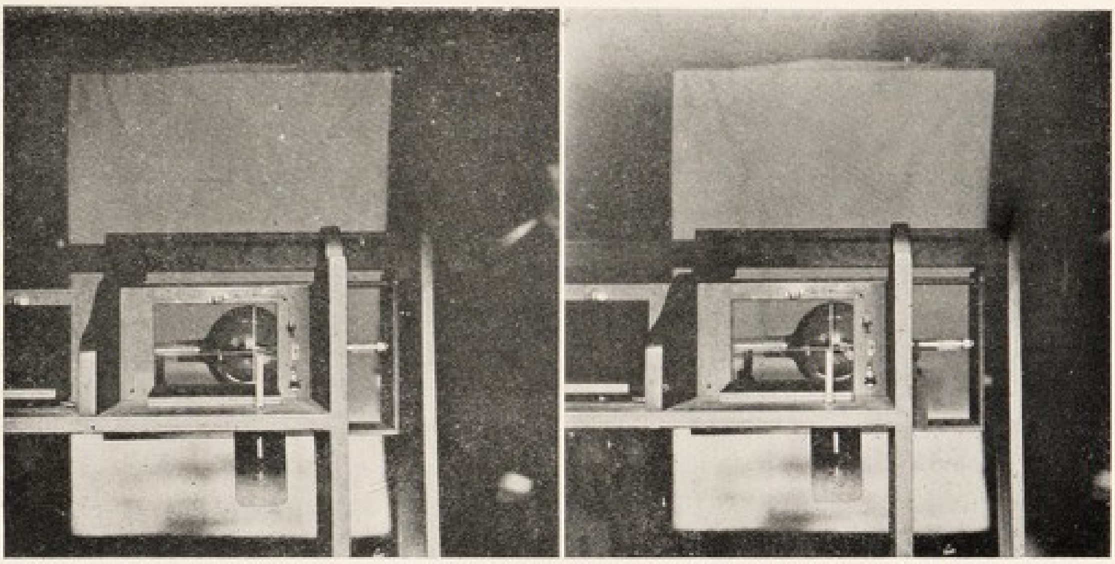


FIG. 28.—HEAD-REST FOR EYE LOCALIZATION.

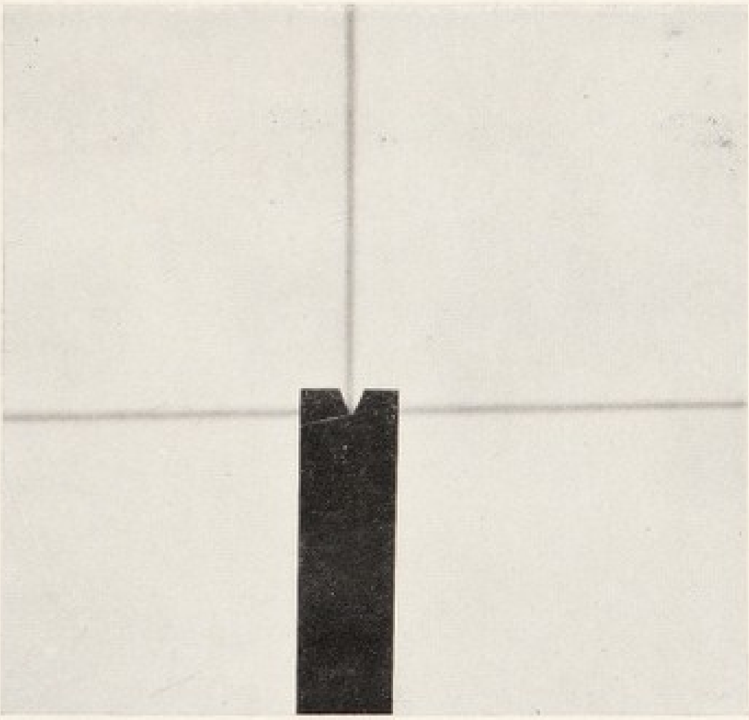


FIG. 29.—THE SHADOW OF THE PIANO WIRES OBTAINED ON A PHOTOGRAPHIC PLATE WHICH WAS PUT UP AGAINST THE RIFLE SIGHT, SHOWING THAT THE ANODE OF THE TUBE HAS BEEN ACCURATELY CENTRED.

To face p. 48.

PLATE XII.

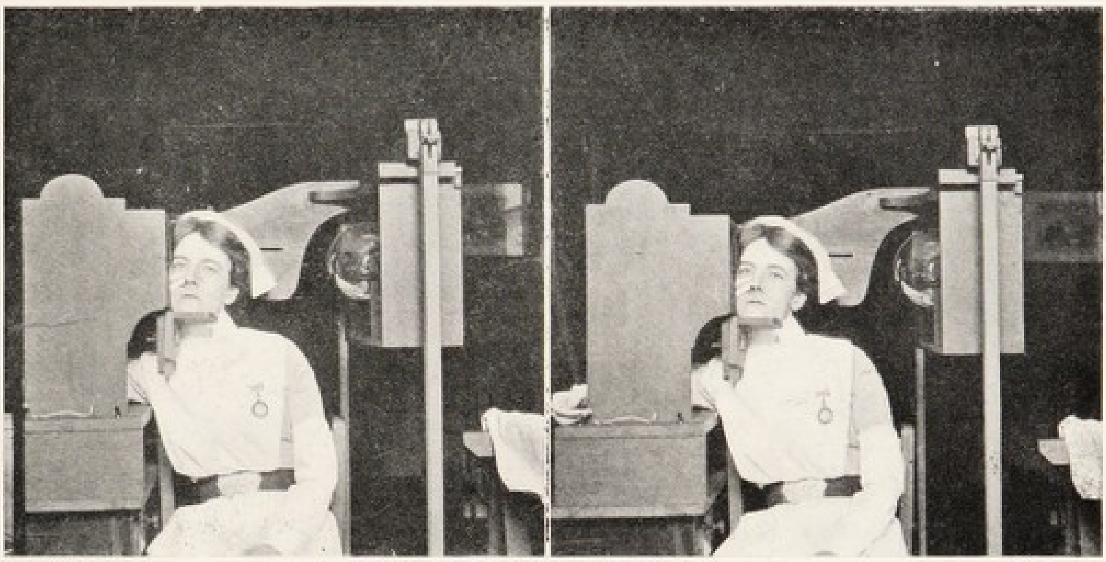


FIG. 30.—HEAD-REST FOR EYE LOCALIZATION WITH PATIENT IN POSITION.

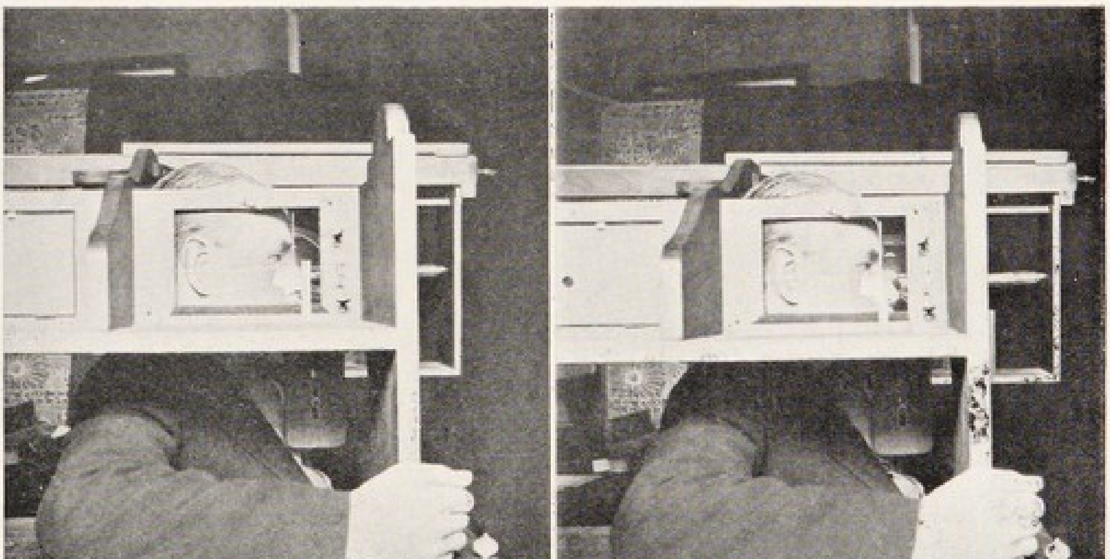


FIG. 31.—SIDE VIEW OF HEAD-REST.

[*To face p.* 48.

Position of Tube.—The tube is held in a sliding support, and adjusted carefully, so that the fine point of the anode from which the linear rays originate is at right angles to the point of intersection of the wires. When it has been approximately so placed, it can be excited, and with a fluorescent screen close up against the rifle " sight," the exact central position of the tube can be secured by bringing the shadow of the point where the wires intersect right into line with the " sight " (as in Fig. 28). The distance between anode and intersection, usually 42 cm., is carefully noted. Some definite mark—a small black spot on a piece of rubber plaster, like a bull's-eye on a target, answers well—is placed at some distance in front of the patient in such a position that, when he is fixing his gaze upon it, the eye under examination has its visual axis parallel to the horizontal piano wire. The patient being in position, and the vertical wire in advance of his eye, the position of the horizontal wire can be marked upon his temple. Another very important point is the placing of a piece of lead wire or foil, 1 cm. in length, on the patient's lower eyelid, as close to the eyeball as possible (Figs. 30 and 31). The position of this landmark, which can be secured in place by two strips of adhesive plaster, has then to be most carefully noted in relation to the eyeball itself when the patient under examination is gazing at the fixed point. It is necessary to discover whether this identification mark is vertically below the centre of the cornea, or behind, or in advance of that plane; also how many millimetres it is to the right or left of the vertical line through the middle of the cornea, and how far below the corneal centre.

One very simple addition which the author has lately made to this method, and which is the final adjustment so far as the patient is concerned, consists of a loop of fuse wire with a prolongation to serve as a holder, in the manner depicted in Figs. 32 and 33. The loop is of such size and shape as to fit into the orbital cavity, and, once it is in place, the globe of the eye is maintained perfectly rigid during examination. It is placed over the eyelids, which are slightly open, and with gentle but firm pressure the eye is "fixed" in the position of gazing at the "bull's-eye mark." An X-ray photograph of the eye, obtained with this arrangement in position is reproduced in Fig. 34. Absolute immobility is now secured.

Displaced Negatives.—The photographic plate in its usual paper envelope is placed against the piano wires, which should be in contact with the patient's temple, and is kept in position by means of a hinged lid. The tube is then displaced in the usual way, in the plane exactly parallel with the horizontal wire, 3 cm. to one side of the central or zero position, and 3 cm. to the other, and an exposure—on a separate plate, of course—is made at each displacement. From the two negatives tracings are taken as before, and the geometrical relations worked out on the cross-thread localizer. The point of importance here is that the worker is enabled to arrive at the exact relation of the foreign body or bodies to the point of wire nearest the eyeball—first, by ascertaining the three co-ordinates of this known point; then the three co-ordinates of the unknown foreign body; and, finally, by making a simple subtraction. These measurements being noted down, a convenient method of obtaining the position of the foreign body is to take a model eye, five times larger than the average human organ

PLATE XIII.

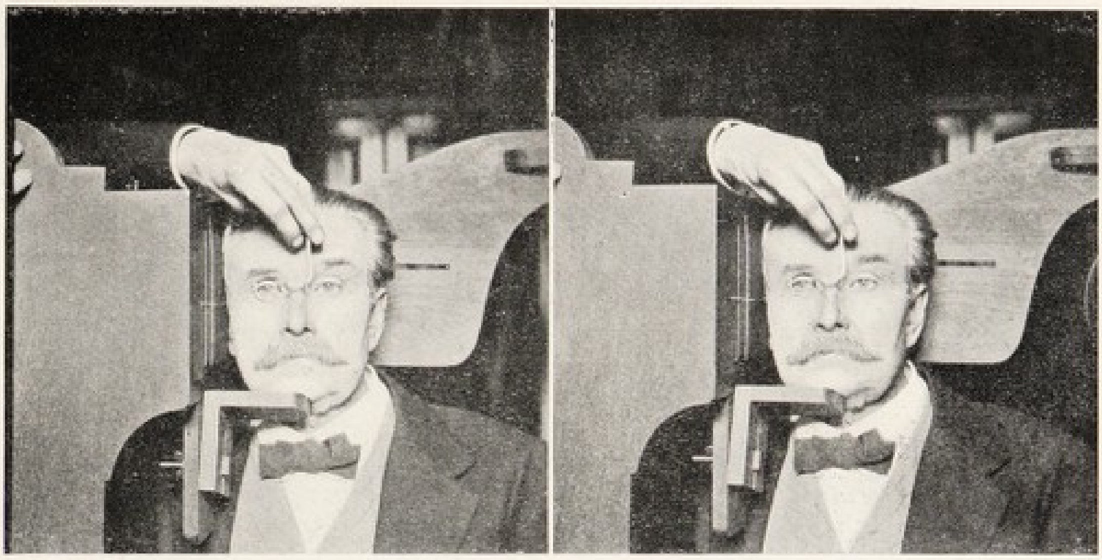


FIG. 32.—SHOWING LOOP OF WIRE TO KEEP EYE IMMOBILE, ALSO TO FACILITATE LOCALIZATION (*See* FIGS 34 *and* 58).

