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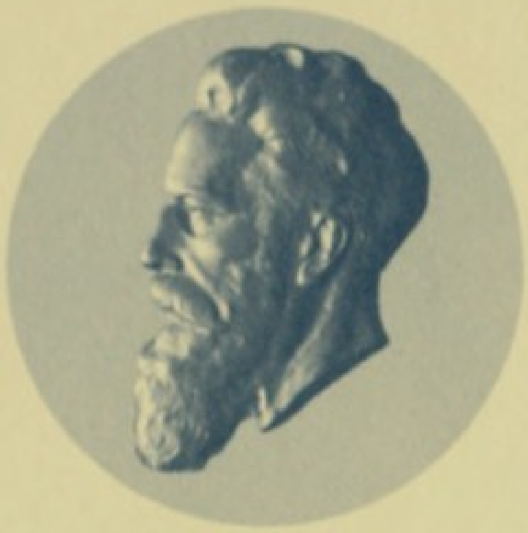

RÖNTGEN

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VERITATEM PER MEDICINAM QUÆRAMUS

X-RAYS

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The "Model Engineer" Series. No. 19

X-RAYS

SIMPLY EXPLAINED

A Handbook on the Theory and Practice of Radiography

BY

R. P. HOWGRAVE-GRAHAM

ASSOC. INST. OF ELECTRICAL ENGINEERS

SECOND EDITION

FULLY ILLUSTRATED
WITH SIX FULL-PAGE PLATES

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PREFACE

In writing this handbook I have endeavoured to give a clear and concise account of the sequence of experiments, discoveries, and improvements which have led up to the present knowledge of Röntgen rays and their application to pathology. While it is intended specially for students and amateurs, and gives no account of the more complicated and expensive apparatus, nor of the latest developments in hospital methods, I hope it will be in some degree useful to the practical man, and that he will find full explanations of all that is properly within the scope of a small and elementary book.

There are still many persons who have not learnt the lesson which James Mill endeavoured to impress upon his son, that there is no antagonism between theory and practice, but that success in the latter must depend on accuracy in the former. The truly practical man is an admirable, but rare, phenomenon; he feels with his mind as well as with his fingers, and he can not only produce a required result with ease and certainty, but knows the principles involved, and, understanding the whys and wherefores of his difficulties, has the patience to surmount them. He is the "clairvoyant" of science; though this term, in spite of its recent degradation in the service of doubtful or pseudo-science, is most worthily applied to such pioneers in the world of knowledge, as Faraday and Sir W. Crookes—the clear-seers, whose minds foresaw results, and who *then* obtained them experimentally. "Through faith obtained promises, having seen them and greeted them from afar."

The mere production of fairly good radiographs does not entitle a man to call himself practical; unless he understands some of the principles which underlie the work, he is more hopelessly unpractical than he who is frankly and modestly ignorant.

It is easy to produce shadow-pictures of hand-bones, coins in purses, and the like; the experimenter is filled with mild wonder at his skill, and proudly exhibits his wizard-like powers to a few admiring friends. Then the interest dies out, and the apparatus ceases to be used, having served little better purpose than that of a plaything.

In the following pages I hope to give a thorough understanding of the elementary principles involved in Röntgen ray work, and of the use and management of the essential pieces of apparatus employed, including the taking of radiographs and the construction of fluorescent screens. The last item will be more fully dealt with in a further book to be published in this series, which will also contain details of many other interesting experiments.

I must acknowledge my indebtedness to Mr Cossor and Mr Hillier for their help, and for allowing me to see tubes in process of exhaustion, and to Mr A. C. Lock for his valuable assistance in the preparation of diagrams. My thanks are also due to the friend who kindly read through and corrected both manuscript and proof.

R. P. HOWGRAVE-GRAHAM.

HAMPSTEAD.

EXPLANATIONS OF TERMS USED

Annex.—Annex is the term applied to a side bulb or tube communicating with the main portion of a Crookes' or X-ray tube. The projections surrounding the electrodes in the various examples, illustrated in Plate I., are all instances of the annex.

Anode.—The anode of any piece of electrical apparatus, such as a plating bath, accumulator, or vacuum tube, is the electrode by which the current enters the said apparatus. (*Note*) This statement is made on the usual assumption of direction.

Electrode.—The electrodes of a vacuum tube are pieces of metal of any desired shape placed within the tube and usually attached internally to a small piece of platinum wire which passes out through the glass and is sealed into it. Currents can thus be led to the electrodes by connecting the source of supply with the platinum which projects ontside the tube.

Electrostatic Attraction is the attractive force between two bodies charged with opposite "kinds" of electricity.

Electrostatic Repulsion is the repulsion between two bodies charged with similar "kinds" of electricity.

Electromotive Force or E.M.F.—An electromotive force is a force whose tendency is to move electricity, that is to drive an electric current through a resistance or against an opposing E.M.F. The unit for its measurement is the volt.

Fluorescence.—Fluorescence is the direct conversion into light of some other form of energy imparted to a body from outside, and can only last while the exciting cause continues.

Kathode.—The kathode of any piece of apparatus is the electrode by which the current leaves it.

Mean Free Path.—The mean free path of a gaseous molecule is the average distance to which it can move without coming into collision with other molecules.

Molecule.—The word molecule literally signifies a *little mass*, and, as used in this book, must have no further meaning attached to it. The ultimate state of division of the rapidly moving stream which constitutes *radiant matter* cannot be dealt with here, and the terms *particle* and *molecule* must both be taken only in their widest sense.

Phosphorescence.—This term as applied to vacuum tube phenomena is used for the emission of light by certain substances after the excitation of fluorescence has ceased; thus the glass of a Röntgen-ray bulb often continues to glow after the cessation of the discharge.

Radiability.—This is a term suggested by Mr Hyndman for the degree of penetrability or transparency of a substance to any given kind of radiation.

X-RAYS SIMPLY EXPLAINED

CHAPTER I

HISTORICAL AND EXPLANATORY

Preliminary.—The phenomena accompanying the discharge of electricity at high electromotive force through gases at pressures ranging from two or three atmospheres to $\frac{1}{10000000}$ or $\frac{1}{20000000}$ of an atmosphere are varied and full of interest, and will be discussed, in order, up to the discovery of the X-rays by Professor Röntgen. The work which has been done since the first publication of Röntgen's results, must, for want of space, be dealt with in the further book on this subject. (See Preface.)

To study the effects of discharges at comparatively low vacua the bulb shown in fig. 1 is usually considered the most suitable.

A and B are two knobs, A being attached to a brass rod capable of sliding up and down a tightly-fitting packed neck C, and thus making adjustment of the discharge distance possible. B is attached to the base of the bulb, which is arranged so that it can be screwed on to an air-pump and exhausted to any desired degree. At atmospheric pressure the ordinary well-known discharge phenomena occur when the two balls are connected with the secondary of an induction coil. If the balls be placed too far apart for any actual spark to pass, thin purple tree-like streaks proceed from the electrodes and appear to bush out from them in all directions, while from the tips of the smallest twigs, if one may call them so, perfectly straight, radial, fine blue lines seem to stick out like the hairs of a brush, and it is from this appearance that the effect receives its name of brush discharge. This occurs to a far greater extent if the discharge takes place between points. When the distance between the balls is reduced until it is equal to the maximum length of spark the coil is able to produce, the discharge becomes a long purple thread with abortive

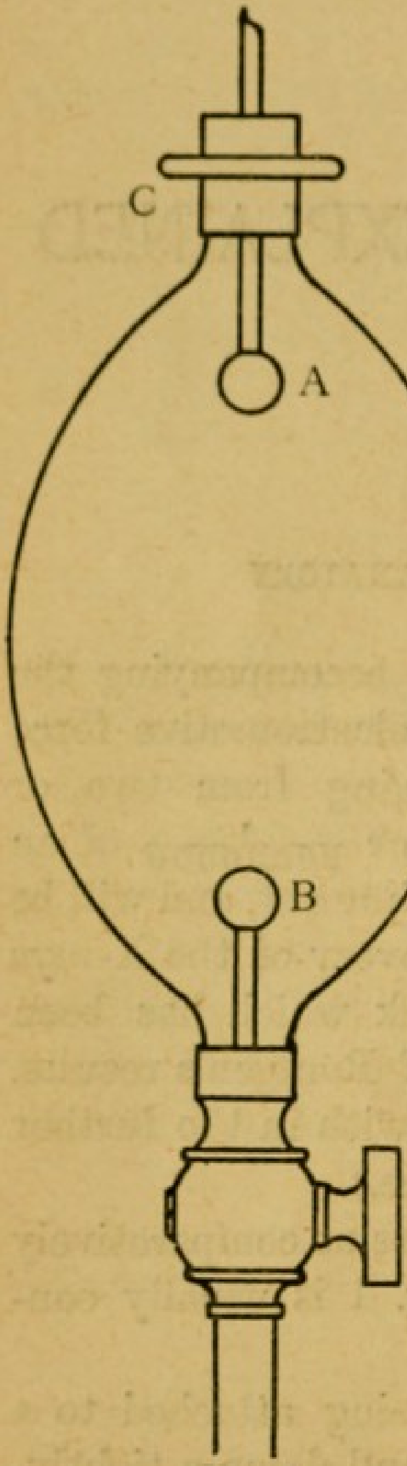


Fig. 1.

tree-like branches leaving it at different points along its track. These subdivide into finer and finer streaks until they are lost to sight and reach their destination as silent discharges.

At a still shorter distance the spark is wavy and free from ramifications. Its colour is bright blue, and it is accompanied by a loud snap.

As the balls are approached even closer the spark becomes reddish in colour and apparently thicker. Its noise is much reduced, and it has considerable heating effects. The maximum heating effect is produced when the balls are quite close together, the sparks appearing as a very thin blue streak surrounded by a thick yellow sheath of hot gas.

These phenemona at atmospheric pressure are best observed without the bulb, fig. 1, a pair of ordinary adjustable discharge rods being most suitable. Interchangeable balls, discs, and points on their ends, produce varying effects which cannot be dealt with here.

If the pressure in the bulb, fig. 1, be made greater than that of the atmosphere, the length of spark which can be passed becomes less than is possible in ordinary air. At the same time the spark is louder and more violently sudden.

If, however, the air be gradually exhausted, a most interesting and beautiful series of phenomena takes place, and these shall be described briefly in order.

1. First, when the pressure is not much less than that of atmospheric air the discharge occurs on separating the balls to two or three times the length

possible in the ordinary way, and it still passes as a spark.

2. Purple glows extend outwards from the anode and at a certain exhaustion fill the whole bulb.

3. The glow contracts to the space directly between the balls, and swells in the centre, falling gradually away until it is quite narrow near the balls.

This purple rod seems to start from the anode and fade off before it quite arrives at the kathode, which is surrounded by a sheath of violet light.

4. With a further lowering of pressure the violet glow detaches itself from the kathode and gets increasingly farther from it, the space between them being devoid of light.

5. The reddish-purple discharge from the anode becomes divided into *striæ,* which increase in number as the exhaustion is carried on. They have the appearance of stationary nebular balls or ellipsoids of light with dark spaces between.

6. At a still higher exhaustion the gaseous condition in the tube becomes what is known as a Crookes' vacuum and most remarkable changes in the discharge occur, changes of great importance, and bearing directly on the production of X-rays. For the proper study of these effects the bulb hitherto used is abandoned, and other types of tube differently arranged are adopted, but first a few words may be said concerning the phenomena connected with discharges at such degrees of exhaustion as have already been described.

If a conductor be brought to the side of the bulb the purple stream (3) is deflected towards it. The stream is, in fact, a column of gaseous molecules probably passing on charges by a process somewhat akin to the electrolytic conduction of liquids. The molecules, therefore, act as carriers of charges, and the conduction of the current by the rarefied gas, may be likened, by the help of a vivid imagination, to a line of men passing buckets of water from hand to hand to extinguish a fire.

A column of gas conveying charges in this manner, at a considerable velocity, is in many respects equivalent to a stationary conductor carrying an ordinary current.

A wire carrying a current sets up a magnetic field in circles round it, and on the approach of a magnet a force is exerted on the wire which tends to move it at right angles to the lines of force of the magnet. (See any elementary book on Electricity and Magnetism.)

In a like manner the conducting column of molecules in a vacuum behaves like a flexible wire, and is deflected on the approach of a magnet towards the outside of the tube. De La Rive showed also that the stream, like a wire carrying a current, can be caused to rotate round a magnet placed inside the bulb and lying vertically along its axis. The magnet was, of course, enclosed in insulating material.

Geissler showed the same result obtained with much simpler apparatus.

The purple light of the discharge is accompanied by invisible light, the rate of vibration of which is greater than that of ordinary light.

The electro-magnetic ether vibrations of light range from *about* 400 to *about* 800 billions of complete vibrations per second, the slowest being those of red light and the most rapid (800 billions) being those of violet light. The ultra-violet (beyond violet) light, which is quite invisible, ranges in frequency from *about* 800 billions to *about* 1619 billions per second. The arc lamp and the mercury vapour lamp are both rich in these rays, but we are chiefly concerned with those produced by the vacuum tube.

Ultra-violet light has a wonderful power of producing fluorescence in certain materials and this property is made great use of in vacuum tubes intended for ornamental effects.

Sometimes parts of the tube are made of uranium glass which fluoresces a dark rich green colour. Solutions of eosin, uranine, fluorescein, sulphate of quinine and many other substances fluoresce with different colours if exposed to the action of vacuum tubes, and the effects are best shown by dissolving the substances to be tested in a solution of gelatine, and painting on card or paper. The explanations put forward to account for striæ are various, and cannot be dealt with here.

In many cases a powerful magnet helps in the production of striæ, and very slight variations in other conditions produce curious movements, and alterations in their number.

Mean Free Path.—There is now little doubt that the molecules of a gas are in a state of constant and violent commotion, each molecule moving with great velocity in continually varying directions and independently of, or rather unattached to, any other molecule.

In hot gases the molecules move with greater velocity than in cold, and it is clear that the average distance which a molecule can travel, without colliding with another, must be inversely proportional to the number of molecules in a given volume of the gas. If the number of molecules per cubic inch, centimetre, or other measure, be halved, the average distance between one molecule and the others surrounding it, is obviously doubled, and, therefore, the average or mean free path is doubled.

The Crookes' Dark Space.—Now it will be remembered that in Stage 4 of the exhaustion of the bulb (fig. 1) the glow surrounding the kathode detaches itself, leaving between itself and the kathode a *dark space.* To this the above name is given, and it is a most important and significant phenomenon.

As the vacuum gets higher the dark space gets increasingly larger, and the purple glow increasingly less, until *at a very high exhaustion the dark space occupies the whole of the bulb;* in other words, there is no purple glow throughout the whole of its interior. Let us now stop and consider briefly the meaning of this fact.

The violet glow seen at comparatively low vacua is probably caused by the energetic collision of the molecules of gas under the influence of the charges imparted to them, and the beginning of the dark space shows that the mean free path has become sufficiently long for the molecules which have been negatively charged at the kathode to move an appreciable distance from it, before colliding with those which are uncharged or differently charged. What is to be expected if the air be further exhausted? Clearly the number of molecules in a given space is less, and the mean free path is consequently longer, the result being that the collisions occur at a greater distance from the kathode, and the glow which they cause is correspondingly farther away. Furthermore, it is found, as might be expected, that the boundary between the dark and the glowing spaces is very brightly illuminated, for it is the region where the highly-charged particles, moving away from the kathode with enormous velocity in straight lines, first meet those which are moving chaotically.

When the mean free path becomes longer than the distance between the kathode and the wall of the the bulb, very little collision takes place; what there is, is more generally distributed, and the dark space fills the whole interior of the bulb, the luminous gas being reduced to a faint blue cloud which, as the exhaustion is carried still further, retires behind the anode, eventually vanishing altogether.

During the stages of exhaustion described, the resistance of the bulb to the discharge has fallen to its lowest value, and commenced to rise again, until at an even higher vacuum than we have at present, considered, no considerable discharge can be forced through the bulb, however high an electromotive force is applied.

