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P

Practical Radiography.

A Handbook of the Applications of the X-Rays, with many Illustrations.

By A. W. ISENTHAL and
H. SNOWDEN WARD.
(Editor of "The Photogram.")

THE SECOND EDITION.

Entirely Re-written and Up-to-date.

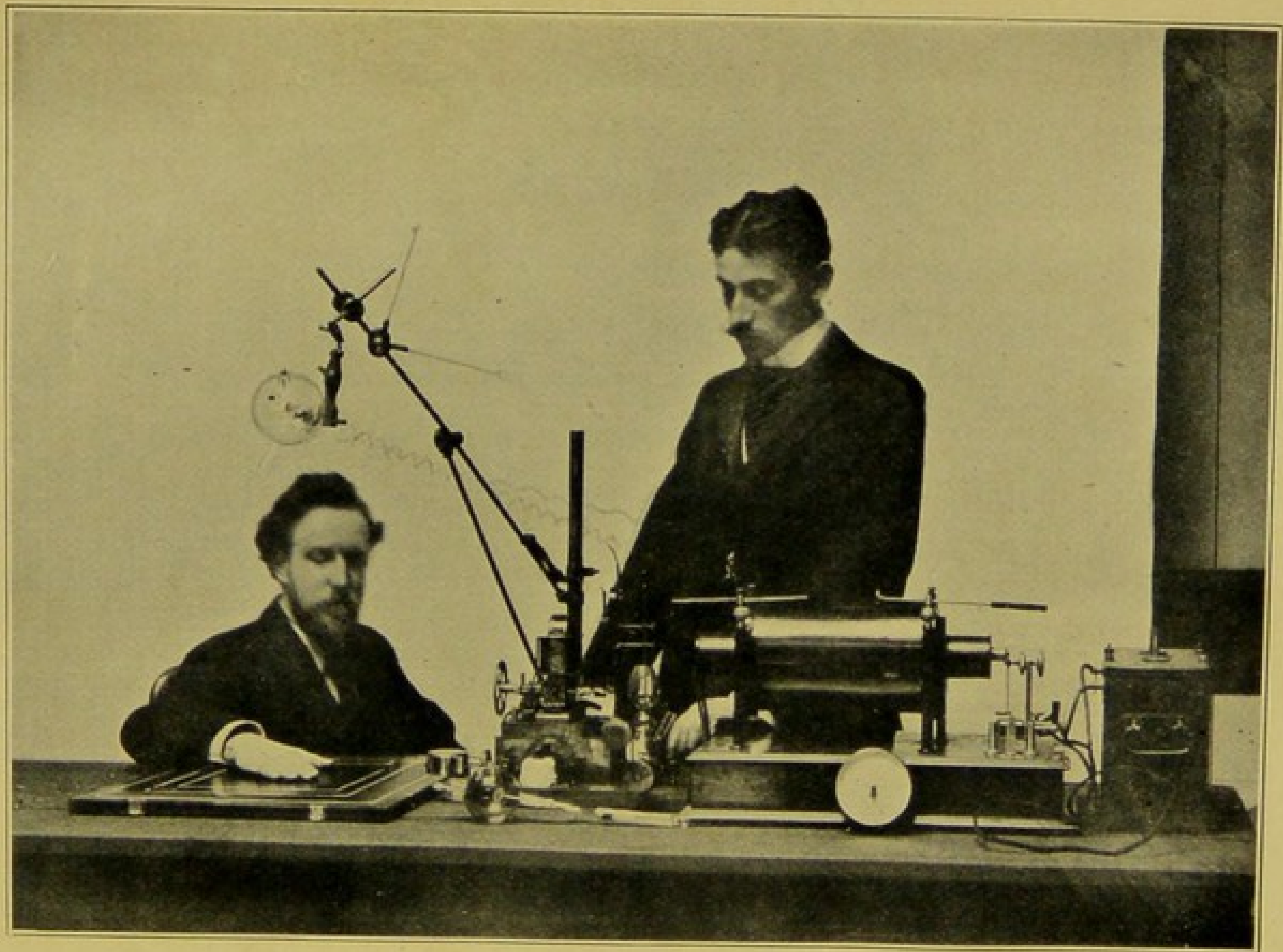
Published for The Photogram, Ltd.,
BY
DAWBARN & WARD, LTD., 6, FARRINGDON AVENUE, LONDON, E.C.
1898.

5

Introduction to Second Edition.

THE first edition of this little book, issued in May of 1896, when the subject of which it treats was less than six months old, had become so far out of date as to render necessary a complete re-writing. The original writer, feeling that many workers had passed far ahead of himself in practical acquaintance with Radiography, cast about for one of these specialists to assist in preparing the second edition, and was fortunate in obtaining the co-operation of Mr. A. W. Isenthal, whose work has been so thorough that practically nothing of the original little book remains.

We wish to sincerely thank all who have assisted, by communicating from their experience, or by loan of their radiograms for reproduction. Their assistance is acknowledged in detail in various parts of the book. At the same time, we would urge upon all into whose hands these lines may fall, that they contribute to the sum of our knowledge, as they may have opportunity, as freely as those early workers in the subject whose names are honored amongst us. For such contributions there can be no better medium than The Röntgen Society; of which Prof. Silvanus Thompson is the President, and of which the Secretary is David Walsh, M.D., 187, Gloucester Terrace, Hyde Park, W.



A Radiographic Outfit.

(Arranged for a demonstration by A. W. Isenthal, before The Royal Photographic Society, Feb. 22nd, 1897.)

The Authors as Operator and Subject.

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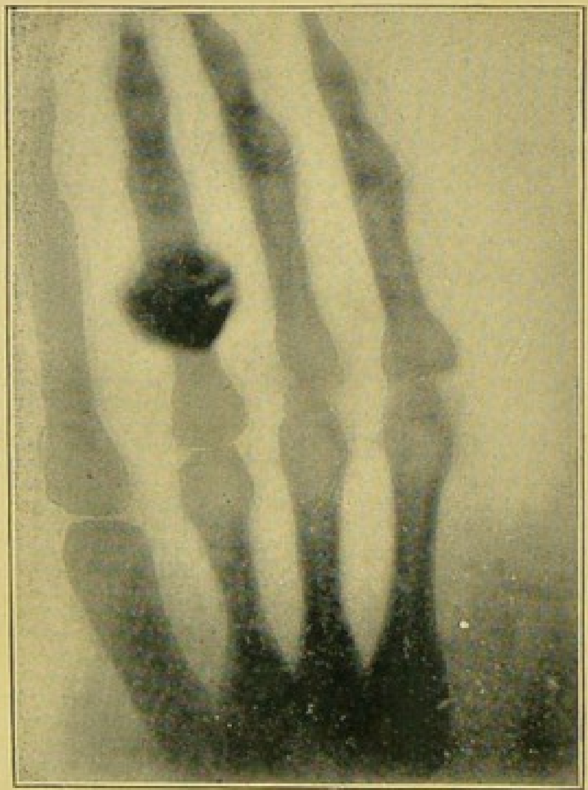
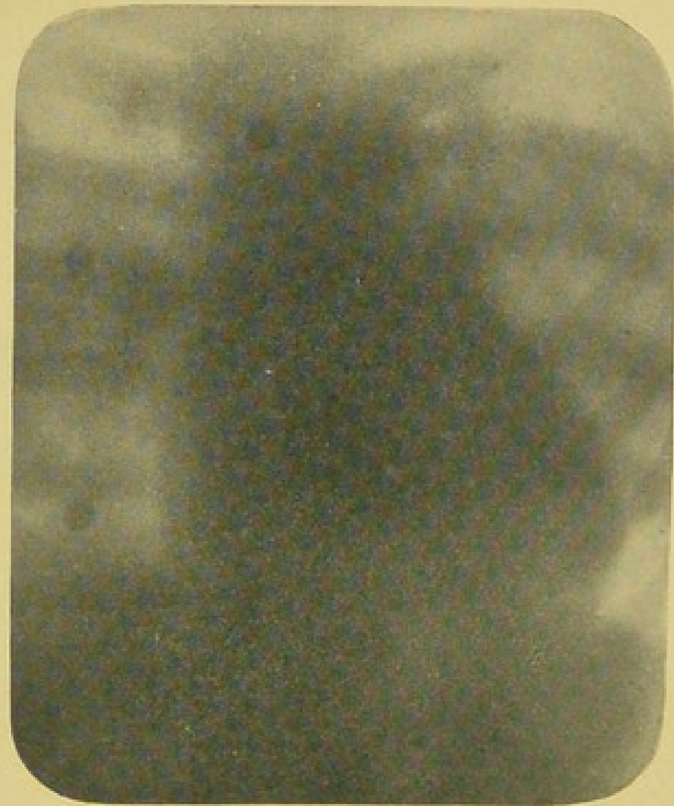


The Earliest Radiogram.

Hand of Prof. Röntgen ; radiographed by himself.



The Human Heart; *in situ.*

Earliest radiogram of this subject.

(By Dr. Macintyre.)

CHAPTER I.

HISTORICAL REVIEW.

ALTHOUGH to the physicist the discovery of Prof. Röntgen meant but another most important advance in the evolution of our knowledge of Nature's most intimate secrets, yet to those who have not closely followed the series of investigations begun by Sir William Crookes and now so successfully applied to practical uses by Prof. Röntgen, its announcement came so unexpectedly that absolute incredulity but slowly gave way to scepticism, which ultimately became transformed to awe and wonder. Our notions of opacity and transparency, which were exclusively derived from everyday observations, had to be entirely modified. In connection with one form of energy only—light—were we in the habit of applying the terms transparency, translucence and opacity, denoting the degree to which light is able to pass through certain media and affect the retinas of our eyes. We call glass transparent and gold opaque, although a sufficient thickness of the former and a very thin film of the latter behave in quite the reverse way. Again, if we analyse white light by means of a prism into its constituent spectral rays and take any one colour, say for instance red, we find that such rays will not pass through green glass, being absorbed by the glass, which even in thin films must be considered opaque to this particular kind of light.

The various colours of the spectrum are produced by different frequencies of the transverse vibrations of the luminiferous ether, which we perceive as light. This ether is capable of vibrating at widely different frequencies, thus producing the phenomena of electro - statics, electro - magnetism, of heat, light, photo-chemical action and all those various radiations which have their origin in certain forms of electrical discharge.

The visible spectrum is limited by the physiological constitution of our eyes and brains, and ranges from a deep red through orange, yellow, green, and blue to violet, the respective frequencies or number of ether vibrations per second having been found to lie between 395 billions for the red and 758 billions for the violet ends. The actually existing spectrum, however, is many times greater than the visible part, and its presence can be demonstrated in various ways.

Beyond the violet end, or as we call it, in the ultra-violet spectrum, we find energetic photo-chemical action for ten times the length of the visible part, the frequencies rising to 1485 billions per second, and fluorescent action to nearly twenty times the extent of the visible spectrum. Beyond the red end of the visible spectrum (for a distance of fifty times the visible length) in the infra-red part there are to be found the heat rays, which have been most carefully studied by Prof. Langley, with the bolometer, and by Prof. Rubens. Some of these rays have only a frequency of twelve billions per second, and show well-marked peculiarities, for instance in their ability to pass through certain substances. A solution of bisulphide of carbon, which to luminous radiations is completely opaque, offers no obstruction to dark heat waves, whilst on the other hand a clear aqueous solution of alum cuts off 88 per cent of all heat rays. Going still further in the infra-red direction, the frequencies of the ether-vibrations become slower still, and their wave lengths correspondingly larger, until we enter the range of electro-statical radiations with frequencies of only a hundred millions and wave lengths of several metres.

The first investigator to point out and mathematically establish a connection between electricity and light was Prof. Clerk Maxwell, who in his treatise on the "Electro-magnetic Theory of Light" (1864), showed that "since luminous and electro-magnetic waves are transmitted in one and the same medium, and with the same velocity, they are identical in kind." Prof. Hertz, of Bonn, in 1888, succeeded by his beautiful researches on electric waves in experimentally demonstrating Prof. Clerk Maxwell's theory; he showed that these long waves follow precisely the same laws of reflexion, refraction and polarisation which govern the infinitely smaller light waves; and Prof. Oliver Lodge, and later on Prof. Righi most successfully continued these researches, working with shorter electric waves and elucidating the polarisation of such waves.

Reverting again to the question of opacity and transparency we find some startling results. Solid bodies like glass, wood and stone are quite transparent, whilst metal is opaque and reflects the waves. Quite recently this transparency of most objects is being taken advantage of in order to transmit electric signals for considerable distances, and through intervening obstacles, like buildings, land, &c., without the aid of telegraph wires. These waves represent at present the extreme end of the infra-red spectrum, although no finality can be reached. The ultra violet extreme is represented by certain vibrations which are of paramount importance for our subject.

If we enclose the sparking points of a Rhumkorff or Apps coil within a glass tube and gradually exhaust the air from this tube, the visible electric discharge between the points undergoes a series of changes, its appearance of a bright and well-defined spark or stream changing to a broad luminous ribbon which, when the gas pressure within the tube sinks below ½mm., breaks up into various striæ separated by dark bands, their colour depending upon the degree of vacuum and the nature of the residual gas or vapour. Such tubes are well-known under the name of their original maker—Geissler.

Sir William Crookes made an exhaustive series of experiments on these discharges in very highly exhausted tubes and succeeded in attaining by mechanical and chemical exhaustion vacua registering only 1-2000th of a millimeter, or about a twenty millionth of an atmosphere. Under these extreme conditions the residual matter in the tubes becomes invested with some altogether new properties, which Prof. Crookes has fully dealt with in his lectures before the Royal Institution in 1879, and again summarised in his Presidential Address to the Institution of Electrical Engineers in 1891, entitled "Electricity in Transitu: from Plenum to Vacuum." It is here but possible to briefly outline some of the phenomena with which we are more intimately concerned.

In a Crookes' vacuum the striæ have entirely disappeared, and the dark space which at lower vacua separated the striæ from the negative terminal or *cathode* has increased to the full volume of the tube, the interior of which shows no luminous discharge A discharge is still proceeding, however, but no longer from terminal to terminal. It is now propagated in a rectilinear way from the surface of the cathode, no matter what be the position of the positive terminal or anode. This dark discharge is now generally termed the cathode stream, and produces a vivid fluorescence wherever it strikes the glass wall of the tube or any similar materials (marble, shells, gems) which are brought in its path. In other words, the cathode rays, which are partly invisible, are partly absorbed and their energy re-emitted in the form of ether vibrations of such an order that they produce a sensation of light. If we bring the cathode rays to a focus, by forming the cathode as a cup, we produce a strong thermal effect. If the glass wall of the tube happens to be near the focus the glass will rapidly soften, and in consequence of the outer atmospheric pressure will become perforated; or a thin metal plate will rapidly become intensely heated when the cathode rays are focussed upon it. Chemical effects may be shown by the blackening of sensitive photographic films; mechanical effects are demonstrated by means of delicately suspended wheels with mica vanes in the tube, &c. Another very important characteristic of the cathode rays is their deflection by magnetic forces, the amount of deflection for a certain magnet depending upon the vacuum in the tube. As regards the opacity and transparency of bodies to these rays it may be stated that the latter pass easily through thin metal foils, cardboard, wood, &c., but are completely stopped by the glass of the tube, by thick metal and by quartz.

In the earlier experiments by Hittorf and Crookes only the cathode rays within the tube were observed. In 1894 Prof. P. Lenard, the former assistant of Prof. Hertz, carried on some classical experiments in which he substituted at one place a thin foil (window) of aluminium for the glass wall of his tube and succeeded in tracing the existence of some cathode rays outside the tube in the surrounding air of ordinary atmospheric pressure. These external rays preserved all the characteristics of the true cathode stream as regards their fluorescifient and photographic action, their rectilinear propagation, penetration, and deflectibility by a magnet, although in the latter respect some heterogenity of the radiation was even then shown to exist. Lenard and Goldstein also made use of the chemical action of the cathode rays to produce photograms of metallic objects through intervening wood and cardboard, and even aluminium.

Next, and most important of all, came Prof. K. W. Röntgen's communication in December, 1895, to the Physio Medical Society of Würzburg, which contains the announcement of a new kind of rays, called, in the absence of any definite indication of their true nature, the X rays.

Prof. Röntgen made his discovery whilst following up some of Hertz's and Lenard's investigations by means of a Crooke's tube covered with light opaque cardboard, and it was the fluorescence of a specially prepared paper lying some distance from the tube which drew his attention to the probable existence of some new kind of radiant energy, which would penetrate through opaque substances such as cardboard. Further experiments demonstrated the fact that this radiation, whatever it be, exhibited photo-chemical effects, and amongst the various objects interposed between the source of radiation and the sensitive plate was Prof. Röntgen's hand. The resulting image of the bones inside their fleshy coverings at once suggested the tremendous possibilities of the discovery, and it was the immediate cause of the enthusiasm with which it was received—not only by the scientific world, to whom it suggested new problems and for whom it opened out a new field of fascinating research, but by all intellectual classes, the world over; an enthusiasm which for intensity and permanence surpassed any which had been previously evoked by other scientific achievements.

Prof. Röntgen's two original papers on the subject are masterpieces of thoroughness and scientific accuracy; and it is certainly remarkable, that notwithstanding the incessant work of the ablest investigators since 1896, no further fundamental facts have been brought out with regard to the nature of the X Rays.*

Broadly speaking, the new Rays exhibit many analogies to the cathode—and the Lenard Rays, differing only in degree. They are thus able to excite fluorescence, to affect light sensitive films, to proceed rectilinearly from their source, and to be subject to a selective absorption in their passage through solid bodies, which absorption stands in a certain relation to the atomic weight of these bodies. The X Rays show no regular reflection, no appreciable refraction, polarisation, or diffraction, and they discharge like Cathode Rays (and ultra-violet rays) electrified bodies. In one respect, however, do they differ fundamentally from Cathode Rays, in so far as even the most powerful magnetic fields are unable to deflect the Röntgen Rays.

We are, as far as the immediate practical object of our book is concerned, exclusively dealing with the selective absorption of the Röntgen Rays; but in so far as the scientific aspect of the new radiation is most fascinating and also largely bound up with probable future development of radiography, we shall treat of the theoretical part in a special chapter at the end of the book.

This short review would not be complete without mentioning the numerous names under which our subject is spoken of:

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* Prof. Röntgen's original paper, with reproductions of his earliest radiograms (including the first picture of his own hand, and with other papers and many illustrations), was published as a special issue of *The Photogram* early in February, 1896. This special issue, entitled *The New Light*, and *The New Photography*, may still be obtained. Price 3d.; post free 4½d.

Röntography, Shadowgraphy, Skiagraphy, Ixography, Pyknoscopy, Electrography, Scotography, Kathography, Fluorography. Actinography, Diagraphy, Radiography. The latter term, introduced by Dr. Hill Norris, is by far the most suitable and popular, and will be retained throughout these pages.

CHAPTER II.

APPARATUS.

THE generation of the X rays for practical application being at the present stage of our knowledge entirely an electrical process, it will be necessary at first to consider the various sources whence we derive electrical energy.

First, in the chronological order, we ought to deal with the machines for the generation of frictional electricity, but since they occupy at present a minor position amongst our up-to-date outfits, they will be described at the end of this section.

GALVANIC BATTERIES.

Without going minutely into electro-chemical theories, it behoves us to briefly explain the fundamental phenomena which are made use of in the construction of "electric batteries."

A galvanic cell is a combination of metals and solvents, which is able to convert chemical actions (representing a certain amount of energy) into an electric current.

The simplest form of a galvanic cell is given by a couple of chemically different metal plates, say one of copper and one of zinc, which are partly immersed in a vessel containing a dilute solution of sulphuric acid (Fig. 1). Each metal, owing to chemical action, becomes charged with electricity; in our example the zinc negatively, the copper positively. If we connect the two metal plates outside the liquid (electrolyte) by means of an electrical conductor (say a wire) the two electrical charges tend to combine, thus setting up a flow of electricity, or, as it is properly called, an electric current through the cell.

What we term the positive current flows from the copper plate through the outer metallic connection (or circuit) to the zinc plate, and from there through the electrolyte back to the copper. The negative current starts outside the electrolyte from the zinc and flows in the opposite direction. These electric currents are maintained as long as the chemical action continues, for this provides the driving power, or as it is termed, the electromotive force (E.M.F.) of a galvanic battery.

The absolute value of the E.M.F. depends solely upon the chemical character of the cell, and its maximum (for practical purposes) is attained in those cells, the electrodes of which are respectively zinc and carbon. The size of the cell has absolutely no influence on the E.M.F.

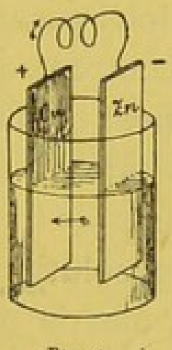


Fig 1

The value of the *electric current* obtainable from a given cell depends greatly upon the *size* of the immersed part of the electrodes (not upon their shape), increasing with the dimensions.

The *capacity* of a galvanic cell, that is, the length of time during which it is able to maintain a given electric current depends upon the mass of chemically active material it contains. It is, however, largely influenced and greatly limited by *Polarisation*. The effect of an electric current flowing through the cell is to decompose the electrolyte (water) into its constituent chemical elements in such a way that these accumulate in the form of gas bubbles round the electrodes, which they cover, and thus interfere, more or less, with the chemical activity between liquid and metal; so that the resulting E.M.F., an with it the current, rapidly decrease. This polarisation may be got rid of to a considerable extent by either mechanically or chemically removing the gas bubbles. The latter method is always resorted to in the so-called *Constant Batteries*. The positive electrode, on which the hydrogen appears, is usually surrounded by some oxydising material, such as nitric or chromic acid (separated from the proper electrolyte by a porous partition) which liberates oxygen, and thus with the hydrogen developed forms water.

From a consideration of the above characteristics we may now select those types of galvanic cells, which would be best suited to our purpose. It will be necessary, however, before so doing to shortly introduce to the reader some very simple but exceedingly important relations governing the application of any type of battery or source of current, and also the more important units, which have been adapted for the various electrical factors.

The unit of the E.M.F. is called a *volt*, and is about equivalent to the E.M.F. of a cell having for its electrodes zinc and copper, and for its liquid an aqueous solution of copper sulphate.

The unit of resistance, that is of that physical factor of a conductor, which (similar to friction in any kind of motion) tends to obstruct the passage of an electric current, is called an *ohm*, and represents the resistance of a column of mercury (at 32° F.) of one square millimeter section, and 1·06 metres in length.

The unit of current is called an *ampère*, and is present whenever an E.M.F. of one volt is acting in a circuit of one ohm resistance. The above electric definitions are in a certain dependency to each other, which is expressed by *Ohm's Law*:

$$\text{Current} = \frac{\text{E.M.F.}}{\text{resistance}}$$

The current equals the E.M.F. divided by the resistance—and this enables us to deal with the various questions arising during the use of batteries.

The resistance in the case of a galvanic cell sending current through a circuit is made up of the resistance of the circuit plus the resistance of the cell itself (internal), which latter decreases with the size of the immersed plates, and increases with the distance of the plates.

Example: A galvanic cell, having an E.M.F. of two volts, and an internal resistance of 0·3 ohms when working in a circuit of 0·15 ohms produces a current of

$$\frac{2}{0·3+0·15} = 4·44 \text{ ampères.}$$

Since both the E.M.F. and the current which we can produce from certain cells are greatly limited by some specific peculiarities, we must resort to *combinations* of several cells in order to obtain a higher E.M.F. or larger currents.

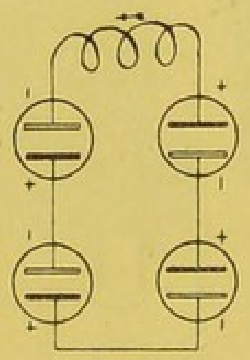


Fig. 2.—Series Connection.

Any such combination of cells is called a *battery*, and we distinguish two typical combinations, namely, *series* and *parallel*.

Connecting in series. — By connecting each negative electrode with the positive electrode of the following cell, forming a simple chain, we add the respective E.M.F's of the various cells together, their sum being available between the free ends of the first and last cell. The resistance of the combination is given by the sum of the individual cell resistances.

Example: Taking 4 cells of the same kind as in the previous example, and connecting them in series, we obtain from the combination a current:

$$C = \frac{4\times 2}{4\times 0·3+0·15} \text{ or about 6 ampères.}$$

Connecting in parallel.—By connecting up all the positive electrodes of a number of cells, and similarly all the negative electrodes, we add together the active surfaces of the cells, thus reducing the resistance of the combination, and obtaining larger currents.

Example: The same four cells arranged in parallel give a current:

$$C = \frac{2}{\frac{0{\cdot}3}{4} + 0{\cdot}15} \text{ or about } 8{\cdot}8 \text{ ampères.}$$

This latter combination may also be resorted to when each cell gives sufficient current, but when it is desired to increase the capacity of the battery.

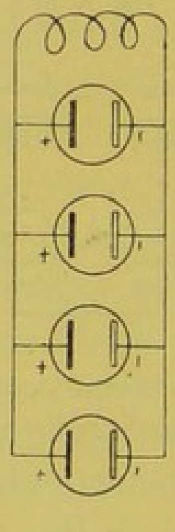


Fig. 3.—Parallel Connection.

Besides the two above combinations there are a great number of other connections representing amalgamations of the typical cases, but since, as a rule, suitable cells may be purchased in the first instance, we need not further consider these combinations.

Although the number of existing types of cells is immense, our choice for a suitable battery is rather limited, since but few cells satisfy the conditions which are necessary for effectively working an induction or spark coil, viz., high E.M.F., large currents, and great constancy and capacity.

We give below a table comprising the best types and some of their electrical particulars.

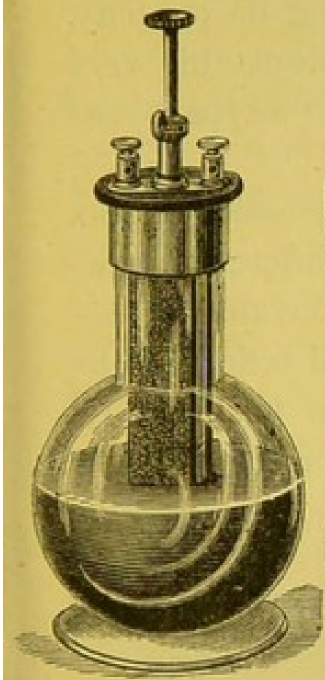


Fig. 4.

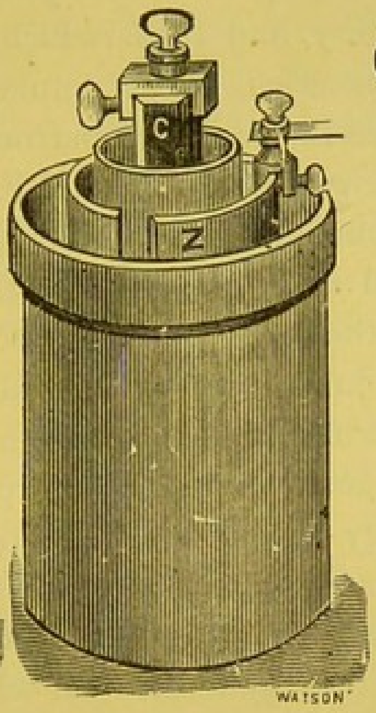


Fig. 5.

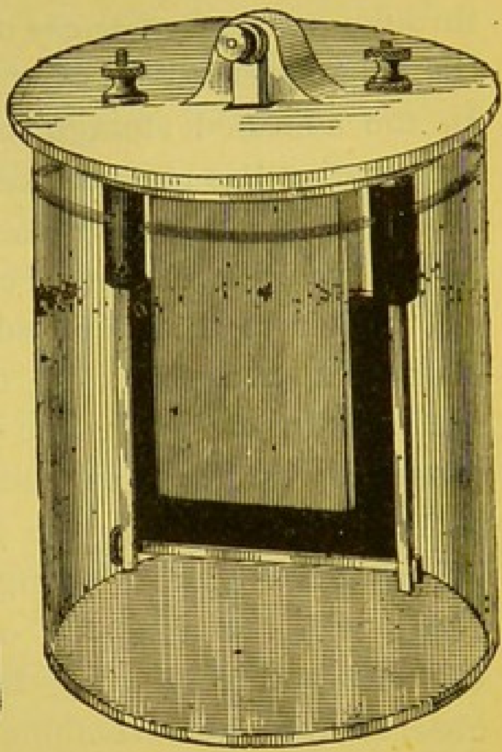


Fig. 6.

Name	Construction	E.M.F.	Capacity
Bichromate cell	*Zinc* and *carbon* in solution of 1 oz. Bichromate of Potash 10 oz. water 2½ oz. sulphuric acid 3 oz. bisulphite of mercury	volts 1·9	6 large cells (qt size) will work 8in coil for two hours. [Fig. 4
Bunsen Grove	*Zinc* in dilute sulphuric acid (1 pt. to ten parts) *Carbon* or *Platinum* in nitric acid or in saturated solution of nitrate of soda and nitric acid (equal parts) and a little bichromate of soda.	1·1-1·9	6 to 7 hours [Fig. 5
Edison Lalande	*Zinc* and oxide of *copper* in solution of 1 lb. caustic potash 3 lb. water.	0·85	3 sizes of 25, 50, and 100 hours respectively at 6 ampères. [Fig. 6

STORAGE BATTERIES.

We have seen that the passage of an electric current through a primary battery sets up an electrolytic action causing the polarisation of the battery, and thus reducing its capacity. In the so-called storage batteries, or accumulators, this very polarisation has been utilised in order to construct a type of cell which possesses great capacity and a high E.M.F.