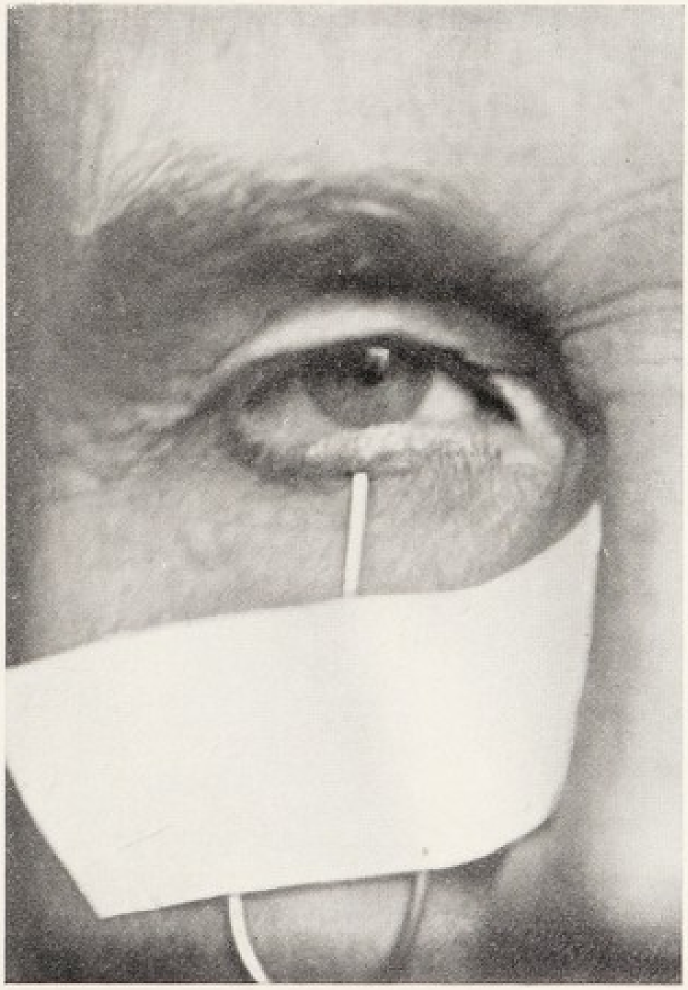


FIG. 33.—METHOD OF FASTENING INDICATOR WIRE TO LOWER EYELID.

[*To face p.* 50.

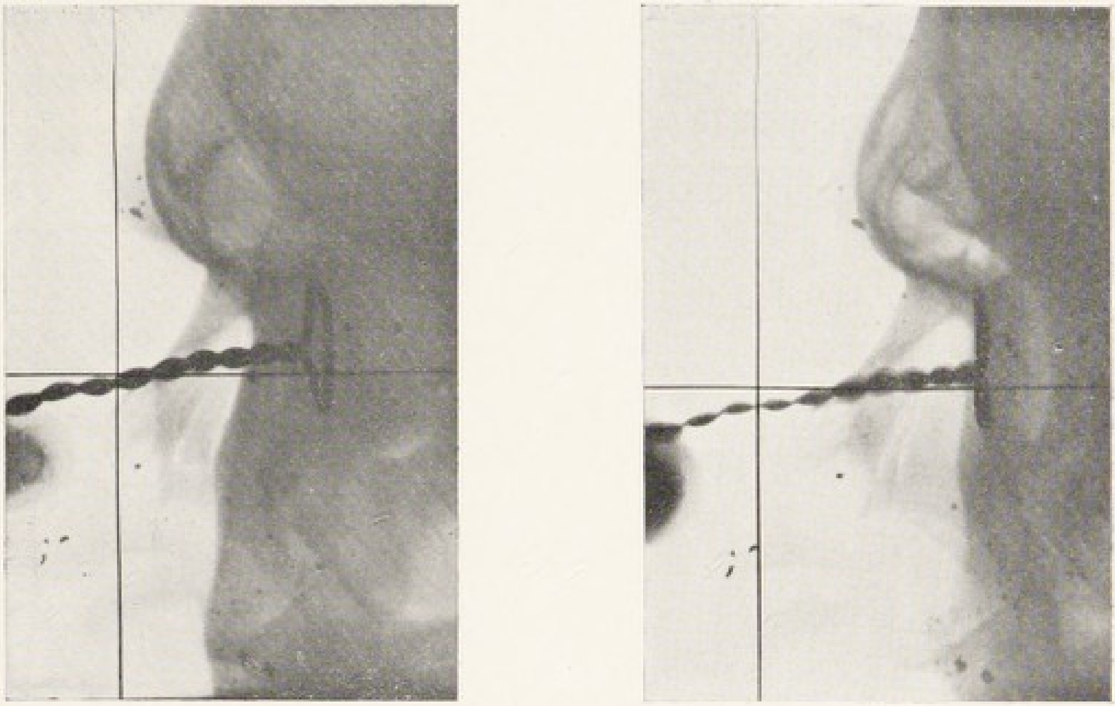


FIG. 34.—X-RAY PHOTOGRAPH OF EYE WITH LOOP IN POSITION (*See* FIG. 32).

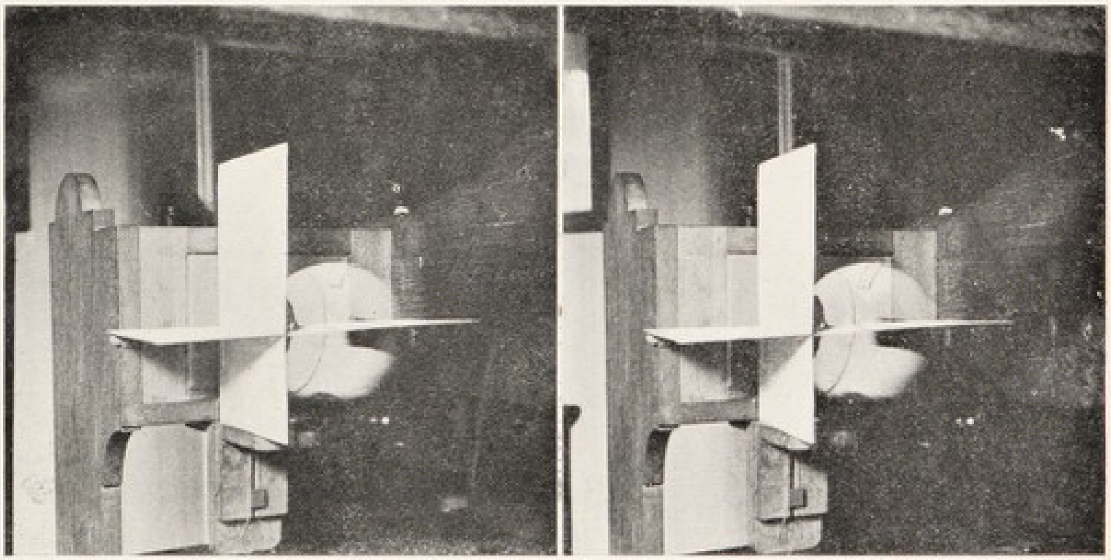


FIG 35.—"GHOST" PHOTOGRAPH OF MODEL EYE PLACED IN HEAD-PIECE, TO ILLUSTRATE THAT THE STRETCHED PIANO WIRES FORM THE BASIS OF PLANES FROM WHICH CO-ORDINATES CAN BE MEASURED.

[*To face p.* 50

(Fig. 35), and then, by means of a surface gauge, to so adjust its point of wire as to reproduce on the model eye the relationship which the same identification mark bore to the eye of the patient. The co-ordinated measurements are then applied, and it is noted that the foreign body is situated so many millimetres above or below this landmark, so many millimetres to the right or left, and so many millimetres directly backwards parallel to the visual axis. In this manner the position of the foreign body in the eyeball, however small that body may be, can be ascertained with great accuracy, and its size also can be determined. Figs. 35 and 36 show the model eye and the human eye respectively, bisected by planes (the images being obtained by double exposure), so that the position of any foreign body could be measured in relation to these imaginary planes. Fig. 37 is an attempt to show, also by double exposure, the X-ray tube in position, and the head of the patient beyond.

A Stereoscopic Result.—In this case, again, the pictures thus obtained give stereoscopic relief, and when viewed either in the Wheatstone stereoscope or by converging the visual axes, and so fusing the pictures, a single image in relief is seen, giving the relative position of the parts. Further confirmation of the position of the foreign body can be obtained by keeping the tube in a known position—say central to the central point—and taking two photographs, either on the same plate or on two different plates, the eyeball being made to look first in one position and then in another at a known angle to the first—say vertically downwards, at an angle of 45 degrees from the horizontal, or vertically upwards at an angle of 45 degrees, or laterally to the right or left at an angle which is to be noted. When the tracings from the displacement of the shadow of the foreign body are made, its depth being 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 of the eyeball being taken as a point 10 mm. in front of the centre of the retina.

An Example in Detail.—Although the principle and method of localization have already been expounded as fully as possible, the application to a particular case may still seem to present difficulties. The author has judged it well, therefore, to take a specific instance, and describe the whole procedure from beginning to end, even with painstaking minuteness and some repetition. If the directions in this example case are studied carefully, the worker should be able to apply them without difficulty to the case with which he is actually dealing, making, of course, the modifications which the different conditions of every individual case require.

The case selected is that of a gentleman who, while shooting, was struck in the right eye by a pellet. The accident occurred about a week before he came for X-ray examination. The shot had been fired at about sixty yards. The interior of the eyeball was full of blood, and the patient could just perceive the difference between light and darkness. The question to be decided was whether the pellet was inside the eyeball, in which case the eye would have to be excised.

The X-ray tube was carefully "centred" in the headpiece already described, and a small piece of fuse wire was fixed to the patient's lower eyelid with rubber plaster. The upper end was on a level with the nasal

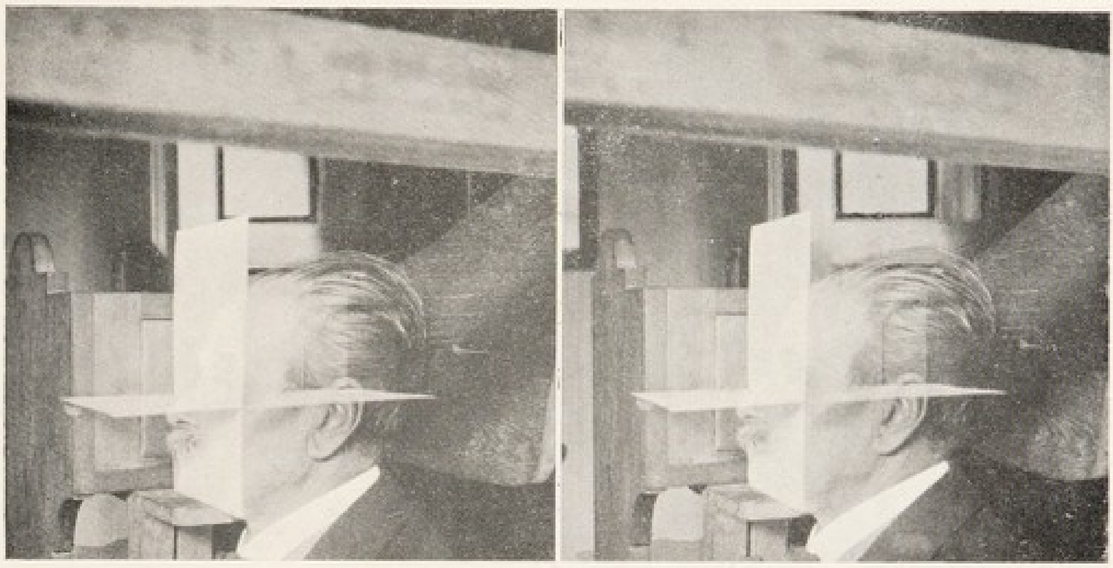


FIG. 36.—"GHOST" PHOTOGRAPH WITH HEAD IN POSITION FOR LOCALIZATION, SHOWING INTERSECTING PLANES: VIEWED FROM TUBE SIDE.