The reader may have hastily concluded that, the dark space having spread as far as the walls of the tube, the phenomena are at an end, but though the molecules proceeding from the kathode meet with no serious obstacle until they strike the glass of the bulb, an entirely new set of phenomena, of greater interest and beauty than any yet encountered, is presented.

Kathode Rays.—These phenomena were thoroughly investigated by Sir William (then Mr) Crookes in a series of intensely interesting experiments which opened up a new field of research, and paved the way for Röntgen's discovery in November 1895; and it has been thought strange that Sir William Crookes, and the investigators immediately following him, did not discover X-rays, which were continually being produced in a greater or less degree in the course of their experiments. The fact remains that only during the latter portion of the sixteen years which elapsed between the discoveries of Crookes' and of Röntgen a series of experiments led up to the final researches which preceded the publication by Röntgen of the account of his new "X-rays."

The present purpose is to outline, in brief, the sequence of the more important experiments from those of Sir W. Crookes to those of Professor Röntgen, and before proceeding further, a few terms which are likely to be used, may with advantage be briefly explained.

For fluorescence and phosphorescence see alphabetical list of definitions, p. 8.

A Crookes' tube was so called because the word "tube" had come to be the generic term for all exhausted glass vessels arranged for studying the discharge of electricity through rarefied gases.

A Crookes' tube may be either straight, bent, bulbous, or of any other shape that may be suitable for particular experiments.

The *essential* of a Crookes' tube is that it must have been exhausted to such a degree that the dark space occupies the whole of its interior, all the phenomena of any importance being produced by a stream of negatively charged particles moving outward from the kathode, with enormous velocity, in perfectly straight lines, unless disturbed by certain means, of which more will be said hereafter.

Radiant matter is the term applied by Sir William Crookes to this stream of charged molecules, which is more usually alluded to at the present time as the kathode stream, or collectively, as kathode rays.

Fluorescence.—The first important phenomenon which is noticeable in a Crookes' tube, is that wherever the kathode stream impinges on the wall of the bulb, its energy is converted into light. In other words it causes the glass to fluoresce. The light given out under the action of this violent molecular bombardment is dependent upon the chemical constituents of the glass, uranium giving dark green and lead-glass blue (see the paragraph, p. 60, on the materials used in the construction of Röntgen-ray bulbs).

Crookes' tubes, however, are usually constructed of German or soda-glass, which gives a bright apple-green flourescence, the total light emitted by a large bulb being often considerable. Although they are very occasionally of other kinds of glass the presence of this peculiar canary-yellow or apple-green light emanating from the bulb itself is an infallible sign of a Crookes' vacuum, which may also be recognised by an *almost* total absence of illumination in the residual gases in the bulb; that is, the occupation of the whole bulb by the dark space. Many different materials of a mineral nature fluoresce when mounted so that they lie within the tube, in the direct path of the stream of radiant matter, and some of the effects so produced are among the most beautiful and fascinating that physical research has given to us, both in their appearance and their meaning.

Let it be clearly understood that fluorescence is an actual conversion of the energy of charge or momentum or both, given up by the molecular stream as it hammers or bombards the bodies placed in its path. The effect is one of primary generation of light, and the colours produced, which depend on the frequency or wave length of vibration excited in the particular material in question, have no connection whatever with the natural colour of the substance. Some of the most beautiful effects are produced by materials which, under ordinary circumstances, are perfectly white.

Diamonds do not always emit the same colour, but one mentioned by Sir W. Crookes gave a brilliant green light.

Rubies, which in their valuable form consist of red crystals of alumina, fluoresce a deep rich crimson, even if coarse rough specimens, almost, or quite devoid of colour, are employed.

Sir W. Crookes also found that precipitated alumina gave the same rich red as its aristocratic relation and, what is more interesting, that after continued action the powder assumed a permanent pink tinge and became possessed of certain properties identical with those of crystalline alumina. It seemed as though the continual battering and jostling rough treatment by the kathode stream, had worried the alumina into a different molecular arrangement—had perhaps even tidied it up into some degree of crystalline respectability.

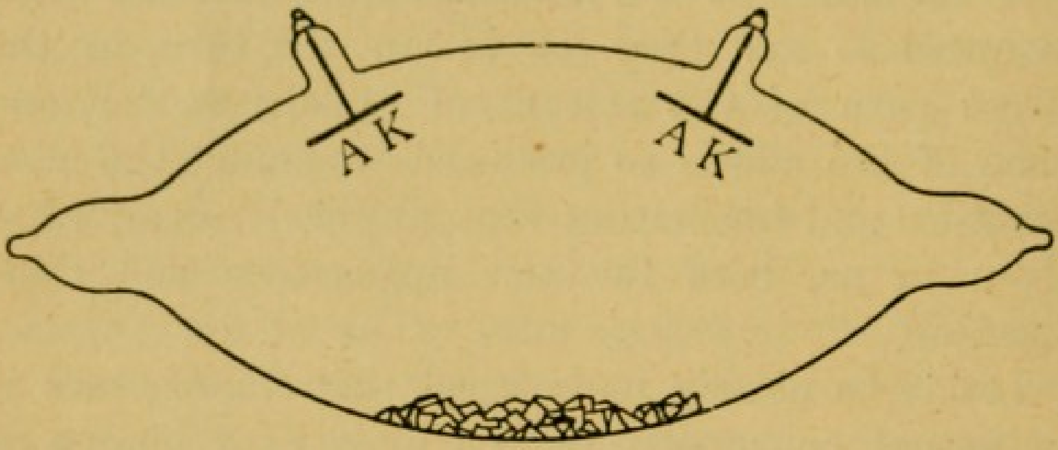


FIG. 2.

Dolomite, a double compound (magnesium carbonate and calcium carbonate), shines red, and has the appearance of a piece of glowing coal.

Willemite (mineral silicate of zinc) gives an intense green light, sometimes amounting to two or three candle power, and zinc sulphide glows much the same colour but somewhat less yellow. Many other minerals show fluorescence of various hues, but the colour effects, produced by carefully calcined shells, are, perhaps, most wonderful of all. A common whelk shell with the carbon dioxide expelled by ignition gives delicate blues and pinks according to the nature of the slight chemical impurities retained on various parts of its mouth and exterior.

Mr Cossor now makes Crookes' tubes containing several small shells lying loose in a bulb of the type shown in fig. 2, and often used for minerals in a powdery or broken form. The two small aluminium electrodes A, K are placed at an angle, so that whichever is kathode sends the stream of radiant matter downwards on to the shells or fragments below.

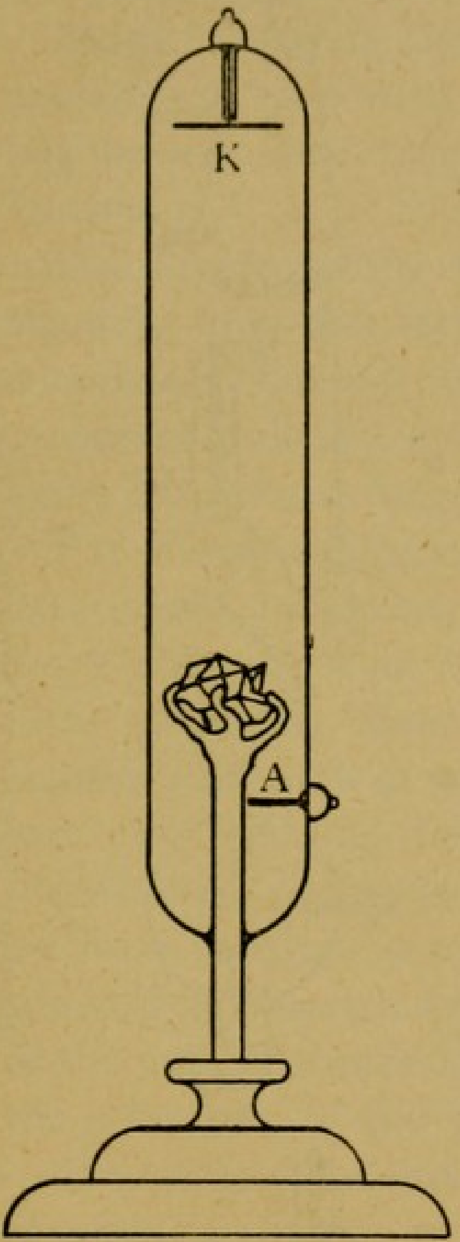
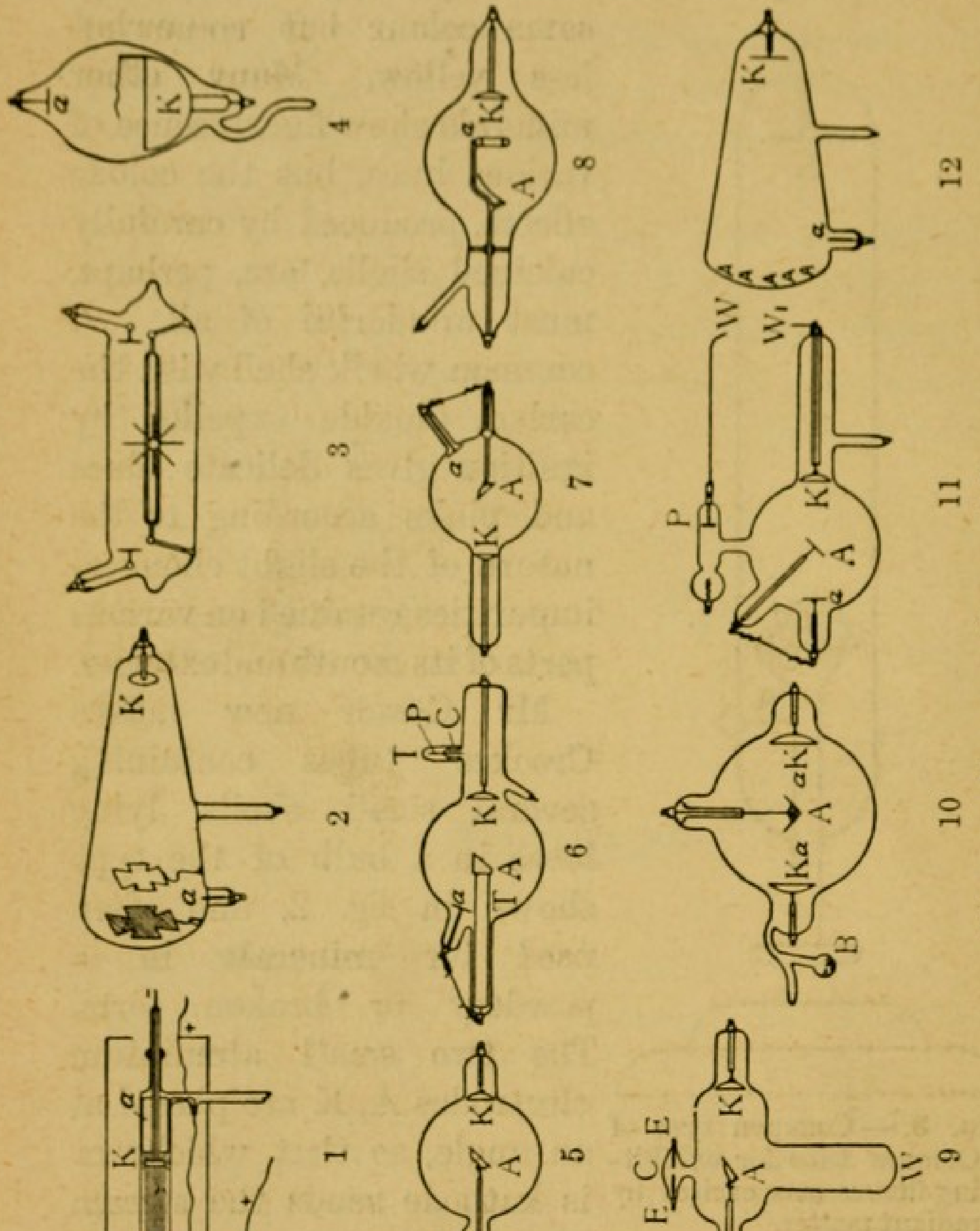


FIG. 3.—Common type of Crookes' tube for exhibiting fluorescence excited by radiant matter.

Fig. 3 shows a type of tube arranged for showing the fluorescence of one large piece of mineral held in

PLATE I.



RÖNTGEN RAY AND CROOKES' TUBES.
K—kathode; A—antikathode; a—anode.

a claw of glass. Sometimes the glass-supporting stem branches into three or four claws, each holding a separate piece of mineral.

Many materials (sometimes the glass of the bulb) continue to glow with a pale light after the discharge has ceased (see "phosphorescence" in list of definitions).

Before proceeding further, the author cannot too strongly urge the fact that the stream of charged molecules, shut off from the kathode, travel with enormous velocity and momentum, and behave in many respects as larger projectiles do.

For instance, neglecting for the time the effects of extraneous influences and mutual repulsion, they move outward from the kathode *in perfectly straight lines.* This has been well shown by means of a V-shaped tube with an aluminium disc electrode at each end. On making the right-hand disc the kathode, the whole of the right-hand portion of the tube *up to the bend* is illuminated by green fluorescence light, while, if the current be reversed, the left-hand portion of the tube becomes illuminated up to the bend, while the other arm of the V remains dark.

The extraneous influence referred to above is that of magnetism.

Magnetic Deflection of Kathode Rays.—It has been already shown that the purple stream in a vacuum tube of comparatively slight exhaustion can be deflected by the approach of a powerful magnet to the side of the tube, the deflection occurring only where the magnetic field crosses the path of the stream, which resumes its former direction when it has got beyond the disturbing influence.

In a Crookes' tube, however, the kathode stream is bent down in a curve which distinctly resembles the trajectory of a projectile drawn out of its otherwise straight path by the earth's gravitational force. In fact its behaviour is that which would be expected of a stream of particles possessing momentum and subjected to a transverse force. The low-vacuum stream is a kind of electrical convection current, and, therefore, behaves like a flexible conductor carrying a current from the positive electrode to the negative, being pulled aside by the magnet and returning back to the easiest path between the two electrodes.

The dotted line in fig. 4*a* shows the nature of the deflection which the low vacuum stream undergoes when a horse-shoe magnet is placed beneath it; fig. 4*b* shows the path of deflection of a pencil of kathode rays under the influence of a similar magnet, the change of direction making itself evident by a new place of illumination on the wall of the tube. Sometimes the whole path is shown by allowing the stream to graze along a strip of some suitable material coated with a fluorescent substance.

Again, just as two parallel currents flowing in the same direction will cause the wires conducting them to repel one another, so two kathode streams which move along parallel paths when produced independently, will diverge if they travel simultaneously side by side.

The second influence capable of deflecting kathode rays from their straight course is electrostatic attraction or repulsion (see list of definitions) by neighbouring charged bodies, but the effect is not very easy to demonstrate.