If we send an electric current from a primary battery into a cell similar to that depicted in Fig. 1, with the difference, however, that two plates of the same metal—preferrably lead—are substituted for the zinc and copper, a chemical action will be produced, resulting in the formation of peroxide of lead ($Pb O_2$) on the plate to which the positive pole of the primary battery was connected, and of spongy metallic lead (Pb) on the negative plate. On removing the outside supply of current—charging current—and connecting the two lead plates by a wire, we observe that the combination generates an electric current having a direction opposite to that of the charging current. Whilst this discharge is maintained the chemical condition of the plate-surfaces undergoes a change: the peroxide of lead is reduced to oxide of lead (Pb O), the spongy lead is oxidized to lead oxide as well, until the two plates are again chemically identical, when the combination becomes chemically and electrically inert until by a fresh electrical charge the process is repeated.

Such combinations have been termed *Secondary or Storage Batteries*, or *Accumulators*, although the former name must not be taken to imply that electricity is stored, since we only accumulate or store its primary cause, viz., chemical energy.

Of accumulators we have two distinct types, called after their inventors, the *Planté* and the *Faure* type respectively.

In the former, which was the original type, we have solid sheets of lead for electrodes, which, either by a special method of casting or by chemical means, are made porous and suitable for being converted into active material—peroxide and spongy lead—through the repeated process of charging and discharging (forming).

In the Faure system the active material is prepared before hand, and spread on a suitable support or grid of lead in such a way that it is well retained and offers but a slight electrical resistance. The active materials are, for the positive plates, a mixture of red lead and sulphuric acid (50 per cent.), and, for the negative plates, either litharge and sulphuric acid or porous lead. This system almost dispenses with the necessity of preliminary "forming."

As the *capacity* of an accumulator depends upon the amount of active material which is in contact with the Electrolyte, it may be understood that this capacity reaches its maximum after the accumulator has been several times charged and discharged; since by these means the layer of active material gradually gets thicker and more porous.

Most accumulators, instead of possessing only two plates, have several negative and several positive plates connected "in parallel," so as to keep the size of the accumulators within reasonable limits. The plates are suspended or otherwise suitably supported in glass or ebonite boxes, which, for convenience and portability, are enclosed in wooden boxes. The great advantage of an accumulator consists of its high and constant E.M.F., which, during discharge, is practically maintained at two volts. Its size also is very compact when compared with primary batteries of equal capacity. Capacity is usually expressed in "Ampère-hours": that is to say, the number of hours for which the accumulator may be discharged with a current of one ampère. From this figure we can calculate for what length of time we may discharge with any other current that may be within the limits allowed by the makers of such accumulators.

If the guaranteed capacity of a certain type of accumulator be, for instance, thirty-two amp. hours at the maximum discharge of eight ampéres, then we may use the battery at one charge:

With 1 ampère for 32 hours				normally.
" 2 " " 16 "				
" 4 " " 8 "				
" 8 " " 4 "				

Should we find it necessary to discharge with stronger currents for short periods, then we need, in a well-constructed accumulator, have no fear of damaging the battery in so doing, although we would thereby somewhat reduce the capacity for that particular charge only.

The outside source of electrical energy we have to use for charging may be a primary battery, a thermo battery, a dynamo, or the electric light supply, if it be of the continuous system. Primary batteries, as may be seen from a numerical example, are hardly advisable for this purpose.

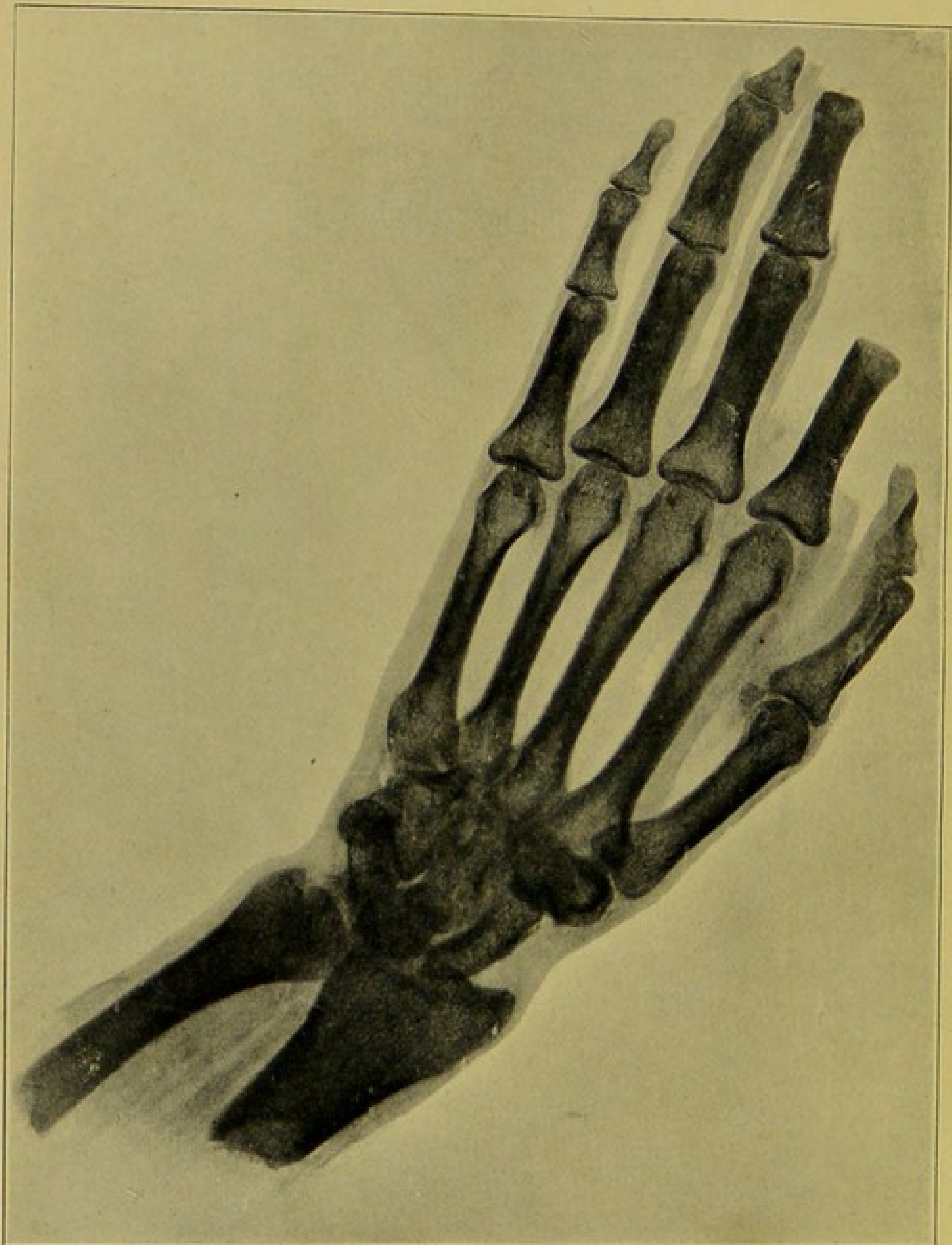
The initial E.M.F. of each accumulator being 2.5 volts, a six-cell storage battery requires about fifteen volts for charging. If the capacity of the accumulator be 33 amp. hours, and our primary charging cells give 1.5 volts and 3 amp., these cells would have to discharge continually for eleven hours, which is not possible, owing to the polarisation. It would become necessary to use twice the number of cells—that is, twenty in two parallel groups of ten each, which means expense, labor, and loss of time.

The suggestion to continually compensate for the discharge of the accumulators by keeping them connected to a primary battery during use is theoretically perfect, but too clumsy and expensive for actual work.

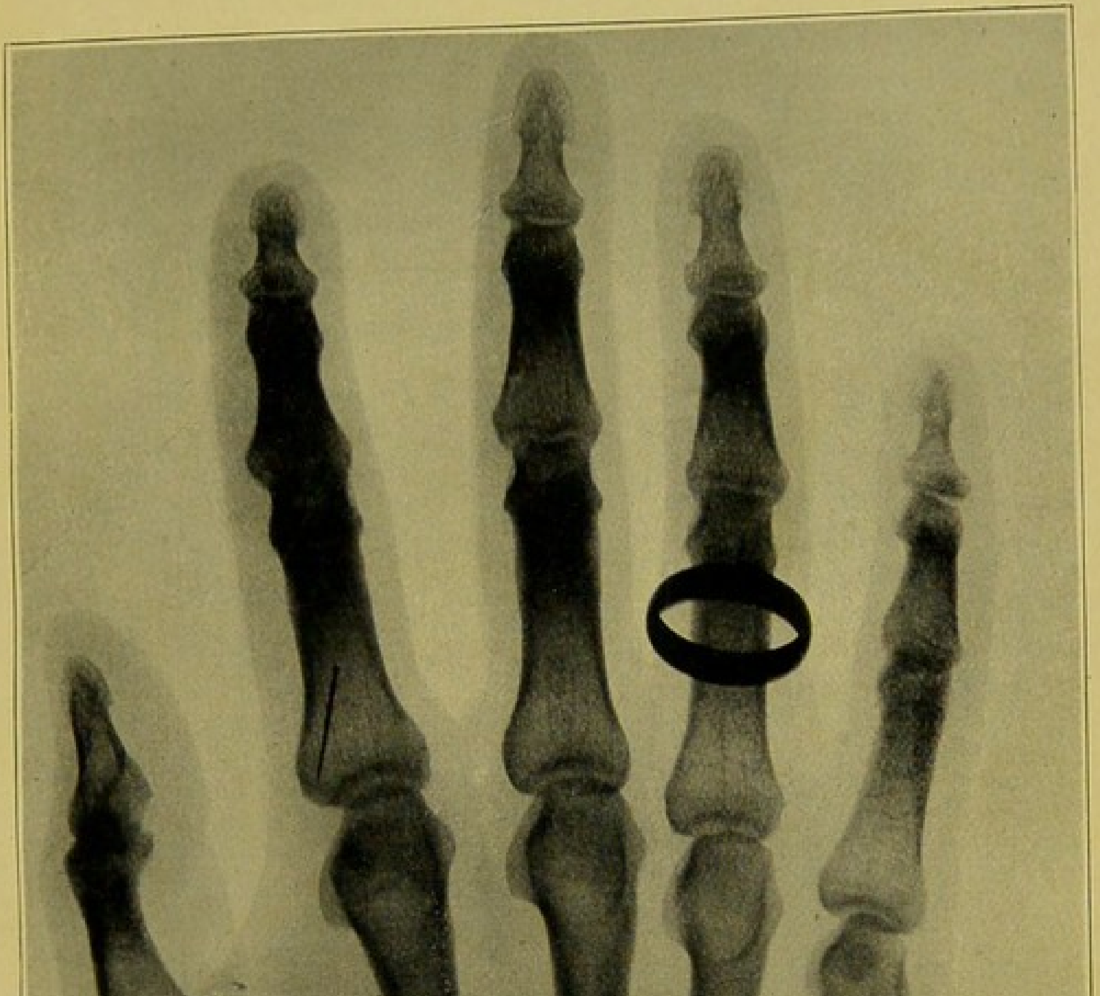
To other charging methods we shall revert in the Chapter on the Maintenance of the Batteries.

Both the Planté and the Faure types of accumulators are represented by very numerous makes.

As regards portability and capacity, we have found the *Q* type Cell (manufactured by the Electrical Power Storage Co., Ltd.) most satisfactory. These are built as single cells, or as 4, 6, 8, and 12-volt batteries, and are contained in teak boxes lined with ebonite, fitted with outside terminals and acid-tight lid.



Mummy's Hand. (By A. W. Isenthal.)



Hand with Needle and Glass Splinter.

For average coil work (up to 10" sparks), either the Q VII. or the Q XI. types are suitable. We give below some particulars of this type, which is illustrated by Fig. 7.

Type.	Current.	Capacity.	Weight.	Volts.
Q VII.	4 amp.	21 ampères	21 lbs.	8 volts.
Q XI..........	6.5 ,,	35 ,,	35 ,,	8 volts.
Q XXI.......	13 ,,	70 ,,	164 ,,	12 volts.

For accumulators which need not be taken about, or which can be charged in situ, a larger capacity will be found more useful and less expensive, both in first cost and maintenance.

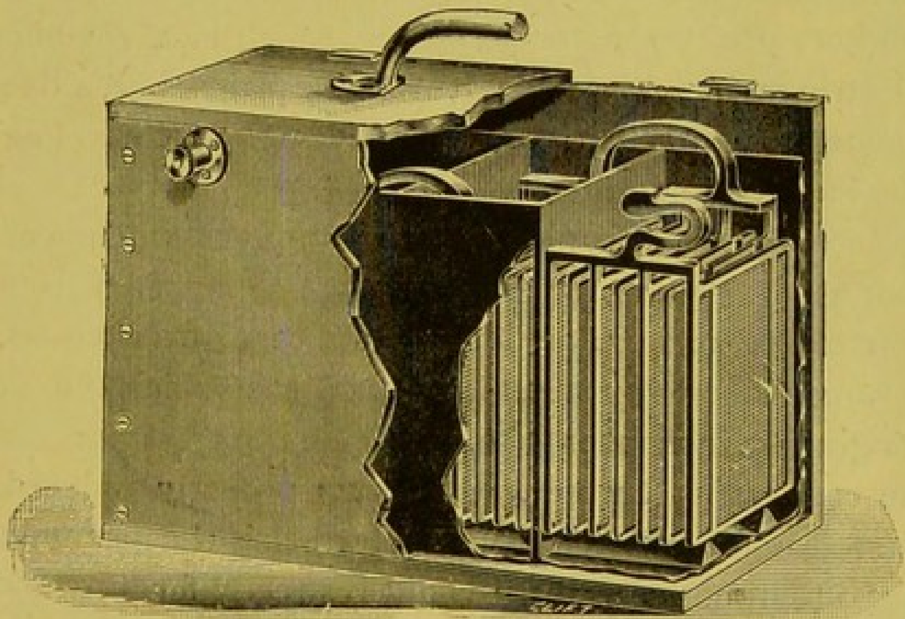


Fig. 7.

CONTINUOUS AND ALTERNATING SUPPLY CIRCUITS.

With the rapid increase in public and private electric lighting from electric central stations the use of electric supply circuits for working our radiographic instruments is daily becoming more general. The two principal systems of electric distribution—by continuous or by alternating currents—necessitate separate means of utilizing them for our purpose. In both cases, however, generally the first step to be taken is to reduce the E.M.F. or the electric pressure of the existing supply circuit, which in most instances averages 100 or 110 volts, to the working pressure of the coil, as fixed by its maker, which varies from 6 to 20 volts. This is accomplished by interposing between the supply wires and the coil a suitable resistance or rheostat, several varieties of which will be described later on. The exact amount of this resistance can be easily calculated from Ohm's law, but since the safety of both the radiographic apparatus and of the electric house installation itself depends very much upon the efficient and proper connection, it is advisable to have the work done by a qualified electrician.

In so far as rheostats waste a certain amount of energy and the contact breaker of the coil is subjected to severe usage, some workers prefer a motor-generator, which is a combination of an electric motor, driven direct from the mains, and a dynamo which generates sufficient current and of a suitable voltage to work the induction coil direct.

The economy of this plan becomes apparent when we consider that a motor-generator only takes 1 to 2 ampères from the mains instead of 10 to 20 ampères in the case of a rheostat, and for this same reason any small lamp circuit is sufficient to attach the radiographic instruments to.

The continuous current, when thus properly reduced, will work the coil most satisfactorily, besides being cheaper and more convenient than batteries, as it is always ready for use and requiries no further attention even when running the coil continuously for days.

The alternating current, when reduced in pressure, may be used to run a small motor-generator, which is the combination of an alternating current motor directly coupled to a small dynamo machine. The latter furnishes continuous current for the coil; more frequently, the alternating current is at first increased in pressure by means of a "step-up transformer" to about 2,000 volts, and is then utilised for the Tesla coil, which will be dealt with in the next chapter.

The continuous current supply is much the simpler to use, requiring no special apparatus and no special tubes, because it is unidirectional; that is to say, the positive current preserves the same direction throughout exactly as in the case of battery—or accumulator—or thermo currents.

The alternating current, however, constantly changes its direction, generally between 80 and 120 times per second, which produces entirely new phenomena, necessitating considerable changes in the transforming and generating instruments.

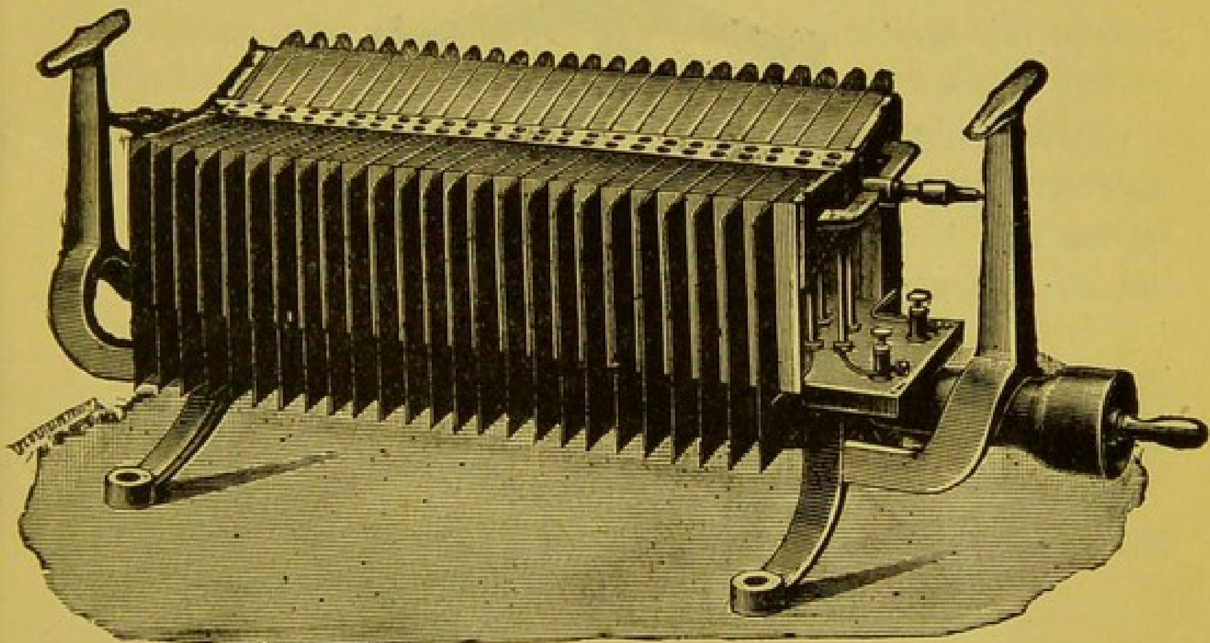


Fig. 8.

THERMO-BATTERIES.

In 1821, Prof. Seebeck of Berlin, found that an electric current was produced when heat was applied to one of the junctions of a circuit consisting of two different metals in contact. The generation of current also takes place when one of the junctions is cooled, or—generally speaking—whenever and as long as there exists a difference of temperature between the two junctions; the direction of the resulting current being always from the warmer to the colder junction and the strength of the current increasing with the difference in temperature. The E.M.F. of such a thermo-electric couple depends upon the nature of the metals in contact, and for practical purposes attains a maximum in the case of the couple *Bismuth-Antimony*, amounting to 0,000057 volts for each centigrade difference of temperature. In order, therefore, to produce any useful E.M.F. within workable limits of temperature we must connect several thermo-electric couples in series (similar to galvanic cells in series), that is, the antimony element of each couple to the Bismuth element of the next couple. Such a combination constitutes a thermo-electric battery or thermo-pile. In practice a very great number of

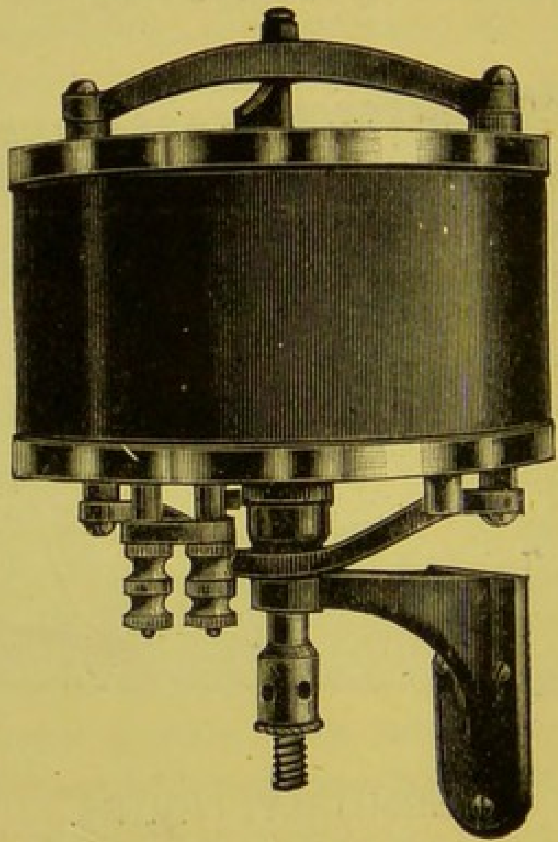


Fig. 9.

couples are joined to a battery, and are so arranged that the heat, which in most instances is furnished by an atmospheric gas burner, is directed to all the junctions of one kind, whilst the other junctions are either cooled artificially or are kept fairly cool by means of suitable radiating surfaces.

The most successful constructions are those of *Becquerel* (consisting of artificial sulphuret of copper heated to 200°—300°, and copper or german silver (90 parts copper and 10 parts nickel), of *Clamond* (consisting of an alloy of two parts of antimony with 1 part of zinc and tinplate), of *Gülcher* (fig. 8), and quite recently the Cox thermo-electric generator (fig. 9).

Such thermo piles generate an absolutely steady current even for months, so long as the difference of temperature between positive and negative junctions remains constant. They are very convenient, simple to use, and require little or no repair so long as they are not accidentally damaged.

A few seconds after the burner is lit they are ready for use, and they may be put aside for months without detriment to their after efficiency.

On the other hand their E.M.F. is very small, so that several batteries have to be connected up in order to work a coil, and as each battery is rather expensive, this source of electric energy is very costly in the first instance. Moreover, the direct conversion of heat, although theoretically the most desirable method of generating electricity is, as yet, with the present types of thermo piles a most wasteful process.

A thermo-generator of the latest type (Cox), which would satisfactorily work a coil, requires about 40 cubic feet of gas per hour, which when reduced to the same standard of comparison, would place thermo piles a long way behind other current generators as regards efficiency.

STATICAL MACHINES.

In all the preceding cases we produced electrical energy, the E.M.F. of which was comparatively low, so that we required such special transformers as will be described in the following chapter, in order to obtain the very high electrical pressure which Röntgen tubes necessitate.

Frictional or static electricity furnishes this high E.M.F. *direct*, and on this score offers certain considerable advantage for radiographic work On the other hand, the efficiency of this system has been much discussed, and the concensus of opinion tends to reject the use of statical machines for X Ray work. Still, although by far the greatest amount of useful work has n done with other apparatus, it would not be fair to ignore this system, since for light work and in many special instances it offers the greatest facilities.

It does not come within the scope of this work to explain the various phenomena of frictional electricity, and it must suffice for our immediate purpose to state that according to the generally accepted theory, every body originally possesses two exactly equal charges of positive and negative electricity, which exactly neutralise each other, so that as a rule the body does not exhibit any electrical property. If by some means we upset this balance and remove, say the negative charge, the remaining positive charge will assert itself in various ways, which we cannot here consider.

Statical machines are all based upon this principle, which has been put into practical shape in various ways. The older forms were very inefficient, and depended to a great extent upon atmospherical conditions, so that they are now almost entirely superseded by the more recent influence machines, in which a certain multiplication of the separated electricities takes place (by the influence of one charged body upon another) so that the resulting output of electrical energy is more ample and steady. Of the three representative types, the *Holtz*, the *Voss* and the *Wimshurst* machines, we can only consider the last named, which is doubtless the most efficient and reliable type, and with which the authors have obtained fair results. As will be seen from Fig. 10, it consists of several pairs of circular glass or ebonite discs mounted on a fixed horizontal spindle in such a way that they may be rotated in opposite directions at a distance of about ¼ in. apart; both discs are (when of glass) well varnished, and attached to the outer surface of each are narrow radial strips (sectors) of tinfoil, arranged at equal angular distances apart; attached to the fixed central spindle on either side of the rotating discs, at right angles to each other, and at 45° to the collectors, are curved conducting rods or tubes having at their ends fine wire brushes, which just touch the passing tinfoil sectors. The collectors consist of two forks provided with combs directed towards the rotating discs.

They are supported on suitable insulating pillars, and are connected to the discharging electrodes. For certain purposes a Leyden-jar is connected to each set of collectors.

These machines are self-exciting, and provided they are kept in proper condition they are always ready for use after a few rotations of the handle.

As the theory of the action of these machines is rather complicated, we will not attempt to record it here, particularly

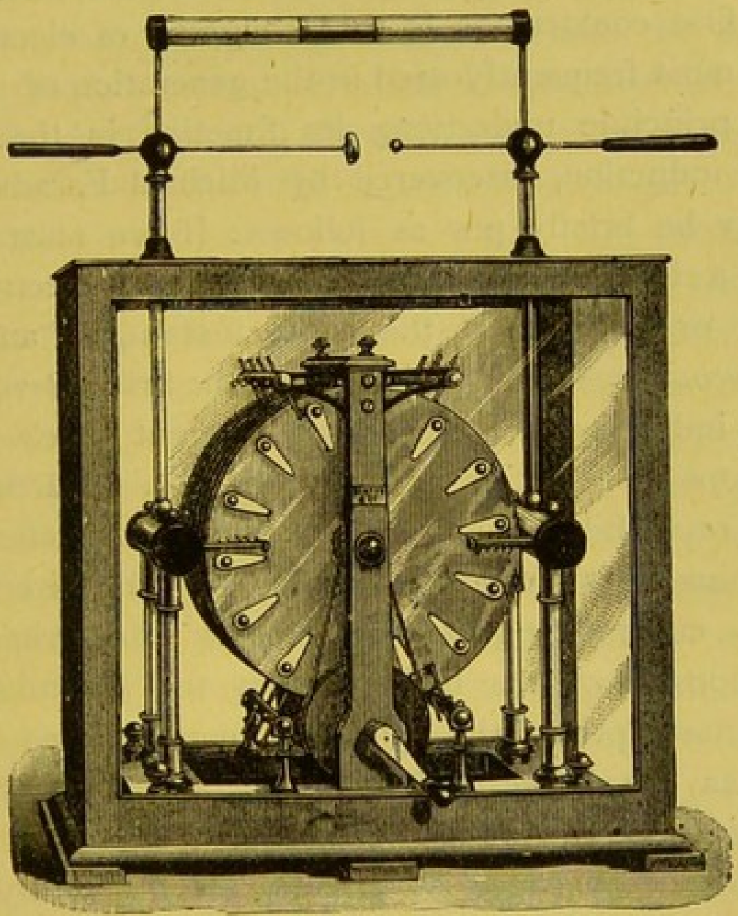


Fig. 10.

as the management of the machines (described in another place) does not at all presuppose a knowledge of this theory.

The primary energy, which is in these machines converted into electrical energy, is supplied by mechanical power, usually furnished by the arm of the operator, or—as becomes necessary with longer periods of working—by some motor. The latter in many instances is electrical, and is again run from a battery or accumulator; but since one of the prime objects of statical X Ray work is to dispense with batteries altogether, such motors should not be used. A good plan is to gear the Wimshurst machine to a small hot air, or gas engine, or even a small water motor, which will develop sufficient power from the water supply in the house.

INDUCTION COILS.

The induction coil, sometimes called the Ruhmkorff coil, after its first constructor, is that converter of electrical energy which is most frequently used in the generation of the X Rays.

The principle underlying its function is that of electro magnetic induction, discovered by Michael Faraday in 1832; which may be briefly put as follows: If we start an electric current in a closed metallic circuit, then another electric current is produced, or induced, at the same instant, in another quite separate *secondary* circuit, which is near the first or *primary* circuit. The same induction of a secondary current takes place when we interrupt an existing primary current. Further, by approaching or withdrawing a magnet to or from a closed metallic circuit, a current is induced in the latter The direction of the secondary current induced by closing the primary circuit is the opposite of the latter, whilst the secondary current due to interrupting the primary current, has the same direction as the latter. If we close and open the primary circuit rapidly we obtain in the secondary circuit an alternating current, so called because its direction is constantly changing. The E.M.F. of the secondary current depends upon the length of the secondary wire, or as the latter is generally arranged in coils, upon the number of turns of secondary wire relative to the number of primary turns; the greater this ratio, the higher the induced E.M.F. so that we are able to produce from a low E.M.F., such as a battery would give us, a very high electric pressure by simply employing considerable lengths of wire suitably arranged.

Moreover, the stronger the primary current the higher will be the induced secondary pressure. The latter is also increased by the presence of a core of iron within the primary coil, and by the close proximity between primary and secondary circuits, as well as by the suddenness and rapidity of the interruptions in the primary circuit. From these relations we may easily deduce the best design for an induction coil : First we want a core of soft iron, capable of being rapidy magnetized and demagnetized y the primary current, which—as usual for electro-magnets—is circulating round the core along the primary turns of wire. It will be seen that this arrangement, in which the make and brake of the primary current are almost synchronous with the production and destruction of the core, magnetism should result in very powerful inductive effects, particularly if the secondary circuit is wound close upon the primary coil, as is usual.

The secondary currents of such a coil are not perfect alternating currents, equally strong and equally timed in both directions, for the following reason. Owing to the presence of an iron core in the primary coil and to the arrangement of the primary wire in parallel adjacent turns, a certain amount of induction (self-induction) takes place in the primary coil itself, resulting in the so-called extra current, which of course flows along the same wire as the primary current. They re-act upon each other in such a way that in closing the circuit, the extra current being contrary to the original primary current, must weaken the latter, and consequently lower the induced E.M.F. in the secondary circuit. The extra current induced by breaking the primary circuit will not assert itself so long as we take care that the break is sufficiently rapid and complete to prevent the extra current from lasting any appreciable time and the induced secondary E.M.F. will not be lowered. We thus obtain in practice an alternating current of which the E.M.F. in one direction practically overshadows that in the other direction—that is, a pulsating or unidirectional current such as we require for the working of the ordinary Röntgen tubes. In order to ensure this suddenness of the break we must endeavour to avoid or minimise the opening sparks which take place between the contact points of the interruptor; this may be effected in various ways. Either the spark is blown away by means of an air blast (mostly used in America), or the energy represented by the spark is deflected into a condenser, of large capacity (Fizeau's method), the two coatings of which are connected to the two contact points of the interruptor. The spark energy charges the condenser, and the discharge of the latter taking place previous to and during the closing of the primary circuit, and being contrary in direction to the primary current, quickly destroys the core magnetism, and still further reduces the induced E.M.F. of the closing current.