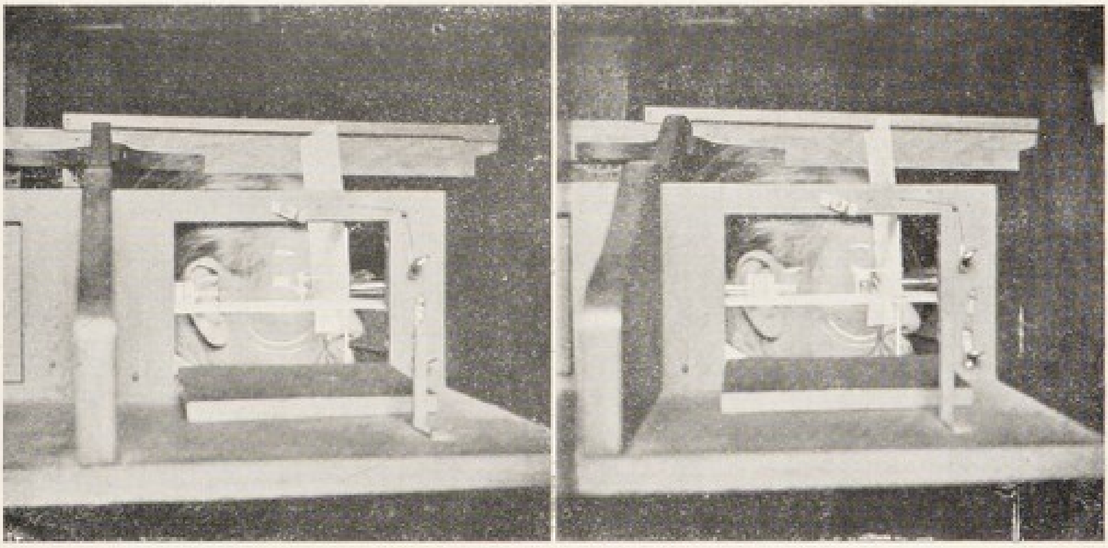


FIG. 37.—"GHOST" PHOTOGRAPH VIEWED FROM OPPOSITE SIDE.

[*To face p.* 52

end of the horizontal diameter of the cornea, but it only occupied this position when the head of the patient was in the head-rest, and his eye was gazing steadily at a small point some distance in front of him, placed in such a manner that the visual axis was parallel with the horizontal piano wire. It was in this position that the photograph was taken. It is of the utmost importance that the patient should keep his eye looking steadily at the same point during the two exposures. The patient was placed in the head-rest, as already described, the anticathode being 42 cm. from the cross wires, and the first exposure was made with the tube centrally placed—that is to say, at right angles to the intersection of the cross wires. One exposure was given for about fifteen seconds, and then the plate was changed without disturbing the position of the patient, and the tube was moved by sliding its supporting cage 6 cm. backwards, the second exposure being then given. The negatives were developed and fixed, and tracings were taken from both negatives on one piece of transparent gelatine tissue. The tracings were taken from the glass side, a pencilled cross on the sheet of tracing material being brought into register with the white lines of the cross wires on each negative. The two images of the indicator wire and of the shot were traced, and the tracing was then placed on the stage of the cross-thread localizer, the cross being vertically below one of the end notches of the small T-piece. The ends of the cross threads were then placed on the upper ends of the indicator wire shadows, and the three co-ordinates of this point were measured and noted down. In the same way the three co-ordinates of the shot were ascertained. Thus we decided the relative position of the shot to the indicator wire, and it was found that the shot was close to but outside of the eyeball; indeed, the position was such that we could assert confidently that if our measurements were correct we ought to be able to feel the shot against the sclerotic. The ophthalmic surgeon who was with the case thought that the shot could not be felt, as he had very carefully examined the eye and could detect nothing. It was pointed out to him that shot often moved forwards, and the matter was easier when one knew the precise spot where the shot was situated and could look for it there. A few drops of cocaine were dropped into the eye, and on making the patient look upwards at an extreme angle, the finger being introduced gently into the orbit, the shot could be felt rolling under the finger up against the sclerotic. This was next day easily removed, and the blood in the vitreous would gradually be absorbed, and the patient retain a useful eye. (This is illustrated in Fig. 54, Plate XXIII.)

APPENDIX I

The Telephone Attachment in Surgery

THE use of the telephone as an aid to the surgeon in the detection of embedded bullets and splinters of shell has gained considerable acceptance since it was brought forward by the author in a paper read before the Medical Society of London in January, 1915.[1] It is not, however, offered as a substitute for the X-ray method, but, rather, as an additional procedure, the purpose of which is to ensure that the advantage gained by a previous X-ray localization is not lost in the exigencies of the actual surgical extraction. The ideal plan would be, first to localize a foreign body by the X-ray method, and then to guide each step of its removal by means of the telephone.

The author's first experiments with the telephone in surgery were made in the eighties, soon after its use in this connection was suggested by Professor Graham Bell. It was Graham Bell who pointed out that if a probe were fixed to one terminal of a telephone and a plate of metal to the other terminal, the plate being laid on the skin of the patient, a galvanic battery would be formed within the body whenever the probe struck an embedded piece of metal, and the current thus produced would be sufficient to operate the telephone receiver. One condition laid down by the American electrician, however, was that the instrument attached

[1] *Lancet*, January 30, 1915.

to the one terminal must be of the same metal as the plate attached to the other terminal, and it is only since the war suggested a fresh recourse to the method that the author finds that this condition is not essential to success.

If a steel, silver, or nickel-plated instrument is attached to one terminal of the telephone, and the embedded metal to be sought for is lead, nickel, copper, iron, or certain of the iron alloys used in shell manufacture, the loudest sound is elicited on contact when a carbon plate is attached to the other terminal. The carbon plate which is used in an ordinary bichromate cell answers the purpose quite effectively, but it should be as large as is convenient. The carbon and also the patient's skin upon which it is placed should be moistened with a salt solution in order that the conduction may be as good as possible, and if the skin beneath the plate is brushed with an iodine solution the result is still more satisfactory. The currents generated under this arrangement are, naturally, extremely small, and in consequence are better detected by a telephone of 60 ohms resistance, or even less, than by the more expensive high-resistance telephones used in wireless telegraphy.

An idea of the general arrangement can be obtained from Fig. 38. Affixed to the surgeon's head are, preferably, double receivers, though a single receiver can be used if the hearing is acute. The carbon plate is held in position by means of plaster or bandage upon the patient's moistened skin. To this, which forms the positive element, one terminal of the telephone is attached. The other terminal is connected to a lead which is detachable for sterilizing purposes, and need only be handled by the surgeon or his assistant, exercising the usual antiseptic precautions. This section of wire is spring-clipped on to the surgeon's instrument, be it knife, probe, needle, or forceps. The foreign body is the negative element, and when the circuit is

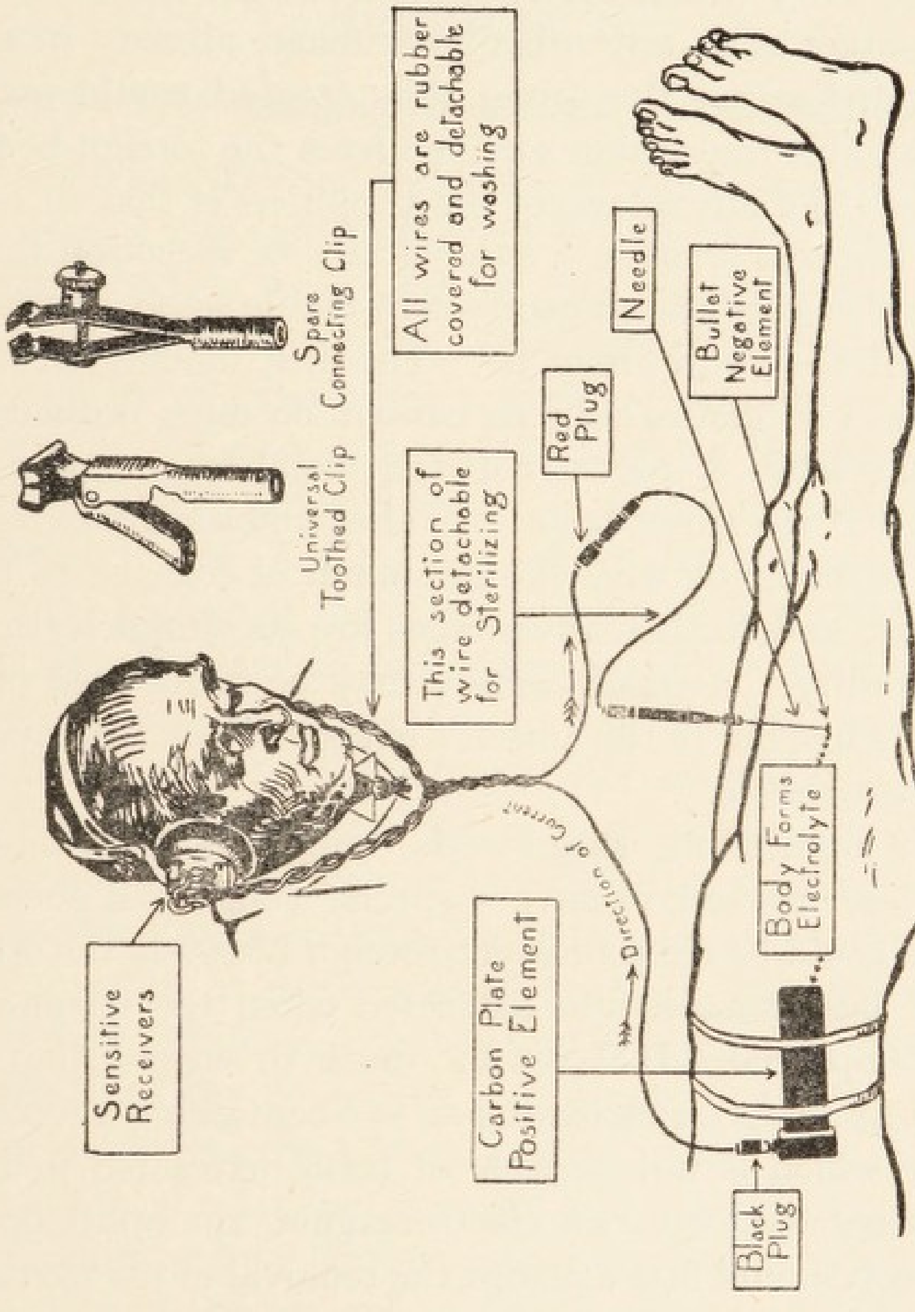


FIG. 38.

completed by contact between the negative element and the positive element in the shape of the plate, the current is produced, and an unmistakable click is heard in the receiver; while, if the exploring instrument be moved slightly so as to make a rubbing contact, the click becomes a sharp rattle. This microphonic impression enables the surgeon to exercise a continual control over the foreign body. The most obvious of the precautions he must take is never to allow the instrument to which the telephone is attached to come in contact with any other instrument already in the wound, because the sound thus created would mask the audible impression received from the foreign body.

The chief advantage of the telephone is that in certain respects it offers a surer means of detection than is furnished by the surgeon's own tactile sense, however refined the latter may be. The instrument, for example, can distinguish, as cannot be done ordinarily by the sense of touch, between metal fragments and pieces of fractured bone. It also enables the extraction to be made with the minimum of damage to the tissues, and further advantages are its simplicity and portability. A small battery may be introduced into the circuit, but in the author's experience its advantage is questionable.

In ophthalmic surgery the telephone attachment has been proved to have a special value, and several cases could be cited in which foreign bodies in the orbit have been successfully extracted when the telephone was employed. It is not too much to suggest that in all cases, before enucleating an eye containing a foreign body which is not capable of being extracted in the ordinary way with an electromagnet, the ophthalmic surgeon should first attempt the removal of the particle with the assistance of the telephone attachment.

APPENDIX II

The Electromagnet as an Aid to Localization

RECENTLY Professor Bergonié, of Bordeaux,[1] has introduced a large electromagnet as a means of detecting foreign bodies embedded in the tissues. Professor Bergonié has conceived the idea of exciting the electromagnet by an alternating current of 110–120 or 220–240 volts. If, under these circumstances, the magnetic field embraces the projectile, a vibratory motion is induced in this latter, the vibrations synchronizing with the pulsing of the current, and having a frequency generally between 48 and 55 per second. The magnet is, preferably, suspended from a wall bracket, and the extremity of its core, in a sterilizable covering, is passed over the suspected part, but is never allowed to come in contact with the skin. Any vibration in the tissues is observed by palpating the part, and this indicates the presence of a metallic projectile. The point of maximum vibration is then found by more careful palpation, and the projectile accordingly is localized as being nearest to the surface at that point. Here, if it is possible, the incision is made, and the magnet again used, followed by a further digital exploration, and the deepening of the incision in the direction indicated by the vibrations. A very few of these alternations of procedure, even in the more difficult cases, usually suffice to reach the foreign body, but the surgeon must

[1] *Archives d'Electricité Médicale,* May–September, 1915.

take care that the current is switched off every time he uses his instruments.