Recoil.—Tubes have been constructed with kathodes consisting of four vanes, all coated on the same side with mica so that the under side gives off the kathode stream, the anode being placed for convenience at the top of the bulb. The four vanes are placed at the ends of four wires projecting from a centre at which the whole is pivoted, the appearance of the bulb being not unlike that of a Crookes' radiometer. When the discharge is passed the molecules are thrown

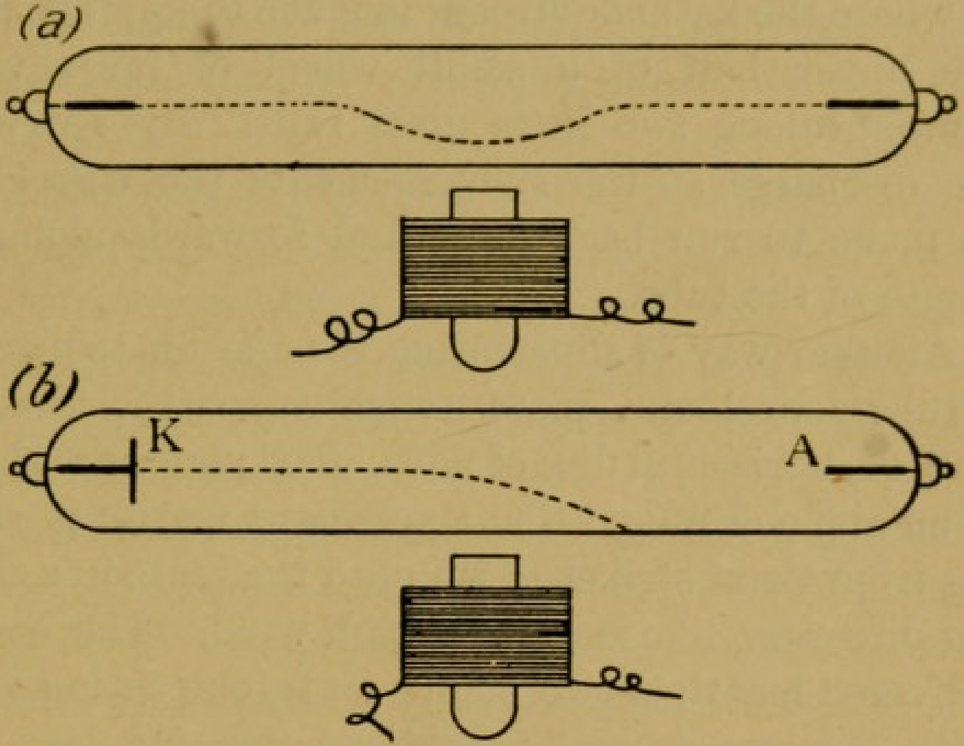


FIG. 4.—Effect of a magnetic field on the directions of deflection of—
(*a*) A *conducting stream* of gas at a comparatively low vacuum.
(*b*) A stream of *negatively charged particles* thrown off from the kathode at a high velocity.

violently off from the bare sides of the vanes, and produce a recoil effect which causes them to rotate as though pushed on their uncoated faces.

Direct Mechanical Effect of Kathode Stream.—The effect which can be produced by the mechanical momentum-energy of the kathode stream is more directly shown by the tube illustrated in fig. 3, Plate I., where the kathode stream is made to impinge upon the upper half of a small wheel of mica vanes running along two little glass rails. By reversing the discharge at the right moments the wheel may be made to run backwards and forwards along the length of the tube.

Another way of illustrating the effect is to place in a tube four metal plates, equally spaced, above a pivoted, horizontal disc of mica. The plates are sloped at an angle of 45° so that the radiant matter proceeding from them strikes down onto the plate in a slanting direction, like rain in a high wind. The energy delivered has thus two components, one acting vertically downwards and probably producing heat and fluorescence, the other producing a certain amount of tendency to horizontal motion and therefore to rotation, and also probably some fluorescence and heat.

Considerable velocity of rotation of the disc may be set up, and the effect is made most striking by previously dividing the disc into four quadrants painted with minerals of different fluorescence colours. The effects of the quivering and shifting colours, seen as the various minerals momentarily fluoresce, are very beautiful until the rotation becomes so rapid that the colours are blended and undistinguishable.

The same thing is sometimes done with the vanes of the little wheel mentioned immediately above.

Heating Effect.—One other experimental proof of the violent nature of the molecular bombardment from the kathode, is given by the tube illustrated in fig. 4, Plate I. The kathode is a large cup of aluminium, the use of which must be explained first.

It has been shown that the molecules thrown off from the kathode follow paths nearly at right angles to its surface (the word *nearly* is used because in ordinary Crookes' tubes this rule holds good to a fairly approximate degree, though it ceases to be true when X-ray vacua are reached).

Now it is clear that if radiant matter is proceeding from the whole interior surface of a cup-shaped kathode in straight lines normal to that surface, there must be a kind of focus where the lines meet or are concentrated. This focussing effect, both in ordinary Crookes' tubes and in X-ray tubes must not be confused with the reflection of parallel beams of light, heat, sound or Hertz waves by parabolic or spherical mirrors. The case in question is *not* one of reflection, for the rays actually come into being at the surface of the cup.

To the edge of the cup, fig. 4, Plate I., a small piece of platinum or platinum-iridium foil is attached by an upright support so that it lies just in the focus of the kathode stream. When the discharge is started the piece of foil is so violently bombarded by the concentrated stream of projectiles that it rapidly becomes red or white hot, or even melts.

Sometimes the foil is placed just out of the path of the stream, which is deflected onto it by a magnet, two properties of radiant matter being thus simultaneously illustrated. The same phenomenon was beautifully illustrated by a lecture experiment arranged for lantern projection by Sir W. Crookes.

In the lantern was placed a small Crookes' tube with a concave kathode arranged to send the focussed beam along the axis of the tube. The stream of rays came to a focus just above the kathode, and while thus working nothing very remarkable occurred. On deflecting the stream to the glass walls of the tube however, so that the bent rays were focussed thereon, a coating of wax on the outside of the glass was seen to melt, and in a short time small cracks appeared until the heated glass finally collapsed, allowing the atmospheric air to rush in and destroy the vacuum.

The dotted lines in (*a*) and (*b*), fig. 5, show respectively the path of the rays when undisturbed, and when deflected by the magnet.

This action of the molecular stream is comparable to that of rifle bullets, which often develop so much heat at the moment of impact on an iron target that they melt and splash in all directions.

The heating effect of the focussed kathode stream is of great importance in X-ray work, and gives rise to practical troubles which are dealt with fully in the chapter on X-ray tubes.

Kathode Ray Shadows and Fatigue.—If an object be placed in the path of the kathode stream the latter is stopped by it, and a shadow is cast on the walls of the tube or on any screen of fluorescent material placed therein. If the object be at some distance from the kathode and fairly near the tube wall or the screen, and if the kathode be not too large, very sharp shadows are obtained.

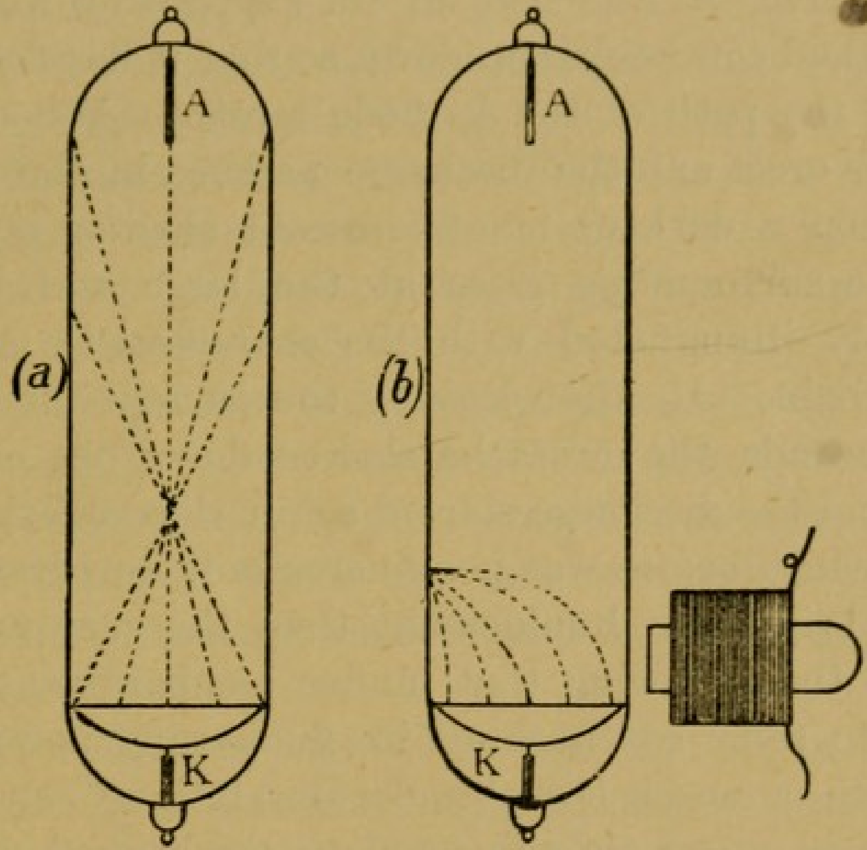


FIG. 5.—Experiment for showing the fusing of the glass wall of a Crookes' tube by a magnetically deflected, focussed kathode stream.

By a shadow is meant a non-fluorescent area of the same shape as the object.

The beauty of the little "railway" tube, previously described, is greatly enhanced by the remarkable play and movement of the glass fluorescence as the rotating vanes alternately stop the stream and allow it to pass.

Fig. 2, Plate I., shows a tube (often as much as 10 in. in length) with a kathode at the small end and a mica cross near the large and slightly curved front. The cross, which is difficult to represent in correct perspective, is attached to its support by a small hinge, and can be shaken down so that it lies flat and out of the path of the kathode stream. When the cross is erect and the discharge passing in the right direction a dark or non-fluorescent shadow is cast, all the surrounding glass at the large end being brightly illuminated with the characteristic apple-green light. If, after leaving the current on for a few seconds, the cross be shaken down out of the way and the discharge started again, the cross-shaped area, which before was non-fluorescent, now becomes more brilliantly luminescent than the surrounding parts, thus showing that, under bombardment, the glass to some extent loses its fluorescing power, or exhibits a species of "molecular fatigue" such as occurs in materials subjected to mechanical strain, and also in many other circumstances.

It has been thought that the effect is due to the heating, in the first instance, of the glass surrounding the shadow, but the author's experiments do not seem to confirm this view.

Whether or not we have in this phenomenon a true molecular fatigue, the effect is most marked and has been known almost to eliminate the fluorescence in the glass of X-ray tubes after prolonged use.

This does not mean deterioration of the powers of the tube in any sort of way and, if anything, is advantageous, as less energy is absorbed in producing light waves over the area of impact on the glass. Moreover, a decrease of emitted light from the bulb renders screen work easier. (See Chapter on X-ray Bulbs.)

Electric Charge carried by Kathode Rays.—Mons. Perrin (*Comptes Rendus*, 121, p. 1130, 1895) and Prof. J. J. Thomson (*Proc. Camb. Phil. Soc.*, ix., 1897) have made experiments which show that kathode rays convey a considerably large negative charge, and can give it up to a body which they strike.

Up to the present the phenomena considered have been entirely those connected with the streams of radiant matter which are thrown off in straight lines from a kathode within the tube, and produce certain definite results *without regard to the position of the anode.*

Kathode Rays in Air.—Professor Lenard in 1894 has shown by a most interesting series of experiments that the kathode rays can pass through a very thin aluminium disc, and that if such a disc forms a kind of window to a Crookes' tube they will emerge into the air, the supposition among English scientists being that their power of penetrating gases at atmospheric pressure is imparted to them by the velocity and momentum which they gather in the bulb.

In Lenard's tube, fig. 1, Plate I., the kathode K is an aluminium disc with which the negative terminal of the induction coil is connected by the platinum wire (marked —) which is fused into the end of the tube.

The anode *a* is a brass cylinder fitting tightly into the main glass tube and terminating 12 mm. behind the kathode. It is connected with a wire which is fused into the glass and outwardly joined to both the outside case and the earth.

At the left hand end is a metal covering cap which is pierced by a small hole over which a very thin aluminium disc is cemented with marine glue. The disc and cap are in metallic connection with each other and with the wire. To prevent the aluminium window from acting as an anode, and thus becoming corroded, it is screened at the back by a perforated metal cover.

The whole tube is enclosed in a metal case provided with an opening opposite to the window, and earth-connected (see above).

When such a tube is in action, the path of the rays is seen as a faint brush-like glow spreading outwards in the directions indicated by the lines in the figure to a distance of about 5 centimeters ; this is perhaps due to the collision of the issuing radiant matter with the molecules of the air. By exploring the field in front of the tube by means of a screen covered with fluorescent material, Lenard showed that after "passing through" the aluminium the kathode rays spread out, much as light spreads on emerging from some cloudy substance such as smoke, milky water, or opal glass. This was demonstrated by placing metallic wires at varying distances between the window and the screen, and observing the shadows cast by them.

When the screen was placed 3 cms. from the window, a wire 2 mm. thick at 3 mm. from the window cast no visible shadow. As the wire was brought increasingly near to the screen a shadow appeared, but was not well-defined and sharp until they were in contact.

Professor Lenard also showed that the patch of fluorescent light on the screen was brightest at the centre, and in fact had much the same general appearance as the patch produced by a beam of light after passing through a trough of milk. This he took to be a proof that the rays had actually passed through the aluminium and were not produced at the outer surface of the plate by some action conveyed from within.

Many substances were rendered fluorescent by the Lenard rays, including calc spar; the phosphides of the alkaline earths; uranium glass, common glass and flint glass; specimens of quartz and rock salt (fluorescence blue), alumina produced by corrosion of aluminium, various platinocyanides; salts of manganese, lithium, cadmium and strontium; anthracene and hydroquinone; also salicylic, benzoic and hippuric acids. Many of these substances also phosphoresce brightly. The best screen was made by painting with a brush on tissue-paper, melted pentadekylparatoleketone which gave bright green fluorescence.

Liquids such as fluorescein, Magdala red, sulphate of quinine, etc., which all fluoresce with light, showed no effect whatever. Among these, quinine gave a brilliant blue when in the solid state.

The rays penetrated through gold, silver and aluminium foil; two thicknesses of tissue-paper showed a faint shadow; writing paper showed a distinct diminution of the rays; and cardboard 3 mm. thick was quite opaque. Water was only transparent when in very thin layers, but gases were considerably more radiable.

There is now little doubt that the kathode rays, which Lenard observed outside the tube, were abundantly mixed with the yet undiscovered Röntgen rays, though the silhouettes he produced on photographic plates were probably partly due to real kathode rays. That the phenomena were not wholly of the X-ray nature is proved by the fact that he passed the radiation into a second tube, also exhausted, and there deflected it with a magnet, which is impossible with Röntgen rays. This short account of Professor Lenard's experiments is drawn in the main from Mr Hyndman's most interesting book "Radiation," and from Professor J. J. Thomson's works.

Theories of Kathode Rays.—During the whole of the foregoing account kathode rays have been described as streams of charged particles thrown off by repulsion from the kathode, and capable of gathering enormous velocity and momentum. All the effects that they can produce have been explained on this hypothesis, and satisfactorily so if attention be paid only to their behaviour inside the tube, but the properties of Lenard's external kathode rays and, perhaps, partly the fact that they can be brought outside the tube, have led many physicists of eminence to consider them as some kind of disturbance of the ether.

Generally speaking, the English scientists adopt the radiant matter theory originated by Sir W. Crookes, while the Continental explanation is ethereal. It is to the Continental scientists that we owe the term "Kathode Ray," and though it was used by them in contra-distinction to Crookes' name —"Radiant Matter," it has gradually made its way into England where it has been generally accepted.

One of the arguments brought forward by the supporters of the ether theory is that radiant matter could not penetrate the aluminium window of Lenard's tube, and to overcome the difficulty it has been suggested that the radiant matter strikes the inner surface of the window inducing Lenard's rays on the outside. This seems to be unlikely in view of the nature of some of the effects produced by Lenard, but Professor J. J. Thomson seems to think it an unnecessary assumption that the molecular stream is incapable of penetrating the window.

One more experiment which Professor Crookes performed at a later date to support his radiant matter theory, may be mentioned here with advantage.

A tube was constructed with two mica wheels like that depicted in fig. 3, Plate I. One of these was placed so that the kathode stream impinging on the vanes caused it to rotate while the other was in such a position that any gas returning from other parts of the tube to the kathode would cause it also to rotate, the supposition being that there must be a return and equalisation of the molecules shot off from the kathode. The expected result was obtained.

Mechanical effects are explained by Continental scientists as of a secondary nature, and heating effects put down to direct conversion of the energy of the ether disturbance into heat.

Suggestions having been made that the kathode rays were particles of metal torn off and projected from the kathode, Sir W. Crookes proved the stream to be gaseous by using external electrodes acting on the interior of the tube by electrostatic induction, the kathode rays being produced as before. Metal can be torn off in considerable quantities, but there is no doubt that the main effect is due to the residual gases within the tube.