One other point which must be attended to is the necessary ability of the iron core to quickly follow the magnetic changes to which the primary current subjects it. Practice has shown that only very soft iron can do this. Besides, the changes in the primary circuit also induce currents (Foucault and eddy currents) in the mass of the core iron, the effect of which would be to heat the core, and thus waste energy; against this, provision is made by suitably subdividing the core.

Bearing all these theoretical considerations in mind, it will be easy to understand the construction of the induction coil, a typical example of which we will now describe.

The *Core* (C) fig 11, is made up from a cylindrical bundle of thin, soft iron wires, bound together, and for good insulation against eddy currents, thoroughly impregnated with paraffin wax, the whole being wrapped round with tape. The *primary circuit* (P) is next wound upon this core. It consists of two (or more) layers of stout silk-covered copper wire, the whole also being insulated by immersion in paraffin wax; when cool, the whole is pushed into a properly fitting ebonite tube in order to thoroughly insulate it from the secondary circuit. The reason for this very high insulation throughout a coil becomes apparent when we consider that the secondary E.M.F. of a coil giving only one-inch spark is close upon 50,000 volts, rising to prodigious pressures when we employ coils capable of producing a ten-inch or longer spark.

In winding the secondary circuit it will be found that though there is very little potential difference between contiguous turns, yet this potential difference, and consequently the tendency to discharge between, increases when we wind one layer and then on top of this wind a second layer, going back in the same direction, reaching such a degree that the spark would pass internally and of course would ruin the coil. Such simple winding is therefore only applicable to very small coils below one inch spark length. For larger coils, the sectional system introduced by Messrs. Siemens and Halske, of Berlin, is now generally adopted. It consists of sub-dividing the secondary winding in the axial direction of the coil into sections of such lengths that

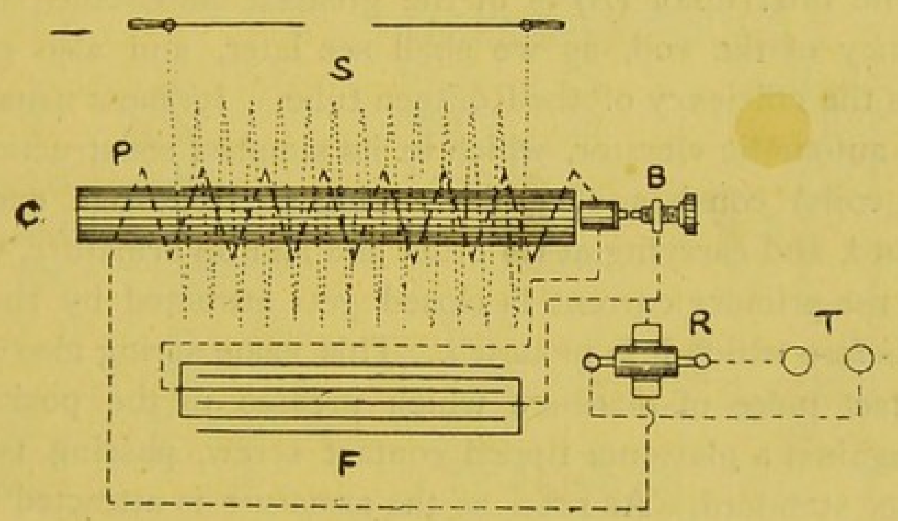


Fig. 11.

there is no great electrical strain between contiguous layers. For coils up to four-inch spark two sections are usually quite sufficient. Above this size, and particularly for very large coils, the number of sections must be increased uutil each section is only a fraction of an inch in length (down to $\frac{1}{8}$in.), and represents a flat disc. Each section is wound separately with very fine silk-covered copper wire (No. 36 or 38), thoroughly soaked in paraffin wax and slipped over the tube containing the primary wire. A thin ebonite disc is placed between each two sections for further insulation; the wire ends are soldered together, and the whole coil is waxed in and finished with an ebonite cover. The ends of the secondary wire are generally brought to two discharging pillars of ebonite which are mounted on the coil base. The latter is hollow and contains the condenser (F.), which usually consists of sheets of tinfoil separated from each other by paraffined paper, the latter being somewhat larger than the former, to avoid leakage round the edges from tinfoil to tinfoil. Each sheet of foil has a small strip so placed as to project alternately at one end, and the two bundles of strips are connected respectively to the two contact pieces of the interruptor. As a rule the base of the instrument also carries a current reverser (R) in order to facilitate the connections from coil to tube with the proper polarity. Fig. 11 represents diagramatically the electrical connections in a Rhumkorff coil.

The interruptor (B) is of the greatest importance to the efficiency of the coil, as we shall see later, and also greatly affects the efficiency of the Röntgen tube. Its most usual form is the automatic vibrator, which in its simplest construction (for small coils) consists of a flat spring fixed at one end to a standard, and carrying at its other end an iron armature, which, when the primary current is closed gets attracted by the iron core, before which it is mounted. This same spring also carries a contact piece of platinum which presses in the position of rest against a platinum tipped contact screw, passing through another standard. As soon as the armature is attracted by the core the two contact pieces separate, and the current is interrupted, the core demagnetized and the armature and contact fly back to their position of rest, re-establishing the current and so repeating the play. The fault of this primitive form is that it does not allow of much adjustment in either frequency or suddenness of interruption.

The modification of this type of vibrating interruptor, illustrated in figure 12, was introduced by Mr. Apps, in 1867, to whom we are also indebted for many practical details in coil construction. H is again the iron armature fixed to spring S. The contact pieces are made of stout platinum wire and are coaxial with the core. Besides the screw-adjustment B, there is another adjustment by the screw spindle T, which is insulated from the contact standard in M, so that we may also regulate the tension of the spring S, increasing it when we wish to make the interruption very sudden and violent, which means, of course, increasing the induced secondary pressure.

During the past year, when Röntgen's discovery brought induction coils into prominence again, another improvement on the above described vibrator was brought out simultaneously, but quite independently, in America and in England. Fig. 13 shows the English design due to Mr. James King. Its object is

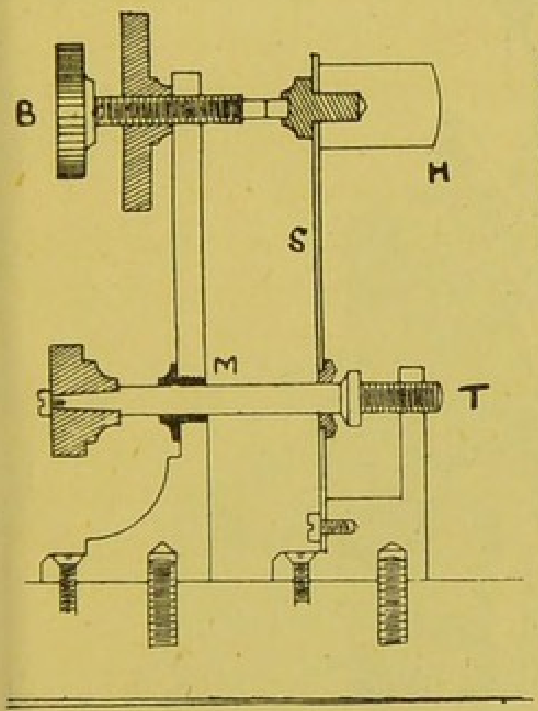


Fig. 12.

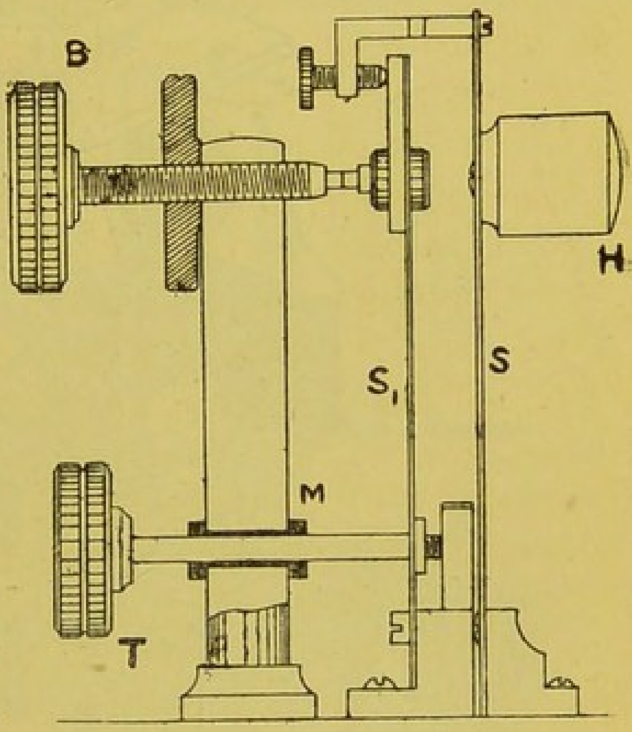


Fig. 13.

to allow the core to become more nearly saturated before breaking the contact, thus inducing a higher secondary E.M.F. The difference in E.M.F. thus obtained is most remarkable, whilst at the same time, sparking and consequent wear of the contacts, as well as the heating and untempering of the contact spring, are greatly reduced. This is attained by providing a separate spring for the vibrating contact piece, so that the armature may move through a certain space without at once breaking the contact. A fuller description of the manipulation of these interrupters will be found in Chapter III.

One disadvantage with these types of platinum-interruptors is the irregular wear of the contacts, particularly in the case of large coils with heavy currents, and the consequent irregular action of the tube. Moreover, this requires a constant adjustment of the contact, which is most inconvenient during long exposures. The noise made by large interruptors of this type, and the strong mechanical vibrations they produce, are often a source of annoyance to the patient under examination.

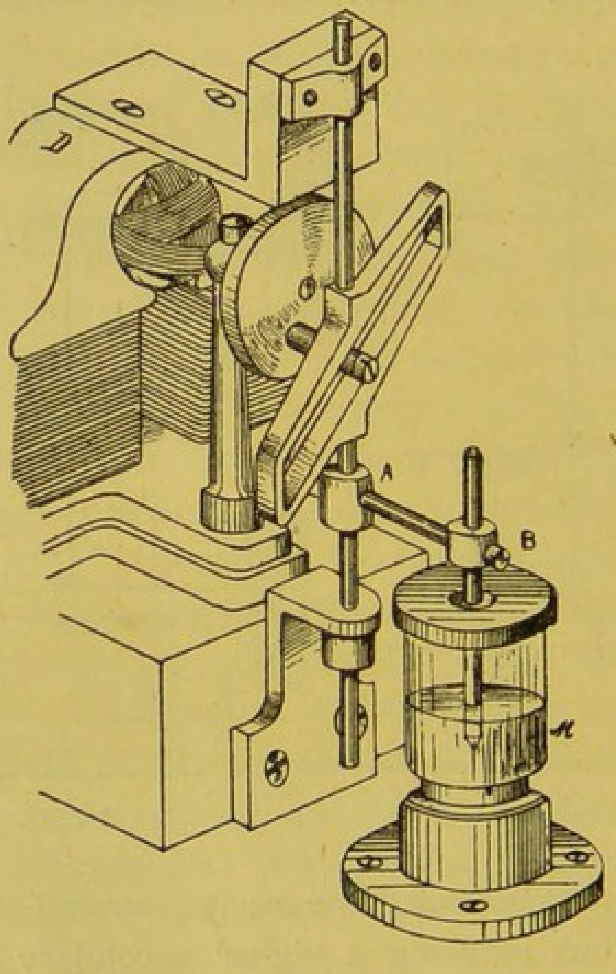


Fig. 14.

Various other constructions embody a revolving disc or drum with contact pieces suitably arranged, against which contact brushes are pressing, and are said to give very regular and superior results, but they require some separate motor, either mechanical or electrical, to actuate them.

The General Electric Company, of Schenectady, New York, have introduced a vibrating percussion breaker, which makes about 850 breaks per minute, but can be adjusted through a wide range by changing dead weights. Contact is made and broken under water, and at two points simultaneously between renewable copper studs, and it is claimed that the opening spark is immediately extinguished.

In order to secure uniform wearing of the contacts, Gaiffe so arranged the latter (at least, the stationary one) that a slow rotating motion is imparted to it by some motor. To minimise the contact sparking, both Thuma and Moore arranged the armature spring in a suitable tube, so highly exhausted that but

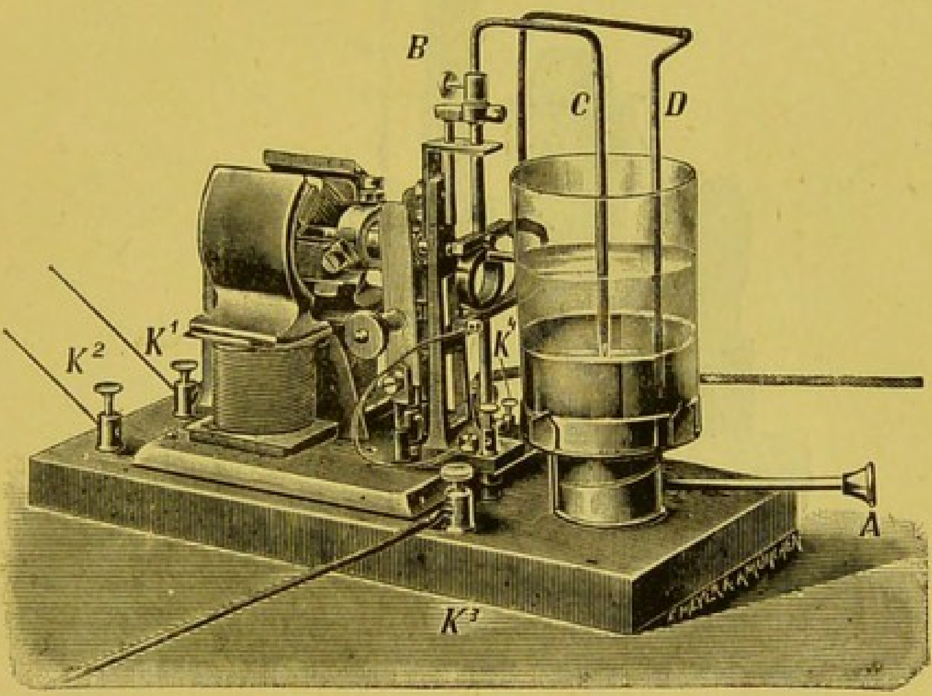


Fig. 15.

very small sparks can pass. Instead of a condenser, a Crooke's tube or a spark gap (about one inch long) is arranged in parallel to the vibrator or to the coil.

Instead of using two solid contacts, the stationary one may be represented by mercury or mercury amalgam in a suitable vessel, and the moveable contact by a rod, to which a reciprocating motion is imparted by mechanical or electromagnetic mechanism worked from the primary current itself, or from a separate source of current, and may be adjustable in speed by adjusting the actuating electrical energy.

In order to prevent oxidation of the mercury, the latter is covered with an insulating layer of alcohol or petroleum, over an inch in depth, which, being a better insulator than air, also makes the interruptions more complete—even water will do very well for covering the mercury. The interruptions follow each other much more slowly than with the automatic vibrator, and the resulting E.M.F. in the secondary, though more pulsating, is much higher.

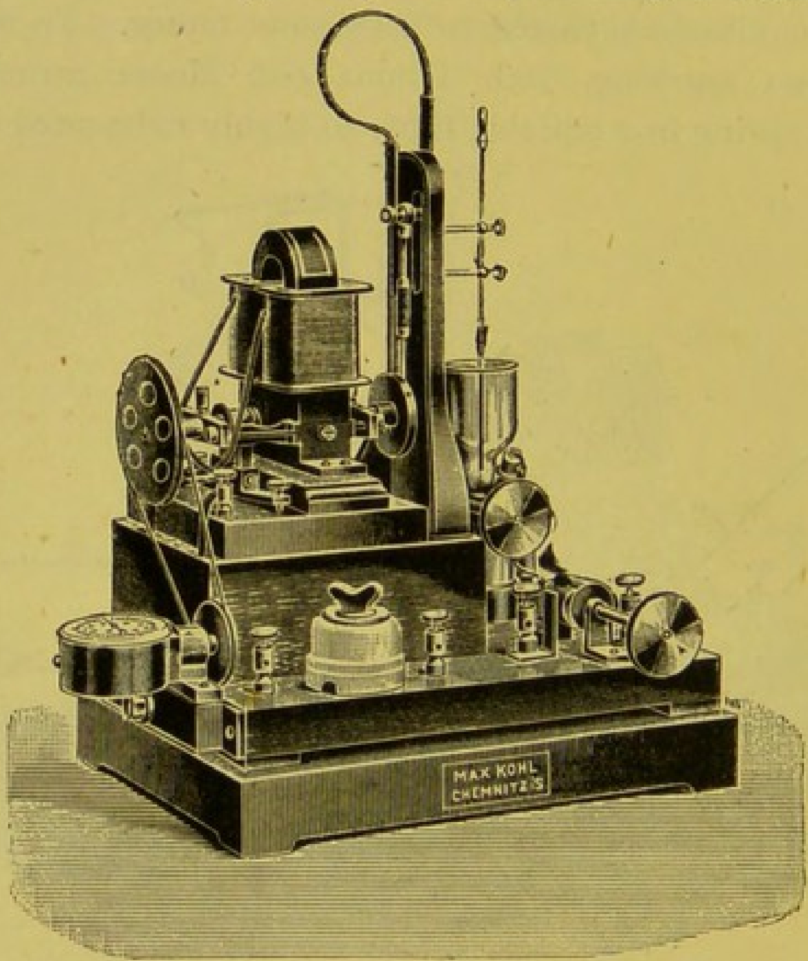
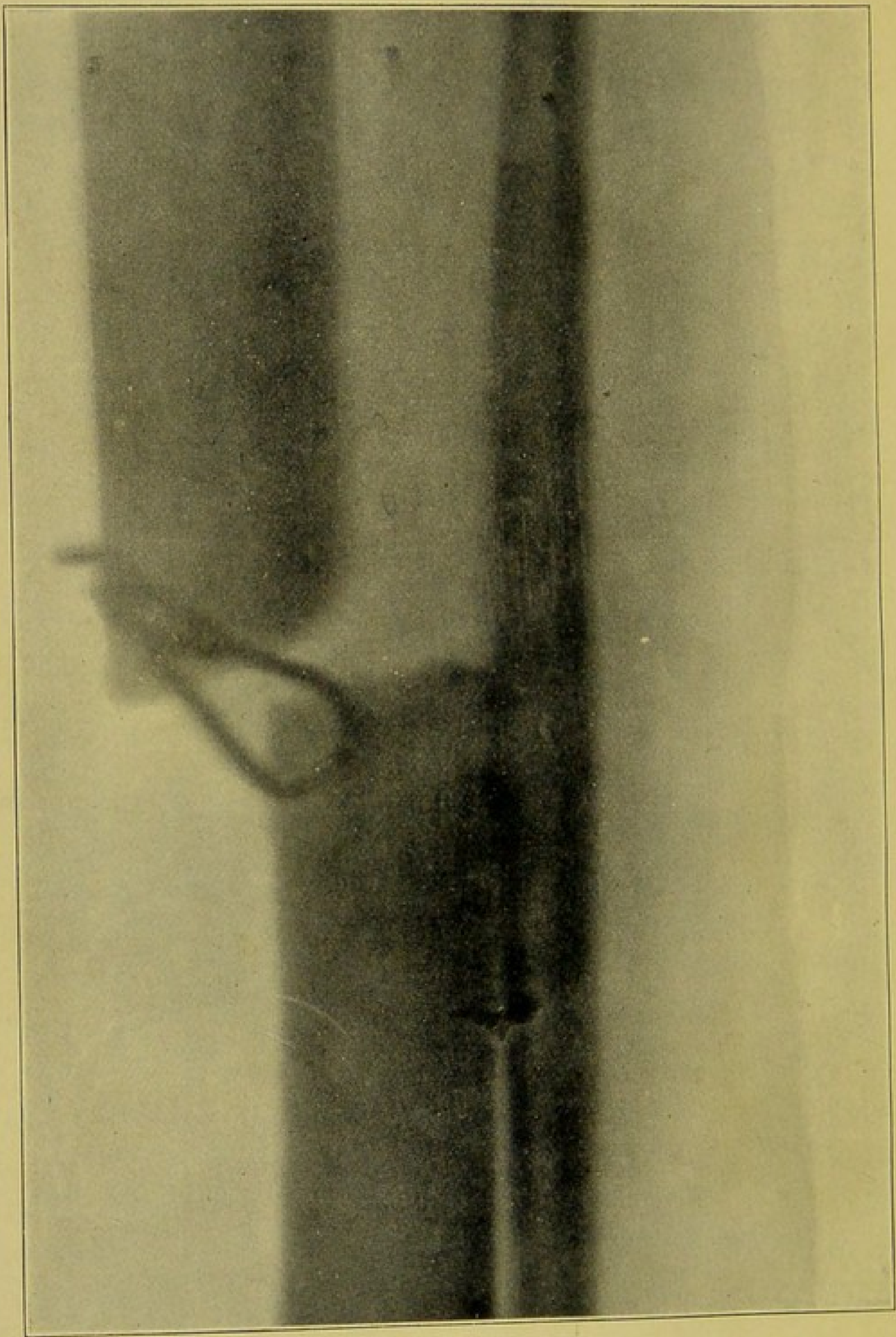


Fig. 16.

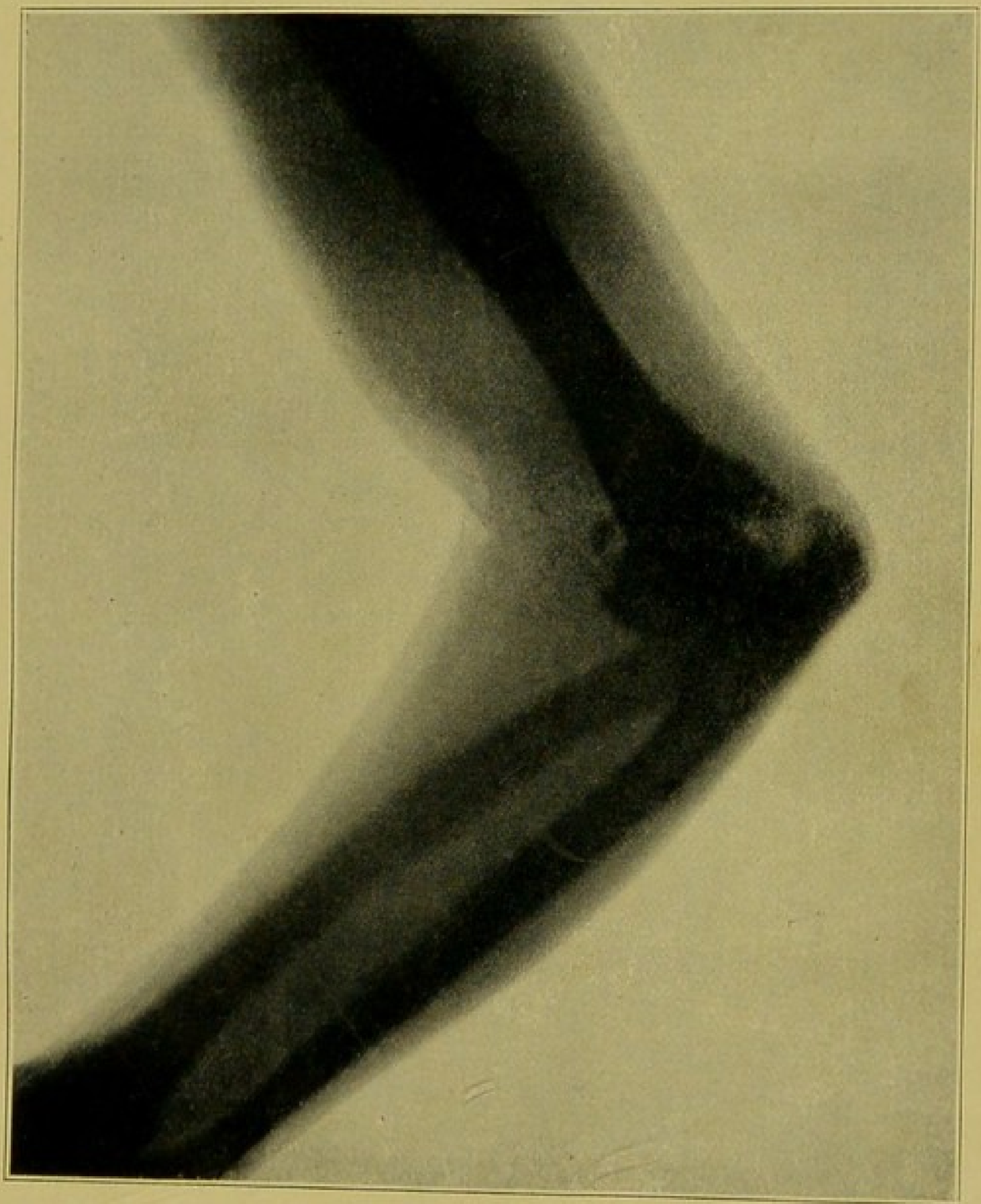
Care must be given to let the dipper enter the mercury quite vertically; otherwise the mercury is stirred up, and by incorporating the insulating fluid becomes muddy, and must be frequently filtered. Figs. 14 and 15 show several forms of such mercury breaks.

The mercury break illustrated by Fig. 16 (system Max Kohl) is also provided with a Tachymeter, that is, a dial which permits us to read at a glance the number of interruptions per second, and also shows whether the break works regularly and does not



Fractured Right Tibia with Silver Wire Inserted.

(By Dr. W. Newman, Stamford.)



Dislocation of Elbow-joint. (By A. W. Isenthal.)

change its speed. This addition is a most useful one, especially for comparative and accurate work, as it permits us to exactly repeat the electrical conditions of a given experiment.

The typical appearance of an induction coil is represented in Fig. 17.

Some time ago Messrs. Norton and Lawrence, of Boston, suggested a new method of working an induction coil from the electric light circuit. They first charge a condenser of considerable capacity from the supply circuit, then disconnect it and discharge it through the primary of an ordinary induction coil, which primary consists of a few turns of heavy wire, enclosed in an ebonite tube, filled with oil for insulation. The charging and discharg-

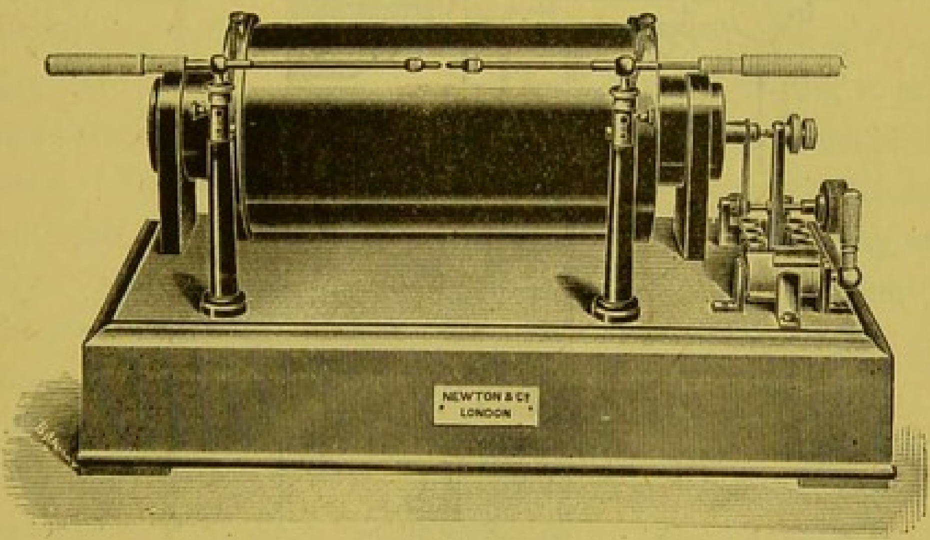


Fig. 17.

ing of the condenser is effected by a rotary commutator run at sufficiently high speed, and it is claimed that the results are far more powerful than in the case of an ordinary induction coil.

A greatly improved induction coil of high efficiency was recently shown by Messrs. Rochefort and Wydts, before the Société des Ingénieurs Civils de France, and the Röntgen Society of London.

According to these gentlemen, the present form of induction coil has an efficiency of 20 per cent. only; that is to say, only 20 per cent. of the energy supplied to the primary terminals is available at the secondary terminals, and they assume that this is caused by the great length of secondary wire as usually employed, and by the fact that no solid insulator will stand for any length of time very high voltages. Liquid insulators, as oil, are modified by the constant electrical strain, and in time contain suspended carbon.

In the new coil the insulation consists of some special hydrocarbon in the form of a paste, which is said to be free from the above defect of carbonising.