This method at first sight, of course, is only applicable to the detection of splinters of shell and bullets of magnetizable metal, thereby excluding lead projectiles, but Bergonié now states that his electrovibrator is capable of inducing vibration even in non-magnetizable bodies. This is brought about by eddy currents induced in the metal. For this purpose a more powerful instrument of 8 or 10 kilowatts is necessary. Of the non-magnetizable metals, aluminium has been found to give the most marked vibrations, with copper and silver the next in order, while it is still difficult, unless the induction of the instrument is largely increased, to bring about any vibration in the case of German silver, which forms the sheath of revolver bullets, or of lead, which forms the charge of shrapnel shell.

Many French military surgeons speak highly of the method, which, it should be clearly understood, is purely a method of localization; the magnetic action has no part to play in the actual removal of the foreign body. The extraction is a matter for the surgeon's fingers or instruments, and for those alone. If the magnet is kept on too long, the currents induced in the metallic body make the latter hot, and for this reason the magnet should be used only for brief séances. Bergonié does not bring forward the method as a substitute for X-ray localization, but simply as an addition to the armamentarium of the military surgeon.

APPENDIX III

Localization from a Single Photograph

By means only of a single photograph the X-ray worker may be enabled to ascertain the distance of the tube from the plate resting on the skin of the patient, and the depth of any foreign body below the skin. In order to carry out this method he must be provided with a small hollow box or frame having a cross of fine wire at the top and another similar cross at the bottom. The intersections of the wires must be exactly opposite one another, and the distance between them—*i.e.*, the thickness of the box—must be accurately known. A convenient distance is 20 mm. This box rests on the patient's skin. The tube below being excited, a small fluorescent screen is placed on the upper cross wires of the box, and this and the tube are moved about until the shadow of the lower cross is seen to be accurately superimposed on the shadow of the upper cross. Then it is known that the radiating point on the target of the tube must be situated vertically below. A little further combined adjustment will secure that the shadow of the embedded bullet falls accurately in a line with the superimposed crosses. When this is obtained, it follows that the two crosses and the bullet are all situated in a direct vertical line above the radiant point of the tube target. The skin is now inked at the spot where the lower cross rests upon it, a photographic plate is placed on the upper part of the box, and the tube below is displaced a known distance, 60 mm. for example. Save for this adjustment of the tube, everything remains as it was before, and at this point one photograph is taken.

From the data afforded by this single negative, the distance of the tube from the patient's skin, upon which the lower cross rested, and also the depth of the bullet can be ascertained. On developing the negative, it will be observed that there is one shadow of the cross wires which has suffered no parallax; this is the one upon which the plate was actually resting. The other cross will be seen as displaced, and the distance between the two crosses is carefully measured on the negative. An equally careful measurement is made of the distance of the shadow of the bullet from the centre of the first cross. The same measurements can be made directly on the fluorescent screen if no photograph is taken.

In the annexed diagram (*a*), *T* represents the original position of the tube, and *D* the displaced position at which the single photograph is taken. The distance of the tube from the patient's skin (which has to be found) is *TS*, and the distance of the bullet beneath the skin (also to be found) is *SB*. The distance between the two cross wires in the frame is represented by *CS*, and the direct vertical line when the double cross and the foreign body are seen in superimposition is represented by the line *CSBT*, *B* being the position of the foreign body. *G* represents the displaced image of the lower cross on the negative, and *E* the image of the foreign body. Diagram (*b*) shows the same displacements on the flat.

From these data the following can be ascertained:

DIAGRAM.

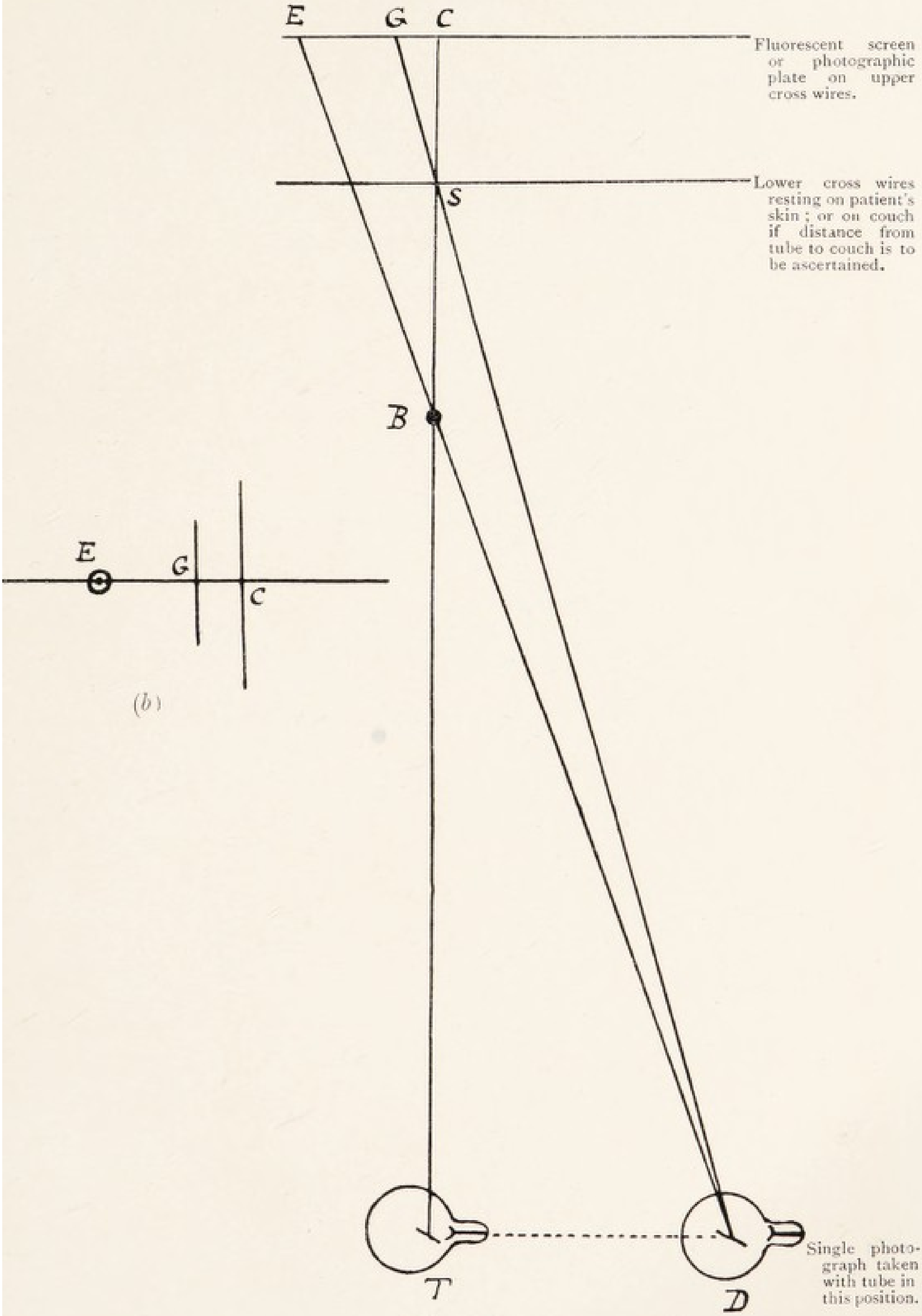


FIG. 38A. (a)

[To face p. 62.

(1) The distance of the tube from the patient's skin.

(2) The depth of the bullet beneath the skin at the point already marked on the skin, *i.e.*, the position of the lower cross.

The matter resolves itself into a simple calculation, and may be expressed in this way:

$$CG : CS :: TD : TS$$

The distance CG is measurable on the negative, and if the distance CS is 20 mm., and the distance TD 100 mm., then $TS = \frac{20 \times 100}{CG}$, and gives us the distance of the tube. To find the depth of the bullet, we have the following equation:

$$EC : (CS + BS) :: TD : TS - BS$$
$$EC\ (TS - BS) = TD\ (CS + BS)$$

The distance EC is measurable on the negative, and if CS is again 20 mm., and TD 100 mm., while the distance TS is known from the previous calculation, the distance BS is readily discoverable.

APPENDIX IV

The Rectification of the Current supplied to the X-Ray Tube[1]

IN the early days of X-ray work, the currents employed to excite the tube were so weak that the disturbance and difficulty caused by the inverse or "make" current did not arise. When strong currents came to be used, however, this "make" current became a source of trouble and anxiety to X-ray workers. Valve tubes are largely used to overcome the difficulty, but these in themselves are subject to disturbances.

Since the major part of this book was written, the author has constructed a device in the shape of a commutator attachment for bringing about the rectification of the induction-coil currents. Being much troubled by the easy reversal of his tubes when trying to get rapid exposures, and not possessing a Snook apparatus, which embodies a rectifying device for making an alternating current unidirectional through the tube, he set about some means of trying to overcome the inverse current difficulty. The result is a device which is so extremely simple that it seems incredible that it should not have been worked out before.

[1] Being the substance of a communication made by the author to the Electrotherapeutic Section of the Royal Society of Medicine on January 21, 1916.

At first it seemed advisable to try to prevent the production of the inverse current rather than to stop it after production, as in Dr. Reginald Morton's or Mr. Miller's arrangement. With this object in view the author attached to the spindle of his little rotary dipper interrupter a series of studs connected with resistances, and so arranged in relation to the position of the blade that when the blade was just dipping into the mercury to close the circuit in the primary, the finger attachment pressing on one of its sides introduced into the primary circuit a resistance of from 40 to 60 ohms. As it rotated, it came on to other studs, and gradually cut out the resistance, until, just before the break, there was no resistance interposing at all. As the output in the secondary is a function of the rate of change of the primary, this gradual building up of the saturation of the primary through these resistances resulted in no inverse current being passed, and an X-ray tube, which would readily allow inverse current to pass if such current existed, showed no signs of it at all when worked with this arrangement.

This led immediately to the consideration that it would be still better if this "make" current could be utilized by being passed in the right direction through the tube. As a preliminary to the construction of a commutator for this purpose, several experiments were carried out with the interrupter in order to determine whether there was any appreciable lag between the moment of make and the occurrence of the make current in the secondary. To one of the author's interrupters which had the spindle prolonged, a disc of cardboard was attached so that it rotated with the interrupter itself. This disc was then marked at a certain point corresponding to the position of the dipper blade. The interrupter was coupled up to a 10-inch coil in the usual way, and two wires were brought from the secondary terminals of the coil and fixed on either side near the periphery of the disc. When the interrupter was started, and the current sent through the coil, there was a series of sparks from the secondary terminals, which punctured the cardboard as the latter rotated. Punctures were obtained in this way for the "make" and "break" currents, and their exact position was ascertained. The make and break were found to be practically instantaneous, and with the blade employed it was found possible to obtain an angle of separation of very nearly 180 degrees.

The question then became one merely of commutating these currents in the most convenient manner. In 1898, when devising a stereoscopic fluoroscope, the author employed a commutator for the current from the induction coil, using in that case a vulcanite disc with a metal spoke or radius, and so diverted the currents which were to illuminate each tube alternately. Commutation can certainly be carried out quite simply. The method the author has adopted in the present instance is to attach to the prolonged spindle of his interrupter an insulating rod about 10 inches long, made of wood or vulcanite. From each extremity of this insulating rod projects a light, rigid metal rod or wire, about 8 or 10 inches in length. To each end of these fingers, which have insulated bearings, are attached the secondary terminals of the coil by rubbing contact. Further, these rotating terminals of the secondary coil—which is what the fingers really become—are adjusted to be parallel to the dipper blade, so that if these fingers are pointing vertically downwards, then the dipper blade is also pointing vertically downwards and into the mercury; and as they rotate together, they always maintain the same relative position. The next thing was to ascertain the exact position occupied by these fingers at the moment when the dipper blade was dipping into the mercury. This was easily done by putting a little milliamperemeter into the circuit with a dry cell and turning round the revolving part until the meter indicated the current. At this point two supports, curved so as to represent the arc of a circle, were introduced, the fingers forming the radius, but with a clear space between the extremity of the fingers and the supports. Strips of metal lined these supports on their inner face, and they were electrically connected to the terminal to which the wires from the tube were attached. As the interrupter rotated, the current through the milliamperemeter remained constant until the blade came out of the mercury Just at that point the fingers were rotated at a considerable angle to the other side, and here the concentric arcs of the circle with the metal lining were fixed, and to these the break discharge sparked. Insulated wire was carried from this point to the break take-offs in a diagonal direction. By this simple construction, when the interrupter is started, and the current in the primary turned on, the tube is illuminated by the "make" or inverse current as well as by the "break" or direct current of the coil. If the two take-offs of the "break" current are connected together by wire, and the wire to the tube allowed to come only from the "make"-current take-off, the tube will be found to be quite well excited by the "make" current alone. With this arrangement, when the "make" current alone is passed through a low-resistance tube, a current of 2 milliamperes is obtained. When the wires from the coil are connected directly to the tube, so that the commutator is entirely cut out, a little over 4 milliamperes is registered, but owing to the inverse current getting through, the needle vibrates so as to make the reading a little indefinite, and the tube presents a remarkable appearance of unevenness.