Röntgen's Discovery.—In 1895 Professor Wilhelm Konrad Röntgen announced his discovery of a new kind of radiation capable of penetrating considerable thicknesses of substances which are quite opaque to ordinary light.

The announcement was received with much incredulity at first, especially by those people who were interested in physics but who knew little of the more recent work with kathode rays, and were case-hardened by the scientific rubbish which is still periodically produced with a flourish of trumpets by the daily newspapers, the most modern and pushful of which are, strange to say, the most persistently absurd and clap-trap in their statements.

Professor Röntgen found that when using Crookes' tubes of somewhat higher vaccum than was usual, rays emerged from the tube, and that they differed from kathode rays in that they could not be deflected by a magnet. Photographic plates were found to be sensitive to the new rays and shadow pictures were produced by laying opaque objects on a plate and then exposing it to the radiation.

Röntgen produced radiographs which were not excelled for some time after the publication of his results. He also experimented on the radiability of various substances, and found that wood, paper, leather, celluloid, certain kinds of glass, diamonds, etc., were almost transparent to his "X-rays," that bone, lead-glass and other substances were semi-opaque, while the opacity of metals seemed roughly proportional to their atomic weights, aluminium being very radiable, iron less so, and lead or platinum practically entirely opaque.

He also mentioned that shadow pictures of the bones could be made on photographic plates, but did not seem to fully realise the importance of the fact.

Fluorescent Screens.—Röntgen also experimented on fluorescence, and mentioned screens made of barium-platino-cyanide, by means of which the shadows of opaque bodies could be rendered visible.

Many radiographs were shortly afterwards published in England by Mr. Campbell Swinton and others, and public attention was thus concentrated on this aspect of the subject, few people realising the use of fluorescent screens.

Mr Edison made an exhaustive series of experiments on the fluorescence of different materials when under the influence of the new rays, and sent a telegram to Lord Kelvin to the effect that sheelite (calcium tungstate) gave very good results, claiming that it was superior to any platino-cyanide.

The news was immediately spread in England (by the daily press of course) that Mr Edison had discovered a method of "seeing" the bones by X-rays, and, as a consequence, further rubbish was talked about "cameras" being set up outside rooms so that such a thing as real privacy or secrecy would become impossible.

Röntgen was the true inventor of the fluorescent screen, which enables one to see *shadows* only of one's bones. The shadows on a fluorescent screen are non-fluorescent areas similar to those produced by the cross in the radiant matter tube (fig. 2, Plate I.).

Calcium tungstate has *not* proved superior to barium-platino-cyanide, except for a certain special purpose, which will be set forth in the second book on X-rays (see Preface).

Production of Röntgen Rays.—Wherever kathode rays strike a solid body they produce Röntgen rays, which, if the body is transparent to them, pass through to its other side as well as being radiated from the side at which they are generated.

Early Tubes.—In the early type of tube illustrated in fig. 12, Plate I., the rays are produced where the kathode stream from the aluminium disc at the small end strikes the surface of the glass at the large end.

If the molecular stream is powerful the glass is easily melted, and even if this does not occur the area of radiation is so large that sharply-defined shadows cannot possibly be produced. Nevertheless wonderfully good results were obtained, considering the disadvantages of such apparatus.

The Focus Tube.—In 1896 a fundamental improvement of great importance seems to have been originated almost simultaneously by Professor Elihu Thomson, Mr Shallenberger, Mr Scribner, and Professor Herbert Jackson of King's College. The latter experimenter is generally credited with the first use of the focus tube in England at any rate, and it is usually known in this country by his name.

It is illustrated in fig. 5, Plate I., where K is a concave kathode of aluminium which directs the torrent of radiant matter to a concentrated focal point on the anode or antikathode A (see Chapter on X-ray Bulbs). At this point of impact on the molecular target the X-rays are abundantly generated, and as the target is of platinum it is not only enabled to stand any heat developed, but it also allows no penetration of the X-rays to its reverse face.

The rays which are generated at the point of impact on A proceed radially outwards in straight lines in all directions, and as A is placed at an angle of 45°, with the axis of the tube, the rays pass out through the glass opposite to the centre of the plate without encountering any considerable opposition.

Fig. 6 shows by the dotted lines the direction of the kathode stream, and by the dot-and-dash lines the path of the Röntgen rays.

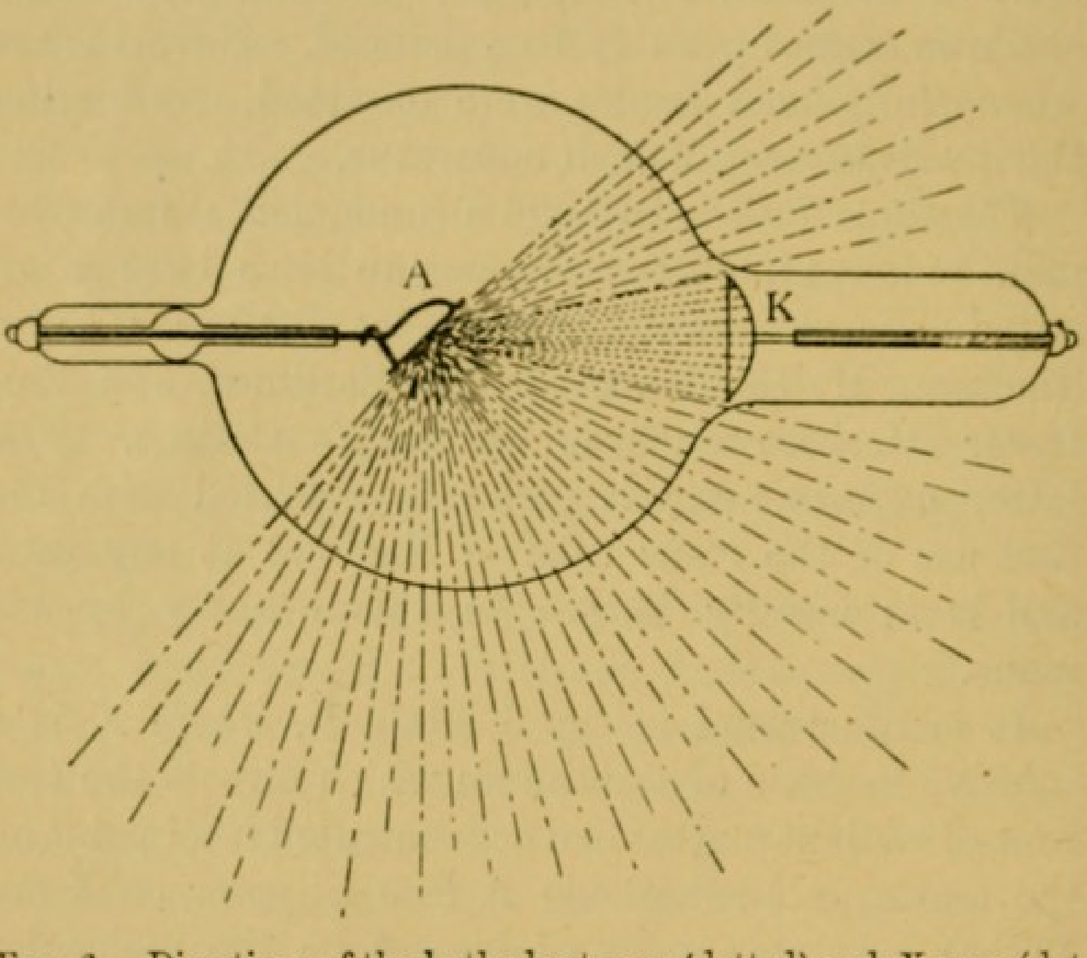


FIG. 6.—Directions of the kathode stream (dotted) and X-rays (dot and dash) produced in a focus tube.
(*Note.*—The X-rays pass through the space occupied by the kathode stream and have only been omitted there to avoid confusion.)

As the latter pass out through the glass they produce fluorescence, usually of a canary-yellow or apple-green colour which varies according to the material of the glass and the degree of exhaustion. It is often bright, and occurs exactly over the area which is exposed to the Röntgen rays. The results obtained with the focus tube accord with what one would naturally expect when the source of the rays is almost a point:—radiographic and screen effects are thereby rendered enormously sharper and more detailed without the necessity of working with the tube at some distance from the plate. A full account of different types of tube is given below, but a short description (due to Mr J. H. Gardiner), of the different stages of exhaustion of a focus tube, commencing with its first production of kathode rays will, it is hoped, be of interest.

Stages of Vacuum.—(1) The kathode rays are visible as a faint gaseous luminosity coming to a focus in front of the anti-kathode which is uniformly red hot.

Considerable gaseous luminescence is seen round about and behind the anti-kathode, the dark space is just visible and the resistance is equal to that of an air gap between points separated by about ¾ in.

(2) The cone of kathode rays is fainter and seems to have spread more so that it focuses upon a bright, red-hot spot on the dull red surface of the anti-kathode. The glass-fluorescence is greater and there is less luminous gas visible. Resistance = 1¼ in. of air.

(3) The cone of rays is invisible, there is a faint nebulous glow in front of the anti-kathode, the fluorescence is more brilliant and the resistance = 1¾ in. of air.

(4) The nebulous glow has crept up the front and over the back of the anode, detaching itself and form-

ing a faint cloud behind it. The fluorescence is at its maximum and the anti-kathode is red-hot at its centre.

(5) There is now a sudden change. All trace of the nebulous cloud has gone, the target is no longer red-hot, the fluorescence has diminished to ¼ its maximum intensity, and the resistance = 4 in. of air.

During the latter stages of exhaustion the kathode stream, as far as it is visible at all, is seen to diverge to a steadily increasing degree, so that the focus or crossing point approaches nearer to the anti-kathode.

Mr Gardiner found that the effect on a fluorescent screen increased throughout these stages, but that the maximum photographic effect coincided with (4), which gives the maximum fluorescence in the glass.

The subsequent history of X-ray research must be given in the second book (see Preface), the different pieces of apparatus required needing our next attention and careful consideration.

CHAPTER II

APPARATUS FOR THE PRODUCTION OF SUITABLE DISCHARGE.

THE reader will have realised already that the source of supply to the tube must be one of very high electromotive force or electrical "pressure," and that for satisfactory and efficient working the electrode which has been designed to act as a kathode should not be negatively charged at one moment and positively the next. In other words the source of supply should be unidirectional unless special tubes are employed. (See Chapter on "Tubes.") Professor Trowbridge has obtained remarkable results with a battery of 20,000 storage cells, the total voltage being 40,000, but though his results are of interest they are absolutely beyond the resources of the average experimenter, and are not of sufficient importance to justify a detailed account.

The Induction Coil.—The induction coil is undoubtedly the best and most convenient source of high voltage electricity for X-ray work, and though radiographs have been taken with coils giving 1 in. spark and less, the reader is not recommended to make the attempt. A 2 in. spark coil gives good results with very long exposures, a 3 in. works well, while a 5 in. or 6 in. coil allows of the use of comparatively hard tubes. Few cases require anything larger than a good 6 in. coil, though an 8 in. or a 10 in. spark gives a heavier discharge through any tube, and shortens the exposures.

For X-ray work the induction coil should have a commutator.

Platinum Breaks.—It would be out of place to discuss here the comparative merits of the different platinum contact-breakers now on the market, but a word must be said for the Vril which not only increases the spark-length of a coil which has been arranged with the common type of break, but positively refuses to work nicely unless the battery power is considerably diminished. When properly adjusted a coil with a Vril break gives a regular and heavy discharge.

The author has found that the working of a Vril break for X-rays is greatly improved by substituting for the heavy hammer usually fitted, a light one turned out of soft iron or mild steel and shaped as in fig. 7. Lightening the brass attachment of the hammer by filing it down *where safe* is also advantageous. These alterations increase the frequency of discharge and even seem to augment the spark length, after careful adjustment. A greater illumination of the screen and a shortening of exposures are the chief gains of increasing the frequency. Possibly the same alterations would prove useful with other types of break.

Mercury Breaks.—Most coils give far better results with a good mercury break than with platinum contacts of the ordinary type. With a mercury break, either of the Mackenzie Davidson or the so-called "turbine" type, a comparatively high voltage can be used on the primary of the induction coil, and the contact can consequently be made and broken with far greater rapidity, the time required for the core of the coil to become magnetically saturated being much decreased. This allows of a torrent of sparks, following each other in very rapid succession, and usually looking thick and hot.

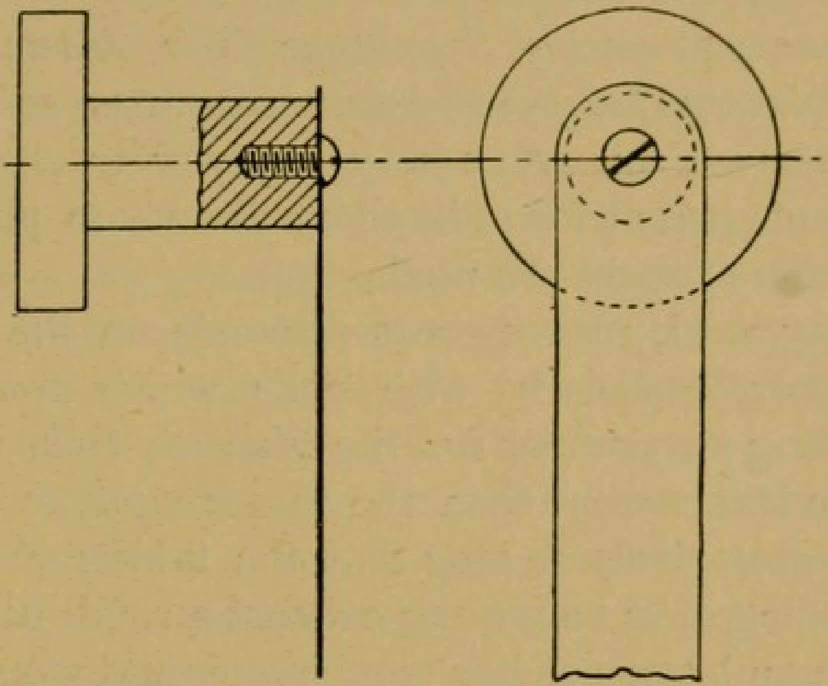


FIG. 7—Induction coil hammer turned down to a T section to increase the frequency of sparking.

Such a torrent is ideal for X-ray work, though watchful care must sometimes be exercised to make sure that no damage occurs to the tube through excessive discharges (see Chapter on "Tubes").

The Wehnelt Break.—This produces very heavy and rapidly succeeding discharges, and in X-ray work gives brilliant screen effects and short exposures. It is, however, best left alone unless a specially suitable tube is available (see Chapter on "Tubes").

For the construction of mercury and Wehnelt breaks reference must be made to articles in the "Model Engineer," vol. iii., p. 2, Jan. 1900, and vol. vii., p. 209, Nov. 1902.

Primary Sources of Supply for Coils, Accumulators, and Primary Batteries.—Accumulators or secondary batteries are in every way superior to any other source of current for induction coils where platinum or mercury breaks are used.

X-ray work makes great demands on the source of supply, especially with coils which necessitate very long exposures, for though such coils usually require less current than the larger sizes, exposures are comparatively so long that the taking of one or two radiographs may quite exhaust a small battery.

Accumulators are less troublesome and messy than primary batteries and, if of moderate size, last much longer before giving out. They can be made more portable and have a lower internal resistance and higher E.M.F. cell for cell. On the other hand, primary batteries do not have to be taken away to be charged, and *if* only a small amount of work is required of them they are cheaper than accumulators.

Where a continuous current lighting circuit is at hand (especially if the experimenter has a large coil and means business with it) accumulators can be hardly too strongly recommended, and will probably prove cheaper in the end than any primary batteries could possibly be.

If primary batteries must be used, the bichromate or chromic acid cell is perhaps best, or, if the expense is not too great, the Edison Lalande.