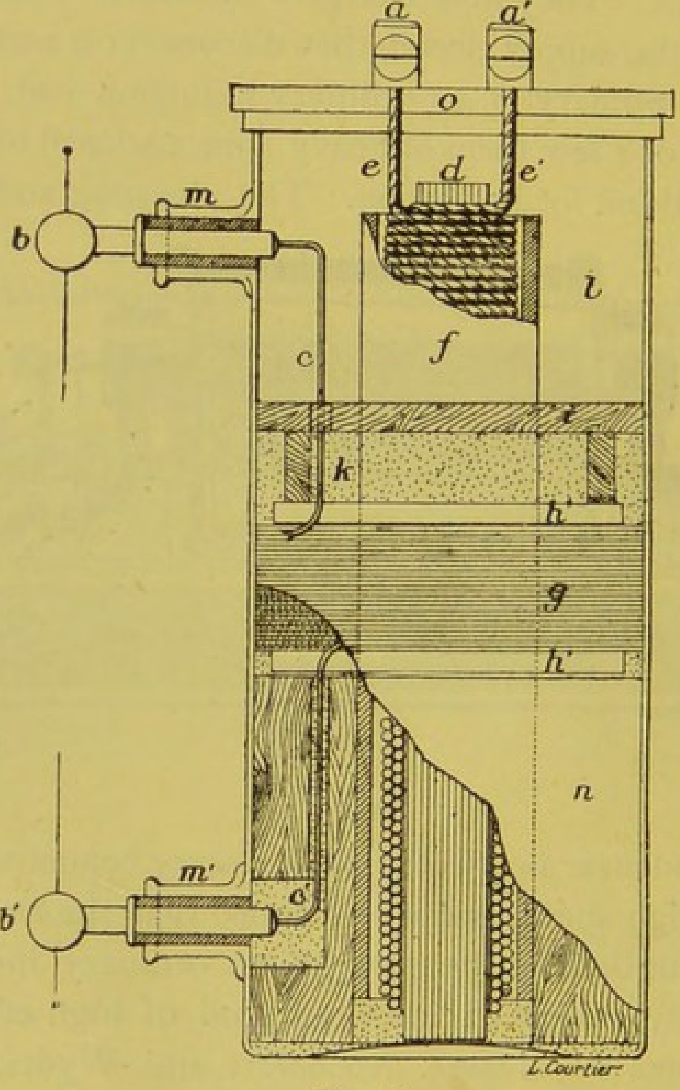


Fig. 18.

Fig. 18 shows the arrangement of such a coil; the primary is similar in all respects to that of an ordinary induction coil. The secondary, however, consists of a *single* bobbin of fine wire, weighing about $1\frac{1}{2}$ lbs. only, which is placed midway on the primary, and supported by a block of wood (by means of two glass tubes, *h*); the whole is enclosed in a glass cylinder and filled with the special insulating paste. To give an idea of the relative efficiencies of the old coils and the new one, it may be stated that in the case of an 8" coil the new instrument worked with 6 volts and 3.3 amp., or 20 watts. The old coil of equal spark length took about 120 watts, and its secondary weighed 13 *lbs.*

Owing to the small resistance of the secondary, the new coil gives very heavy sparks, allowing thus of shorter exposure.

TESLA COILS.

When Röntgen's discovery was first experimentally verified in this country, the use of a Tesla—or high frequency, high tension alternating current was considered a *sine qua non* in order to obtain any results at all. Gradually, however, the ordinary induction coil proved to be equally effective, until, owing to its comparative simplicity, it became almost the exclusive converter for the purpose. The Tesla apparatus, however, has certain undoubted advantages, and can be easily worked from an alternating current supply. Moreover, many prominent investigators besides its inventor strongly advocate its use, so that we must give a brief outline of its action and construction.

The essential characteristic of Tesla alternating currents is their exceedingly high frequency, attaining to about ten millions per second as compared with the 200 or 300 obtainable in the case of Ruhmkoff coils with mechanical contact breakers, and the induced secondary E.M.F. of a Tesla coil runs into hundreds of thousands of volts. The only means to produce such rapid oscillations is the discharge of a condenser or Leyden jar, which is oscillatory in nature, and surges to and fro between the coatings many million times per second. These discharge currents are passed through the primary (consisting of only a few turns of stout wire) of a special induction coil without iron core, the secondary of which has also only comparatively few turns of wire. Since the E.M.F.'s in such an arrangement are so extremely high, ordinary insulation like paraffin wax and ebonite would be quite inadequate, and the only possibility is to bodily immerse the whole coil in a suitable oil bath, from which only the ends of the primary and the secondary wires protrude. In order to be able to charge the condenser, the alternating current from the supply current must first be passed through a transformer T, which raises it to a pressure of about 6000 volts. The discharge of the condenser manifests itself as an exceedingly bright and snappy spark in the adjustable spark gap G.

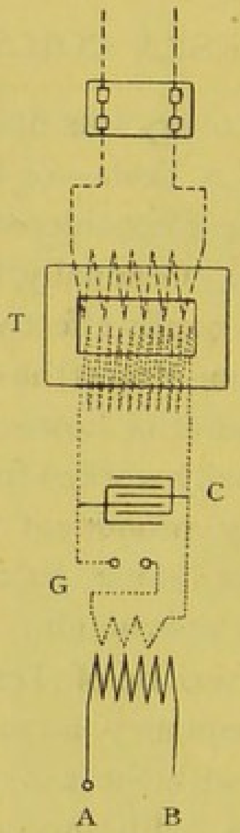


Fig. 19

The intensity and frequency of the resulting sparks at A and B are extraordinary, and in consequence of this less exposure is needed in radiographic work, and the screens are better illuminated in radioscopy. Besides, the influence of the vacuum of the tube is not so pronounced upon the resulting radiogram.

On the other hand, the *primary* circuit of the coil, including transformer, condenser and gap, must be made quite inaccessible, since shocks from it would be most dangerous. Sparks accidentally taken from the secondary terminals of the Tesla coil are harmless, and scarcely excite the sensory nerves at all, owing to their extreme frequency.

Generally speaking, these Tesla coils behave essentially like ordinary induction coils without condensers and worked with alternating currents, but the former are electrically more complicated, are not so clean in use as induction coils without oil insulation, and require specially-constructed tubes. Further, the noise caused by the gap spark is a most serious drawback when applying the rays to nervous or weak patients.

Fig. 19 shows the electrical arrangement of such a coil.

TESLA OSCILLATOR.

Quite recently an entirely new convertor has become known, and was first shown in Europe by Prof. Silvanus P. Thompson

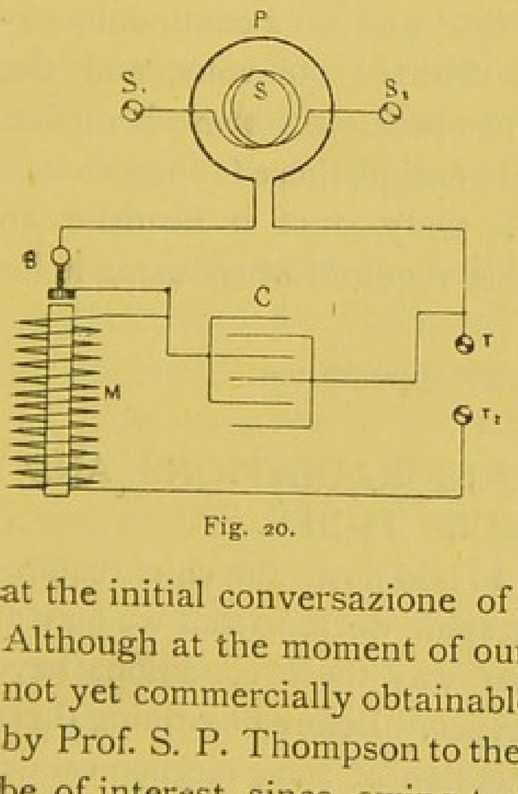


Fig. 20.

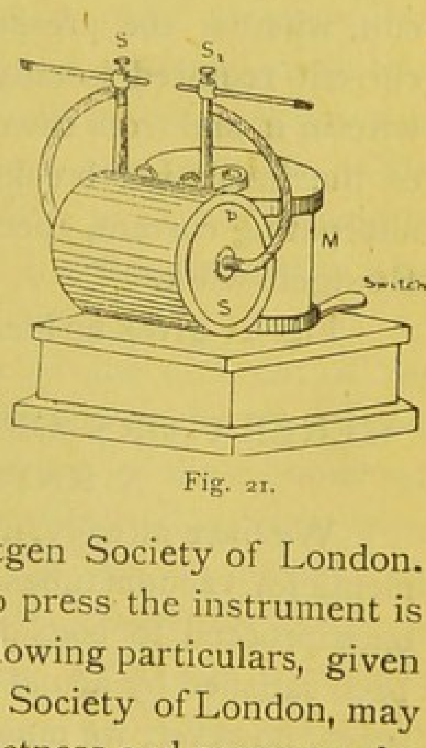


Fig. 21.

at the initial conversazione of the Röntgen Society of London. Although at the moment of our going to press the instrument is not yet commercially obtainable, the following particulars, given by Prof. S. P. Thompson to the Physical Society of London, may be of interest, since, owing to its compactness and economy, the oscillator is certain to come into extensive use for Röntgen work. It consists essentially of three parts: a vertical electromagnet (*M*), Fig. 20, wound round with a great number of turns of rather thick wire and having considerable self-induction; a condenser (*C*) of from three to four microfarads capacity, which is charged by the self-induction of the electromagnet on breaking circuit, and which discharges into the primary (*P*) of the horizontal transformer. The latter is composed of a single turn of a copper ribbon, about six inches wide, and its secondary (*S*) consists of one layer of thick wire.

The action is probably as follows: The current from the terminal T_2 magnetises the electromagnet *M*, which, in attracting its armature, breaks the circuit at *B*, and the high E.M.F., due to the self-induction of the magnet, charges the condenser *C*. Its discharge being extremely rapid and oscillatory and flowing through the primary *P* (which has a very small resistance) is raised to higher voltage in the secondary, *S*. The rate of vibration of the break is very important, and should be tuned to somewhat less than a hundred per second. Otherwise the management of the oscillator is exceedingly simple and safe; it works equally well on an alternating and on a continuous circuit, whether the pressure be 10 volts or 150 volts, and the current required is only half an ampère. As there is no fine wire in it, and from the nature of its design, there is little chance of the insulation breaking down. Only, since it furnishes an alternating current, special tubes are required when using it for Röntgen work.

Fig. 21 gives an idea of its outer appearance.

GENERATORS OF ELECTRIC RADIATIONS AND X RAYS—VACUUM TUBES.

We have already, in Chapter I., laid down the chief requirements for vacuum tubes for radiographic work, so that we may at once proceed to consider in what way these conditions have been satisfied by actual working types. Before describing these types, however, we must make mention of some mechanical details in the construction of tubes which are common to all types.

The glass from which the tubes are blown ought to be of such a chemical composition as to offer the least amount of opacity to the X rays. The best kind for this purpose is the hard German sodium glass, which is easily distinguished by the bright apple-green colour of its fluorescence, which sometimes even appears yellow-green. Less suitable, although frequently used on account of the ease with which it can be worked, is the English soft lead glass, the characteristic fluorescence of which approaches pale blue.

The tube itself should be free from flaws or enclosed air bubbles, and for that reason it is preferable to blow it from a lump of glass rather than from tubing. The walls should be kept as thin as is compatible with the great atmospheric pressure to which the tube is subjected.

The internal electrodes (cathode and anodes) must be made of aluminium, since this is the only metal which does not appreciably disintegrate under the influence of the electric discharge. Owing to the difference in the co-efficient of expansion of glass and aluminium, the latter must be fused to platinum wires, which are sealed into pieces of lead glass, and these again are fused together with the sodium glass of the tube proper. The terminals ought not to be the ends of the platinum wires bent into rings or hook-shape, but these should be soldered to substantial metal caps, which are cemented to the glass The exhaust tube, which is generally sealed off to a point, should be protected both from breakage and from the frequent perforation by sparks by means of a small rubber cap.

The variation in the construction of the different X ray tubes is so enormous that their description would fill a good-sized volume. By far the greater number of these, however, were constructed during the early days of radiography, when the essential conditions which go to make a good tube were not yet so fully understood. Now, with better knowledge and experience to guide us, although many new forms are constantly being devised, the construction of the tube follows essentially the same lines, and only differs in detail.

Broadly speaking, then, the tubes may be dealt with under two heads, namely, *ordinary* tubes, the vacuum of which cannot be varied during their period of utility, and *regenerative* tubes, in which by certain means the vacuum and consequently the penetrative value of the resulting radiation may be modified during use.

ORDINARY TUBES.

These comprise particularly the *earlier* forms, of which we can only consider a few types which are still met with. The first tubes were not specially designed for radiographic purposes, but having been used in every physical laboratory for certain Crookes' experiments, and possessing the proper vacuum, they had to do service for the earliest X ray work. They were plain *cathodal* tubes (of the form illustrated by Fig. 22). Both the cathode and anode were flat discs of aluminium, so placed with respect to each other that the anode should not obstruct the cathode stream, which impinged upon the glass wall opposite the cathode and produced there vivid fluorescence and secondarily X rays. This type, though capable of yielding fair results when judiciously arranged and manipulated, soon

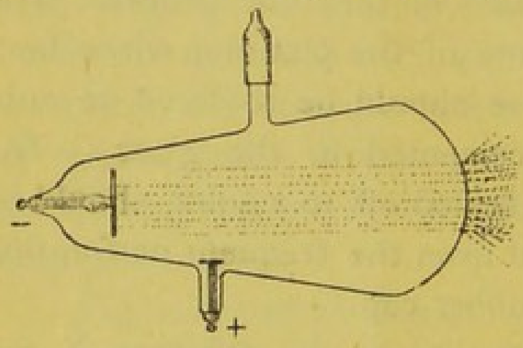


Fig. 22.

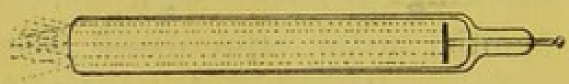


Fig. 23.

fell into disuse, owing to various serious defects inherent in the design. In the first place, the constant bombardment by the cathode rays of a particular portion of the glass, not only heats and eventually (with long exposure) cracks or melts the glass, but even if the glass should hold out, the spot is subject to "fatigue," a peculiar physical condition in which the generation of the X rays, eventually shows a decided diminution.

But still a graver defect is introduced by the flat shape of the cathode, which produces a large fluorescent spot. As this is the source of the X rays, it follows that there is a considerable amount of diffusion, and that, in order to counteract the resulting penumbra of the radiographic outlines, we must increase the distance between tube and object, which again means longer exposure.

Cathodal tubes are to-day of merely historical value, only one variety—the Tesla tube (Fig. 23)—being retained for practical work. This requires the high frequency, high potential current furnished either by oil coils or by the oscillator.

The next and most important step forward in the evolution of X ray tubes is marked by the introduction of what is now commonly called the focus tube. The credit of its inception is

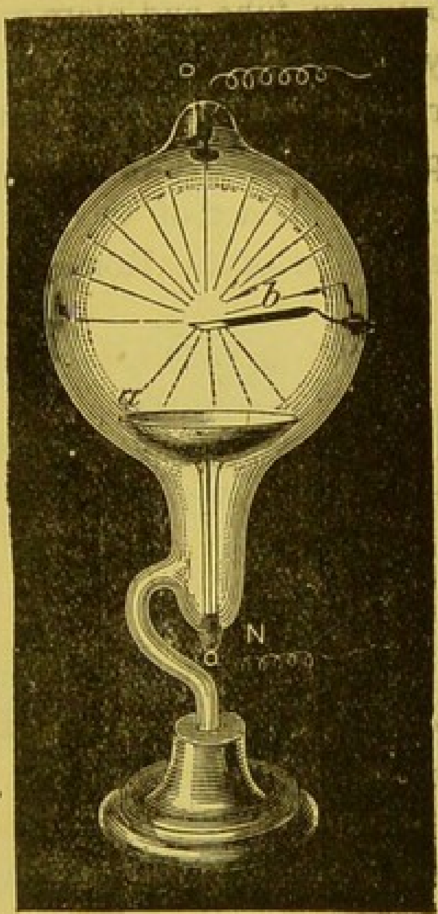


Fig. 24.

given to three different investigators, namely, Prof. Röntgen himself, Prof. Elihu Thomson, who is said to have worked with a focus tube in January, 1896, and Mr. Herbert Jackson, of London, who, at any rate, as far as England is concerned, was the first to use it publicly. The prototype of the focus tube, however, as illustrated in Fig. 24, was due to Prof. Crookes, who by its means, in 1879, showed the heating effect of the cathode rays.

The design of the focus tube at once obviates the above-mentioned defects of cathode tubes, in so far as the point upon which the cathode rays strike is no longer the glass of the tube, but a suitable metal (platinum) which may become white hot without endangering the tube itself. Moreover, as the cathode is of concave shape, the cathode rays converge to a focus, so that the source of the X rays becomes limited in size, and so permits of superior definition in the resulting radiograms, even at short distances between tube and plate or object.

In the ordinary focus tube the anode serves also as the *anti-cathode*, this expression having been introduced by Prof. Silvanus P. Thompson to denote the solid body in the tube, which receives the first impact of the cathode stream, and is supposed to be the source of the Röntgen rays. In the later

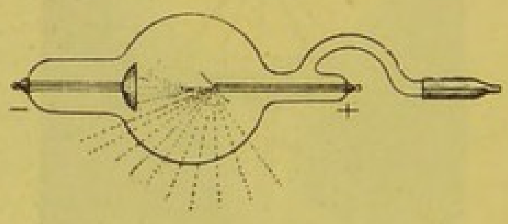


Fig. 25.

types, particularly of Continental origin, the tube is provided with a separate anode, which may at will be connected to the anticathode, and permits of a certain degree of regulation, as we will see later on.

The construction of the original focus tube is shown in Fig. 25. According to Porter's investigations, the cathode should be well polished and its edge be free from roughness or indentations. The size of the cathode and the distance between the latter and the anticathode largely determine the working qualities of a tube, as will be shown in the chapter on regenerative tubes. Broadly speaking, the distance should be somewhat larger than the focal length of the cathode, decreasing for higher vacua. The anticathode must be made of platinum, and should be backed by a substantial disc of aluminium, in order to prevent its rapid and intense heating, which would lower the vacuum, and might cause the supporting wire to part from the platinum foil.

Several forms of *multianodal* focus tubes are illustrated by Figs. 26 to 28.

Another variation of the focus tube is represented by Fig. 29, showing the *double* focus tube, which was designed to utilise an alternating discharge, such as is derived from Tesla coils, and under certain conditions from a Rhumkorff coil. For use with Tesla coils the two concave electrodes are made the cathode and

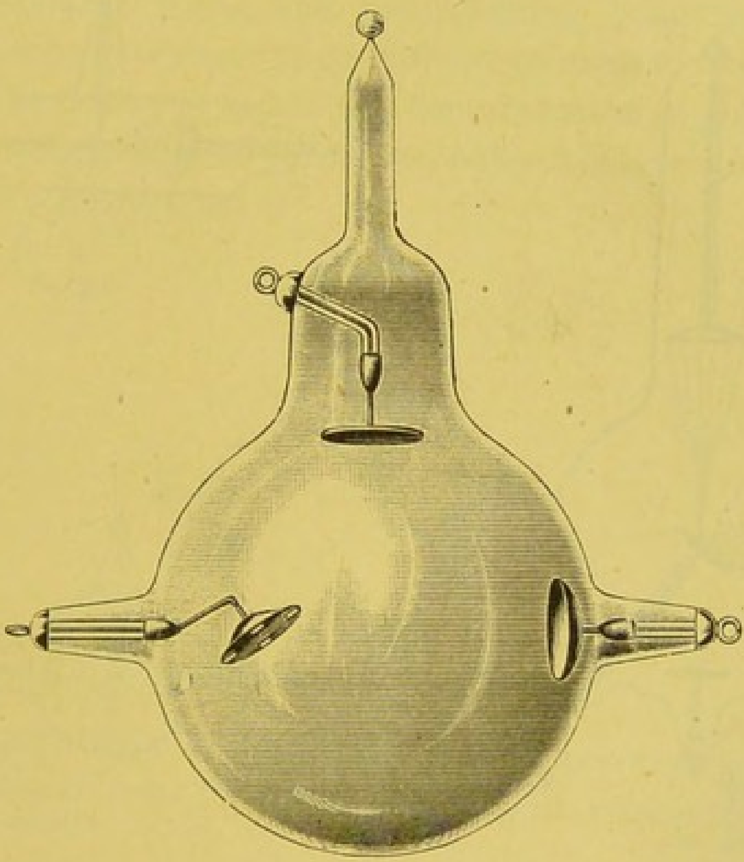


Fig 26.

anode respectively, and the wedge-shaped anticathode is either left insulated or else connected to earth; when using uni-directional currents or statical electricity, both concave electrodes are connected to the cathode, and the anticathode is made the anode.

The life of a vacuum tube, barring such accidents as breakage or perforation is largely influenced by a peculiar phenomenon, which may be observed with all types alike, and which asserts itself in the gradual rise of the vacuum, after the tube has been working for some time. This rise is, of course, accompanied by a corresponding rise in the resistance of the tube, and continues until a stage is reached when the electric discharge no longer is able to pass through, but preferably passes round the tube from terminal to terminal in the form of a spark, and no Röntgen rays are generated. The most feasible explanation which has been advanced to account for this peculiarity assumes that the platinum anticathode and other platinum parts become disinte-

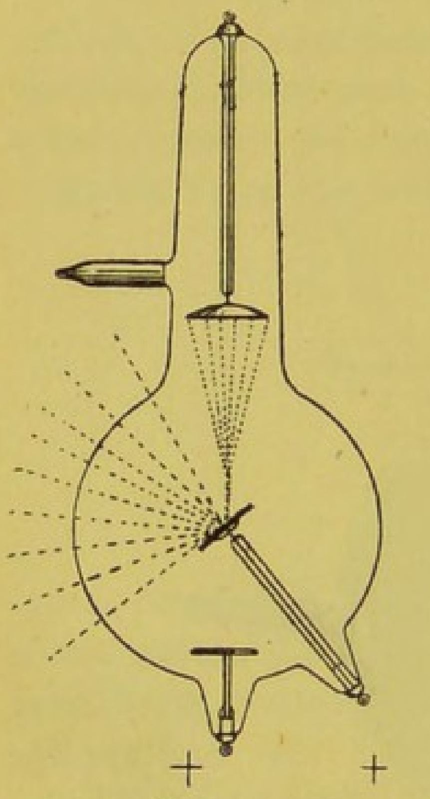


Fig. 27.

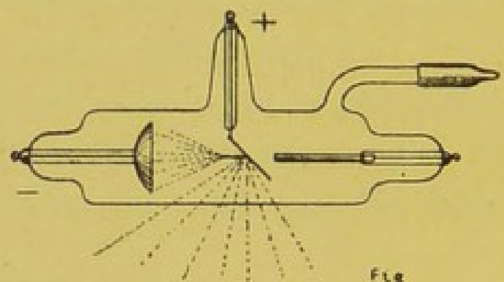


Fig. 28.

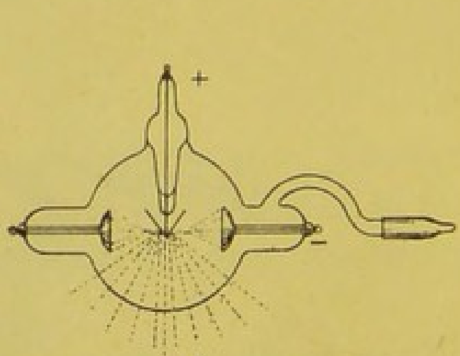


Fig. 29.

grated under the action of the discharge, and that the separated particles, on cooling, occlude some of the residual gas or air, which originally was condensed at the inner glass surface.

In consequence of this increase of vacuum, the penetrative character of the radiation undergoes a steady change, so that in ordinary tubes, such as we have hitherto dealt with, no constancy of the actinic or fluorescent properties of the X rays can be expected, a most serious disadvantage, especially in the case of long exposures, since it makes our work largely empirical.

Starting, for instance, with a comparatively low vacuum, and taking for test object a hand, we find that at this stage the bones are projected on the fluorescent screen intensely black, without detail, and the fleshy parts also are more or less well marked. With increasing exhaustion the rays become more penetrative, and the screen image shows much detail in the bones, the fleshy parts being less marked. Finally, the residual gas becomes exceedingly attenuated, and the rays correspondingly energetic; so much so, in fact, that they seem to pass easily through the bones, and the resulting image is then of a flat and monotonous description without contrasts.

The prevention, or rather the compensation of this automatic increase of exhaustion forms the subject of our next section, namely, the consideration of

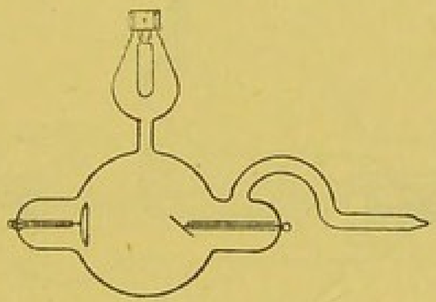


Fig. 30.

REGENERATIVE TUBES.

The regeneration of the tubes, or more accurately speaking, the restoration of their initial vacuum may be effected in various ways.

1. *By the application of Heat.*—Assuming, as we have done that air is occluded and condensed in the tube after some working, we may to some extent liberate it and so increase the internal pressure by warming the tube, either from the outside by means of a Bunsen burner or spirit lamp, or by temporarily forcing such a powerful current through the tube that the anticathode gets incandescent; the former is the more usual method, and easier to apply.

This treatment, of course, does not pre-suppose any particular design of the tube, and, therefore, is universally employed in the case of the ordinary tubes just described.

2. *By the Introduction of Certain Absorbent Substances into the Tube.*—In order to keep a larger reserve of air or gas than that which usually becomes occluded, some experimenters have made use of the property of certain substances to liberate occluded gas when heated, and we find thus some constructions of tubes, in which a small auxilliary tube contains either caustic potash, palladium, permanganate of potassium, or carbon. Here, again, the way was indicated by Prof. Crookes, who, in his early classical investigations, used potash in order to demon-

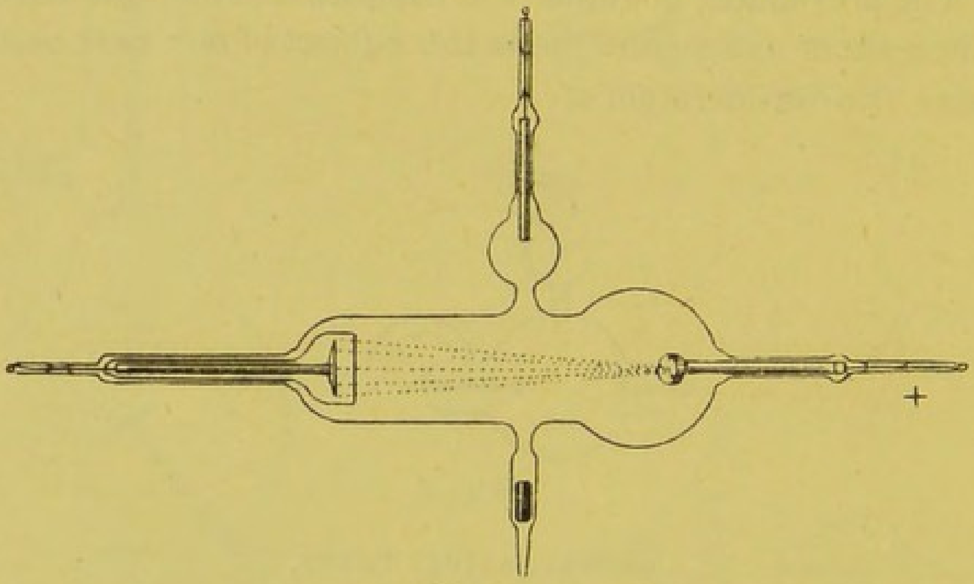


Fig. 31.

strate the gradual changes undergone by the discharge in a vacuum.

Dr. W. J. Morton, of New York, joined to the main tube an ordinary electric incandescent lamp, and exhausted the whole to the proper Crooke's vacuum without passing current through the lamp; if, then, the tube has become too highly exhausted after some use, the vacuum may be lowered by sending the electric light current through the lamp (Fig. 30), the heated carbon filament of which drives air into the main tube.

A more recent construction by Prof. Zehnder utilises the same principle and the same material, namely, carbon, which, however, is contained in an auxilliary tube, and must be heated from the outside (Fig. 31), care being taken that the heating is done very slightly and gradually, as otherwise the vacuum would sink below the X-ray stage.

In the penetrator tube (Fig. 32), a small piece of palladium replaces the carbon, occluding hydrogen.

Siemens and Halske, of Berlin, supply the tube illustrated in Fig. 33, in which all the regulation is effected in an auxiliary bulb, which may be heated to reduce the vacuum; the supplementary anode is placed opposite a thin tube containing a trace of phosphorus, and is connected to the positive pole of the coil when the vacuum is too low, so that the discharge, or if necessary, a very slight outside application of heat will cause the phosphorus to combine with the air, and so to raise the vacuum.

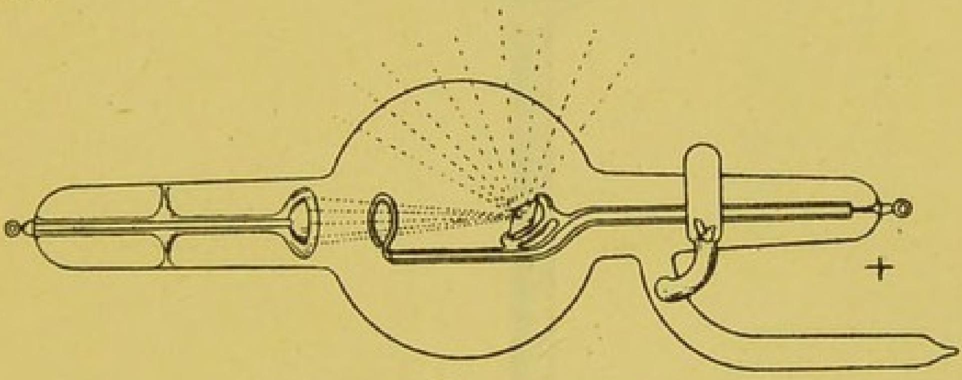


Fig. 32.

This tube, although adjustable within very wide limits requires great attention, and must be constantly manipulated, in order to obtain the best results.