Hitherto the "make" current has been a source of serious wastage, not to speak of damage to the tubes and embarrassment to the worker. With the arrangement just described, it may be hoped that the wastage will be stopped, and that whatever "make" current may exist in any given coil will, so far as it is effective, go through the tube in the right direction and increase its output. The different appearance presented by a low tube when worked in the ordinary way, illuminating very badly, and giving, of course, unsatisfactory photographic results, as compared with the appearance presented when the commutator is attached to the interrupter, resulting in a unidirectional current, is very striking. This apparatus should enable the ordinary induction coil to compete favourably with the Snook apparatus, which hitherto has been the most powerful means of exciting the X-ray tube.

Should it be found that the "make" current, from its lower voltage, heats the tube without a corresponding gain in increased X-ray output, it is quite easy to join the "make" take-offs with a wire and—cutting the crossed commutating wires—join them directly to the X-ray tube. In this way the tube would be excited only by the usual strong "break" current from the coil.

APPENDIX V

Rules for the Protection of X-Ray Operators

THE Röntgen Society has made the following recommendations for the protection of X-ray operators:

The harmful effects produced by X rays are cumulative, and do not generally appear until some weeks or months after the damage has been done. It is to be noted that X rays of any degree of hardness are capable of producing ill effects, although it is commonly supposed that soft rays only are harmful.

It is undesirable that any X-ray treatment should be carried out except under the direction of a qualified medical practitioner experienced in X-ray work.

All X-ray tubes must be provided, when in use, with a protecting shield or cover which prevents the access of rays to the operators and which encloses the tube, leaving an adjustable opening only sufficiently large to allow the passage of a sheaf of rays of the size necessary for the work in hand. Even with this shielding the operator may not be completely protected in all cases (*e.g.*, especially in screen work), and the use of movable screens, gloves, and aprons is recommended.

Operators should be warned that shields obtainable commercially are often ineffective, and tests of their opacity should be made.

Whenever possible the cubicle system should be used for X-ray treatment and the operator should be able to make all adjustments from a protected space.

When screen examination is required it is essential that the screen should be covered with thick lead glass of proved opacity and that the screen should be independently supported and not held in the hands of the operator. If the hands are so used they should be properly protected.

The hand or any portion of the body of the operator should never be used to test the hardness or quality of the X-ray tube; any simple form of penetrometer can be easily arranged for this purpose.

APPENDIX VI

Plates Illustrating Special Cases (from Stereoscopic X-Ray Photographs).

PLATE XVI.

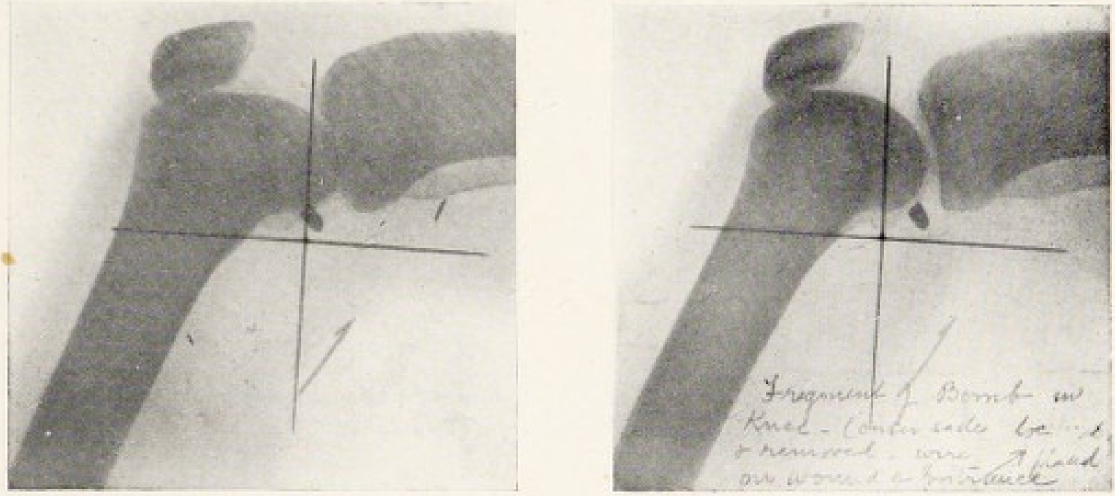


FIG. 39.—FRAGMENT OF BOMB IN THE KNEE, PRECISELY LOCATED AND SUCCESSFULLY REMOVED.

The piece of wire represents the position of the entrance wound.

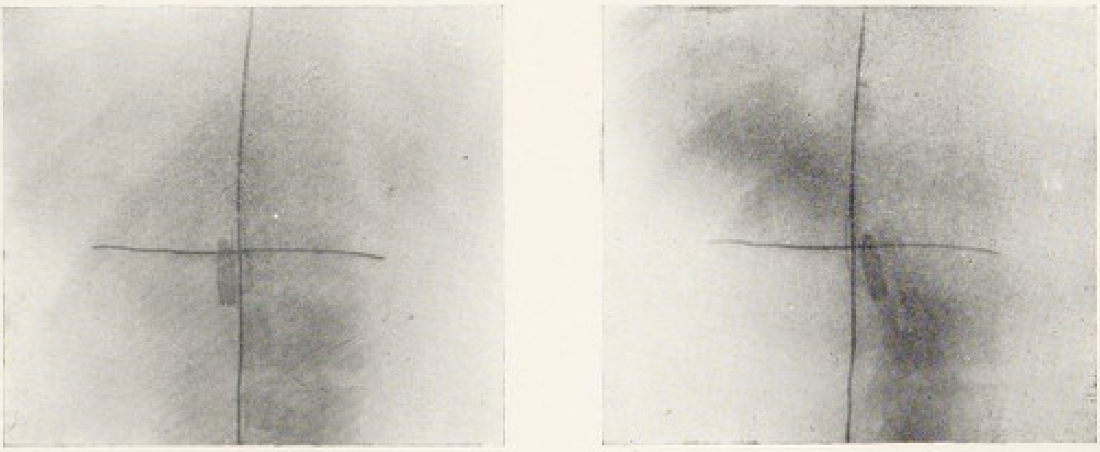


FIG. 40—A RIFLE BULLET LODGED VERY NEAR TO THE SECOND LUMBAR VERTEBRA, ON ITS LEFT SIDE.

This was successfully removed by Mr. Sherren.

PLATE XVII.

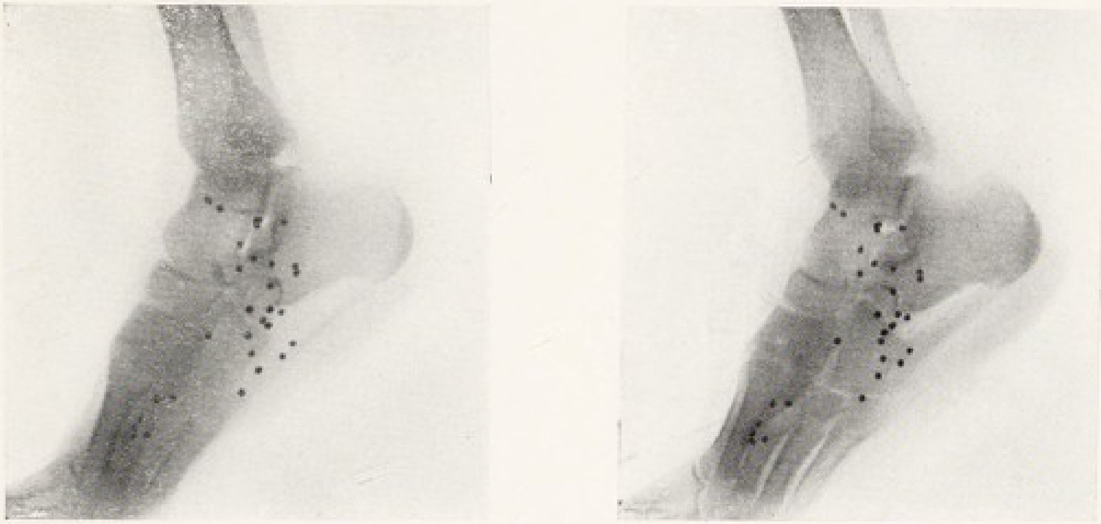


Fig. 41.—Gunshot Wound in the Foot.

This illustrates the advantage of stereoscopic work, or it is possible by means of the stereoscope to see the position occupied by each shot in relation to the bones of the foot.

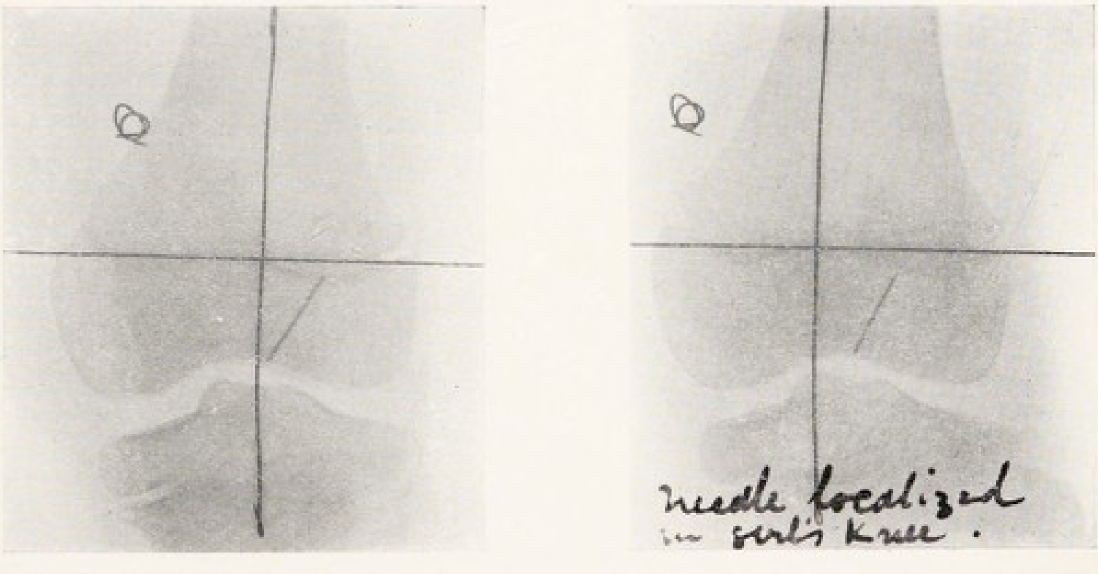


Fig. 42.—A Needle lodged in a Girl's Knee.

In this case, on the information afforded by a single (*i.e.*, a non-stereoscopic) photograph, an attempt had been made to remove the foreign body from the front part of the knee; but the stereoscopic picture showed conclusively that it was situated at the back of the knee. Cross wires placed on skin behind the knee.

PLATE XVIII.