The latter gives a low electromotive force, and a larger number of cells must be used in series than would be required with bichromates. The great advantages of this cell are that it has a very low internal resistance and large âmpère-hour-capacity, both very important qualities for radiography.

If a good high-speed rotatory mercury break is used on a fairly large coil the battery power may be advantageously very much greater than is possible with platinum contacts. Forty volts direct onto a 10 in. spark coil with such a break gives a torrent of full-length sparks and brilliant illumination of a fluorescent screen. For the construction and maintenance of secondary batteries see the M.E. handbook, "Small Accumulators."

Dynamos.—A dynamo may be used direct or through a suitable resistance when a coil is worked with either a mercury or a Wehnelt break. Dynamos are also used for charging accumulators either direct or through lamps. (See paragraph on Wehnelt Breaks and Chapter on Röntgen Ray Bulbs, also "Small Accumulators," Model Engineer Series.)

Wimshurst Machines.—Excellent results can be obtained with Wimshurst or Holtz machines, and in some respects they are superior to induction coils.

The fluorescent-screen effects, produced by a large Wimshurst giving a continuous, long and heavy discharge, are wonderfully brilliant.

It is difficult to give any definite statement as to the minimum size of Wimshurst which will produce radiographs, though quite respectable specimens have been published, to obtain which a $\frac{3}{8}$ in. spark machine was used. The sparks given by different Wimshurst machines are various in quality; some are short and thick, which indicates the discharge of a considerable quantity of electricity at a comparatively low electromotive force, and some are long, purple streaks which show the discharge of a small quantity at a very high electromotive force or "pressure."

The addition of the small Leyden jars so often supplied with such machines affects the question greatly, but, broadly speaking, any Wimshurst giving fairly frequent sparks 2 in. long will produce X-rays, though the worker may find it necessary to confine himself to radiographs, leaving screen work until he has more suitable apparatus.

A large well-made machine with four or more plates usually works best if its discharge is sent directly through the tube, but with machines of less power it is better to insert a small spark gap between each terminal or discharge ball of the machine and the corresponding terminal of the tube (see Chapter on *Radiography*). Experiments with any given machine and tube will soon show which of these two arrangements is more satisfactory.

The continual necessity of keeping one hand occupied in turning the handle of a Wimshurst machine is apt to grow very wearisome, besides giving uncertain and variable results, but if a sufficiently powerful and suitably-geared motor be available the apparatus becomes very convenient, especially if a controlling rheostat be used.

Water motors or small gas engines may be used where electricity is not available.

Tesla Coils.—When a Leyden jar suddenly discharges across a spark-gap and through one or more turns of wire which are capable of producing a magnetic field, or, in other words, possess the property of self-induction, the spark is oscillatory, that is, it consists of a series of reversals or alternations of current occurring in very rapid succession, each impulse being less than the last, until like the vibrations of a disturbed spring, they die away. The frequency of vibration may easily reach a million per second.

If such a discharge be sent through a helix of thick wire round which a secondary coil of thin wire has been wound with special care of insulation, currents are induced in the latter at a very high electromotive force, and still of an oscillatory nature. Such a combination of primary and secondary windings for the transformation of high frequency currents is called a Tesla coil. No further account of the remarkable phenomena connected with oscillatory currents can be given here, and for the details of construction of a small Tesla coil for X-ray work the reader is referred to an article by Mr J. Pike in the "Model Engineer," May 28th, 1903. Such a coil sometimes renders the production of X-rays possible when the induction coil used to work it is not sufficiently powerful, but it cannot be recommended except for occasional use. The reader will remember that for the proper generation of X-rays the concave cup must be kathode. Reversal of current causes the kathode stream to proceed from the anti-kathode, and as it produces X-rays wherever it impinges, those portions of the bulb which should be merely transmitting the Röntgen rays become actual sources thereof, the whole advantage of the focus tube being lost and the radiation probably weakened.

It is clear, therefore, that if a tube be actuated by alternating discharges or a Tesla coil, every other half wave or reversal not only decreases the efficiency of working, but causes loss of definition, for the rays proceed from a large area of glass instead of from the focalised point on the platinum plate. Furthermore, it is found that either steady or alternate reversal of discharges through a focus tube causes particles of platinum to be torn off from what should be the anti-kathode, and deposited over the interior of the bulb which is thereby rapidly "blackened." Such a platinum deposit has been thought to produce inconstant vacuum. (See paragraph on The Vacuum.)

There is one way only of surmounting these difficulties, and that is to use the specially constructed tube shown in fig. 10, Plate I. This type of tube has two concave cups of aluminium K*a*, *a*K, either of which may be kathode. The anti-kathode A is of platinum and V-shaped, and either face receives the kathode stream from the concave electrode opposite to it.

If the wires from the Tesla coil be connected with the two aluminium electrodes, each of the latter becomes alternately kathode and anode, the kathode stream being received alternately on one face and on the other of the V-shaped anti-kathode. Thus the anti-kathode is not an electrode at all. It is merely a suitably arranged source of radiation,—a target for converting kathode ray into Röntgen ray energy. Sometimes it is earth-connected.

Even this arrangement does not give results quite as satisfactory as those obtainable with an ordinary discharge and a focus tube, for a certain amount of definition is lost by the use of two sources of radiation, even when placed less than ½ in. apart.

CHAPTER III

RÖNTGEN RAY TUBES

THE tube or bulb used for the generation of X-rays is the piece of apparatus which requires, above all others in this work, thorough comprehension, careful usage and thoughtful choice. The general and particular principles of its construction, its physical properties and the phenomena which occur in it, are not only practically important, but are of such great interest that the author feels no hesitation in dealing with it at considerable length.

No attempt will be made to describe the construction of Röntgen-ray tubes as they are beyond the scope of the ordinary amateur, who is *not* recommended to try making them out of glow lamps, which seldom either have high enough vacuum or are constructed of soda-glass. They are also unsuitable in other respects.

Fig. 5, Plate I., shows the ordinary pattern of focus tube introduced by Jackson (see p. 39), and used with no fundamental departure in type up to the present time.

In such a tube the all-important factor, which determines its behaviour under given circumstances, is the resistance offered by it to the passage of the discharge. If the resistance be too high the rays which are produced have great penetrative power and pass through bones almost as easily as through flesh, producing radiographs (loosely called X-ray photographs) of "flat" quality and wanting in contrast. A tube of too low resistance produces rays which have little penetrative power, are almost stopped by the flesh, and entirely so by the bones, which, appear dead black with no structural detail visible.

Between these extremes there is a wide range for choice, and a tube that is good for one class of work may be quite useless for another.

A low resistance tube of small penetrating power is called low, or more usually *soft*, and one of high resistance with great penetrating qualities is known as high, or *hard*. The resistance, though chiefly governed by the degree of exhaustion of the bulb, is also affected by the dimensions of the kathode and its distance from the anode.

The kathode rays have been well called the parents of the Röntgen rays, and accordingly the kathode, from which they proceed, shall receive first attention.

The Kathode.—The kathode (K, Plate I.) is invariably cup-shaped and is made of such curvature that the rays emanating from its surface converge with more or less accuracy upon a point in the centre of the anti-kathode A.

A small kathode gives a high resistance and penetrative rays,—a large one low resistance and soft results. Mr Addyman gives about 1 in. diameter as a good size for ordinary work.

The kathode is made of aluminium, because the discharge would continually tear off particles from any other metal, and distribute them all over the inner surface of the bulb, thereby blackening it. The surface should be of uniform curvature and well polished. Within certain limits, an increase of distance between anode and kathode has the surprising effect of decreasing the resistance, and Mr Campbell Swinton has constructed tubes in which he takes advantage of this fact by making the kathode movable so that by tilting and gentle taps it can be adjusted to the extent of about ½ in. in its distance from the anode.

The greater the accuracy with which the kathode stream can be converged upon a fine point on the anti-kathode, the sharper and more detailed will be the resultant radiographs, for the source of the Röntgen rays is this point of impact, and from it they proceed in straight radial lines.

But here a serious difficulty has arisen. The violent molecular bombardment heats the anti-kathode wherever it occurs, and if the whole effect is concentrated upon a very small point, a hole will soon be burnt, unless very great precautions are taken. As a matter of fact, the concentration is never accurate in ordinary tubes, a compromise being always made between an accurate focalisation and a safe degree of heating. It is clear, therefore, that anything which enables the anti-kathode to lose its heat rapidly or to stand a high temperature without being damaged, also allows of a more accurate concentration of the kathode stream and a greater sharpness in the effects produced. At the same time such non-damageable anti-kathodes, allow of a heavier discharge through the tube, and therefore of greater energy of radiation.

The Anti-kathode (A, Plate I.).—The foregoing remarks show that much depends on the design of this part of the tube.

It is usually a small plate of metal fixed opposite to the centre of the kathode, and slanted at an angle of about 45° with the axis of the tube. The Röntgen rays which emanate radially from it are thus directed outwards through the side of the bulb where no electrodes, thickened glass, or other obstructions are met with.

As regards the material used for its construction, Röntgen states that there is a difference in the degree of emission of X-rays by anti-kathodes of different materials, and that at the point of impact of the kathode stream, platinum radiates much more powerfully than aluminium. Although he further found, as might be expected, that X-rays were either generated at the back face also of an aluminium anti-kathode, or, originating at the point of impact, penetrated through to the opposite side, he still maintained that platinum was superior in emissive power.

As, moreover, platinum has the highest melting point among the less rare metals it is chosen as the most generally suitable material. Excellent results have been obtained with iridium used as a small centre to a disc of platinum, and at great expense and trouble osmium has been similarly employed. Both iridium and osmium have higher melting points than platinum, and the former metal was very successfully employed by Dr Mackenzie Davidson in his remarkable and interesting localisations of metallic particles in the eye.

When a Wehnelt break is used the anti-kathode gets white hot and is rapidly ruined. Fig. 8 is from a photograph of a platinum anti-kathode which has been so damaged. Heavy discharges also sometimes bend the anti-kathode, but this does not seem to seriously interfere with the action of the tube. For such heavy work tubes have been designed with anti-kathodes made of hollow platinum and water cooled, or of solid copper plated with platinum, the object in either case being to carry away the heat as soon as it is developed.

Fig. 6, Plate I., shows a tube sold by Messrs Watson & Son, of Holborn, for Wehnelt-break or other heavy current work. The anti-kathode A is of solid copper plated with platinum, and supported on a hollow tube T. The palladium wire P is referred to in a later paragraph.

In Germany tubes have been made by E. Pabst in which the anti-kathode has been electrolytically covered with platinum-black (platinum in a state of fine division). The rate of heat emission is thus enormously increased, and, should the anti-kathode, in spite of such preparation become incandescent, the platinum-black will become platinum-grey, and even this has four times the heat emissivity of polished platinum. Such an arrangement is obviously less cumbrous and complicated than that of the water-cooled anti-kathode, but neither are very largely used now, for there seems to be a preference for the original simple and comparatively cheap platinum disc.

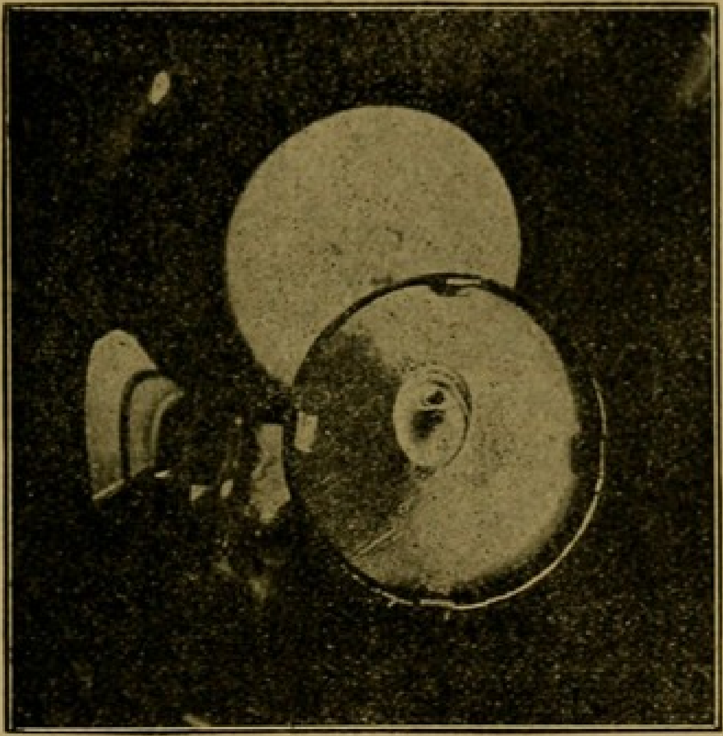


FIG. 8.—Platinum anti-kathode of a bianodal tube which has been fused and perforated by the excessive discharge from a coil actuated by a Wehnelt break. The disc behind is the auxiliary anode, and the markings to the left are the light-reflections on the bulb.

When the Wehnelt electrolytic break was first introduced Röntgen - ray workers thought that nothing could equal it, but the heating trouble and the rapid alterations in vacuum, to which it gave rise, have brought it into some disfavour in spite of the wonderfully rapid exposures made possible by its use.

At various stages in the progress of X-ray work, anti-kathodes coated with fluorescent materials have been suggested, tried, and even described as giving 50% more radiation than platinum. Professor S. P. Thompson has made somewhat exhaustive experiments in this direction, and has found that such devices usually decrease the efficiency, probably by converting energy, which would otherwise be useful, into ordinary fluorescent light.

Bianodal Tubes for Heavy Discharges.—The type of tube known as bianodal is much in use, and seems to be a real advance on the ordinary focus pattern.

It will have been noticed that while the cup-shaped electrode has been called the kathode, the platinum plate opposite to it has been consistently named the anti-kathode and not the anode. The reason for this is that its chief function is to receive the kathode stream and convert its energy into Röntgen rays, this function being fulfilled wherever the anode is placed. (See historical chapter.) In Jackson's focus tube and in most other X-ray tubes the anti-kathode happens to be also the anode, but if a third electrode were fitted and the positive wire from the coil joined to it, the platinum electrode or anti-kathode being disconnected, the kathode rays would proceed from the aluminium cup, strike the anti-kathode, and generate Röntgen rays at their point of impact just as they do in Jackson's tube, although the platinum plate would not be the anode.

Now if the third or auxiliary electrode be joined externally by a piece of wire to the anti-kathode, the latter again becomes an anode, but the tube is bianodal and allows the passage of heavier discharges. Its vacuum may sometimes be lowered slightly by disconnecting the anti-kathode and sending, for a short time, a reversed *and greatly reduced* current by way of the two aluminium electrodes. If the current is reversed in an ordinary focus tube, particles of platinum are thrown off from the anti-kathode and deposited on the bulb. This occurs to some extent when the discharge is in the right direction, and can often be seen as a purple colouring of the glass. The above-mentioned method of lowering vacuum can hardly be recommended, being somewhat uncertain of action. Both Professor Röntgen and Sir Oliver Lodge have found that tubes work somewhat better when the anti-kathode is also the anode.

In bianodal tubes the auxiliary anode, generally consisting of a simple disc of aluminium, is usually placed behind, and to one side of the anti-kathode. A typical bianode tube is shown in fig. 7, Plate I. where *a* is the auxiliary anode.

The penetrator tube, at one time made by Messrs Watson & Son, of Holborn, was formerly much used and gave excellent results. In its simplest form it is shown in fig. 8, Plate I. The anti-kathode A is slightly concave towards the kathode K, and between the two is an aluminium ring *a* attached by an aluminium rod to the anti-kathode. The ring and anti-kathode are thus both anodes but the ring is the practical working anode, and by this arrangement the penetrative power of the X-rays is increased without disturbing the focus of the kathode stream, which passes through the ring and strikes the platinum in the usual way. (See *The Kathode.*)

The Bulb.—Ordinarily the bulb is made of soda-glass, for lead-glass is very opaque to Röntgen rays, this property being made use of in tubes which are designed for the cure of lupus and other skin diseases. One of these is illustrated in fig. 9, Plate I. The whole tube is constructed of lead-glass, with the exception of the soda-glass window W, which enables the operator to apply the rays to the affected area without their spreading to other parts and possibly causing dermatitis (see p. 92). The tube has been drawn rather more cylindrical than is actually the case, the bulb being usually of an oval shape. This, however, is a mere matter of detail. The glass usually used in ordinary tubes fluoresces a brilliant apple-green or yellow colour wherever the Röntgen rays strike it, and as this colour is practically the same as that of the fluorescence in a barium platino-cyanide screen, considerable impoverishment of effect may result unless the screen is placed in some sort of light-proof box with eyeholes, or the tube enclosed in blackened paper or thin cardboard.