The latest and theoretically the most perfect design utilising the absorption principle is the one introduced by Messrs Queen and Co., of Philadelphia, illustrated in Fig. 34. Its essential peculiarity is the arrangement of an alternative discharge path in parallel with the tube, containing an adjustable spark gap. Whenever the vacuum in the main tube rises beyond a certain preconcerted equivalent spark length, the discharge will pass across the gap, and the cathode rays from the auxiliary cathode will heat the potash bulb, driving off vapour into the main tube, which, however, is re-absorbed when the bulb has cooled down.

According to the distance for which the spark gap is set the character of the radiation from the tube may be varied, and may be kept automatically constant for any length of time, since every rise of the vacuum will automatically actuate the vapour discharger.

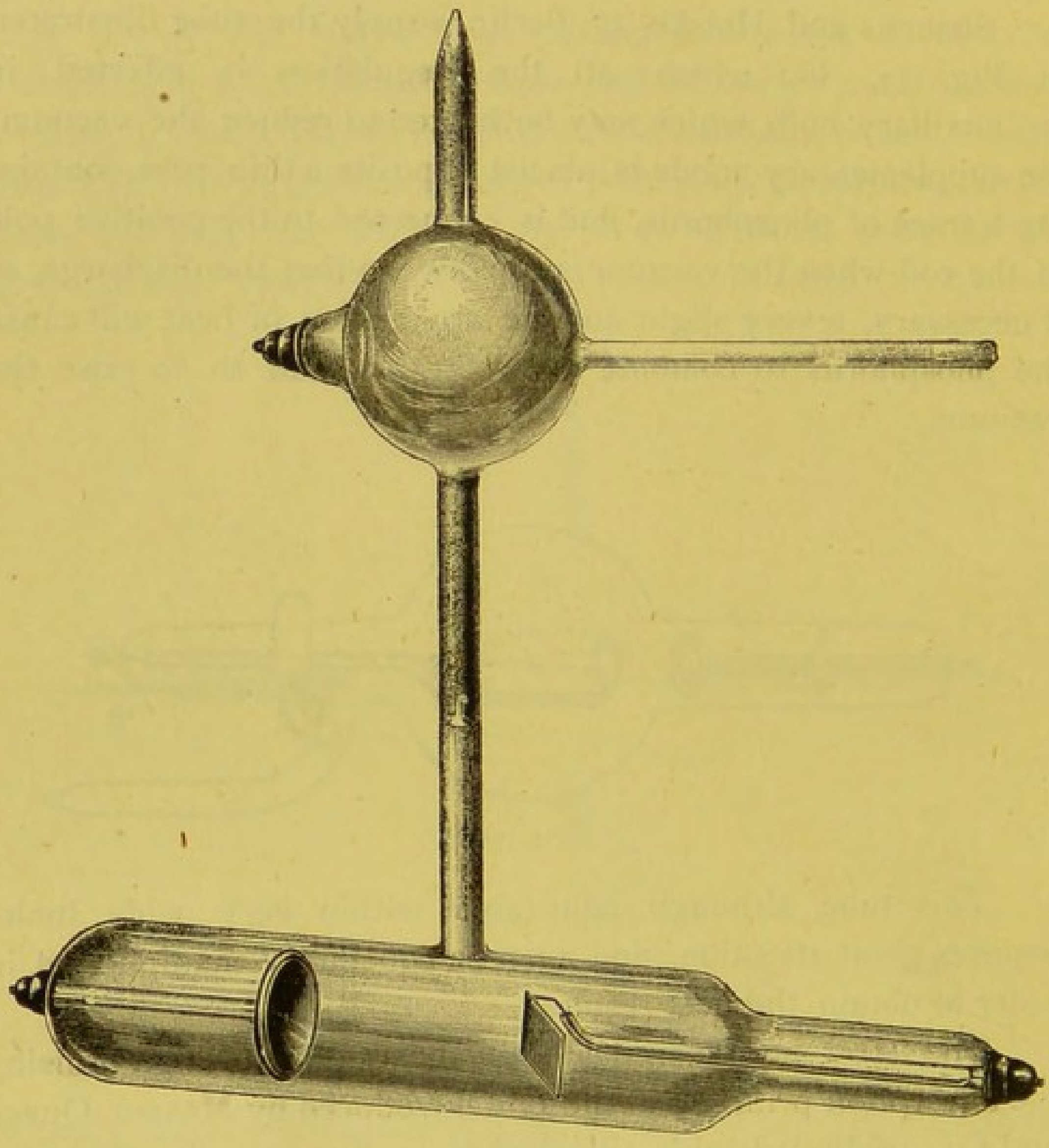
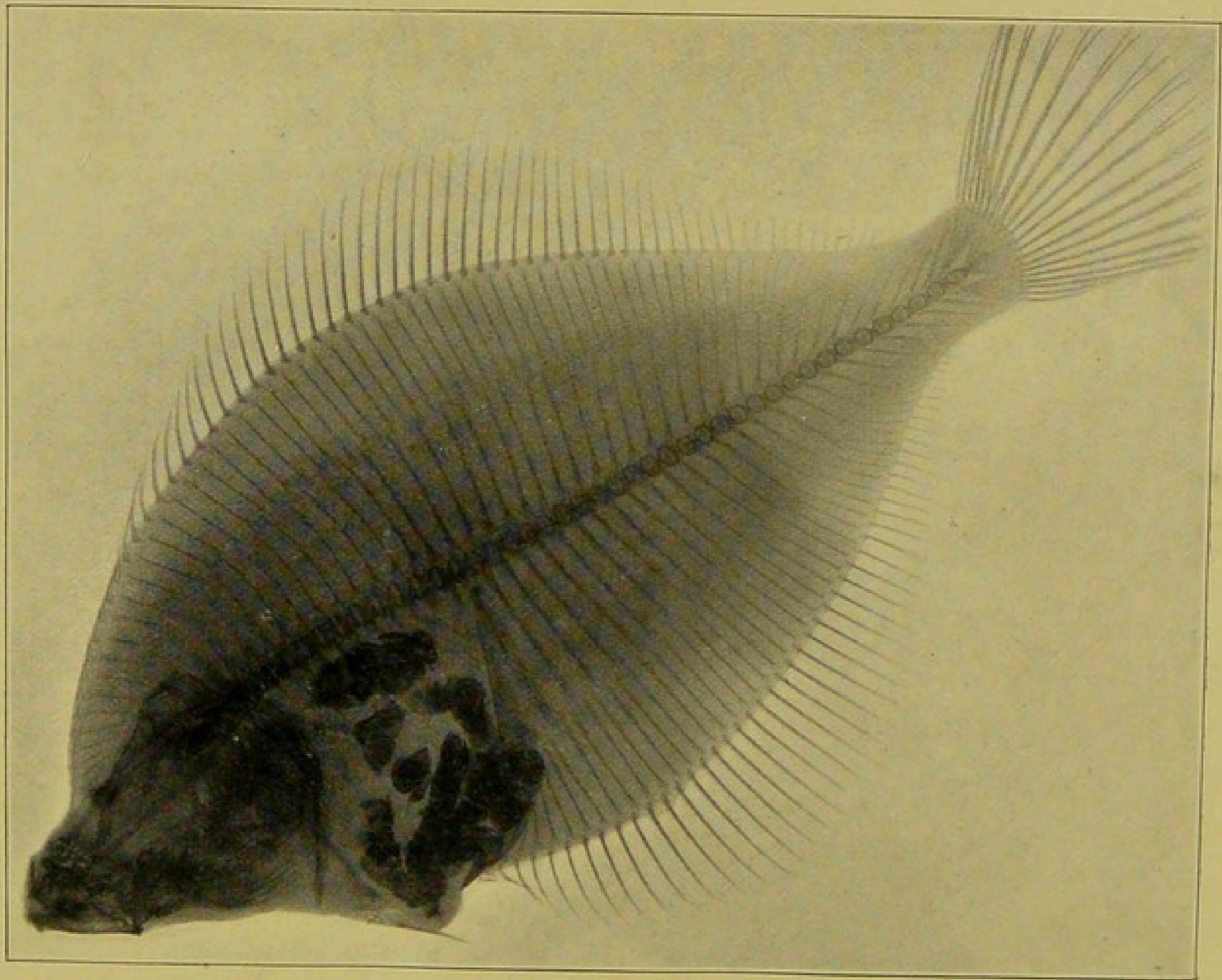
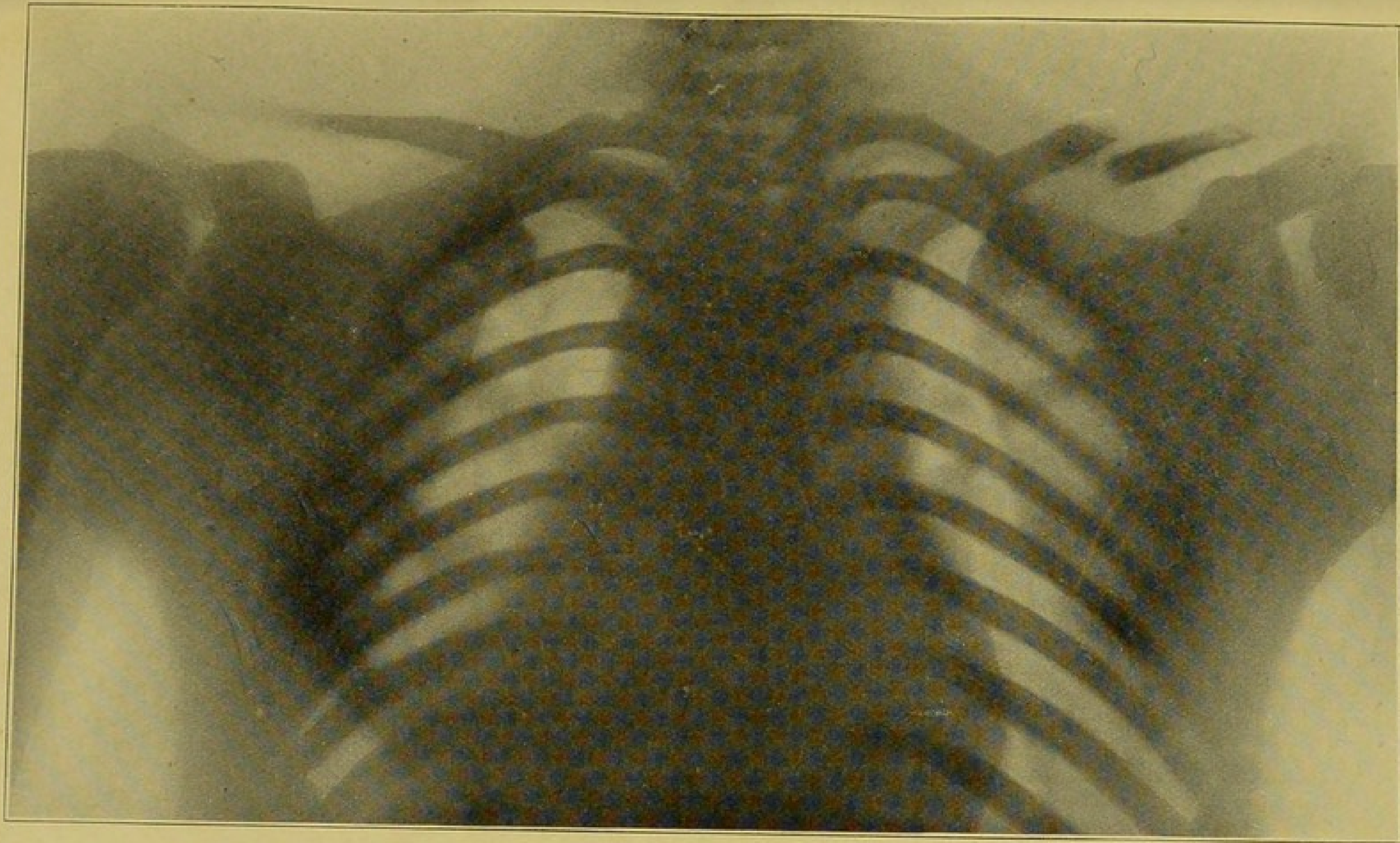


Fig. 33.

3. *Electrical Generation.*—Some experimenters ascribe the gradual increase of the resistance of the tube to the fact that the outside of a tube becomes electrostatically charged, and so reacts by influence upon the working discharge inside the tube. In order to neutralise these charges, some connection must be made between the inner and the



Plaice with small Crawfish in Guts. (By A. W. Isenthal.)



Radiogram of Thorax. Living Body showing Fracture of Left Collar-bone.

(By the Voltohm Company, of Munich.)

outer surface. For this purpose T. C. Porter placed a ring of plain copper wire round the neck of the tube (but not touching it) in the plane of the cathode edge, and brought a wire which was connected with the ground within very small distance of the ring, when a very rapid intermittent discharge between the two wires took place, and the fluorescence of the tube was greatly improved. Similar results are obtained by coating the neck of

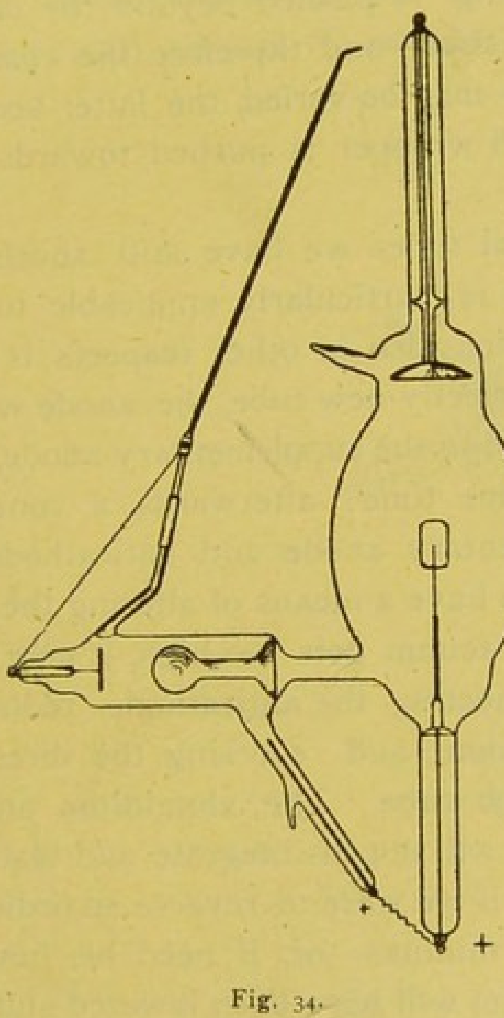


Fig. 34.

the tube with a strip of tinfoil in the plane of the cathode edge, and connecting the tinfoil ring through a small gap with the cathode terminal. Very old tubes, which almost refuse to pass discharge, are at once regenerated, and yield good radiations with smaller electrical energy. As this tinfoil ring diminishes the sparking distance between anode and cathode terminals, the arrangement facilitates the passage of sparks round the tube, and introduces the possibility of perforations. Berliner therefore replaced the tinfoil by a semi-conductor, pushing a wooden cylinder, moistened with glycerine, over the cathode neck of his tubes. A still better and simpler plan is that adopted by Gundelach, who wraps a piece of oiled linen, or of American cloth, round the cathode neck, connecting it to the cathode terminal by means of copper wire, which also serves to fasten the wrapper round the tube. According to the distance to which the wrapping is pushed beyond the cathode edge, the resistance of the tube—and therefore the character of the resulting radiation—may be varied, the latter becoming less penetrative as the cloth wrapper is pushed towards the bulb of the tube.

In multianodal tubes we have still another means of regeneration, which is particularly applicable to the Gundelach tube (Fig. 26), which also in other respects is a very excellent type. With a perfectly new tube, the anode wire from the coil is at first connected to the supplementary anode, and the current turned on for some time; afterwards a connection is made between supplementary anode and anticathode. By applying this connection we have a means of altering the character of the rays. When the vacuum gets too high, it may be remedied for a while by disconnecting the anticathode, reducing the current to a very small amount, and reversing the direction of the discharge through the tube. The aluminium anode being now used as cathode, it will not disintegrate and blacken the tube, as would be the case if we were to reverse an ordinary focus tube; and after several minutes—or, if need be, hours—of reversed running, the vacuum will have been lowered sufficiently.

Mechanical Regeneration.

Although mechanical means and arrangements are resorted to in this class of tubes in order to vary the resulting radiation, the immediate cause of the alteration is again electrical—namely, the variation of the tube's resistance. This method is due to Mr. A. A. C. Swinton, whose researches into the nature of the cathode rays have led to several important practical conclusions with regard to the generation of the X rays.

According to him, the penetrative value of the rays depend for a given vacuum upon the area of the cathode disc, and upon the lineal distance between the cathode and anticathode.

Mr. Swinton has designed two types of adjustable tubes, based respectively upon the above determining features.

In the tube shown in Fig. 36, four concave aluminium cathodes are provided, all having the same curvature, but differing in diameter. The common anode or anticathode is so arranged as to be easily rotated by mechanical vibration from

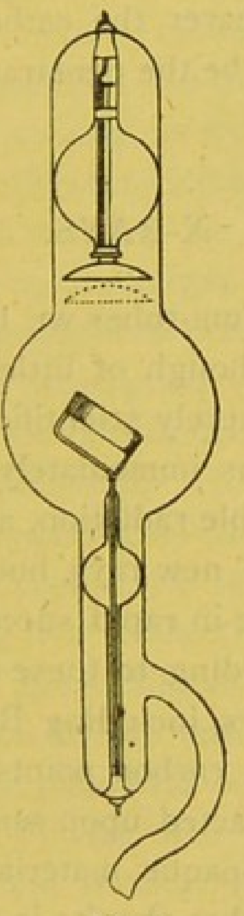


Fig. 35.

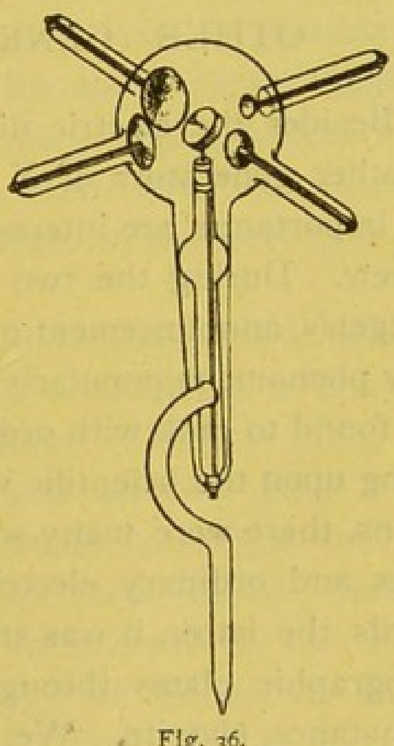


Fig. 36.

the outside, facing either of the cathodes at will. To give the anticathode stability, and to enable the use of high pressure, this support is carried down through a long glass tube. When first exhausting the tube, the residual air must be expelled from all the four cathodes by connecting them in turn to the coil ; the exhaustion is pushed so far that medium penetrative rays are produced with the medium-sized cathode. In actual use the penetration of the rays can be increased by using the smaller cathodes, and decreased by connecting the larger cathodes. These tubes are also multianodal, since any of the three idle cathodes may be used as the only, or as a supplementary, anode.

The other type is based upon the principle that the electrical resistance of the tube, as measured by the parallel spark in air, is highest when the distance between cathode and anticathode is small. The cathode in this tube (Fig. 35) is arranged on a sliding support, so that it may be shifted a short distance to and fro along the axis of the tube. The nearer the cathode is brought to the anticathode the greater will be the penetration of the rays emitted.

OTHER GENERATORS OF X-RAYS.

Besides the electric discharge in vacuum-tubes we have a few other generators of X rays, which, although of little practical importance, are interesting from the merely scientific point of view. During the two or three months immediately after Röntgen's announcement of his new invisible radiation, a good many phenomena popularly ascribed to the new rays, but since then found to rank with ordinary light, were in rapid succession sprung upon the scientific world, and, according to these observations, there were many sources of X rays, including Bunsen flames and ordinary electric arcs between carbon points. As regards the latter, it was shown that they acted upon sensitive photographic plates through intervening opaque material—as, for instance, ebonite. We now are aware that ebonite is transparent to ordinary light, and that those plates were only affected in the usual photographic way, without necessarily assuming the presence of X rays in the electric arc. Another form of electric arc, however, has been found by Tesla to emit powerful X rays. This investigator arranged a platinum terminal and an aluminium plate in a glass jar, and maintained the arc between these two metals. This, however, is attended with great difficulties, since the aluminium is rapidly destroyed by the arc.

As regards other sources of X rays, Messrs. Adams and Dubois are led to assume that such are produced during thunderstorms.

Quite recently Tesla made some experiments on cathode rays outside the vacuum tube, observing that X rays are generated even when the cathode rays impinge upon the dust particles present in air. He also concluded from some previous investigations of his own that the generation of cathode rays is not necessarily conditional upon the discharge taking place in a high vacuum, but that the air pressure may be considerably raised so long as we only effect the electric discharge impulses with sufficient violence and suddenness, such as we have in the case of Leyden jar discharges. Tesla thinks it possible that lightning discharges taking place in the upper rarefied strata of the atmosphere present all the necessary factors for this extra-vacual generation of cathode rays, which latter, on impinging upon the rain-clouds or some other obstacle, generate some form of X radiation.

Speaking of the discharge of Leyden jars, it is known that each spark starts an electro-magnetic disturbance of the ether, giving rise to electric waves—radiations—which in many ways show great similarity to X rays, and possibly have a close relation to the latter. It would, however, overreach the scope of this handbook were we to discuss these electric vibrations here. Those who wish to inform themselves on this subject will find it most lucidly treated in Prof. Dr. Oliver Lodge's "Modern Views of Electricity" and "The Work of Hertz and some of his successors."

CONVERTERS OF RÖNTGEN RADIATIONS.

Having now considered in detail the apparatus required for the generation of the Röntgen rays, it remains to be seen what means we employ to convert these invisible radiations into some form of energy which lies within the range of our perception.

There are two ways open to us—namely, the chemical and the physical effects of Röntgen rays, corresponding with which the practical application of Prof. Röntgen's discovery is being developed in two distinct directions—namely, *radiography* and *radioscopy*.

CHEMICAL EFFECTS.

Generally speaking, the X rays exhibit very feeble chemical effects, so that it is extremely difficult, and even doubtful, to trace any accelerating effect upon the combination of even those elements which show great affinity to each other, like hydrogen and chlorine.

On the other hand, the rays exert a very energetic action in every way similar to that of light and ultra-violet rays, upon certain sensitive silver salts; with the difference, however, that in the case of the X rays the medium with which these silver salts are incorporated greatly influences the result.

It has been shown by various investigators that neither Daguerrotype—nor collodion plates are affected by Röntgen rays. If, however, the silver bromide is combined with gelatine —that is to say, with the ordinary bromide emulsion of photographic dry plates—the X rays decompose this bromide into sub-bromide, and subsequent treatment with suitable chemical reagents (development) further reduces the sub-bromide to black metallic silver. Gelatino-bromide emulsions are the most easily affected (sensitive); next follow gelatine bromiodide and gelatine chlorobromide, all with alkaline development.

We shall revert at some length to the practical application of this re-action in another chapter (Photographic).

PHYSICAL EFFECTS.

Leaving the various phenomena of the discharge of electrified bodies by the X rays aside as being—for the present, at all events—of a more theoretical interest, the only other physical manifestation of these rays is their ability to excite certain substances to fluorescence.

Prof. Röntgen, in his original paper, mentioned this effect of his new radiation. The matter was then taken up by Salvioni, and furthermore by several American and English investigators, who examined an enormous number of chemicals as to their suitability for fluorescence. The only preparations which are to-day retained as the outcome of these experiments are the platinocyanides of barium and of potassium, the tungstate of calcium, and the uranyl fluorid ammonium.

The platinocyanides are undoubtedly the best of these, though their high price in some instances necessitates the substitution of some of the other compounds.

Platinocyanide of barium, the substance originally employed by Prof. Röntgen, has of late been much improved and certainly yields of all preparations the greatest luminosity. By the often-repeated process of crystallisation and purification, its fluorescing powers have been increased to twelve times their original amount. The crystals in this state are exceedingly fine, whereby the definition of the image is considerably improved. The colour of its fluorescence is a bright greenish yellow.

Platinocyanide of potassium was first employed for radioscopic purposes by Mr. Herbert Jackson, and this salt in its crystalline and best form contains three parts of water, and it is therefore advisable to always keep it moist in order to obtain the best results. The definition, depending upon the contrasts obtained in the images, is somewhat inferior to that with barium-cyanide. It fluoresces a pale blue colour.

Tungstate of Calcium, as first suggested by Edison, is, as a rule, inferior to the cyanide salts. Much, however, depends upon the method of preparing it, and some specimens lately prepared by Kahlbaum, of Berlin, have proved highly satisfactory in our hands, fluorescing with a pale purple light.

The double fluoride of uranium ammonium, introduced by F. von Melckebeke does not seem to offer any advantages over the preceding preparations.

In order to use these fluorescent compounds, they are spread by means of some adhesive vehicle on stout paper or cardboard, in such a way that the resulting coating is perfectly uniform, so as to prevent a patchy appearance when fluorescing which in some instances might lead to a diagnostical error. Such a coated surface is called a *fluorescent screen*, which, for better protection against mechanical injury, and also to exclude ordinary transmitted light, is generally backed with thin ebonite or black celluloid. The barium or tungstate screens are protected from atmospheric influences by a coating of varnish, and should be further protected against mechanical damage by being covered in with glass.

The conversion of the Röntgen rays into visible rays by means of these screens is at present very inefficient. It can be shown that after passing through the first screen, the radiation from a good tube is still sufficiently powerful to produce an image on two or three more screens, even at considerable distances. This fact suggested to Dr. Macintyre the use of coarser crystals for screens which gave him greater brilliancy in the image, but, unfortunately, at the expense of definition. Another, and better plan, is to retain the fluorescent material in its minute crystallic form, and to apply two or three layers to the screen, but even then the absorption of the Röntgen rays is far from perfect.

It has been suggested that *phosphorescent* preparations, like sulphide of zinc, would offer great advantages over fluorescent materials, since the former would exert a cumulative effect upon the screen image, causing it to grow brighter and more distinct after the rays have acted for some time. But since the initial luminosity is rather small and insufficient for the radioscopy of the internal organs, it cannot be recommended; particularly since the phosphorescent after effects would blend with the fluorescent image, and tend to confuse the operator when examining moving objects, such as the heart, or the respiratory organs, as those would appear greatly enlarged.

ACCESSORIES.

Besides the instruments proper for generating and utilising the new radiation, it has been found convenient, and in some cases necessary, to employ certain accessories for practical work, which, however, may vary in every case to suit individual requirements, so that we can only give some typical examples in this chapter.

Except in the case of very small coils, run from primary batteries, the need of measuring both the available E.M.F. of the accumulators and the amount of current through the coil soon becomes evident, because, as we have seen, the E.M.F. of the accumulator must be watched in order to prevent its being discharged too far, and because the current through the coil must be known in order to prevent damage to it and the tube, and also to judge the exposure.

The instruments which we use for this purpose are the voltmeter and the ammeter respectively (a convenient form of which is shown in fig. 37).

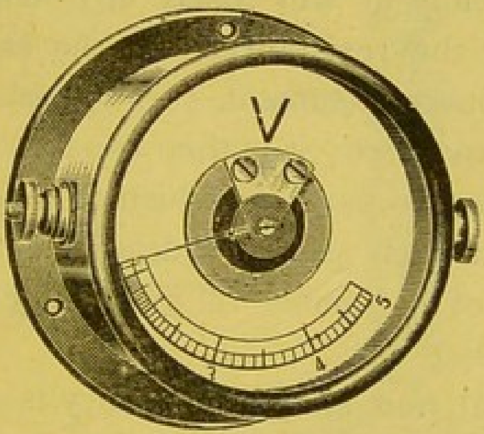


Fig. 37.

The ampèremeter (or ammeter) is wound with stout copper wire, and may be kept permanently connected with the coil, thus showing at a glance whether the current is steady or not, whether it wants reducing or increasing. The voltmeter, however, being wound with very fine copper wire, would become heated if the current were to pass constantly through it, and this would affect the accuracy of the reading. It is therefore only periodically connected to the terminals of the accumulator (through a simple plug switch) and this is also sufficient since the E.M.F. of the accumulator or battery does not fluctuate, but merely decreases at a steady rate. The scale of the voltmeter ought to reach from zero to about fifteen volts, that of the ammeter from zero to ten ampères, for larger coils.

In order to control the current for different tubes we may either reduce the E.M.F. of the battery by cutting out some cells, or we may interpose a variable resistance between source of current and coil. The former plan is not so good, since the regulation would necessitate a re-adjustment of the contact-breaker of the coil. The more usual method is, therefore, to employ a *rheostat.*

The smaller kind, such as may be used between a battery and the coil, consists of a frame carrying several coiled lengths of wire (iron or special alloy) the ends of which are brought to as many contact studs over which a contact lever slides so that we may at will insert any length of wire, and consequently vary the resistance. In the case of the supply circuit being the source of current, such rheostats would have to be too large and expensive; it is then usual to divide the necessary resistance into two parts, of which only the smaller part is a variable rheostat such as above described, whilst the greater part is made up of a number of incandescent electric lamps (coupled in parallel).

Another useful and simple accessory is the "*cut out*" or *fuse.* It sometimes happens (especially when using platinum contact breakers) that the break sticks, owing to the contacts fusing together, when there would be a rush of current into the coil, which would either excessively heat the wire and damage the insulation, or would injure the tube. Against this we can guard ourselves by placing between battery and coil the above-mentioned "cut out," which consists of a wire or strip of a certain alloy, of such a sectional area that it becomes heated and melted as soon as a certain amount of current passes through. If the safe maximum current for the coil, as fixed by its maker, be, for instance, ten ampères, then a 10 to 12 amp. fuse (obtainable from any electrician) should be connected, which will interrupt the current by fusing through, immediately the safe limit is overstepped.

TUBE HOLDERS.