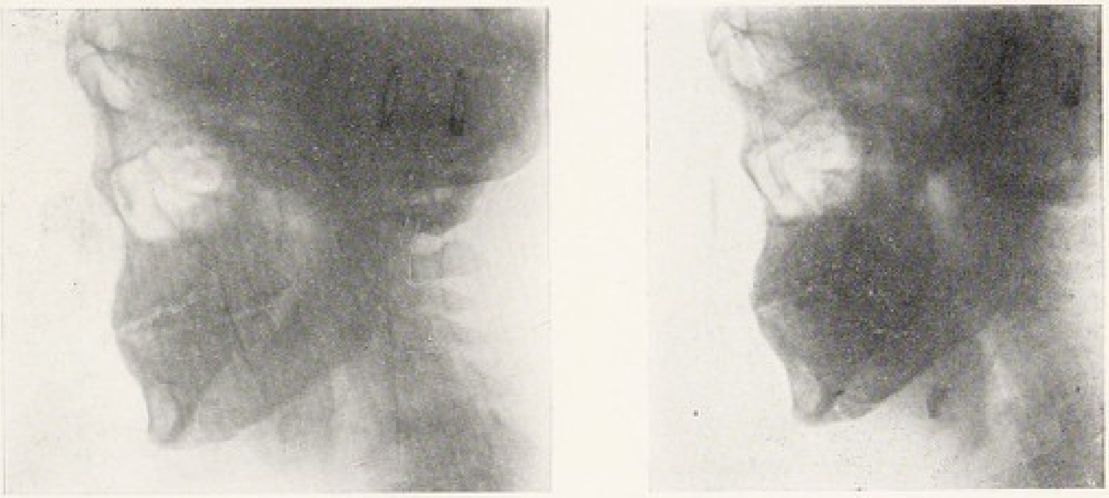


FIG. 43.—FRACTURE OF THE JAW, PLAINLY VISIBLE IN THE STEREOSCOPE.

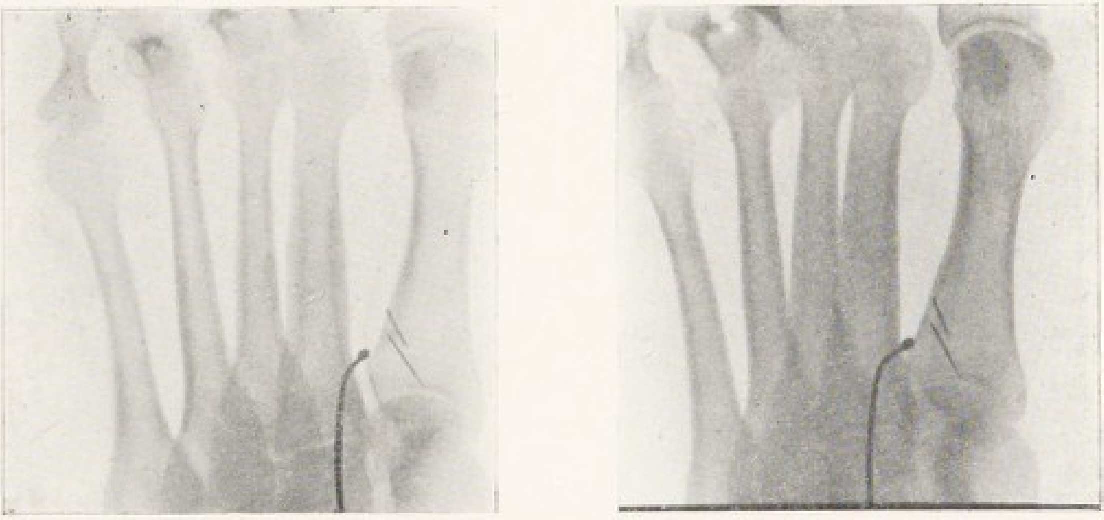


FIG. 44.

The above represents a particularly interesting case. A lady had trod upon a needle, which broke in the foot, and from a single photograph an abortive attempt at removal was made. On a stereoscopic record being made, the two bits of needle were found embedded in the first metatarsal bone During the operation for removal a bent probe was introduced into the wound, the head being placed close to the position where the fragments were believed to lie, and this stereoscopic picture was taken. The fragments were successfully removed.

PLATE XIX.

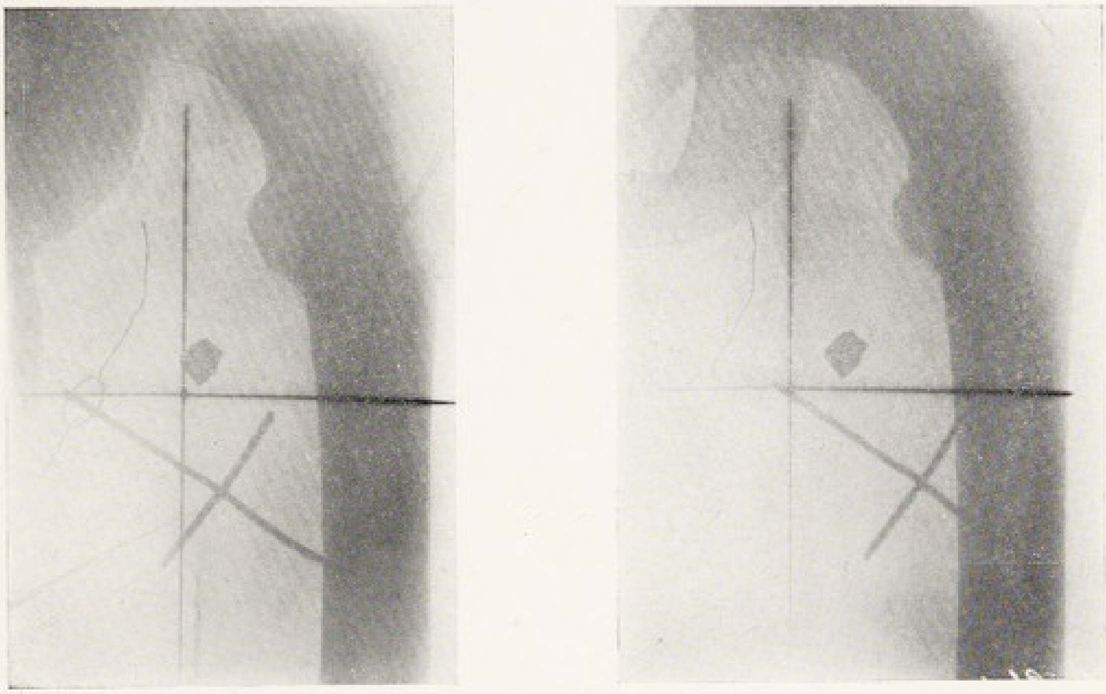


FIG. 45.—A FRAGMENT OF SHELL IN THE LEFT THIGH.

The wire loop was put on the wound of entrance; the smaller cross of fuse wire was placed on the back of the thigh, and the large cross on the front. The stereoscope reveals their relative positions to the piece of shell, which latter was successfully removed.

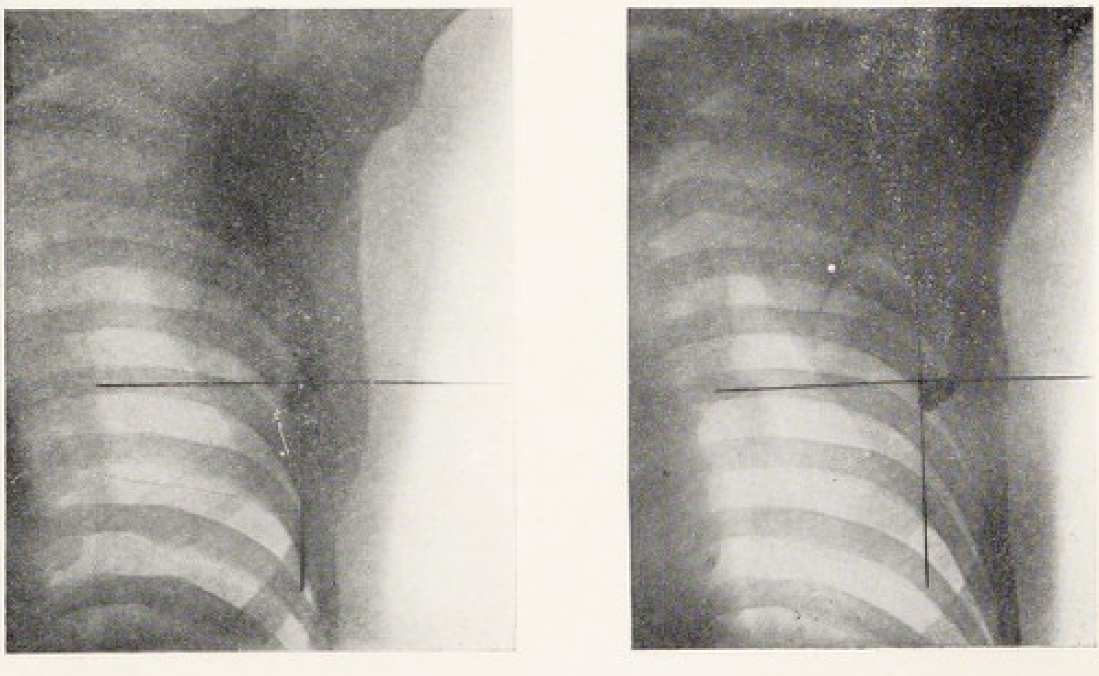


FIG. 46.—A BULLET SUCCESSFULLY LOCATED BETWEEN THE SCAPULA AND THE RIBS.

PLATE XX.

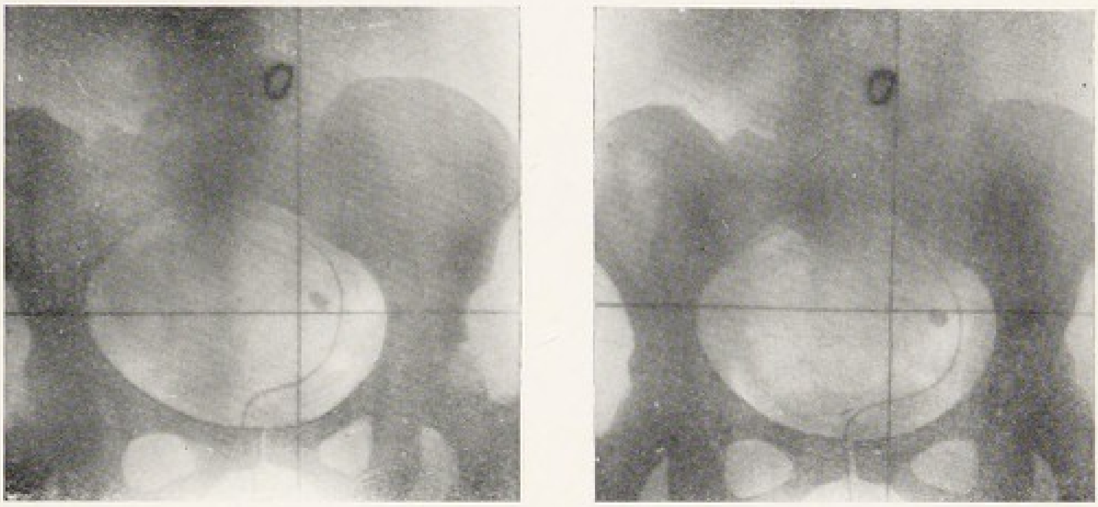


FIG. 47.

One of the earliest cases in which a stereoscopic photograph was secured of the female pelvis, with the ureter (the left) catheterized, and a wire introduced into the hollow catheter. This was done, at the author's request, by Mr. Hurry Fenwick. A small opaque gland is seen lying close to, but outside, the ureter.

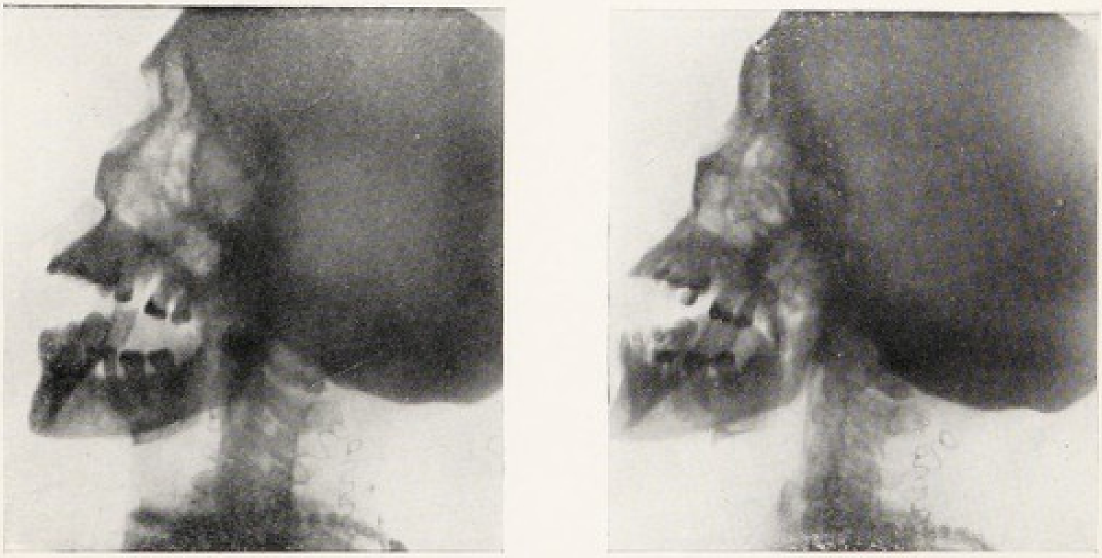


FIG. 48.—A STEREOSCOPIC VIEW SHOWING TEETH, ANTRUM, AND FRONTAL SINUSES.