This difficulty has been surmounted by making bulbs of some material which emits fluorescent light of a different colour from that which is excited in the screen. Lead-glass shows a beautiful blue colour, but does not allow the free passage of X-rays. Lithium glass gives a grey-blue light which considerably reduces the "drowning" effect, but the most satisfactory is a glass containing didymium. This gives red fluorescence, and as the red of the tube with the yellowy green excited in the screen, produces black, the luminescence of the latter is not nullified by that of the tube and no shutting off of the direct light is necessary. G. Séguy and E. Gundelag (*Comptes Rendus*, 125, pp. 602–603) were the originators of this tube in 1897 and their method was to incorporate with a transparent and non-fluorescent glass some carbonate of lime, some albumen in powder, and chloride of didymium. They claimed that twice the amount of radiation was produced by such a tube, but it is not easy to see how this could be if the Röntgen rays are generated at the anti-kathode, unless—

1. The opacity of this glass is less than that of soda-glass or

2. Less energy is absorbed in the production of fluorescence in the glass.

If the latter is the case why allow any fluorescence at all, and why not use the "transparent non-fluorescent glass" without the other ingredients? Possibly these points are easily explained, but however that may be, bulbs of didymium glass do not seem to have come into very general use, possibly by reason of their expense. A glass containing soda (natron) 10 per cent., boracic acid 30, alumina 20, arsenic acid ·4, and silicic acid 39·6 per cent. is mentioned by O. Schott as exceedingly transparent to Röntgen rays. For the effect of the bulb material on the permanency of vacuum see The Vacuum.

The remaining point with regard to the bulb is its size, and though a small bulb is more convenient and portable, a large one is less subject to changes in vacuum.

Occlusion—This is the term applied to a curious power gases possess of soaking into certain metals in considerable quantities. Hydrogen is the most powerfully occlusive of the gases, and a piece of palladium can accumulate a great deal of this gas in its intermolecular spaces. When X-ray tubes are being exhausted in the making, a heavy Wehnelt discharge is periodically passed and immediately frees the electrodes of most of the occluded gas.

Mr H. S. Callendar made experiments on the occlusion of hydrogen in the kathode, and found that it acts as a carrier of the discharges from the metal to the air. He found also that with sufficient occluded hydrogen there is little or no sputtering of the aluminium, and that in the absence of hydrogen, the particles of the metal are the carriers and excite fluorescence and generate rays wherever they impinge. If extreme precautions are not taken for drying and removal of hydrogen from the electrodes, the residual gas is in most cases hydrogen or water vapour.

The Vacuum.—The operation and qualities of a tube *of given type and dimensions* are regulated almost entirely by the degree of vacuum in the bulb and the temperature at which it is working. The reader is here reminded that a very high vacuum gives hard results (very penetrative rays) and that a comparatively low vacuum gives soft effects (rays of very small penetration).

An excessively high vacuum prevents the discharge almost entirely and causes sparks to pass over the outside of the bulb, and if the exhaustion is too low the rays are hardly able to penetrate even the most radiable substances.

The one serious trouble with Röntgen-ray tubes is that with continued use the vacuum gets higher and the tube correspondingly harder. The occlusion of the residual gases by the electrodes may to some extent account for this effect, though experiments made by Mr. R. S. Willows (*Phil. Mag.*, April '01) suggest that most, if not all, of the absorption occurs at the inner surface of the bulb, and he supposes that there is an actual chemical combination of the gases with the glass. Others have suggested that the gases are occluded or absorbed by the platinum which is deposited in a finely divided state on the interior surface of the bulb.

Mr Willows found that with a volume of 108 c.c. and a pressure of 1 mm. a current of ·00108 ampères passing for 30 minutes actually reduced the pressure nearly one-eleventh. As a remedy he suggested the use of Jena glass rather than lead-glass, and of lead-glass rather than soda-glass. (Lead-glass at any rate is too opaque for efficient working.)

However, as present-day tubes do go up in degree of vacuum, and prevention has not been successfully attempted, attention may be turned to the doctoring of tubes of ordinary type and to the design of a few makes of tube in which definite arrangements for cure are provided.

If the vacuum of a tube gets too high, a partial cure is often affected by prolonged and careful heating, and some workers even nurse their tubes regularly after use, in fairly hot ovens.

Sometimes a tube gives bad results for no apparent reason, and, if put by for a day or two, recovers itself perfectly. Such caprice, however, is fortunately not common.

Sometimes the vacuum can be lowered in some degree by the passage of a temporary discharge which is too powerful for the tube in the ordinary way. Perhaps this effects the expulsion of occluded gas from the heated anti-kathode.

If, after treatment by heat, or a heavy discharge, a tube still remains hopelessly hard, nothing can be done except to send it to be re-exhausted.

Fig. 10, Plate I., shows one of the earliest provisions for varying the vacuum of a tube. B is a bulb-shaped annex attached to the tube, and containing a small quantity of caustic potash or other suitable substance capable of absorbing traces of moisture, portions of which, on the application of gentle heat, are driven out with a consequent lowering of vacuum. On cooling, the moisture is slowly re-absorbed. This method is very troublesome in use as it is difficult to avoid driving out too much and making the vacuum impracticably low.

The tube illustrated happens to be of the double kathode type much in use at one time, especially in America. The object of the arrangement is to render the use of high-frequency currents practicable, and a full account of the reasons for its construction is given on p. 51.

Mr Hillier was the first to introduce tubes in which the vacuum could be lowered by a discharge between aluminium wires. Fig. 9, Plate I., shows a lupus tube (see p. 60) fitted with Mr Hillier's device, which has remained in use up to the present time, and is still employed with great success by Mr Cossor, of Farringdon Road, for this particular branch of work. It seems, however, to have fallen out of use in the ordinary X-ray tubes to which it was first attached.

In the glass annex C are two small electrodes EE of aluminium wire in which gases are naturally occluded in comparatively large quantities. When the vacuum gets too high the induction-coil discharge is sent through the annex by way of these electrodes, and some of the occluded gas is thereby expelled. The annex, though drawn for convenience parallel to the axis of the tube usually lies at right angles to it.

Mr Hillier says that this operation can be repeated six or seven times before all the gas is freed.

Another method employed in many makes of tube is illustrated in fig. 6, Plate I.

The small annex shown has a short length of palladium wire P sealed into it. When the vacuum requires lowering, heat is applied to the projecting wire and is carried by conduction to its interior portion where it drives out the occluded gas to the required degree. The glass tube and cork TC are merely for mechanical protection.

In another form (fig. 11, Plate I.) recently introduced in England by Mr Cox, of Cursitor Street, the palladium P is placed between two mica discs, and the vacuum is lowered by approaching the wire W towards the wire W_1, and thus diverting a small portion of the discharge through P until enough gas is freed. By careful adjustment of the spark gap between W and W_1 the arrangement becomes automatic, for directly the vacuum gets too high, a spark passes and liberates a small quantity of gas.

If the vacuum becomes still higher, so that this is of no use, the wire from the source of supply is taken off from W_1 and connected direct to W.

If the tube is too soft the vacuum may be raised by "working the tube the wrong way" for a few seconds without altering the wires. If this does not have the desired effect, the positive wire is disconnected from A*a* and joined to the metal spiral in the annex, and the current turned on from one to five minutes. The author is unfortunately not able to say of what material the above-mentioned spiral is made.

Fig. 12, Plate I., shows the simplest form of tube in which the rays are produced from the glass where the kathode stream strikes it. Good radiographs have been produced with such tubes, especially by the aid of metallic stops which, though they greatly increase the necessary exposure, obviate to some extent the blurring effect produced when the source of radiation has a very large area.

Mr Hyndman mentions a few tubes which may or may not have practical importance, and though not in general use are nevertheless of sufficient interest to call for short notice.

One paragraph quoted from a description by Davies (*Nature*, June, 1896) gives an account of a bulb entirely made of metal and forming in itself the anti-kathode. The front is of aluminium, the kathode being formed by a concave metal mirror behind a smaller plate. Another (Wood's) contained two minute platinum balls, between which a heavy discharge took place, giving a small but intense source.

Although for ordinary work the focus-tube and the bianodal type survive all the complicated and sometimes very interesting arrangements introduced at various times, there is no doubt that where work is constantly being done the vacuum difficulty is very real, and that tubes with regulating arrangements undoubtedly save time, money and worry, being only despised by the casual worker whose tube has never been run for more than five or ten consecutive minutes once in two or three weeks or months.

The Choice of a Tube.—The foregoing remarks should enable the reader to know what to look for when selecting an X-ray tube, but a short summary of the chief points will perhaps be of additional use.

A tube with a large bulb should be chosen to avoid rapid hardening. Perhaps the bianodal type is on the whole best for use with a fairly energetic source of supply. At any rate it enables the curious experimenter to prove that the X-rays are produced without regard to the position of the anode. A common focus tube is quite good enough for anything up to a 4 in. spark. If possible, the tube should be tried to make sure that the shadows thrown on the fluorescent screen or photographic plate have sharp edges when the bulb is at 6 or 8 inches distance from the hand.

The tube must be well made, with substantial and firm supports for the electrodes, and if possible brass caps for making connection with them. Platinum loops, unless very carefully dealt with, are bound to come off sooner or later.

The one remaining important quality is the degree of vacuum in the bulb.

Some makers or vendors will dub an X-ray bulb a 3 in. spark tube, meaning that if it is working from a 6 in. spark coil a 3 in. spark will jump an alternative air-path placed as a shunt to the tube. When the buyer finds that he gets very little effect on connecting such a tube to a 3 in. spark coil, and that a so-called 3 in. spark tube from another maker gives good results, he is naturally mystified until he discovers that only the second tube was suitable for a 3 in. spark coil.

For ordinary simple work one usually uses a tube allowing an *alternative spark* of 2½ or 3 in. when worked by a coil giving anything above a good fat 4 in. or 5 in. spark. The author has seen such a tube show a visible shadow of the hand-bones on a fluorescent screen when actuated by a coil giving a maximum spark of 1 in.

For such coils a tube of even lower vacuum is more suitable. A 2½ or 3 in. alternative spark tube, as above, works well with coils of 3 in., 6 in. or 10 in. spark, and its powers of penetration remain almost the same in each case, but the "quantity" of radiation generated increases with the spark length, because a large coil generally gives a heavier discharge through a spark-gap or tube of given resistance than does a coil only just capable of sending any spark at all through a resistance of the same value.

If a 4 in. spark-coil be available, a 3 in. alternative spark tube may be used, and if a 6 in. (or longer) is at hand a tube may be chosen which allows a 4 in. or 5 in. alternative spark. Such a tube is capable of giving exquisite detail in a hand radiograph.

However, as has already been explained, an increase of resistance (shown by a greater length of alternative spark) means an increase of penetrating power, and a consequent tendency to flatness and want of contrast. This necessitates greater care of exposure than is required with softer tubes, and on the whole the average beginner will perhaps do best to commence with tubes of rather small resistance and low penetrating power. The plates recommended at the end of the book render the use of hard tubes easier and more satisfactory than do ordinary rapid plates. Accurate exposure with a hard tube gives results quite sufficiently "contrasted," and shows far more bone detail than is possible with soft tubes, while, at the same time, the exposure is less, and radiographs can be taken of the thicker and more opaque parts of the body.

Good work may be done with a hard tube which has been "warmed down" (see paragraph on Effect of Heat on Tubes), and many radiographers prefer to get their "soft" effects by this method. Doctors who are constantly using X-ray apparatus usually buy tubes exhausted to a vacuum of about 2 or 3 in. alternative spark. As the vacuum of a tube goes up with continued use it is used for work requiring increasingly great penetrating power, until, when it cannot be warmed down to sufficient softness, a new low vacuum-tube is bought. On the whole the beginner is safest in starting with a low tube, even if his coil be a large one.

There is often a curious amount of variation of quality in the tubes supplied by any one maker. Sometimes a tube which gives excellent results with a Wimshurst seems to work less well with a coil of the same spark length. Again, the same tube which gives fine results with one coil seems much inferior with another of different power or rapidity of break.

The frequency of occurrence of the discharge seems to affect the working of a tube, powerful sparks at short intervals being usually found best for radiographs. If, however, the discharges do not succeed each other with considerable rapidity when fluorescent screens are used, a flicker is produced, and the spaces between the flashes are so long that the whole effect lacks brightness. For such work a rapid succession of smaller sparks is preferable.

It must be remembered also that the maximum photographic effect is not concurrent with the greatest illumination of the screen, so that if possible, a new tube should be tested by both methods.

The reader is finally warned against hastily investing in a tube, which should be suited to the apparatus, and above all should not be too hard for it. One hears of tubes "liking" some particular coil or other source of discharge, and there is no doubt that they do vary in a very curious way with regard to their individual behaviour under various circumstances.

It is hoped that the preceding paragraphs will help in the choice of a tube, and that the somewhat complicated conditions which affect its working will prove a source of interest rather than a discouragment to the beginner.

Effect of Heat on X-ray Tubes.—Experiments carried out by Mr J. C. Porter, of Eton, show that there is one particular temperature at which the production of X-rays is at its maximum with a particular tube, and that above or below this temperature the quality, as well as the quantity, of the radiation is altered. He found the point of maximum illumination to be 12° C. or 54° F., and the tube refused to work at all when cooled down to the temperature of solid carbon dioxide. Mr Porter also tried the following experiment. Half of a plate was exposed for a hand radiograph, the temperature being 15° and the time of exposure 1 minute. The tube was then heated for ¾ minute and the second half of the plate exposed for 6½ minutes. Although the first half had less than ⅙ of the exposure given for the second half, the image of the bones was clearly visible, whereas in the long-exposed portion, only the very faintest trace of bone shadow could be distinguished, the rays having barely penetrated the flesh, although the blackness of the film surrounding the hand-shadow showed that the "quantity" of radiation had been very great.

The effect of heat on a tube, therefore, is to *temporarily* soften it, or cause it to give out rays of smaller penetrative power, and one which is useful for radiographs of the abdomen, skull, or other thick parts can be thus softened sufficiently to give good photos of easily radiable objects. In practice the usual way of effecting this is to heat the tube over a spirit-lamp until the required degree of softness has been attained, immediately adjusting the discharge rods of the coil so that a spark is just unable to jump the gap.

All being ready the exposure is commenced and if, during its progress, the resistance rises, sparks begin to pass, and warn the operator that a little more heat is required.

If a general heating has been applied prior to the commencement of the exposure, the additional warmth is best given to the annex immediately surrounding the kathode, and if care be taken that neither the spirit-lamp nor the operator's hand can come between the tube and the object, the heating can be accomplished without stopping the current. Any such treatment must be applied very carefully and rather gradually, a waving motion being given to the lamp, as otherwise the glass may be cracked and the bulb ruined.

If hard tubes and large coils be used, the lamp must be attached to an insulating handle of ebonite or hard dry wood, as otherwise unpleasant shocks may be experienced and even the tube cracked.

So many simple ways of attaching the handle to the lamp will suggest themselves to the reader, that a description and sketch are hardly necessary. The container of the lamp is best made of glass and the fastening of the handle must, of course, be really firm, for the person whose hand is being radiographed (especially if for an injury), may show marked displeasure if a heavy spirit lamp be dropped, when burning, on to the damaged member.

CHAPTER IV

ACCESSORIES

SOME simple apparatus is required for holding the tube in any position which may be required when in use.