For experimental work, an ordinary wooden Bunsen retort-holder (Fig. 38) is very suitable for fixing the tube in any desired position, as long as the base is sufficiently weighted to give it stability. For clinical and hospital work, however, we require a holder which will enable us to fix the tube at any

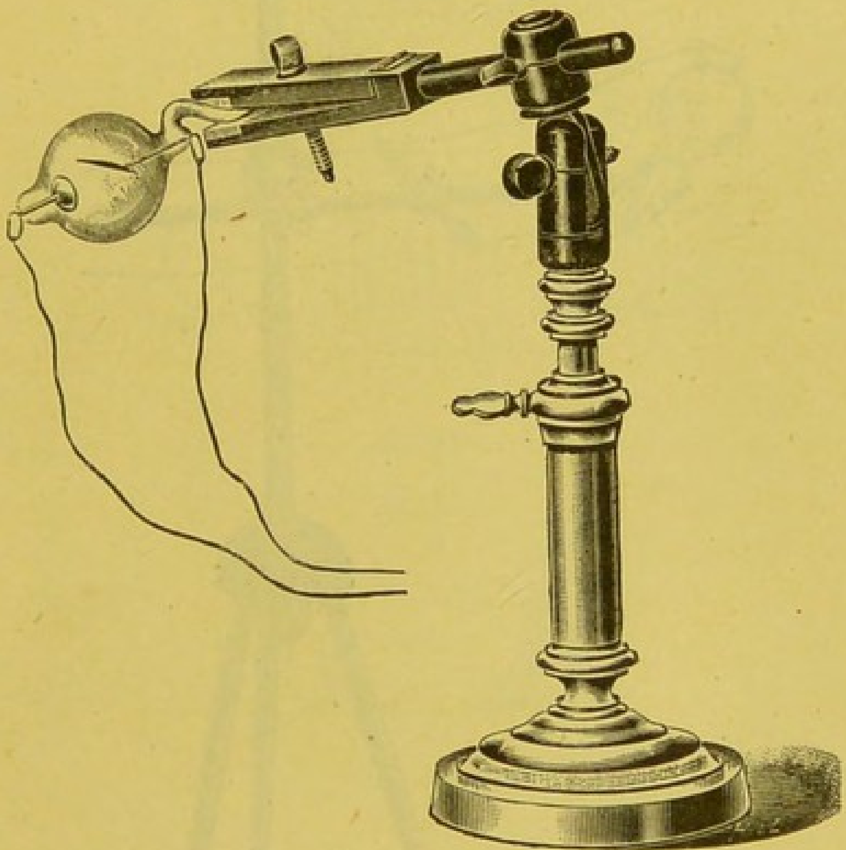


Fig. 38.

height from the floor (for radioscopy), and to make it project far enough from its support to be brought over a bed or the operating table. The base should be very heavy to ensure perfect steadiness, and all the moving parts must be very rigid. If there are any swivel and ball joints they must be accurately worked and must clamp firmly, as otherwise the tube (owing to the vibration communicated to it through the connecting wires from the coil) would change its position during long exposures. If such stands are made of metal, all those parts which are near the tube or the connecting wires, particularly the tube-clamp itself, should be made of wood or ebonite, so as to prevent sparking from the terminals into the metal, which might be dangerous to the patient and also to the tube, which gets easily

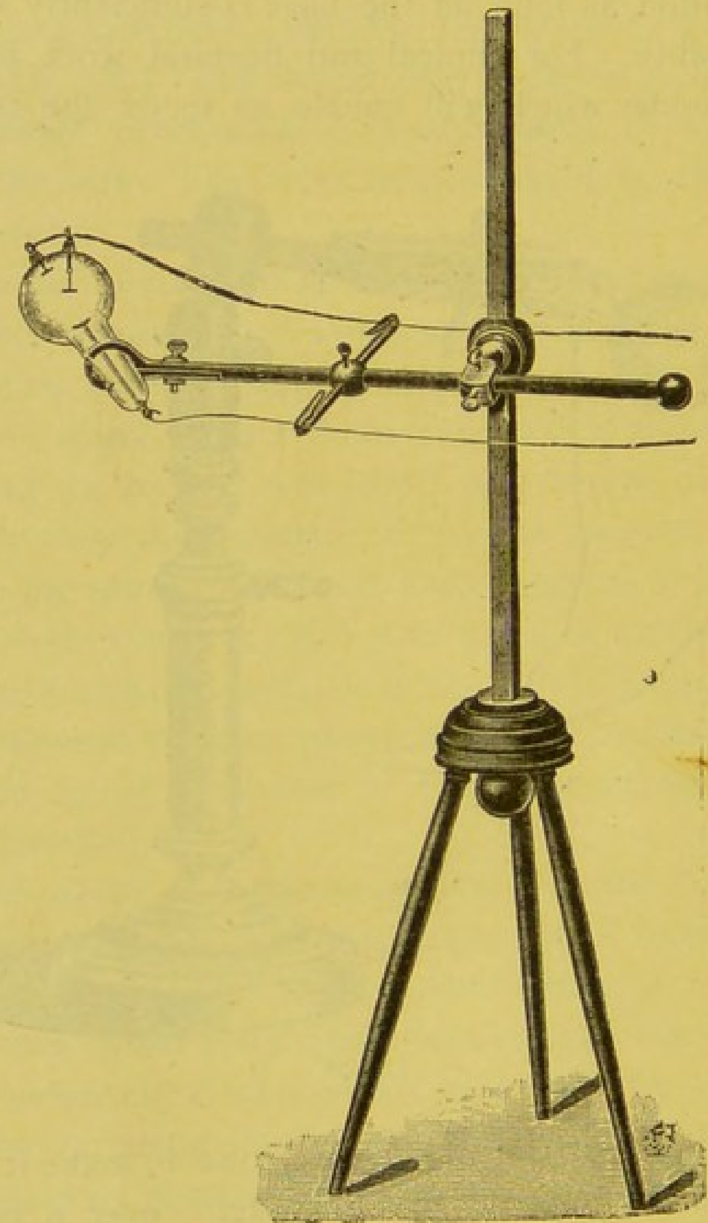


Fig. 39

perforated. Fig. 39 shows a good holder made entirely of seasoned boxwood and having all movements.

For certain purposes (statical machines) a spark-gap is used between tube and converter. Such an arrangement simply consists of a base-board with two ebonite pillars, which are fitted at the top with brass terminals, through which two brass rods with ball tips are passing. The rods are let into insulating handles at one end, so that their distance apart may be varied during working.

The various instruments are connected up as shown in the diagram (Fig 40), these connections being either permanent, as in the case of hospital installations, or temporary, where portability is a condition. The conducting wires which we employ in

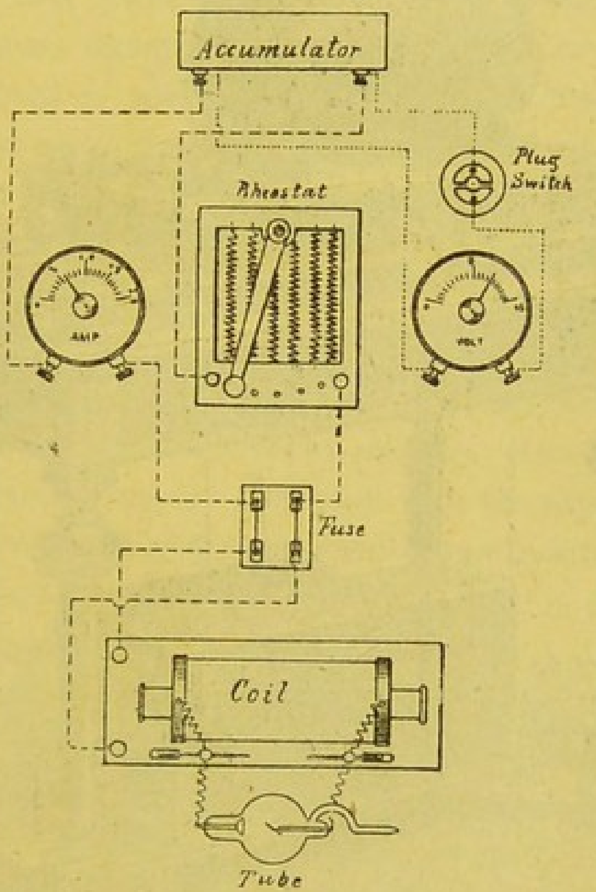


Fig. 40.

the primary circuit—comprising battery, coil, rheostat, &c.—must be of sufficient thickness to carry the maximum current without heating; for coils up to 10" or 12" spark length a No. 16 copper wire with good insulation will be ample. For permanent connections it may be placed in wooden casings, similar to those used for electric lighting; for temporary and portable connections a suitably insulated (braided) flexible cable, consisting of stranded copper wires, should be used. The connections in the secondary circuit (that is, from the coil to the tube or to the spark-gaps) require but very thin wire, say No. 28; but this must be exceedingly well insulated with pure rubber and gutta-percha, and should be kept as short as possible, in order to prevent loss by leakage, and to obviate the possibility of getting electric shocks whilst handling the tube.

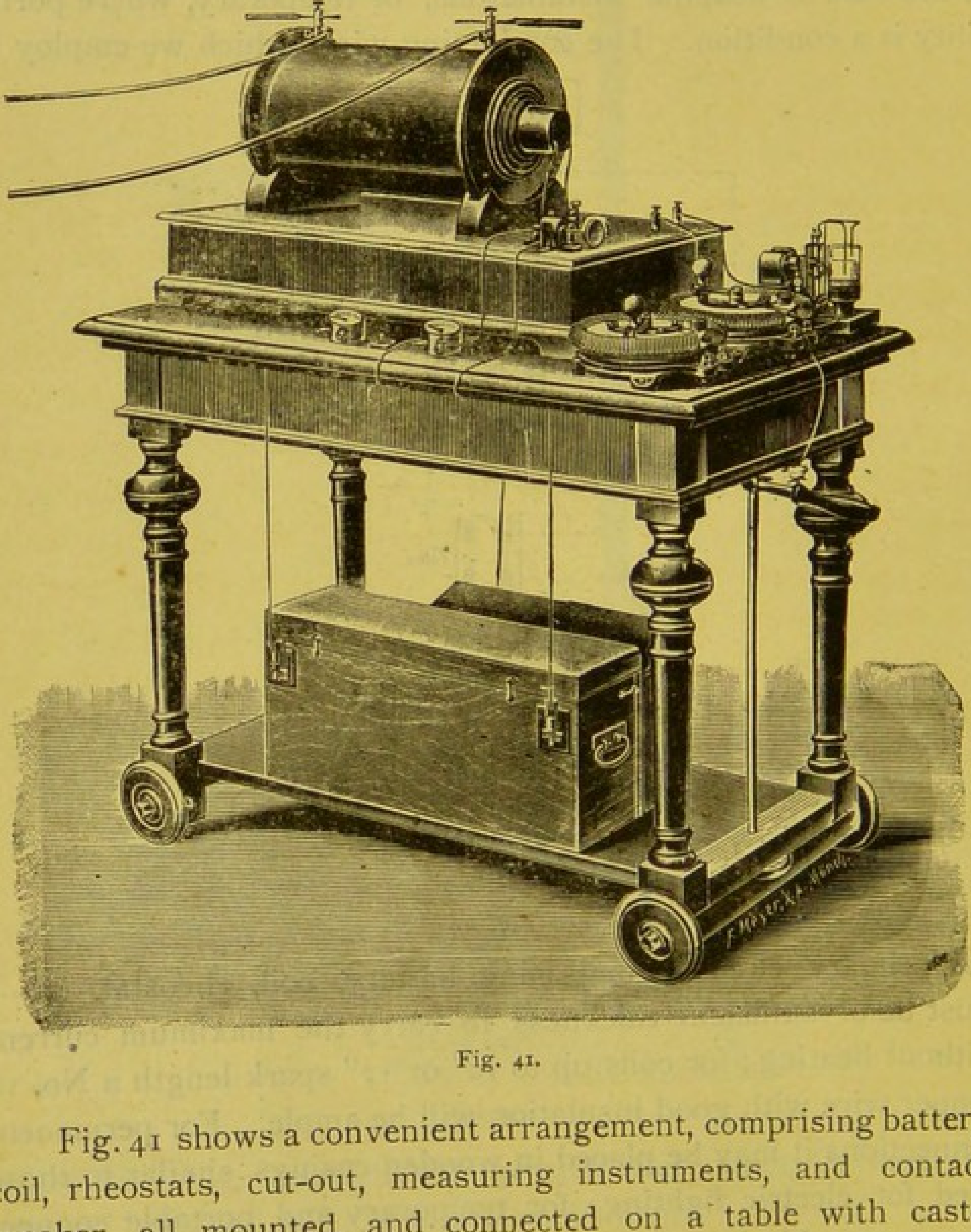


Fig. 41.

Fig. 41 shows a convenient arrangement, comprising battery, coil, rheostats, cut-out, measuring instruments, and contact-breaker, all mounted, and connected on a table with castor wheels.

Finally, some means of testing the efficiency of the tube at any given moment should be available. Of course, a photographic test exposure would show all that we require; but it is too circumstantial a processs in many a case. The appearance of a test object—say the hand—upon the fluorescent screen is therefore usually resorted to, as the quickest way of estimating the momentary condition of the tube. It is, however, only an approximation, as the animal tissues do not form a very definite test object.

To supply this want, certain intensity meters—or X ray meters—have been designed, consisting in every instance of varying thicknesses of some semi-opaque material, which yields a graduated shadow on the screen. Reynolds and Branson first introduced such an instrument, which was represented by a quadrant of aluminium turned down into concentric rings of decreasing thickness, of which, with certain powers of the tube, a certain number could be made out on the screen. Very similar is an arrangement in which a plate of aluminium has been drilled in various places to different depths. Dr. Hall-Edwards super-imposed several square sheets of thin ferrotype plates.

One of the handiest and most readily made intensity meters has been described by A. Parzer-Mühlbacher; a piece of card-board, measuring about 5" by 4" is divided into 32 rectangles, which are successively covered with tinfoil in such a way that the first has one layer and the last 32 layers, and to each space is cemented a small numerical of brass or zinc denoting the number of layers. The whole is then covered in with black celluloid or ebonite, and the edges bound together like a lantern slide. On placing it between tube and screen, at a certain distance from the former, a certain number is just still discernible, and this number permits of making comparative tests of the penetration of a tube, provided the distance and the electric energy remain the same in both experiments, although the visual image on the fluorescent screen does not necessarily permit us of forming an idea as to the photographic action of the tube.

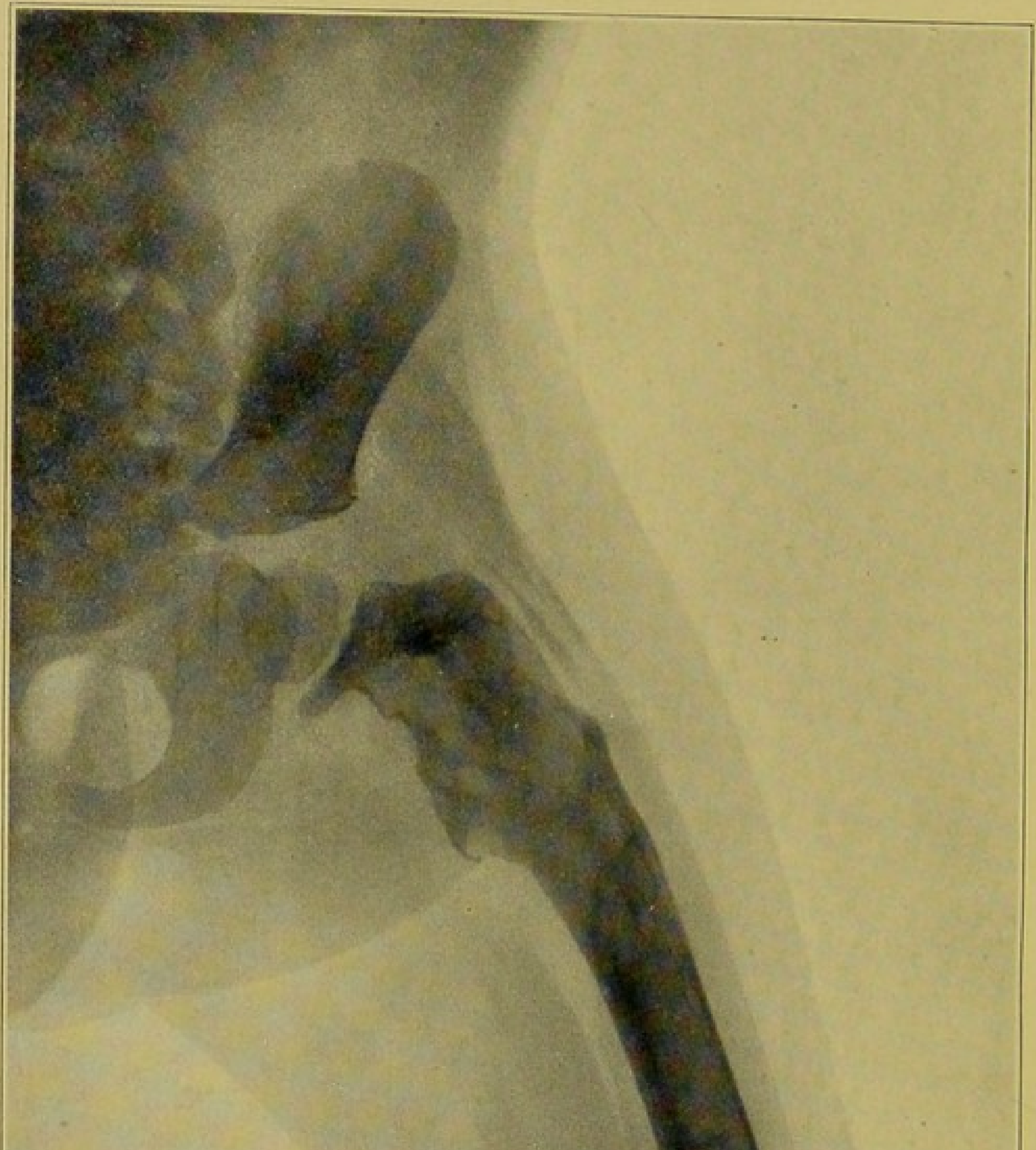
CHAPTER III.

ELECTRICAL.

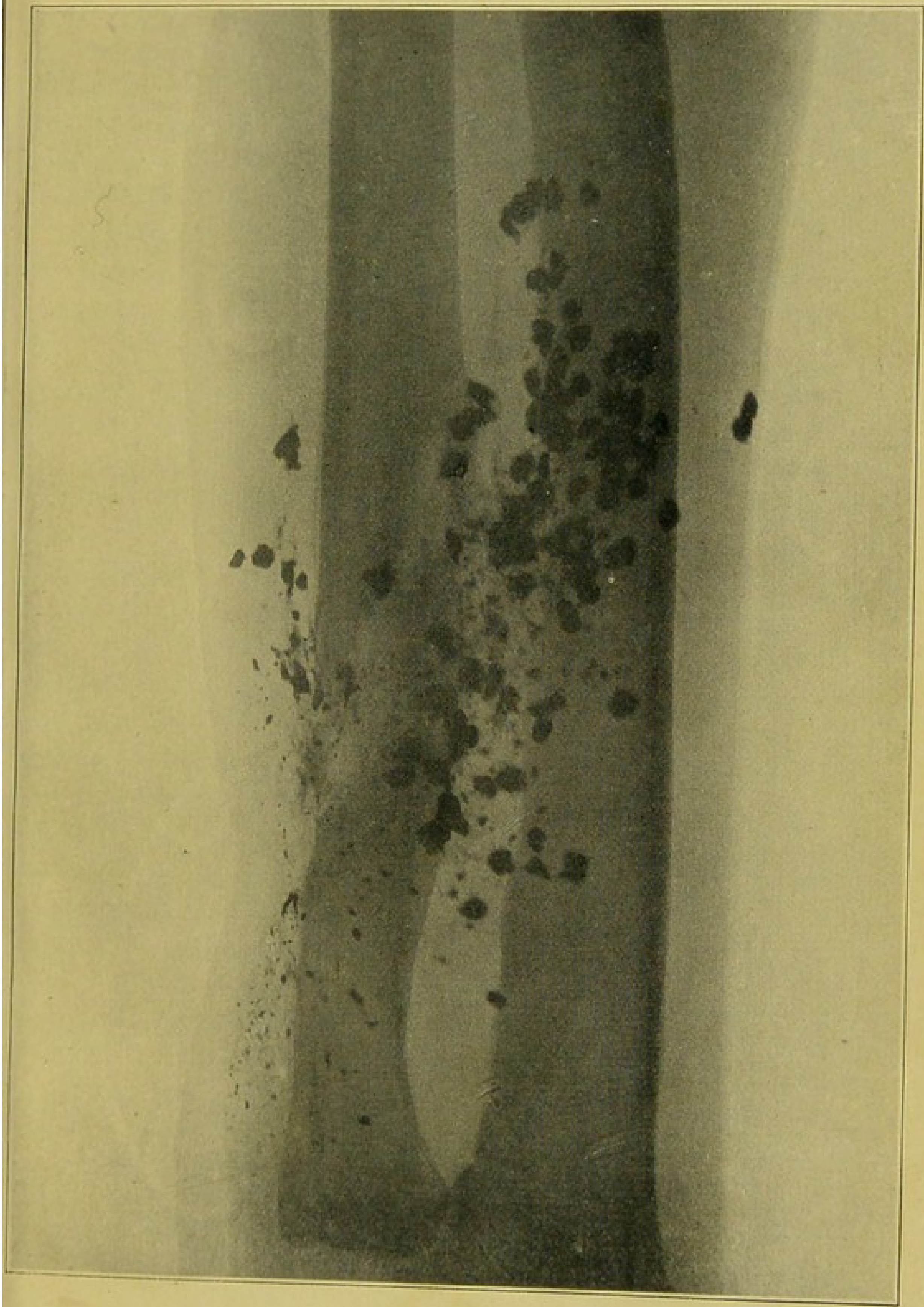
MAINTENANCE OF BATTERIES.

THE proper treatment of primary batteries really becomes obvious from their construction and action as described in a previous chapter. When using perfectly new batteries, it will only be necessary to exactly follow the directions sent out with them, being careful to properly make all the electrical connections between individual cells, and between the battery and the instruments. If we have a bichromate battery, the effect of polarisation will make itself known by reducing the working current. This may be ascertained by observing the ammeter or by noting whether the pitch of the contact-breaker's note becomes lower after the coil has worked for some time. At this stage some improvement may be made by immersing the zinc to a greater depth in the electrolyte, but if the zincs are fixed and the electrolyte has assumed a dark-green colour, it must be renewed.

In the Bunsen and Grove cells, the generation of current lasts until the nitric acid is spent, which may be taken to be the case when the acid ceases to throw off nitrous fumes. In the Edison-Lalande cell the generation of current ceases as soon as the whole of the black copper oxide has been reduced to metallic copper. In this case, it is only necessary to insert one of the spare oxide plates in place of the spent one. Before renewing the electrolyte in the cell, and when putting it aside for any length of time, the zincs must be cleaned in sulphuric acid, and if necessary, re-amalgamated. Carbons and porous pots must be soaked in water, and left there until the crystals



DISEASED HIP-JOINT. (By Dr. Mackenzie Davidson, London.)



FRACTURE OF RADIUS AND GUNSHOT IN FOREARM.
(By Hall Edwards, L.R.C.P., Birmingham.)

formed in their pores are dissolved out. The Edison-Lalande type, however, may be put aside without such precautions being taken. Amalgamation of the zincs becomes necessary, since the zinc as a rule is impure; the admixed metals cause local chemical action, even when the cell is not giving any current. The process of amalgamating the zincs is very simple, and consists in first removing every trace of grease by washing the zinc in soda, and then with a stiff brush rubbing dilute sulphuric acid all over the metallic surface. The zinc is then dipped into a sufficient quantity of mercury under a layer of dilute sulphuric acid (1 to 8 parts), and when uniformly covered with mercury is well washed to remove the acid, and the surplus mercury is brushed off.

ACCUMULATORS.

Although possessing undoubted and great advantages over primary batteries for radiographic work, accumulators require a greater amount of attention if they are to work satisfactorily, and are to last long. The precautions to be observed to ensure success are shortly as follows:—1. When discharging, the E.M.F. of each cell, as measured by the voltmeter, must not be allowed to sink below 1·7 volt; thus, in the case of a six-cell battery, ten volts is the lowest limit for the discharge. Otherwise the plates would buckle and the active material would be loosened, and eventually drop out altogether.

2. The accumulators must be frequently re-charged (about once every three weeks will be sufficient), even if the E.M.F. is well above the discharge limit, or if no discharge at all has taken place. It is most detrimental to the life of an accumulator to put it aside for months, as the plates in this case become covered with sulphate of lead, which is rather insoluble, and thus diminishes the active surface.

3. The plates must be entirely covered with acid. If the latter has been spilled or become partly evaporated, it must be replaced with dilute sulphuric acid (free from arsenic) of 26° Beaumé, or 1·25 specific gravity (when the accumulator is charged).

4. Accumulators, unless specially designed for the purpose, should not be subject to much vibration; they are best placed in a dry and insulated position.

5. Great care must be taken to avoid a "short circuit" (that is a direct metallic connection between the terminals), as this might damage the plates so as to ruin the whole accumulator.

Accumulators are generally used when no continuous supply circuit is available to work the induction coil; they are then always sent out to be re-charged by an electrician, and as this requires a day at least, it is advisable to have a spare set, which alternates with the other set, so that one is never without a battery.

If the continuous current is available, but an accumulator must be used for portable purposes and for work away from the house, the charging may easily be done at home. For this purpose either an adjustable Rheostat or a 32 c.p. or 50 c.p. glow lamp must be inserted between accumulator and circuit in order to prevent an excess of charging current; the positive pole of the accumulator, which is always so marked, must be connected to the positive pole of the circuit, which can be ascertained by means of pole-finding paper, of which several kinds are obtainable. Having one 30 c.p. lamp as a Rheostat, only one ampère current would pass into the accumulator, the charging of which, when of good capacity, would take some considerable time. It is possible, by using two or more lamps in parallel, to work with a stronger current and save time, so long as the charging current is within the limits prescribed by the maker. The charge may be considered complete as soon as the acid turns milky, showing that the developed gases are no longer chemically absorbed by the plates. The E.M.F. of each cell will then register about 2·6 volt on the voltmeter.

If no supply current is available and no electrician within easy reach, the charging of the accumulator must be done by means of a primary battery, thermopile, or a small dynamo driven from a water motor. This, however, is both expensive and circumstantial.

When using a Wimshurst or other statical machine, proper manipulation and maintenance are most essential in order to avoid failures and disappointments. The machine must be kept in a dry atmosphere, as free from dust as possible, and also in the case of machines with ebonite discs should be kept away from stoves or fireplaces, the heat from which would buckle the plates. When putting the machine away for some time it should be covered with a heavy black cloth to protect it from direct daylight or sunlight. Before starting the discs, we must examine the collecting combs, with a view of preventing their scratching the tinfoil sectors when rotating past them; all the parts of the machine should be carefully wiped free from dust with a dry silken cloth, and if the sectors have become oxidised, and the discs clogged with dust, they may be cleaned with a rag dipped in alcohol or benzol. As the latter dissolves varnish, it must not be used on glass parts which are varnished. Every month or so it will become necessary, for a thorough cleaning, to take the machine to pieces, and remove the dust which collects between the rotating discs, also to moderately lubricate the bearings, being careful to avoid any oil getting between the ebonite discs.

Many of these precautions, however, may be dispensed with, or, at least, considerably lessened, if the machine is enclosed in a dust-proof glass-case, from which only the terminals are projecting. As a matter of fact, several of such machines, which, by the courtesy of Mr. J. Wimshurst, we were able to inspect, and which had not been used for considerable periods, at once excited without any previous attention.

The spark length which a machine should give when properly worked ought roughly to equal the radius of the revolving plates. Much, however, depends upon the position of the brush neutralisers. The latter must be so bent that the brush es touch the discs during the whole period of rotation; keeping one neutraliser in a nearly vertical position, the other should be turned so far that the spark between the dischargers attains a maximum when gradually drawn out. This is generally the case when the neutralisers are at right angles to each other and equally distant from the collectors.

It is, of course, important to know the polarity of the discharging knobs, in order to properly connect the tube; the positive electrode may be identified by the sharp hissing noise it emits when in a horizontal position.

The maintenance of *thermo generators* is exceedingly simple; all that is required is to secure a constant size of heating flame and to provide for a sufficient and constant supply of cooling water for the radiating and cooling surfaces.

Passing next to the *induction coils*. It will be obvious from their construction that they must be kept absolutely dry, and also in a fairly cool place, since the paraffin wax whic enters so largely into their construction, easily softens in a warm atmosphere. The whole coil is strongly electrified during use, and rapidly collects dust from the air. It should, therefore, be dusted from time to time with, of course, the current turned off at the current reverser. Since the latter is often the only switch in the connections, it should be made to turn rather stiffly in its bearings, so as to prevent it from accidentally turning into contact position, and starting the coil at the wrong moment.

The interruptor requires a great deal of attention, especially the original model illustrated in Fig. 12. It is important, when not using the coil for several hours, to slacken the tension of the springs, so as to take off all strain. Besides, by screwing the two platinum points out of contact, an additional factor of safety is introduced, preventing the coil from starting, even if the reverser should by mistake have been left in the *on* position. When starting the coil we should see that the contact surfaces are smooth and in good touch (not only in one point), if necessary, ensuring this smoothness by drawing a sharp flat file across the platinum. The current reverser is now closed in the proper direction, which has previously been found by experiment, and the contact screw turned towards the armature until a spark passes between the coil dischargers. After switching off the current the dischargers are drawn to a distance corresponding to the spark length with which we desire to work and, with the current "on," the bottom tension screw is turned back until the resulting tension of the contact spring and the subsequent higher magnetisation of the core produce a good stream of sparks between the dischargers.