PLATE XXI.

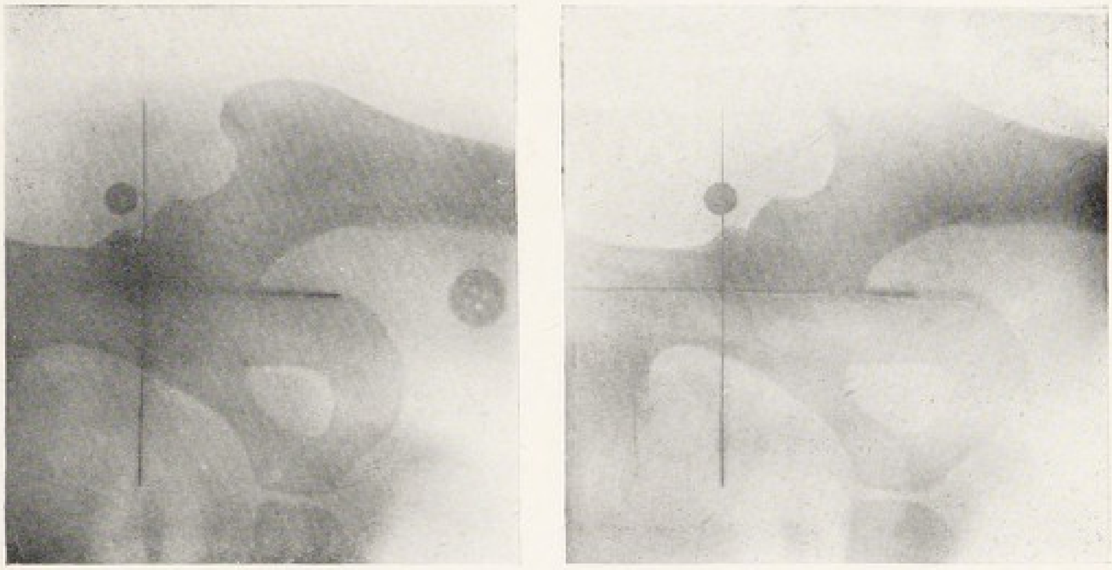


FIG. 49.—A SHRAPNEL BULLET SITUATED ABOVE THE HIP-JOINT.

Its exact position was indicated to the surgeon, and it was easily removed.

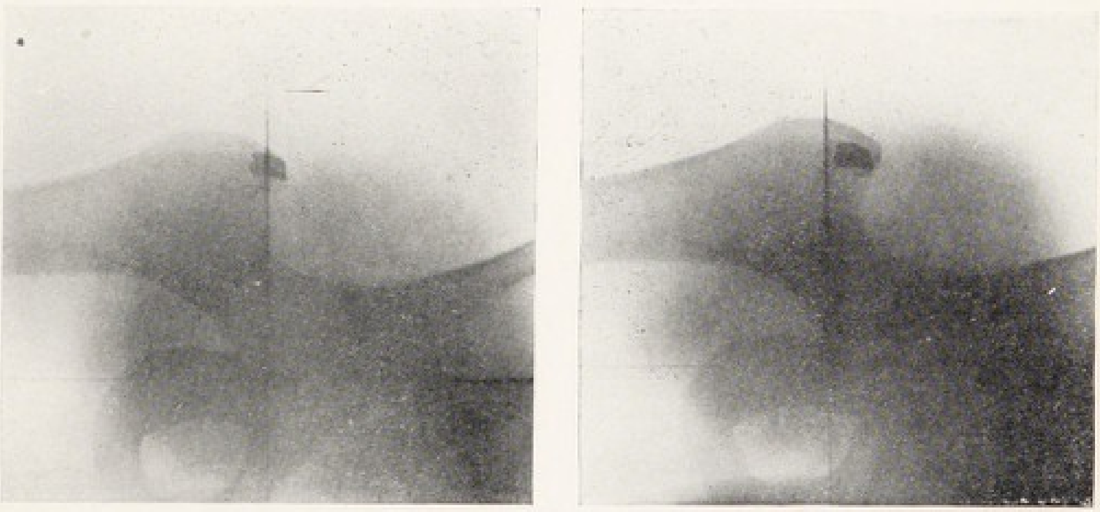


FIG. 50.—A PIECE OF SHELL SITUATED NEAR THE TROCHANTER MAJOR—LOCATED AND EASILY REMOVED.

PLATE XXII.

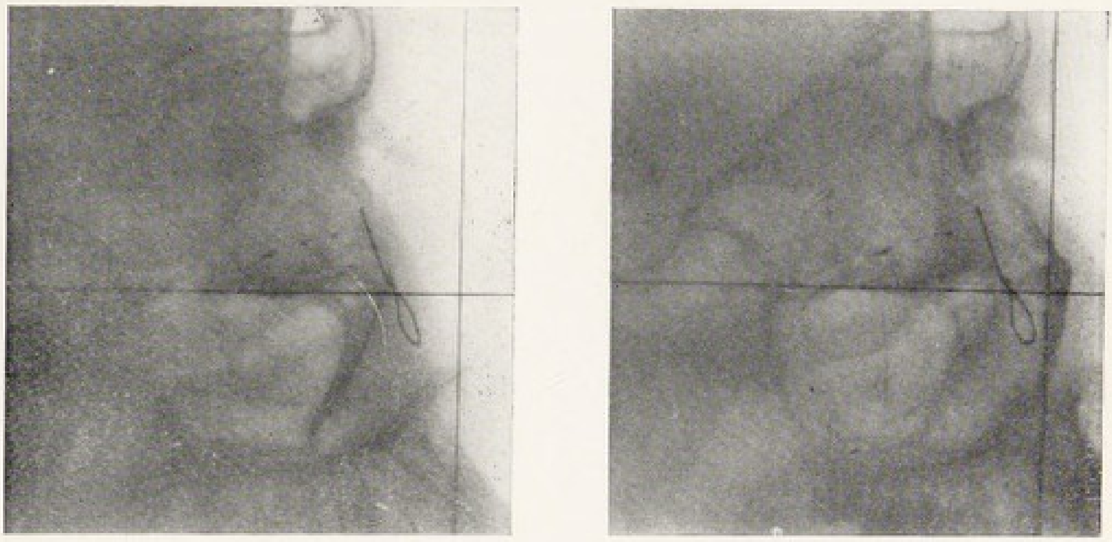


FIG. 51.—STEREOSCOPIC PHOTOGRAPH OF EYE, SHOWING THREE SMALL SPECKS OF LEAD.

In this case a rifle bullet had hit something in the trench and split up, and these minute fragments went in the eye at one point of entrance. The point of the indicator wire is very close to the wound of entrance, visible in the eyeball.

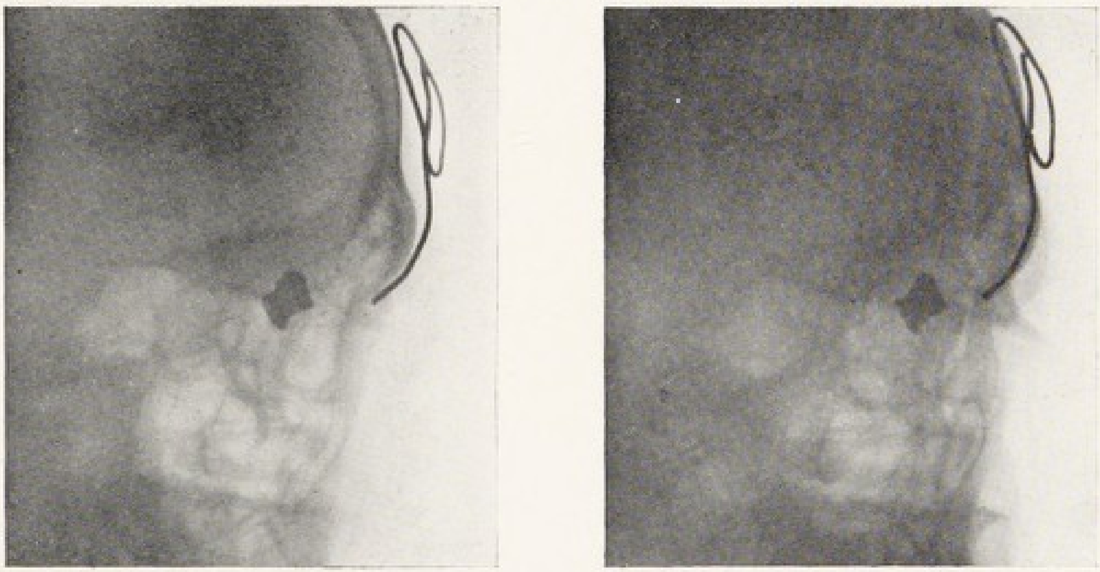


FIG. 52.

The above photograph represents the case of a Belgian officer who had a small scar in the upper eyelid, near inner and upper border of right orbit. He complained of persistent headaches. On X-ray examination it was found that a fragment of high-explosive shell had passed through to the left orbit. This was precisely located and easily removed by Mr. Armour, with complete recovery. The use of the telephone (see p. 55) greatly facilitated the procedure of extraction. In this illustration the lower end of the wire, which is fastened to the patient's forehead, rests on the wound of entrance.

PLATE XXIII.

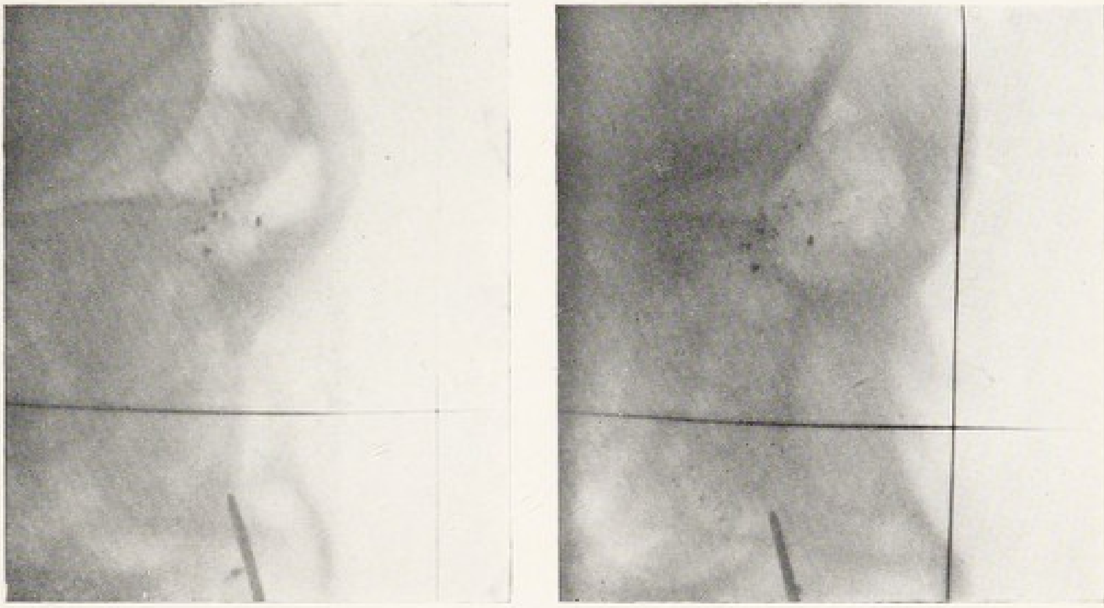


FIG. 53.