The requirements of an ideal tube-holder are:—

1. Universal movement.
2. Rigidity.
3. Lightness as far as is compatible with 2.
4. Insulation.

Rigidity is of great importance in radiography, though of small consequence for screen work, as long as the requirements of safety are met.

Lightness is of importance when the apparatus is required to be portable. Insulation is sufficiently good if the tube-holder be constructed of hard wood. In fact, the wooden retort-stands sold for chemical and physical use are excellent for ordinary X-ray work. Special localising stands will be touched upon in the second handbook on X-rays.

Spark Gaps.—A pair of spark gaps for connection in series with tube and source of supply are very often useful in Wimshurst work, even with large machines. Occasionally improved effects are obtained with induction coils by the insertion of a spark gap, but only for certain purposes. The apparatus, fig. 9, is very simple, cheap, and easily put together.

A is a board 7 in. × 4 in. × ½ in.

C D are upright rods of ⅜ in. ebonite, 3½ in. in clear height above the board, and fastened thereto by drilling the board with ¼ in. holes, shouldering the ebonite to fit, and firmly fastening either with glue or by screwing from beneath.

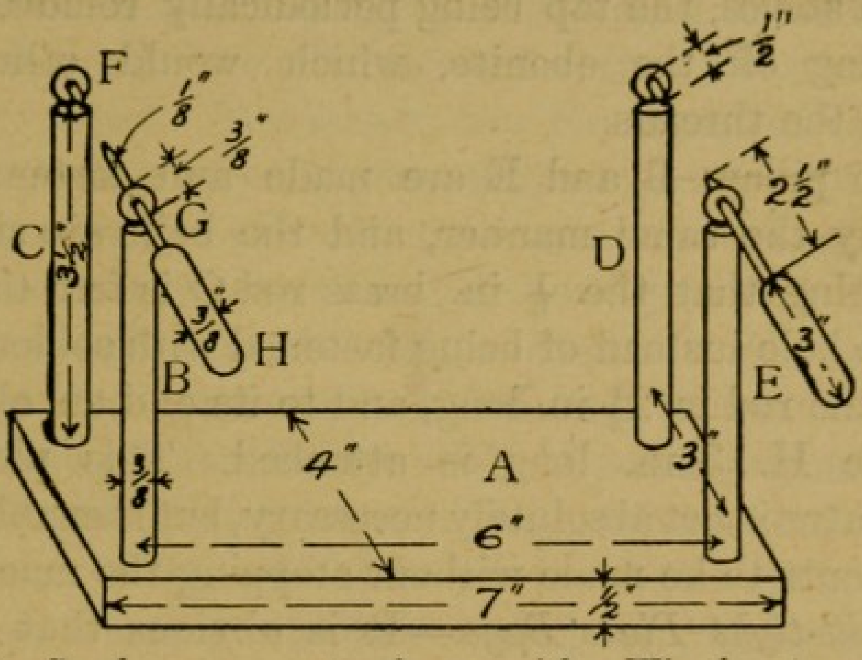


FIG. 9.—Spark-gap apparatus for use with a Wimshurst machine.

The top of each pillar is drilled and tapped ¼ in., and into it is driven a ¼ in. screw of the kind which has a cylindrical head. To avoid brush discharges it is best, however, to turn down the head to a ball, or to solder a suitable ball on to the screw. Into the side of the ball F (previously drilled) a ½ in. length of ⅛ in. brass rod is soldered.

The ball may be also drilled through with a $\frac{1}{8}$ in. hole in a direction at right angles to that of the wire, the hole being for the insertion of the wire from the Wimshurst. The screw may be turned up from an old terminal, and ebonite can be always threaded by filing down the screw, to be inserted, with four tapering flats, so that the end is almost square, the tapering portion terminating at about $\frac{1}{2}$ in. therefrom. Oil should be used and the screw should be cut in stages, the tap being periodically removed for cleaning off the ebonite, which would otherwise choke the threads.

The pillars B and E are made and fastened in exactly the same manner, and the balls are similar excepting that the $\frac{1}{8}$ in. brass rod G is free to slide in the hole instead of being fastened with solder. In each the rod is $2\frac{1}{2}$ in. long, and to its end an ebonite handle H. 3 in. long is attached. This piece of apparatus is not absolutely necessary, but it enables adjustments to be made without stopping the machine.

Light-tight Plate Bags.—It is obvious that some arrangement must be made for screening the photographic plates from the action of ordinary light, and it is also obvious that anything which cuts off the X-rays to any appreciable extent must be avoided. Double envelopes of black paper may be made, so that the plate can be inserted in one, the flap folded over, the end which it covers being again inserted in a larger envelope.

However, the trouble is hardly to be recommended, as excellent envelopes can be procured at a fairly low price. These are known as "Tylar's light-tight bags," and each pair consists of an inner envelope of stout yellow paper and an outer one of black. It is best to get the whole-plate or 10 in. × 8 in. sizes as half- or quarter-plates can be used with them.

The plate is inserted in the yellow envelope *with the film side immediately beneath that part of it which has no folds.*

Now the flap is turned over and the yellow envelope is inserted in the black, *flap foremost*, and with the film side again immediately under the unfolded part of the paper. The black flap having been turned over the plate is ready for a radiograph.

If quarter- or half-plates are used it is well to shake them down into one corner of the bag, having drawn two lines in that corner to show where the edges come.

Metal Boxes.—A stout metal box should always be at hand when X-ray work is going on, and all photographic plates, dark-slides, and hand cameras containing films, should be enclosed therein. In a house containing old-fashioned photographers who still adhere to the obsolete "sun pictures" obtained with the camera, neglect of this precaution is calculated to promote a breach of the peace.

Photographic Apparatus.—For developing-dishes, measures, bottles, scales, printing frames, etc., which are the ordinary stock of a photographer, the reader who does not already possess them must refer to any good book on the subject.

Fluorescent Screens.—Detailed descriptions of the best of ways making fluorescent screens must be reserved for the second book (see Preface), but the following is a rough outline of the method of procedure, which is very simple.

The best substance for ordinary screen-work is barium platino-cyanide, a bright yellow salt which must be specially prepared for this particular purpose if good results are to be obtained. It may be had of Messrs Johnson & Matthey, Hatton Garden, E.C., and as supplied by them is by far the best fluorescent material on the market. It costs 2s. per gram or about 56s. per ounce. The support may be of fairly stout white cardboard, thick enough for strength and not so thick as to cut off much radiation. This is painted over very uniformly with rather thick gumwater, or, more preferably, with celluloid dissolved in amyl acetate, and the platino-cyanide is dusted evenly over the surface out of a sieve of very fine muslin. It is well to practice the process several times with common salt, as, for good results, the spreading *must* be uniform, and if failure is met with the material is wasted.

The superfluous crystals having been shaken off and retained for future use, the screen should be mounted in a suitable wooden frame. Great care must be taken to protect the coated surface from damage, and to this end a covering of thin celluloid may be fastened on the frame and at about $\frac{1}{4}$ in. or more from the screen.

For a complete account of the construction and uses of calcium tungstate and barium platino-cyanide screens see second book.

CHAPTER V

PRODUCTION OF X-RAYS

Connections.—Perhaps it is hardly necessary to explain that if an ampèremeter be used, it should be connected in series with the coil and the source of supply, while a voltmeter should be connected directly to the terminals of the coil. See diagram, fig. 10.

A mercury break should be connected with the spring and pillar of the contact breaker, unless the coil has been provided with special terminals. The contacts should be screwed apart and the hammer wedged to prevent it from chattering.

The wires leading to the tube should be thin, and preferably coiled in a spiral for elasticity. Thin gutta-percha-covered wire is perhaps best in all cases, but should certainly be used with influence machines, silk or cotton-covered copper being good enough in other cases. If a Wimshurst be used, the two spark gaps (see Chapter on Apparatus) are connected in series with the tube, one on each side (see fig. 10 (D)).

It is always well to place the tube at a fair distance from the coil, and to firmly secure the wires leading to it, so as to prevent them from falling off and giving nasty shocks or piercing the tube. The wires should be kept clear of the glass walls of the tube and no adjustments should be attempted in the secondary circuit until the primary current has been switched off.

If there be a choice of two or three tubes, use the harder ones for subjects such as the thorax, head, etc., but for the present we shall assume that the reader is an entire beginner, in which case his first subject had better be a friend's hand, preferably that of a lady, though many of the gentler

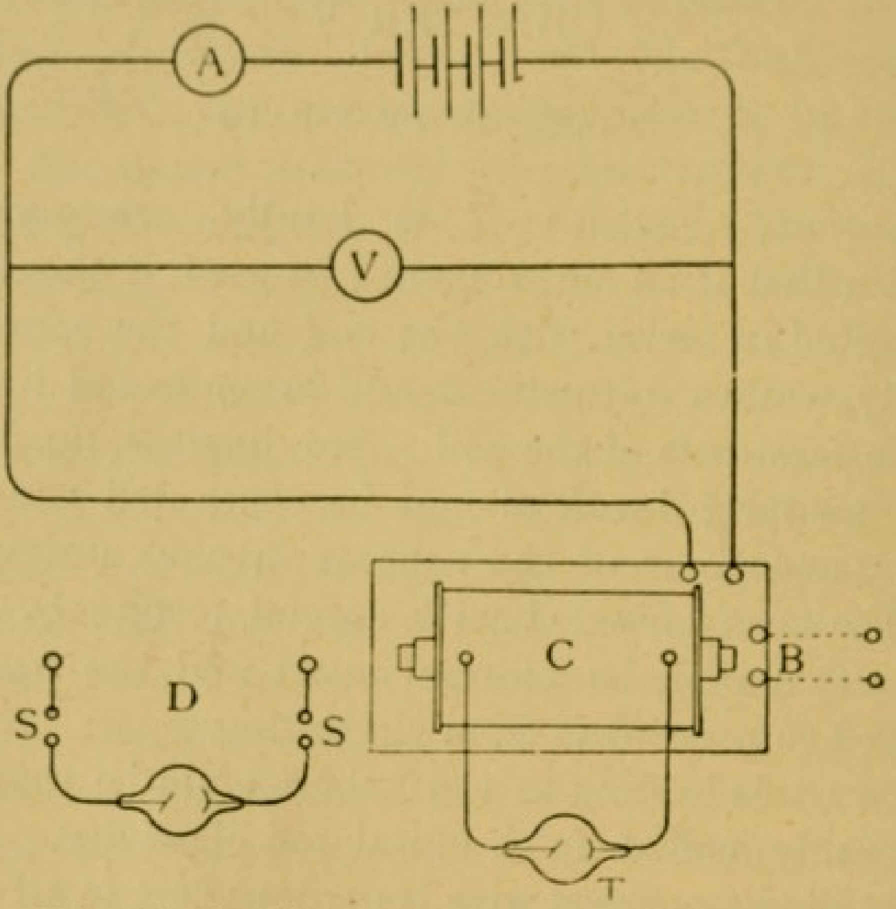


FIG. 10.—Showing diagrams of connections for an induction coil and (D) for a Wimshurst.

C. Coil.
B. Break.
A. Ammeter.
V. Voltmeter.
T. Tube.
S.S. Spark-gaps.

sex say, with one of Dickens' heroines—"I do not wish to regard myself, nor yet to be regarded in that bony light." After getting used to the necessary manipulations the operator may radiograph himself.

The tube having been fastened firmly in its stand the current is *momentarily* turned on, and the appearance noted.

If the bulb be divided into two halves, one being uniformly luminescent with apple-green or yellow-green light, the other being dark or almost so, the current is in the right direction. The plane dividing the bulb should be coincident with the plane of the anti-kathode, and the illuminated half should be that opposite to the point of impact of the focussed beam of radiant matter.

If the bulb does not appear as above but shows curious patches and markings, notably a fluorescent patch opposite to the anti-kathode, and like a magnified image of it, the current is flowing in the wrong direction and must be reversed by means of the commutator. The fluorescent patch opposite to what should be the anti-kathode is caused by the kathode stream from its surface striking the glass, and if the platinum plate is held by two copper rivets which are visible on its working face, these are sometimes reproduced as curious magnified dark patches on the bulb. However, the experimenter's interest in these phenomena must not lead him to keep the reversed current on for more than a second or two, as the tube may be considerably damaged thereby.

When the current is found to be flowing in the right direction, place the screen a few inches from the bulb, and with the coated side towards the eyes, then put the hand behind the screen.

The shadows of the bones should be plainly visible, and with a good tube and coil those of the leg, arm, and foot should also be distinguishable on placing these parts in the proper position. The foot with a boot on makes an interesting radiograph.

The best effect is obtained when the object to be observed is as close to the screen as possible; the hand, for instance, should be flat against it.

Such objects as coins in a purse, mathematical instruments in a case, nails fastening a box, etc., etc., will soon suggest themselves to the experimenter, both for screen work and for radiography. The contact-breaker and the current should be adjusted until the best possible effect is obtained, and if a screen be not available the working of the tube must be judged by the degree of fluorescence in the glass. If a Wimshurst is used the adjustments must be made in the spark-gaps and in the speed of rotation.

Radiography.—Proceeding now to the taking of radiographs it will be assumed that the reader has noted carefully the various directions as to the management of the apparatus, that his tube is in the right condition without need of "heating down," and that he has a whole-plate ready packed in a light-tight bag.

The only additional thing then needed for the first experiment is a sheet of $\frac{1}{16}$ in. lead about 8 in.

× 9 in. The wrapped-up plate which, up to the present moment, should have been safely stowed away in the metal box, preferably in another room, is now laid on the table with the film side upwards, that is, with the foldless side of the black envelope uppermost.

The tube must on no account be set working when once the plate is out of the box, until everything is quite ready for the exposure.

The hand to be radiographed is now laid flat on the plate, care being taken that the tips of the fingers and thumb are well within the margin.

The tube is placed in a horizontal position so that the centre of the anti-kathode is vertically above the centre of the plate, the fluorescent portion of the bulb being between the anti-kathode and the plate.

Here a digression may be made to discuss briefly the question of distance between the plate and the tube, and this involves a compromise between two conflicting advantages. An increase of distance means a lengthened exposure, but better definition and less distortion. What is meant by distortion in this case will be understood when it is remembered that the rays start from a point and proceed in straight, radial lines. The shadows which they cast behave, therefore, much as do the shadows thrown by a point of ordinary light. If the object be at a great distance from the light the angle subtended by it is small and the direction-lines of the radiation are nearly parallel, the shadow of the object being but very little larger than the object itself.

If, however, the object and screen be brought near to the light the subtended angle is large, and the divergence great, the shadows being consequently considerably magnified.

This happens also when the X-ray tube is brought too near to the plate. The best distance depends on the subject, the particular qualities of the apparatus and the length of time available for taking the radiograph. For a hand it should be at least 6 in., preferably 10 in. or 12 in., while 9 in. or 10 in. is a minimum for an arm or the lower part of a leg. For the thorax 18 in. or 20 in. will give good results, but if the apparatus is not powerful and a radiograph is absolutely necessary, less must suffice. 10 in. is a good standard distance for all simple work with a good coil.

Matters having been adjusted as directed, the tube being firmly held and the wires free from possibility of sparking to anything or piercing the tube, a trial exposure is made in the following way :—

Trial Exposure.—Suppose that, from the data given below, the experimenter expects an exposure of about 1½ minutes to be necessary. The current is turned on, the subject of course keeping his hand perfectly still, and at the expiration of ½ minute the coil is stopped, about 1½ in. of the hand at the finger-end is covered by the lead plate, and another half-minute exposure is given. The plate is now moved so as to cover another 1½ in. and a third half minute is given and so on until there is only one small strip left uncovered. If the lead plate so used causes inconvenience, it made be made to rest on suitable

Plate II.

Successive Trial Exposures from 10 to 40 seconds, 9″ spark coil. Cossor's Bianodal Tube warmed down to 3½″ alternative spark. Edwards' Kathodal Plate (whole-plate size). Distance between tube and plate 12″. Metol Quinol Developer applied for 20 minutes as described in text.

wooden blocks placed so that it bridges the hand without touching it.