In order to obtain weak but rapid alternating currents from the coil, the tension is entirely taken off the spring, and the contact screw turned far in towards the armature. When once the proper adjustment has been effected, the position of the contact screw must be fixed by tightening the locknut. When the interruptor works properly, there should be no flaming between the contacts, and the noise of the vibrator should be regular and free from spluttering, the pitch depending upon the frequency of the interruptions.

The *King* contact breaker (Fig. 13) is provided with yet another adjustment screw, which, when screwed right in contact with the vulcanised fibre plate, simply converts the interruptor into the Apps type we have just described. On the other hand, the more we increase the distance between the point of the screw and the fibre end the longer will the contact last and the more sudden will be the subsequent break, so that we obtain slower but more powerful discharges between the secondary terminals. This gives us a most valuable means of adapting the coil to any tube and any kind of work.

When using some form of mercury interruptor, two adjustments are available, namely, the frequency of the interruptions (regulated by the speed at which we allow the motor to work the vibrating rod), and the relative period of contact and interruption (regulated by the relative height of the mercury level).

For radioscopic purposes, long and slow sparks, such as those which a mercury contact ordinarily produces, would be useless, because, although lighting up the screen very brilliantly, this fluorescence would be too intermittent to allow of proper diagnosis. For radiography, however, the intense though slow spark is preferable. It is thus rather impossible to decide once and for all which is the best form of contact breaker, and it seems advisable in the case of large coils to be provided with both a vibrating and a mercury interruptor, so fitted that they may be quickly interchanged when and as occasion requires.

Every coil and battery should have its terminals (both primary and secondary) marked with their respective polarities for a certain marked position of the current reverser, and it would also be well to have the highest permissible voltage and current as well as maximum spark length indelibly stamped upon some part of the coil, in order to minimise the danger of over-taxing the instrument.

As regards possible breakdowns of coils, we would strongly impress the operator, unless he be a skilled electrician, never to attempt to take the coil to pieces, since this is sure to introduce further defects. If the coil refuses to give its proper spark whilst the battery is in good condition the work should at once be stopped, so as not to aggravate the defect, wherever it may be, and efficient professional help must be at once secured.

MANIPULATION OF TUBES.

Having already dealt with the peculiarities and details of the various types of Röntgen tubes, it only remains for us to consider a few working details in this connection.

The tube should be perfectly dry and clean and free from the dust which it is apt to accumulate when working (owing to its becoming electrically charged). The wires connecting it with the coil must be so arranged that they are throughout sufficiently far apart from each other to prevent alternative sparking across. They should not be allowed to touch anything metallic, but more particularly must they clear the glass walls of the tube, as otherwise the latter is almost certain to get perforated by the passage of a spark. The part of the tube at which the latter is clamped in the holder must be protected from being crushed by a soft elastic cover, such as cork. A good plan is to pass the stem of the tube through a cork which is pressed into a stout glass tube, the latter being held in the clamp of the holder.

The tube had best be fixed in such a position that the cathode axis be parallel to the axis of the coil whenever the latter is in close proximity to the tube, for it is to be remembered that the core of the coil is a powerful magnet, the pull of which in certain relative positions to the tube, is able to deflect the cathode rays to such a degree that these would miss the anti-cathode, and the X rays would be generated at some other inconvenient point of the tube. We have already dwelt upon the necessity of sending the current the right way through the tube, in order to prevent blackening it by disintegrated platinum; but if a mistake in this direction is made it will at once be recognised by the appearance of the tube, which in this case shows strong fluorescence behind and round the cathode. The current reverser must then be at once brought into the other position.

The arrangement of a spark gap in parallel with the coil is now almost in every instance resorted to, partly to serve as a safety valve, and partly as an indicator of the tube's vacuum. If, for instance, by some mishap, one of the connecting wires to the tube should fall off there is a tendency for the discharge to pass from the free end of the wire to the free terminal of the tube, which might injure the latter. Should we, however provide a spark gap between the secondary coil terminals, then in the foregoing instance the discharge would pass by preference across the gap.

We have seen that after some time the vacuum of the tube is raised; without a parallel spark gap, the spark, instead of passing through the tube, would then fly around the outside of the tube, possibly perforating it. With the spark gap arrangement, however, as soon as the vacuum reaches a certain degree, sparks will begin to pass across the spark gap, and the tube will simply remain inert, indicating the necessity of resorting to one of the regenerative means for lowering the vacuum.

For regulation, also, the parallel spark gap will do good service, as by its means we may select the penetrative character of the emitted rays from a tube ; we may, for example, if desirable, work a 6-inch tube with only a 2-inch spark, if we set the parallel gap at two inches; whatever the impressed E.M.F. of the coil, no higher pressure than that corresponding to a 2-inch spark will then be able to pass through the tube, the excess going across the gap.

Another means of adjustment is presented by arranging a spark gap in series with the tube—that is to say, on the positive side of the coil; this gap should be just large enough to prevent the alternating discharge, which, as we have seen, is always produced in the secondary of an induction coil, though there be a sufficient condenser. Certain experimenters found that such a gap permitted of the use of lower vacua, in order to generate rays of a given penetration.

Again, in some cases, especially when working with the Tesla, or with Wimshurst, apparatus a double spark between coil and tube may be found very useful to correct and adjust the variation of the discharge through the tube. This, in working with an induction coil we attained by altering the E.M.F. between the tube terminals, by varying the tension of the vibrator spring or the speed of the rotary or mercury interruptor. In our present case, however, we attain the same end by reducing one or both of the spark gaps, and since we may start with two gaps of about 1½-inch width, and reduce them to actual contact, it will be evident that this method affords plenty of margin for adjustment.

Indeed, there are a great many possibilities of adjustment presenting themselves to the practical operator, which we cannot detail here, but the intelligent and persevering worker will, after a little practice (including many failures), elaborate for himself that particular system which most harmoniously meets the exigencies of his own particular class of work.

CHAPTER IV.

PRACTICAL RADIOGRAPHY—PHOTOGRAPHIC.

THE photographic manipulations which are required to produce from a plate which has been exposed to the Röntgen rays a negative and a print are in no way different from those which obtain with ordinary photography, and it will thus be obvious that it is impossible to condense within the frame of a single chapter an introduction into the art of photography, or even that part of it with which we are almost exclusively concerned here—development. We must therefore confine ourselves to a description—without theoretical explanation—of the modus operandi of development, with special reference to a few peculiarities due to the exigencies of radiography, referring the reader who wishes to acquire a more intimate knowledge of the principles involved, to any of the excellent books on photography.*

The sensitive film, as we have seen, is now exclusively a gelatine emulsion, which may be spread on glass or on a flexible support, such as paper, celluloid, or thin iron plates.

The ordinary dry plate with glass support, being the readiest to obtain and the easiest to manipulate is, of course, generally used; the conditions which it has to fulfil to make it suitable for radiographic exposures are, as far as we know, thickness of film and sensitiveness to ordinary light. Taking the latter characteristic first, it would seem that different workers are somewhat at variance on this point, since some profess to prefer a medium rapidity of plate to the most rapid brands. The majority, however, use plates of extreme speed,

*To an absolute beginner we should recommend *Early Work in Photography*, by W. Ethelbert Henry, C.E., as the most simple and practical of all first hand-books.

such as Cadett's Lightning, Paget XXXXX, Imperial Flash Light, Thomas' A1, the Ilford Red Label, Marion's and Mawson's special rapid plates, which are all the ordinary standard plates, without pretending to be specially prepared for radiography. Quite early in the history of Röntgen ray photography an attempt was made to embody certain fluorescent substances in the film in order to increase its sensitiveness to the rays, but the results were not at all encouraging, since a good deal of definition was lost in the negative, and the gain in sensitiveness was rather insignificant. Yet there are several special so-called X ray plates on the market which claim to yield superior results, both as regards speed and density; of these we may mention Edward's Cathodal plates, the X ray plates of Lumière, and of Dr. Smith, Messrs. F. Schüler and Günther, of Berlin, and Dr. Max Levy, of Berlin, as well as the plates manufactured by John Carbutt, of Philadelphia. Certain of these plates, on account of their excessively thick films require much longer development, which is a certain disadvantage, seeing that it excludes the pyro developer on account of the stain produced on prolonged development, and also because it is always desirable to quickly find out the result of an exposure in order to repeat it, should the first plate prove a failure.

The chief drawback of glass dry plates are their weight, and especially their great liability to break, more particularly with the large sizes, which we so often require in radiography. Besides, having a rigid support, it is impossible to adapt them to the position or shape of the object to be radiographed, which sometimes introduces want of sharpness into the result.

Of all the various substitutes for glass, celluloid has been most frequently used, being flexible and transparent; yet for certain chemical reasons celluloid is not a desirable support for emulsions, and the results obtained so far on celluloid films are generally somewhat inferior to those produced on glass plates. But in the case of the double-sided films, to be mentioned later on, they are indispensable.

Paper as a support is preferable to celluloid, but its opacity and grain somewhat interfere when it is desired to print from it by transmitted light. The Eastman X ray paper is a very good example of this type, being easy to manipulate, although not as sensitive as the most rapid plates or films. Instead of obtaining copies by printing from it, they may be produced at one exposure by super-imposing several papers (which are quite transparent to the rays). Development and fixing are the same as are usual for plates.

Ferrotype plates are fairly flexible and exceedingly sensitive. Whether the iron support has any effect upon the incident X rays, as has been asserted, we do not know, but specimens obtained from the Birmingham Collodion Dry Plate Co., and Messrs. F. Schüler and Günther, of Berlin, were very satisfactory. As these ferrotypes are opaque, both to transmitted light and to X rays, they must be copied with a camera in order to obtain duplicates of the radiograms. Development and fixing present no unusual features, but owing to the ground of the image being black, the black, and consequently invisible (or nearly so) deposit of silver must be converted into a white silver salt by subsequent intensification (see below).

Whatever be the sensitive surface which is eventually selected, it will be obvious that greater care must be exercised in storing it than would be the case in ordinary photography, where the only active agent—light—can be cut off by various opaque boxes or envelopes. Keeping plates in cardboard boxes in an establishment where radiographic apparatus is working, is quite insecure, since the rays easily penetrate the boxes at a considerable distance, also through such obstacles as the walls of the operating room; even a wrapper of tinfoil will not protect the plates from fogging. The safest and most convenient receptacles for such plates are zinc boxes. For this reason also no spare plates ought to be taken into the operating room whilst the tube is in action, only the plate under the object to be radiographed being tolerated there.

Usually the sensitive surfaces, whether plates or films require no special preparation before being exposed: they are simply taken from the zinc box and transferred to the paper cover for exposure. This cover, usually of black paper without any pinholes, is opaque to light, but permits the X rays to pass unaffected. Very convenient are the envelopes sold by Tylar, of Birmingham, an orange envelope receiving the plate or film and the whole being then enclosed in a stout black envelope. In order to always know the position of the film side (which in the dark room is readily ascertained by its matt

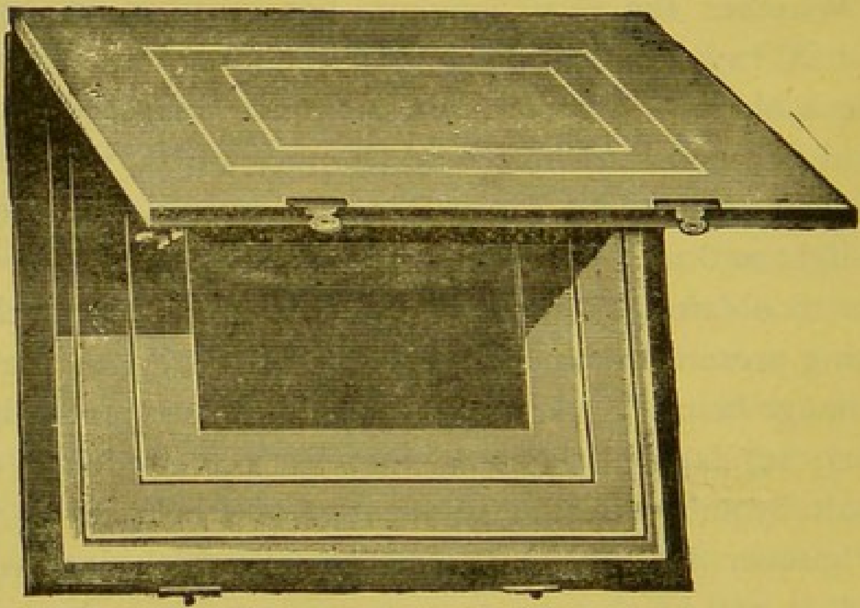


Fig. 42.

surface) it should be made a rule to insert the plates in the bags with the film side turned *away* from the flap of the envelopes.

Better still, because protecting the glass plates from breakage due to the weight of the body to be radiographed are dark slides such as those illustrated by fig. 42, which also facilitate the use of intensifying screens.

For all photographic manipulations, a dark room is an absolute necessity. Any dry and cool room from which every trace of daylight can be excluded may be used for the purpose. Since radiographic work requires large-sized plates and developing dishes, the dark room should not be too small. The presence of a cold water supply is a great advantage, as it saves a great deal of carrying to and fro in the subsequent washing operations. All the light which is required during development and the after manipulations should be derived from a suitable dark-room lamp (either gas or oil or candle) fitted with a ruby red and an orange window, which may be used at will. All the operations previous to and during development must be conducted in ruby light only, subsequent fixing may be done in orange, and the washing in white light.

For developing radiograms, almost any of the usual developers may be employed, although it is advisable to strictly adhere to the formulæ suggested by most makers for their own plates. In cases where several developers are recommended, the one which from its nature may be used for the longest time without staining the sensitive film should be chosen.

Any developer consists of three parts, the accelerator, density giver, and restrainer, which may be in some cases combined to form a one solution developer, but are preferably kept separate prior to development so as to admit of their proportions being varied to accommodate themselves to the variations in exposure, etc. Herein is the art of developing which can only be acquired by experience.

Below we give two alternative developers :

A.		B.	
Pyrogallic acid	1 oz.	Carbonate of soda... ...	12 oz.
Metabisulphite of soda ...	1 oz.	Sulphite of soda	4 oz.
Water	80 oz.	Water	80 oz.

C.

Pot. bromide	1 oz.
Water	9 oz.

To develop mix equal parts of A and B, and add a few drops of C.

or

A.		B.	
Hydrokinone	1 oz.	Carbonate of potash ...	2 oz.
Sulphite of soda	4 oz.	Water to make ...	48 oz.
Water	48 oz.		

C.

Pot. bromide	1 oz.
Water	9 oz.

To develop, mix equal parts of A and B, add C as before.

The pyro formula develops quicker, but is apt to stain the film, whilst the hydrokinone formula, although slower in action, yields clean negatives with plenty of contrast.

The following one solution developer we found very efficacious and convenient, especially in connection with the double-sided films and plates.

Developer:

Rodinal	1 part.
Water	30 parts.

The image quickly appears, but development must be continued until it has such density that no details are discernible in transmitted light (twenty to forty minutes). In case of under-exposure a few drops of a solution of:

Rodinal	1 oz.
Water	1 oz.
Bromide of potassium	$\frac{1}{3}$ oz.

will accelerate the appearance of the image.

Fixing bath. Dissolve:

5 parts of Sodium sulphite (cryst.) in
100 parts of water, acidulate with
1 part of concentrated Sulphuric acid, and then add
20 parts of Sodium hyposulphite.

The dishes in which development takes place may be of celluloid, vulcanite, papiermachè, enamelled iron, or porcelain. For larger sizes than 10" × 8", vulcanite and celluloid trays are useless, as they are not rigid enough, and bend or buckle.

The developer having been mixed in a glass measure, the plate or film is taken from its envelopes and placed, film side upward, in the developing dish. Sufficient developer should be flowed over it in an even wave, beginning near one corner, and the immediate immersion of the entire plate should be assisted by gently rocking the dish, in order to prevent irregular streaky negatives. The developer must be flowed and not splashed on to the plate, or air bubbles will be formed which will cause spots on the negative if allowed to rest long on any one part. The dish may now be held so that the ruby light falls upon it, although with very rapid plates this is not advisable, and should be gently rocked to and fro. In about 30 seconds to a minute, when using pyro developer, or 3 to 5 minutes when using hydrokinone, the plate should begin to change slightly from its creamy appearance to a grey, wherever the rays had access to it, and this greyness will gradually increase in depth to a black. In order to obtain sufficient density for printing, the plate should be kept in the developer for some time after this stage has been reached. Radiograms of the thicker parts of the body should be left developing until the whole surface appears almost uniformly blackened, it will then in the fixing bath be reduced to the proper degree of density. Sometimes, however, when very strong contrasts between bones and muscular tissues are desirable the development should be interrupted at an earlier stage, and the necessary density be produced afterwards by intensification (see below).

We remember one investigator, who uses exceedingly weak developers, gradually increasing their strength and continually developing for as long as three hours.

Another plan to obtain the best possible result from an exposed plate has been suggested by Mr. B. Larus; he commences development with any suitable hydrokinone developer and continues until the outlines show a fair amount of density: the plate is then removed into a metol potash or rodinal developer which brings out the more delicate details which are often wanting in the otherwise excellent hydrokinone development.

On having decided to stop development, the plate must be rinsed in clean water to free it from the developer, and then placed, film upwards, in the fixing bath, consisting of:

Hyposulphite of soda	6 ozs.
Metabisulphite of soda	1 oz.
Water	1 pnt.

In this bath the plate must remain until the parts which were left creamy, and the whole creamy appearance of the plate when viewed from the glass side, have disappeared and then for at least two or three minutes longer. It is then removed, washed by soaking for an hour in several changes of water, or better still in a dish into which a tap is dribbling; after this the plate may be stood on edge on a suitable rack to dry spontaneously, or may be further treated by intensification when necessary.

Double-sided films and plates are rather more difficult to manipulate as it is necessary, at least during the early stage of development, to frequently turn them in the developer, of which there must be a greater quantity than in the case of ordinary plates or films. This handling is generally facilitated by providing the films with clips of ebonite, or by punching holes in the corners or in the absence of any such special arrangements by turning up the corners of the film.

Should the plate have been under exposed, the appearance of the image will take much longer, and the developer must be poured off, mixed with a little more accelerator (B), and flowed over the plate again.

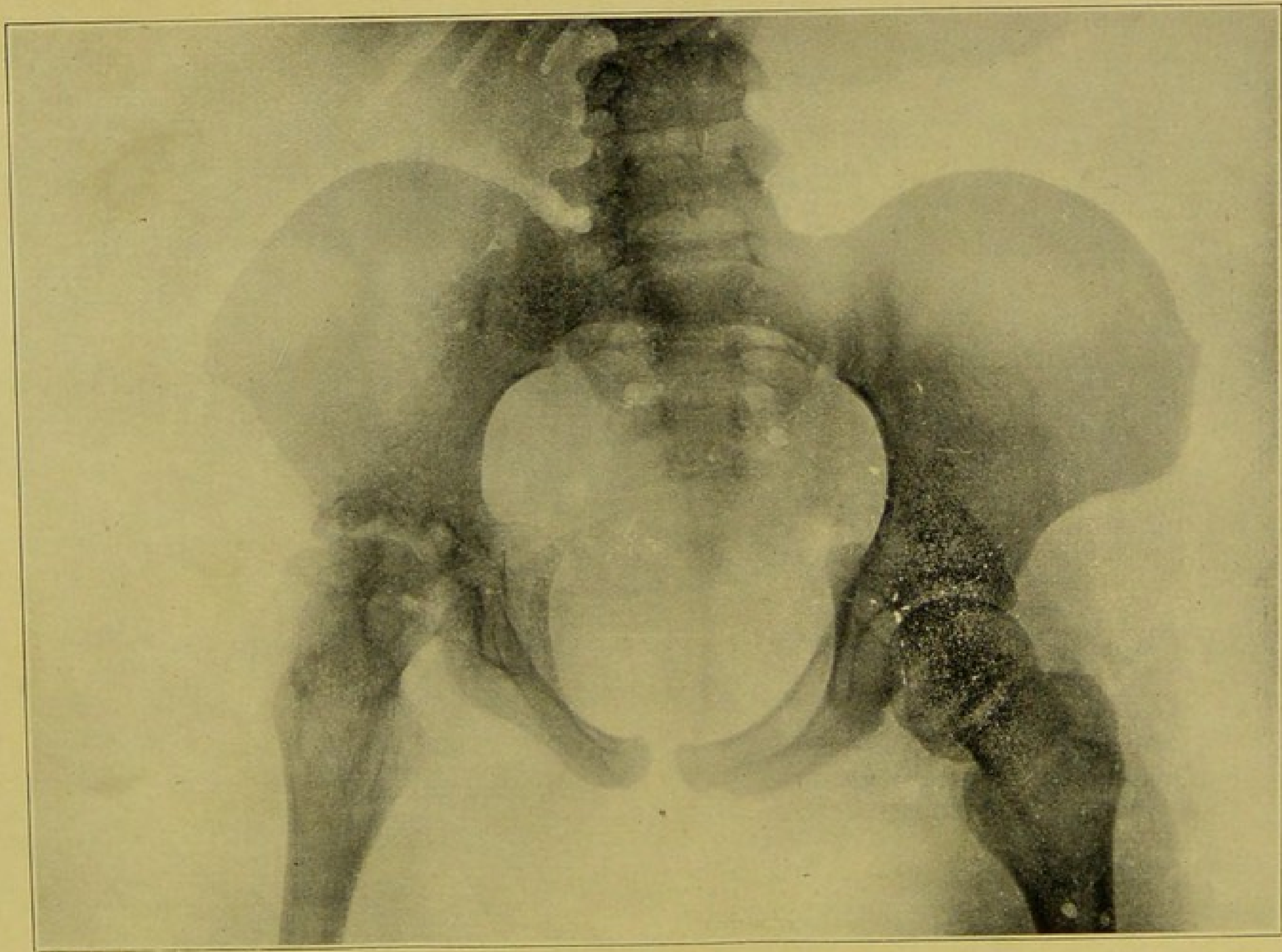
In the case of over exposure the image will flash out immediately upon the developer being flowed on, and it is then necessary to at once pour off the developer, add three times the original amount of restrainer (C) to it, and flow on again.

Where intensification is necessary or desirable, the negative must be particularly well washed, and then immersed in a solution of:

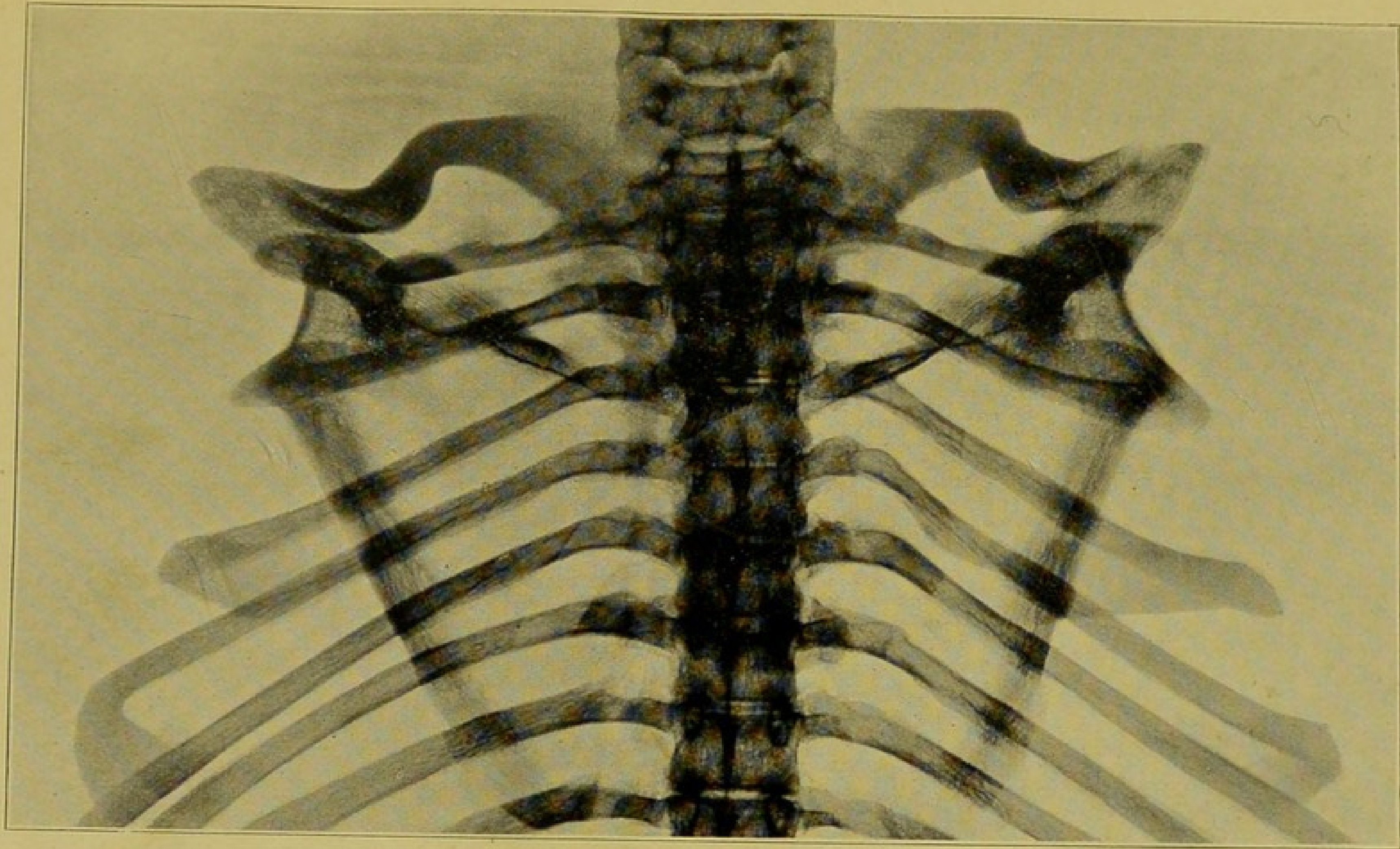
Mercuric chloride	20 grains
Ammonium chloride	20 grains
Water	1 oz.

The black or grey colour of the negative will now change until the whole surface is uniformly bleached white. It is then thoroughly washed and blackened again in

Ammonia	20 mns.
Water	1 oz.



Diseased Right Hip-Joint of Girl. (By W. A. Coldwell, London.)



Radiogram of Thorax. Skeleton only. (By the Voltohm Company, of Munich.)

and when black throughout the film it is well washed and ultimately dried.

Such negatives will give prints in which the softer tissues are almost obliterated, but on account of their general density they print slower.

Development requires great cleanliness in operation, the dishes having to be kept always for their own particular solutions, and all the washing operations requiring thoroughness.

The double-sided films and plates especially require great attention on this point, as naturally the sensitive surface of one or the other side must be in contact with the bottom of the dish.

Some progressive exposures will soon give the necessary experience, and it is advisable when once having found a suitable brand of plates, to always keep to it and to one kind of developer, so as to ultimately completely master this method, and be able to adapt it to all the varying conditions of exposure and subject.

The negatives obtained by radiographic exposures, especially those through thicker parts of the body, which necessitate longer exposures, show a fogged or veiled appearance and an entire absence of clear film or glass in the shadows. M. P. Villard in a note to the Paris Academy of Sciences says that the fluorescence of the surrounding air appears to be the source of the second image and general fog.

From the various attempts to accelerate and intensify the action of the rays upon the sensitive film, only one method has so far survived and is being applied with success, namely, that of bringing certain fluorescent substances, more particularly the fluorescent screen, in contact with the sensitive film during exposure so that under the stimulating influence of the X rays the substance fluoresces and acts upon the plate like ordinary light, intensifying the direct action of the rays. Two factors must, however, be taken into consideration, namely, the granularity of the fluorescing surface, which greatly reduces the definition of the resulting radiogram, and almost effaces the details of the smaller osseous structures; and the necessity of either using colour-sensitive (orthochromatic) plates, or first colour sensitizing ordinary plates, since the best screen (platinocyanide of barium) fluoresces with a yellow green light which does not greatly affect ordinary dry plates.

The accelerating influence of various fluorescing substances upon colour-sensitive plates, according to Gaedicke, was as follows:

Exposure without screen	1
,, with fluor spar	$\frac{2}{3}$
,, with potassium screen	$\frac{1}{4}$
,, with barium screen	[illegible]

The plates are prepared by immersing for four minutes in a bath consisting of

Water	1000 ccm
Alcoholic solution of erythrosine (1/380)	40 ccm
Aqueous solution of silver nitrate (132/1000)	16 dps
Ammonia (·91)	4 ccm

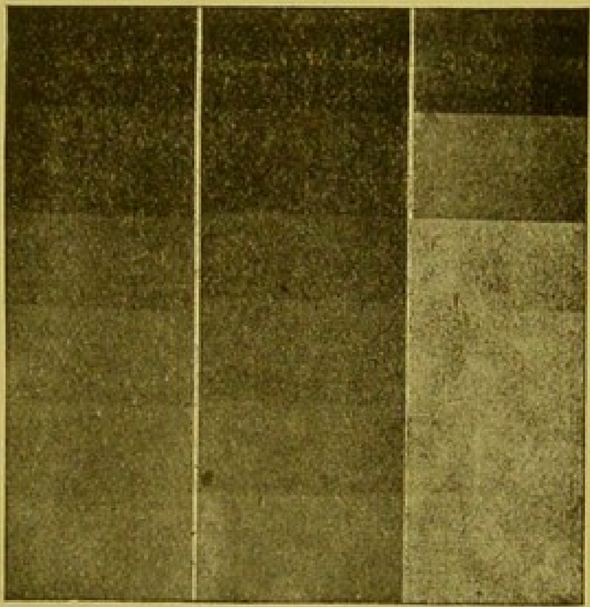
are well dried, in a perfectly light-tight room, and must be used within eight days of preparation.

The fluorescent screen was placed in immediate contact with the sensitive film and the whole enveloped in opaque paper and exposed so that the rays had first to pass through the screen before reaching the sensitive surface.