In this case a rifle bullet struck the patient's own rifle, and small particles injured both eyes. Some lodged in the left eyeball, and had to be removed, and the above is the stereoscopic picture of the right eye, showing some extremely minute particles which were located just outside the eyeball, probably resting upon, or against the sclerotic

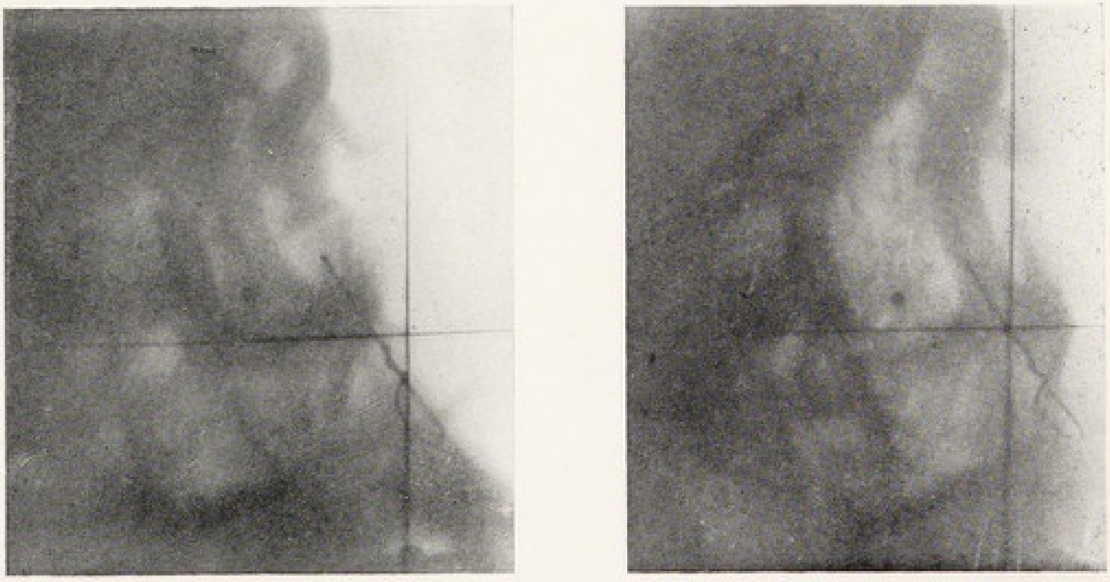


FIG. 54.

The case illustrated above is fully described on p. 52. The wire is on the lower right eyelid. The shot is external to the sclerotic, below it, and on the nasal side.

PLATE XXIV.

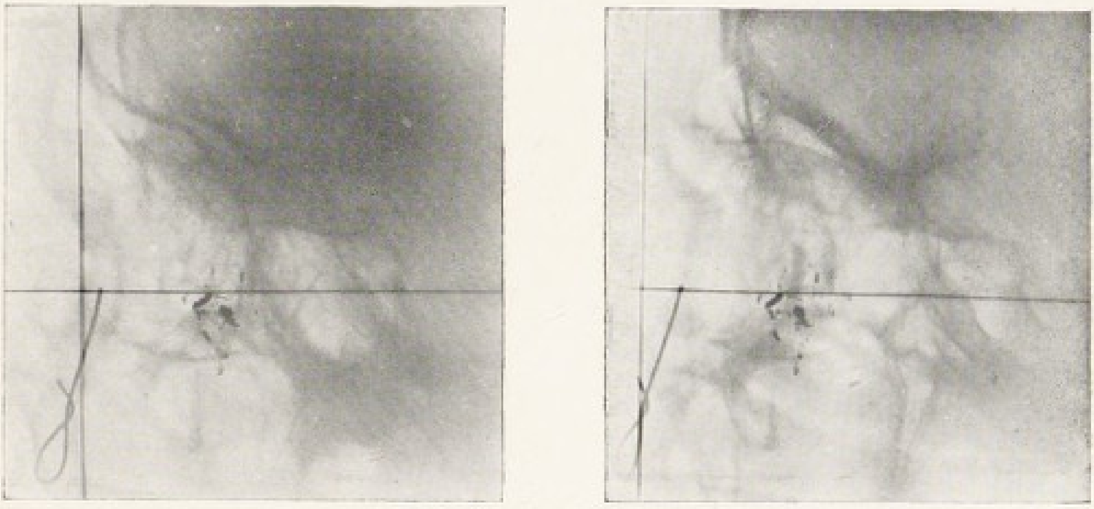


Fig. 55.

A shrapnel bullet entered the outer and upper side of the orbit, and was subsequently removed lower down in the neck, where it had lodged. A certain amount of débris is seen in the outer part of the orbit, but none of the particles, fortunately, were lodged within the eyeball. The indicator wire was placed on the lower left eyelid

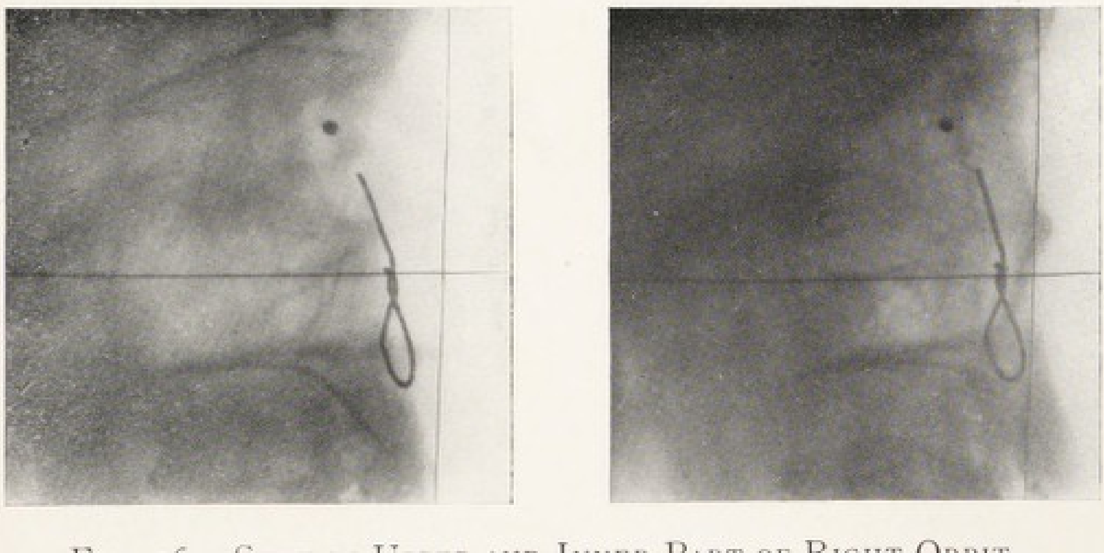


Fig. 56.—Shot in Upper and Inner Part of Right Orbit.

PLATE XXV.

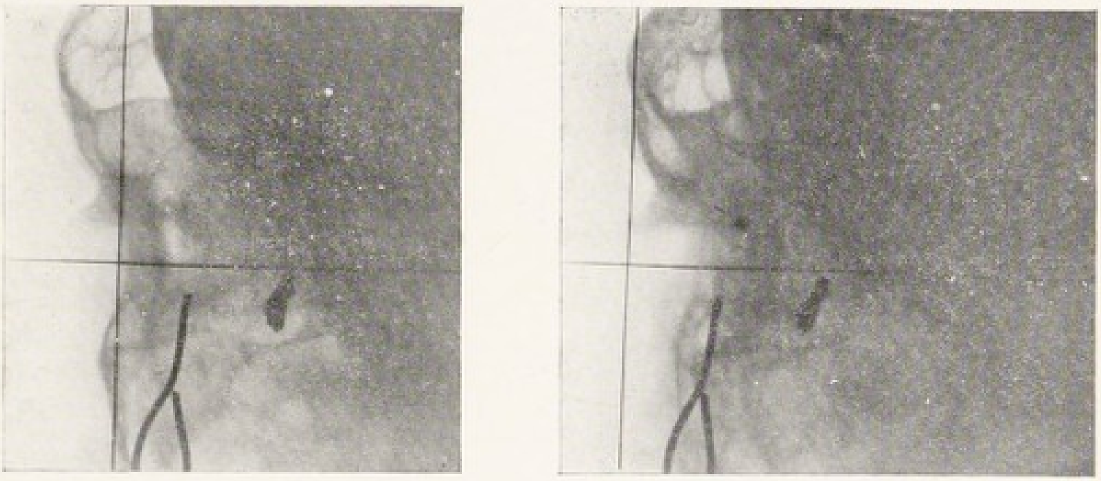


FIG. 57.—PIECE OF HIGH-EXPLOSIVE SHELL IN ORBIT.

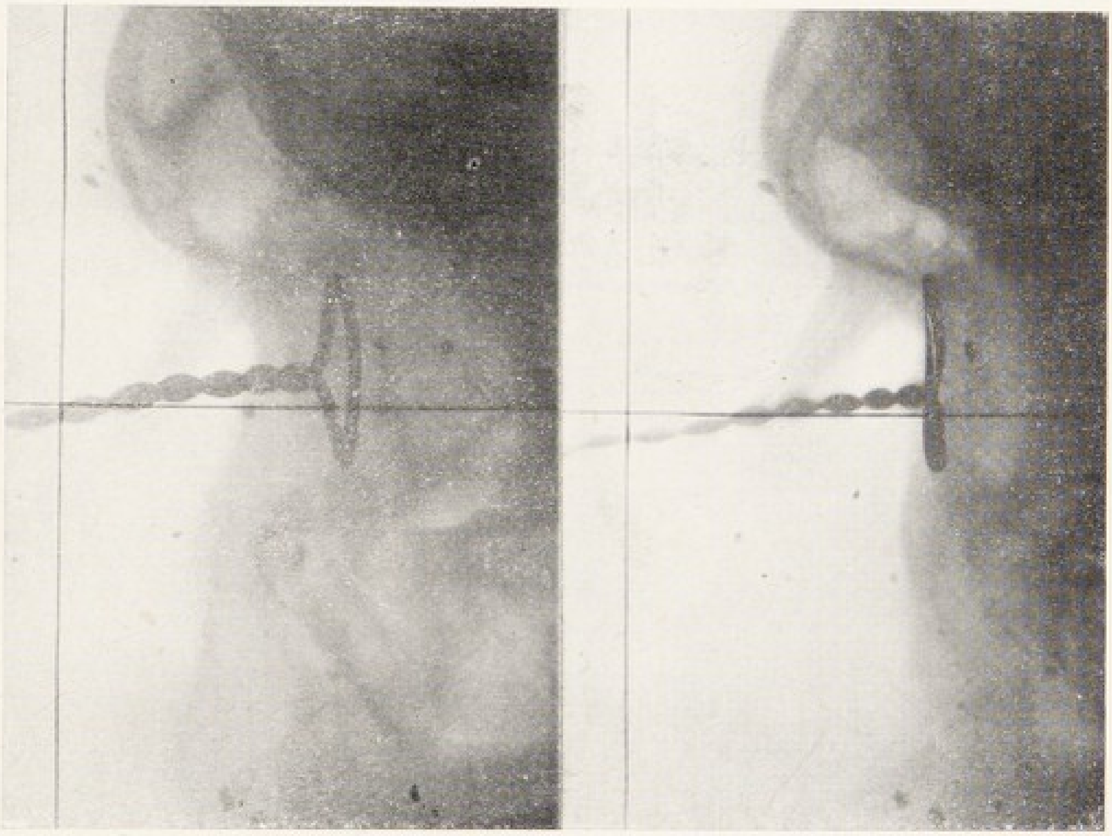


FIG. 58.

The above represents the case of an officer who was injured in both eyes by the fine sputter of a broken-up German bullet. One eye was removed, and the other was so defective that there was great difficulty in being kept steady while being X-rayed. Therefore, the loop made of thick fuse wire was held firmly against the slightly open eyelid, and the eyeball was thereby fixed during the exposure. It was so placed that the centre of the cornea was situated in the centre loop. On looking at this in the stereoscope, the loop standing out in relief will indicate the position, and it will be quite plain that there are two metal particles inside the eyeball. These could be seen subsequently scintillating with the ophthalmoscope.

Fig. 59.—The Coolidge Tube in Action.

Fig. 60.—Pinhole Photograph of Coolidge Tube: Side View.

Fig. 61.—Pinhole Photograph of Ordinary X-Ray Tube: Side View.

Note: The pinhole stereoscopic view of the Coolidge tube in action, represented above, was taken with 30 seconds' exposure, while 1 ma. of current was passing through the tube. The circular focus on the target or anticathode is represented as a round spot of great density, but the whole of the target, even to the tapering end of the support, is shown to be giving off X rays. The rim of the cathode above is shown to be producing X rays, though more feebly. The special X-ray plate employed was protected in the usual opaque envelopes, so that no effect can be ascribed to stray light. When the tube was turned so as to present a view of the back of the anode, a pinhole photograph again showed the X-ray effect in this region, and when the experiments were repeated with the plate wrapped in tinfoil, although the action was enfeebled, the enfeebling was relative, and the rays from behind the anode were as penetrative as before. It should be added that Mr. Coolidge has made a hooded tube to obviate these distributed rays. Fig. 61 is introduced for comparison to show a pinhole photograph of the ordinary tube, 20 minutes' exposure, 1 ma. passing through the tube. The Coolidge tube (Fig. 60), taken under identical conditions, shows less rays from the glass bulb, but a larger diffusion over the surface of the target. The long exposure of 20 minutes was given in order to detect the feeble secondary rays from the glass surface of the tubes.

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