If a whole plate has been chosen it is now divided into differently exposed strips whose time values are ½, 1, 1½, 2, 2½ and 3 minutes.

If there is much doubt as to what may be expected the difference between each exposure and the next may be made greater, but in any case a record must be kept of all the exposures.

The plate is now ready for development, but before proceeding to this stage, a few words may be said about comparative exposure.

It should be *always* borne in mind that as the rays practically emanate from a *point* on the anti-kathode their intensity is proportional to the square of the distance from that point. For example, if, with the anti-kathode at 6 in. from a hand, an exposure of 2 minutes is required, the exposure necessary, when the distance is increased to 12 in., is not 4 minutes (2×2) but is 2×2^2, that is 8 minutes. Mr Lewis Wright gives the following figures for the exposure required for different objects, though in any given case there is nothing for it but trial, figures being given only as a rough guide.

1 in. spark coil.—Hand 20 minutes.

„ „ „ Coins in purse 10 minutes.

A hand may be radiographed with larger coils in 1 minute or even a great deal less.

Mr Wright also gives the following *comparative* values which are roughly applicable to any tube and coil

Plate III.

Radiograph of a Hand. Exposure 20 seconds in accordance with the results of the trials shown in Plate II., where the centre strip shows the best combination of contrast and detail. All conditions the same as for Plate II.

For the foot or ankle: three times what is required for a hand, and for the trunk ten times.

Other comparative results show that the arm or leg below the knee require about four times the hand-exposure. The upper part of the leg requires even more than the thorax, and the abdomen, the most difficult part, may even require 30 minutes with an apparatus which would give a good hand result in 1 minute or less.

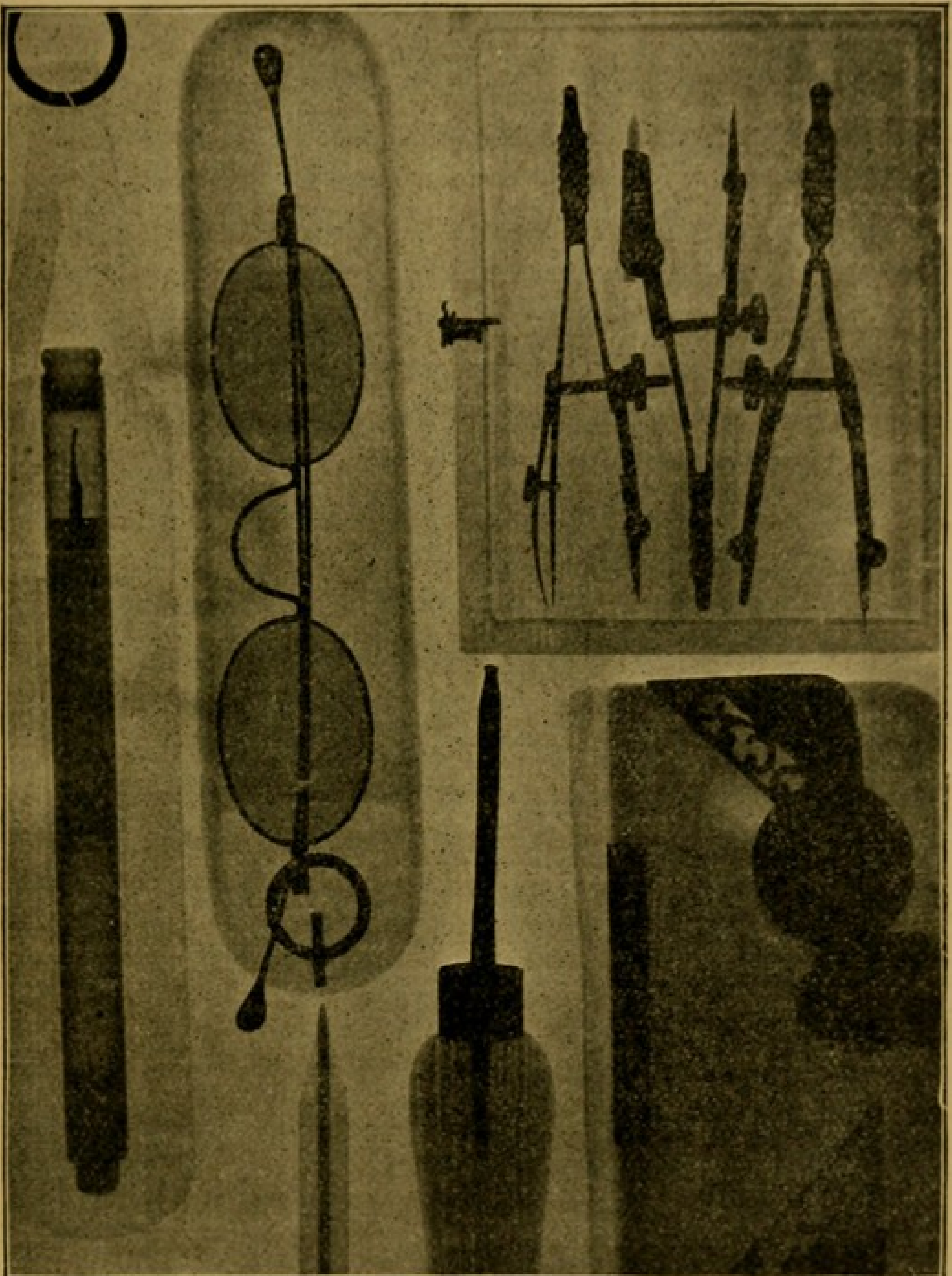
Dry Plates and their Development.—Any good make of rapid plates may be chosen, but the author invariably uses Edward's cathodal plates which are made especially for X-ray work, and are only second to the Lumière brand for this particular purpose. As the latter make is very expensive, the former, which produces excellent results, is recommended and the method of procedure to be adopted with it shall be described.

The developer is made up according to the following list of chemicals and proportions, and the two solutions, if kept separate, will last almost indefinitely.

No. 1.	Hydrokinone	150 grains
	Metol	50 grains
	Citric acid	20 grains
	Sodium sulphite	2 ozs.
	Water	20 ozs.
No. 2.	Caustic soda	150 grains
	Water	20 ozs.

Take equal proportions of No. 1 and No. 2 (about

PLATE IV.



Miscellaneous Group of Objects:—Fountain pen in case; spectacles in case; pencil, showing graphite; bradawl, showing grain of wood; instruments in wooden case; leather purse containing coin, and showing internal and external clasps and ornamental metal corners of flap. Conditions as for Plates II. and III., except exposure, which was 10 seconds.

4 or 5 ozs. will be sufficient for a whole plate) and mix them in a measuring-glass.

If the developer is below 60° temperature stand the measuring-glass in warm water and continually stir its contents until they have reached that temperature.

Dust the plate carefully and lay it film upwards in the tray, then pour the developer evenly and quickly over it, giving the dish one or two sudden sideway jerks to detach air-bells.

Cover the plate as usual (for even the dark-room light will easily fog rapid plates), and rock gently. After 20 minutes' development with continual rocking remove the plate, rinse it, and immerse it in the usual fixing-bath, the rest of the proceedings being identical with those adopted for ordinary photographs.

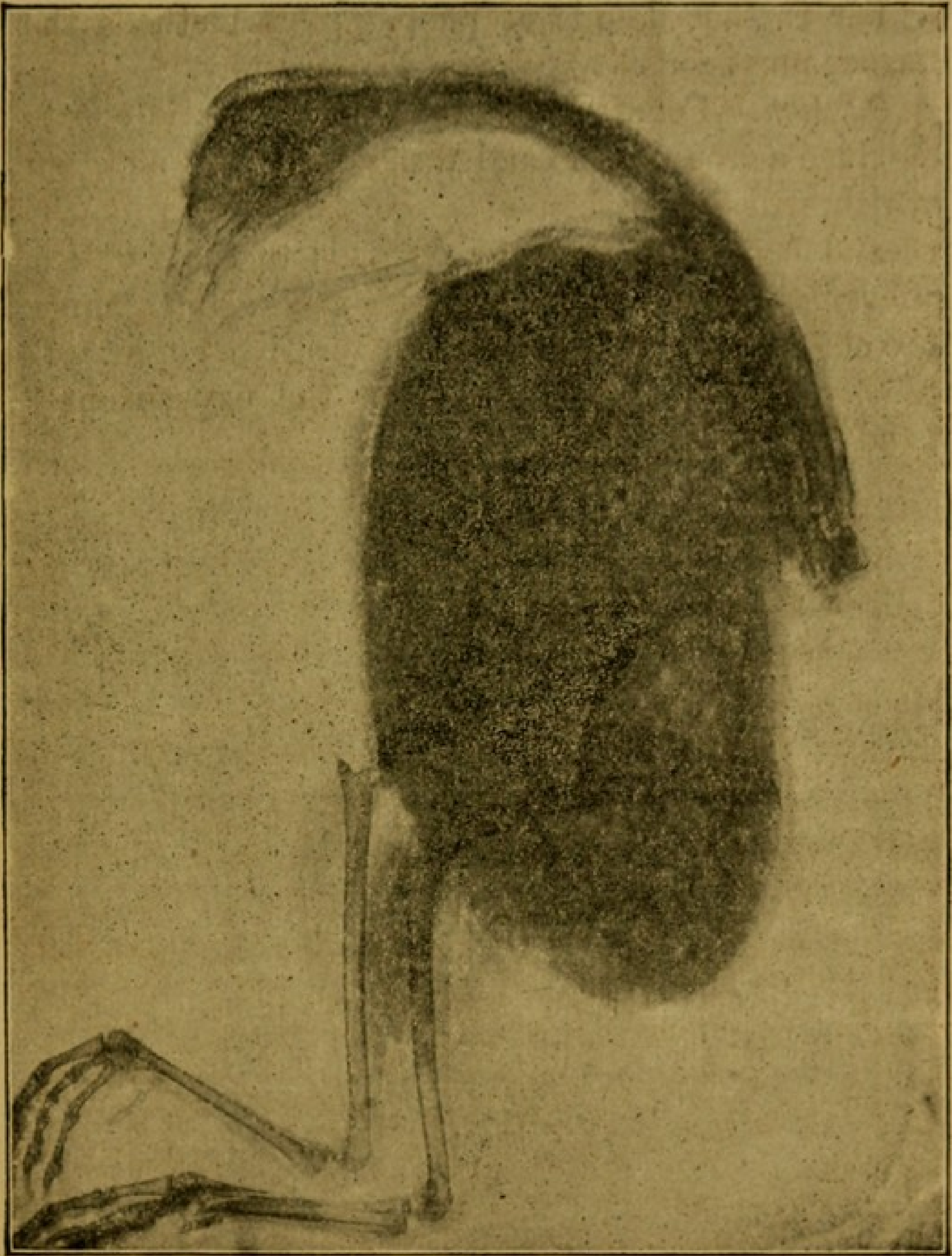
The long development is necessitated by the thickness of the film.

Final Exposure.—The strip of the plate which shows the best detail and contrast is the correctly exposed part, and after this experiment an actual radiograph will be successful if the same exposure be given and the same proportions of developer at the same temperature used (see Plate III.).

In choosing between the strips it must be borne in mind that a longer exposure is required for the wrist and palm than for the finger-tips, and that a compromise must be made between them to get the best general effect.

Printing.—P.O.P. is almost invariably best for

PLATE V.



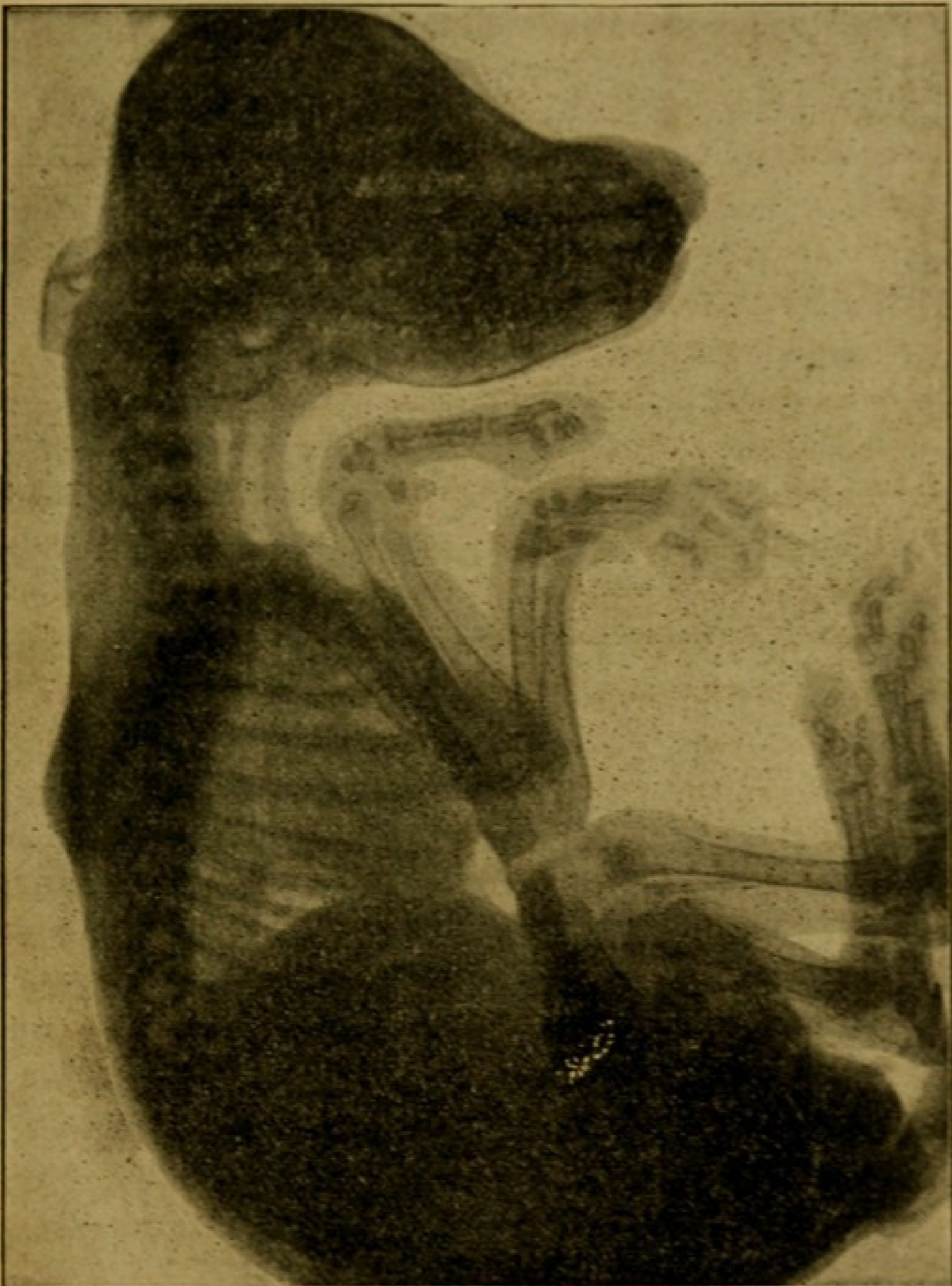
PARTRIDGE, SHOWING FOOT BROKEN BY SHOT. The curious dark patch in the middle of the body is the gizzard. Exposure 1½ minutes. Alternative spark 4″. Distance between tube and plate 18″. Other conditions as for Plates II. and III.

X-ray work though, if a print be urgently required it may be made on glossy bromide paper.

For further details of photographic methods the reader must consult books on Photography.

Caution.—Constant exposure to X-rays is apt to produce a troublesome and disfiguring skin affection which will be spoken of more particularly in the second book (see Preface). This is to some extent preventable as the rays which behave in this manner are chiefly those of the least penetrative power. If much X-ray work is being done the experimenter is advised to wear leather gloves.

PLATE VI.



PUPPY, two months old. The photograph shows the unformed condition of the bones, the joints being chiefly of cartilage. Note the wind-pipe. Exposure 1 minute. Distance between tube and plate 12". Other conditions as for Plate V.

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