More recently special forms and preparations of intensifying screens have been brought out by Kahlbaum, of Berlin, and by Dr. Max Levy. These intensifying screens, either in the ordinary form or more conveniently arranged in an exposing slide for the reception of the sensitive plate or film (Fig. 42), are prepared with tungstate of calcium in a special modification without any appreciable grain, and the results obtainable by their means are certainly exceedingly good, especially since with these screens any dry plate may be used without previous sensibilisation, and since the price is very much below that of platinocyanide screens.

Another and very good plan, devised by Dr. Max Levy, of Berlin, tc accelerate and magnify the action of the X rays upon the photographic plate is based upon the observation that the rays after passing through a film or even a thin glass plate are not appreciably weakened, and should therefore, be better utilised ; this is attained by coating the celluloid or glass support on both sides with emulsion, thus obtaining two images, which being necessarily in perfect register, give double density to the negative, thus permitting of shorter exposures (one-third to one-fourth in the case of films).

A further improvement consists in employing two intensifying screens, in contact with the front and the back surfaces respectively.



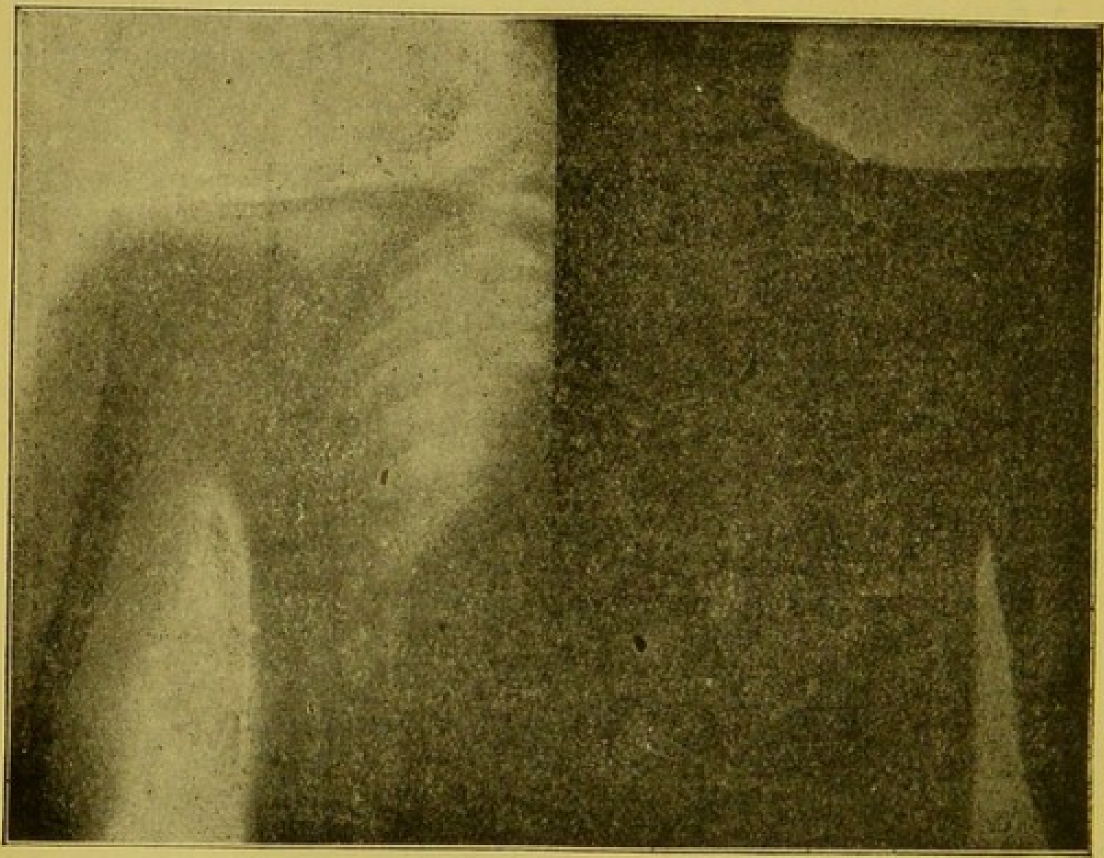
Ord. Plate Coated on both sides. With intensifying screen.

Fig. 43.

Figs. 43 and 44 show the difference which this arrangement makes in the resulting negative.

Photographic Reproduction of Screen Images.—Since, so far, it has not been possible to refract or reflect the X-rays to any appreciable extent, we cannot directly produce a radiogram on a smaller scale than actual size, or even a little above this. There is, however, the possibility of making in the ordinary optical way photographic reductions from the radioscopic image on the screen by means of the camera. The advantages which this method (first introduced by Battelli and Garbasso) offers are twofold. Firstly, we can dispense with those large sensitive plates, which are so difficult to handle, and bring radiograms within a manageable size; and, secondly, it reduces the uncertainty still attending some radiographic exposures through the thicker parts of the body

As a set-off we have to face numerous practical difficulties on actual application. The image on the screen must, of course,



With Screen. Without Screen.
Exposure 30 seconds.
Fig 44.

be perfectly steady, which is to be secured by firmly fixing the absolute as well as the relative positions of screen and subject. As the best definition is obtainable from barium screens, and as the latter emit yellow rays, it is necessary to use special plates for the exposure, and to give comparatively long exposures. Further, the camera must be protected by heavy lead sheathing from the X rays passing through the fluorescent screen, so as to prevent these rays from recording the direct radiographic shadow of the metal parts of the camera upon the plate Lastly, the whole exposure must be made in a perfectly dark-room, which introduces a great many inconveniences. Altogether, it will be seen that screen-radiography is not yet a very promising departure.

We will find, in a subsequent chapter, that the proper interpretation of a radiogram is not always an easy matter, since all the parts lying in nature in different planes are projected into one plane in the radiogram; the idea to impart stereoscopic relief to the radiogram, therefore, soon suggested itself, and Prof. Elihu Thomson was the first to produce such stereo-radiograms by moving the tube horizontally through a distance of two or three inches between the exposures, whilst the object to be radiographed remained in position. So far as we know, only the smaller parts of the body have been thus radiographed, although the method would prove especially useful for the thoracic and abdominal cavities, in order to properly locate the various organs or foreign bodies.

With the improvement of apparatus and the consequent shortening of exposures, the idea of producing *animated* or *kinetographic* radiograms becomes quite feasible, and will eventually constitute a most important branch of radiography. Of course, the practical difficulties so far are numerous, but some work already accomplished in this direction by Dr. Macintyre shows that these difficulties are not insurmountable, and may eventually become less formidable.

CHAPTER V.

PRACTICAL RADIOGRAPHY—MEDICAL.

RADIOSCOPY.

THE examination of the radioscopic image on the screen demands, of course, the absolute exclusion of every kind of light from the screen-surface, a condition which may be fulfilled either by carrying out the manipulation in a perfectly dark room or by enclosing the screen only in a dark chamber with an observation aperture. The latter method is often very useful since it enables us to dispense with special dark rooms, and to practise radioscopy in broad daylight and anywhere. The construction of such a dark chamber with screen—variously called cryptoscope, fluoroscope, or lorgnette humaine—is exceedingly simple. In its crudest form it consists of a conical box, somewhat like the body of a stereoscope, having two apertures at the narrow end, so shaped and lined with plush as to accommodate themselves to the eyes and nose, and to exclude all extraneous light. At the wide end of the box the fluorescent screen is fitted (also light-tight) with its prepared side towards the eye-apertures. In a more perfect form the stiff body is replaced by camera bellows and stiffening guides, so that we may adjust the distance between screen and eye, and the apertures may be provided with suitable lenses. These instruments, however, when used for larger screens than 10" by 12", become rather bulky and difficult to handle, and of course the image is only visible to one person at a time.

When using a dark room for radioscopic work, the screen is frequently held in the hand of the operator, and moved to whatever part of the body we may wish to examine, or it may be conveniently clamped in an adjustable holder.

The back of the screen must be pressed as closely as possible against the object to be examined, so as to obtain sharp, vigorous shadows, not too greatly distorted. The tube should be placed with the anticathode pointing towards the observer, and should be in a suitable box, or be otherwise covered so as to exclude its fluorescent light. A very suitable tube for radioscopy is made of purple Manganese glass, which absorbs the fluorescent light, and is provided with a thin, transparent window opposite the anticathode. Some workers cover their tubes with opaque material, such as paper; but, owing to the consequent increase of heating and the lowering of the vacuum, this method is not advisable. If the coil also is placed in the dark room, it becomes necessary to cover the interruptor spark by encasing the interruptor in cardboard or paper.

The tube must be placed opposite the centre of the screen, so as to evenly illuminate the whole screen surface. For very long screens, such as would be used for the examination of the whole trunk, two or three tubes must generally be used simultaneously—one at the level of the head, one opposite the heart, and one at the level of the abdomen. For the illumination of such large areas, the distance between tube and screen must be increased in order to avoid diffusion of the shadow outlines and distortion. The distance also depends, as we will see later, upon the nature and thickness of the part we wish to investigate.

A convenient arrangement for screen-work is illustrated in Fig. 45, which shows the tube fitted in a box, which may be moved vertically up and down to any desired level. *S* is a switch which allows us to start and stop the coil in the other room without leaving the dark room. The two secondary wires from the tube to the coil dischargers are passed through glass tubes, which are again enclosed in stout ebonite tubes, the latter being built into the wall, and closed at the end to stop all stray light.

When conducting any radioscopic examination it is important, on account of the comparatively faint luminosity of the screen image, to keep the eyes for some few minutes in the darkness before studying the screen, so as to be able to fully appreciate the details, which are always very trying to the eyes. The proper interpretation of the radioscopic image of the internal organs is moreover exceedingly difficult, and requires great practice and perseverance.

As regards the adjustment of the tube for radioscopy, the conditions are the same as those to be observed for radiography and will be dealt with in that section.

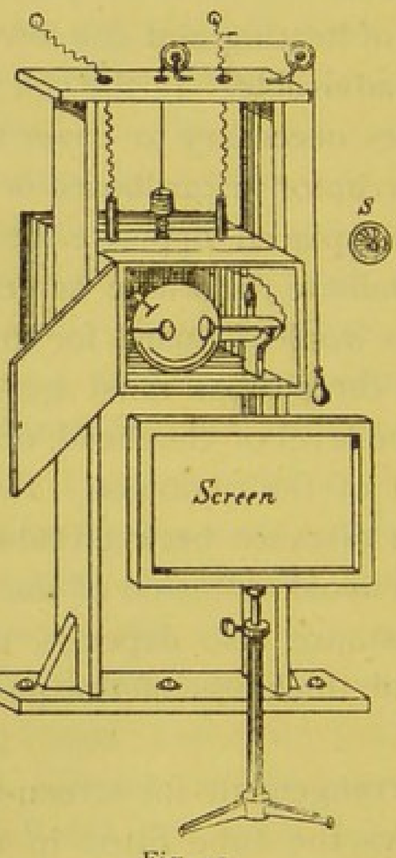


Fig. 45.

The present possibilities of radioscopy are already very satisfactory, and practically include all parts of the body. Its special field of usefulness is the study of the respiratory and heart movements, which cannot very well be recorded photographically. Moreover, the screen has proved an indispensable help to the radiographer to examine the efficiency of the tube, and to determine the best conditions for subsequent radiograms, although it is well to remember that photographic efficiency and fluorescifient action are not necessarily co-existent.

RADIOGRAPHY.

As the image on the fluorescent screen depends for its definition upon the perfection of our visual organs, and leaves no permanent record to serve as guide to subsequent operative measures, it must, in the majority of cases, be supplemented by a radiogram upon a sensitive photographic plate, which gives us the sum of the consecutive visual impressions, so that by exposing for a certain length of time the resulting radiogram will be far more detailed than the radioscopic image can ever be.

One of the most important factors which influence the ultimate result of an exposure is the distance between tube and object. The image will, of course, correspond in size the more nearly with the object itself, and the outlines and definition will become the better the smaller the angle at which the rays traverse the object, so that in order to obtain fairly correct radiograms we must make the distance between tube and object rather considerable; on the other hand, we know that the intensity, and consequently the photographic action of the rays, diminishes at a compound rate with the distance, so that there are limitations in this respect, and we must in every instance determine the distance of the tube with due regard to the size of the object and the penetrative power of the tube. For flat, thin objects, such as the hand, the tube distance is of small influence upon the resulting definition, and we may, therefore, bring our tube very close to the object in order to reduce the exposure. The greater the thickness of the object, however, the farther must we place the tube, since some parts of the object are then at a greater distance from the plate surface, and with the tube placed near, would produce distorted and diffused outlines (Fig. 46). The size of the object *B* near the plate is nearly reproduced in its shadow, *e f*, whatever be the position of the tube; the shadow of object *A*, however, when the tube is in the near position, I is *a b*, whilst it is *c d*, or more like *A*, when the tube is placed in the far position, II. If we really desire to get fairly correct images by radiographic projection of all the structures in a thick body, then we must place the tube at a considerable distance, and employ powerful radiation, and, perhaps, an intensifying screen, in order to keep the necessary exposure within reasonable limits. Generally, however, we only require a record of a particular structure, say *B*, in Fig. 46, and the best way to secure this would be to arrange that part of the body in which this structure lies nearest the surface, in close proximity to the plate, and place the tube as close as possible to those parts which we wish to obliterate in the image. Owing to the great angle at which the rays then embrace these structures, their outlines become indistinct, and their shadows light as compared with the dark and distinct shadow of the part we wish to record.

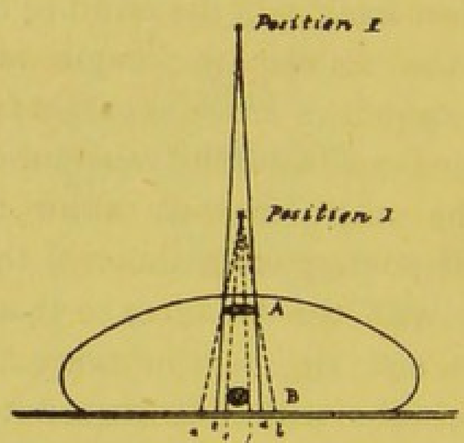


Fig. 46.

Another feature which greatly influences the final result of the exposure is the vacuum of the tube, or, in other words, the penetration of the radiation. It will be obvious that whereas a tube of low vacuum (say one requiring a four-inch spark) yields a good result with two minutes' exposure for the wrist bones of an adult, it would, under similar circumstances, produce an over-exposed plate with the wrist-bones of an infant, whilst, on the other hand, it would (keeping distance and exposure the same) prove utterly inadequate for the thorax of an adult.

A preliminary radioscopic examination should, of course, in most cases settle the question at once, but even without such it will not be difficult, after a little practice, to select for every case the most suitable vacuum. Low vacua, such as fluoresce well with a small spark of two inches or thereabouts, will be required when attempting radiograms of infants, the bones of which are still in a semi-cartilagenous condition, and consequently offer but little obstruction to the rays.

Similarly, when having to discover very small foreign substances (otherwise than metal) in the body, the tube must be of low vacuum, and the exposure short. In a recent case under our observation the presence of a glass splinter 1-32nd of an inch long was detected in the forefinger with the screen; a radiogram taken with a rather high vacuum tube barely showed the glass, whilst with a low vacuum the splinter appeared very clearly in the radiogram, and could easily be removed.

Medium tubes, such as require from four-inch to six-inch sparks, are generally useful. Using short exposures, we may employ them for young subjects, and also for thin parts of the adult body; they may also, without unduly lengthening the exposure, be used for radiographing through the thorax and the shoulder, since both sufficient contrast and also good definitions are thus obtainable. High vacua tubes, from eight-inch to twelve-inch and more equivalent spark length, are, however, necessary where radiograms of such dense and thick structures as the adult abdomen, pelvis, or the skull are concerned. The penetration of the rays from such tubes is extreme, and they would therefore only produce flat pictures of the extremities. Even for the thorax they are rather too powerful, and in order to obtain any record of the internal organs, such as the heart, the distance of the tube must be increased and the exposure reduced. The really useful field of application, however, for these tubes is the skull, the spine, abdomen, and the pelvis; since in the first case the rays have to penetrate the two bony walls of the skull before reaching the plate or screen, whilst in the latter cases the intervening masses of intestines, filled more or less with fæces of high specific weight, present considerable resistance to the rays.

It is not frequently the case that we have on one plate to record the radiograms of thin and of thick parts simultaneously; but if this should happen to be required (hand and elbow), we must adapt the exposure to the thickest part, and lessen the action upon the thinner parts, either by placing the tube nearer to the thick part, or by moving a glass plate or a piece of thin sheet iron to and fro between the tube and thin part.

From the foregoing remarks it will be seen that it is almost impossible, on account of the many determining influences, to establish any definite rules, or standards for the exposure required for various cases; but, whilst fully recognising this fact, we think that the following figures, which refer to typical and specified cases, may at least prove a preliminary guide or approximation for the tyro.

Object and Age.	Spark Length.	Distance.	Exposure.
Skull—Young ...	10 in.	16 in.	8 minutes.
Skull—Adult ...			10 "
Thorax—Young...	8 in.	20 in.	5 "
Thorax—Adult...			12 "
Spine—Young ...	10 in.	20 in.	15 "
Spine—Adult ...			25 "
Pelvis—Young...	10 in.	20 in.	15 "
Pelvis—Adult...			25 "
Femur—Young...	8 in.	12 in.	5 "
Femur—Adult...			9 "
Leg and Arm—Young...	6 in.	9 in.	1½ "
Leg and Arm—Adult...			3 "
Hand and Foot—Young..	4 in.	9 in.	15 seconds.
Hand and Foot—Adult...			25 "

Of course, no allowance is made in this table for either very muscular or very young subjects, and it is assumed that we use a very rapid, thickly-coated plate.

An attempt was made some time ago by Mr. Vandevyver to calculate the necessary exposure for any part of the body, by first making a test exposure of the hand, using the same plate, the same tube distance, and the same amount of electrical energy as those intended for the final exposure. According to Vande vyver, the necessary exposure E_1 for an object t_1 inch thick, would be

$$E_1 = E \left(\frac{t_1}{t} \right)^3$$

where E and t are the exposure and thickness of the test object Applying this formula to a given case, say an elbow measuring 4 inches across, and assuming that a hand measuring two inches in its carpal portion gave a good radiogram with 25 seconds exposure, we would calculate the necessary exposure for the elbow as

$$25 \times \left(\frac{4}{2} \right)^3 \text{seconds} = 3\tfrac{1}{3} \text{ minutes.}$$

Testing the same formula with thicker parts of the body we get rather too long exposures. Taking the depth of a thorax as 8 inches, we would have to expose

$$25 \times \left(\frac{8}{2} \right)^3 = 27 \text{ minutes.}$$

It is probable that a slight reduction of the exponent 3 in the above equation may lead to more useful results, since the method of calculating the exposure from an *immediately* preceding test-exposure seems to fully take into consideration all the various working conditions.

The proper interpretation of the radioscopic or radiographic image is by no means without its difficulties, and requires even for normal structures great practice, since the super-position in one plane, of several structures lying in reality in so many different planes, and also the enlargement of some objects, due to their distance from the plate and the respiratory movement, as also the fore-shortening of others, due to their position, introduce certain sources of error, which can only be avoided in a stereoscopic radiogram The exact localisation and orientation of foreign substances embedded in the body (such as bullets) is of the greatest importance, since subsequent operative measures for the removal of such substances are exclusively based upon the proper reading of the radiogram.

It is but very rarely possible to localise the object from a single radiogram by comparing the relative definition of the outlines of object and other opaque structures. Such a case is, however, present when we radiograph a bullet in the forearm; the negative will, of course, show the ulnar and radius, and also the bullet. If the outline of the latter is very sharp, we may conclude that it is located on the side nearest the plate; if the outline is not as sharp as the outlines of the bones, the bullet must be situated above the plane of the bones. Of course, such

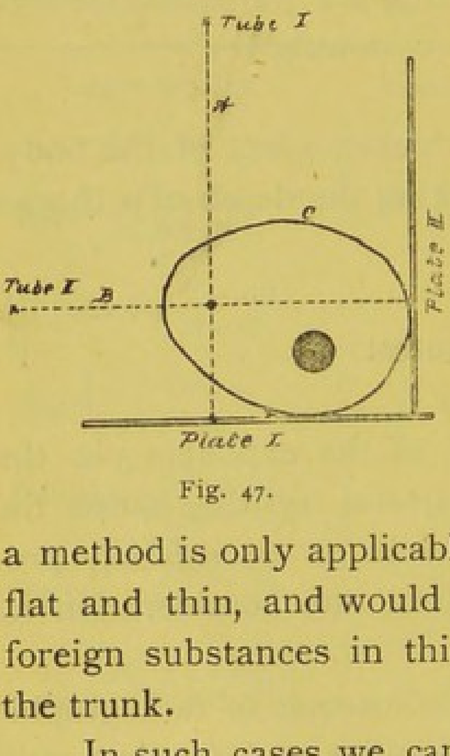


Fig. 47.

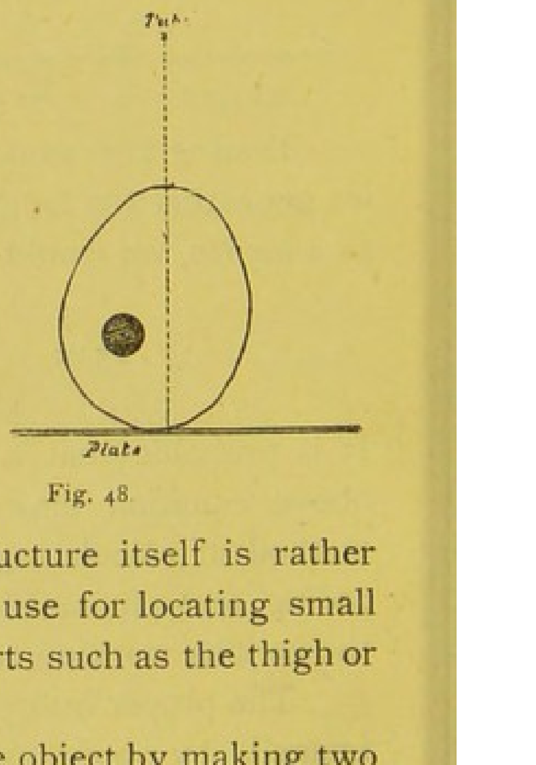


Fig. 48.

a method is only applicable when the structure itself is rather flat and thin, and would not be of any use for locating small foreign substances in thick muscular parts such as the thigh or the trunk.

In such cases we can only locate the object by making two or more radiograms, either in one plane or at right angles to each other. Taking the latter case first, we may either, as in Fig. 47, keep the body in one position and shift the tube and plate, or we may turn the body, as in Fig. 48, and keep tube and plate in one position; one plane in which the object lies is generally marked by placing a leaden wire as a landmark round the body, the shadow of which appears on the radiogram and serves as base line, facilitating subsequent construction of the position.

Another method which is the basis of stereoscopic radiography also requires two exposures, which, however, are made in the same plane by shifting the tube a distance *m* in a plane parallel to the plate (Fig. 49), this will cause the shadows on the plate to be *d* apart and from this, and the tube-distance *a* we can calculate the distance *x* between object and plate from the equation :

$$x = a \frac{a}{m + d}$$

Yet another method has recourse to a little model; two metal buttons are so fastened to the surface of the body that their shadows coincide on the screen with that of the object; this

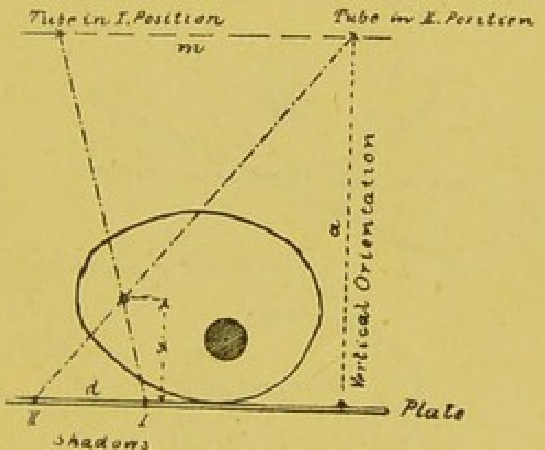


Fig. 49

is repeated with two more buttons in another direction. The profile of the body is then reproduced by laying a pliable wire round it, on which the position of the knobs is marked; from this profile wire the exact location of the foreign body can be easily constructed on a piece of drawing paper, as well as the nearest point to the object on the surface, and the radial depth of the object; when this position has been marked on the ring the latter is replaced on the body, and from it the point of incision marked on the skin (Fig. 50).

A very ingenious and simple method of localisation has been suggested by Dr. Mackenzie Davidson. He makes the usual two exposures with the tube shifted through a certain distance, and afterwards reconstructs the mechanical factors by employing fine threads, the position of which corresponds to the path of the X rays.

In its practical shape the method works out as follows :—

The centre of the plate or film is brought exactly vertically under the medium position of the tube. The plate centre is given by the point of intersection of two thin wires, which record their shadow on the radiogram, and being dyed, also mark themselves on the skin of the limb or body. A certain quadrant is then marked by placing a coin or similar opaque object upon

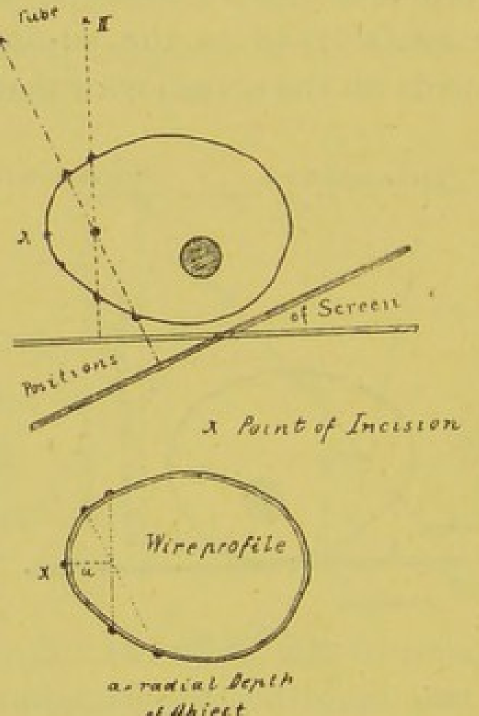
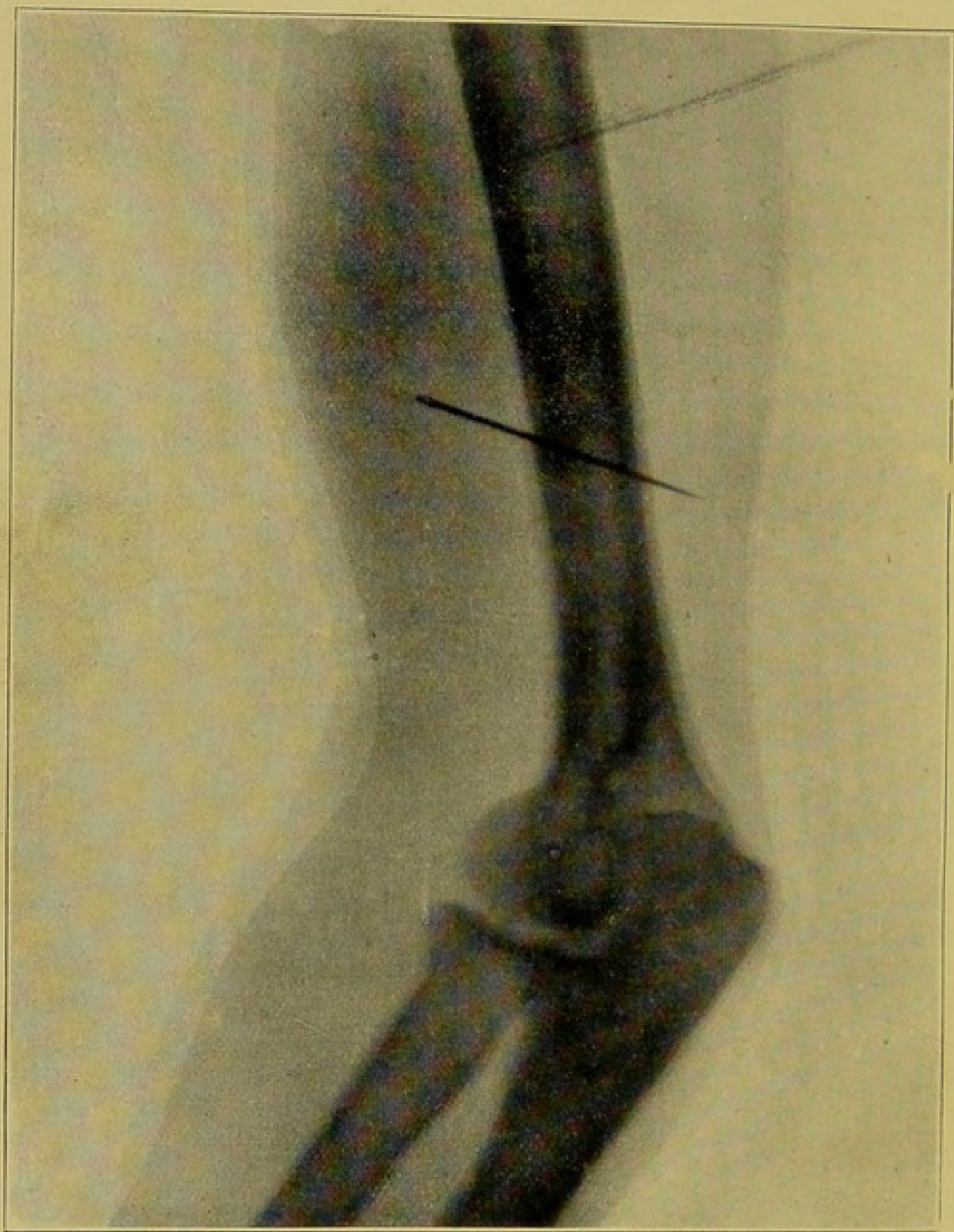


Fig. 50.

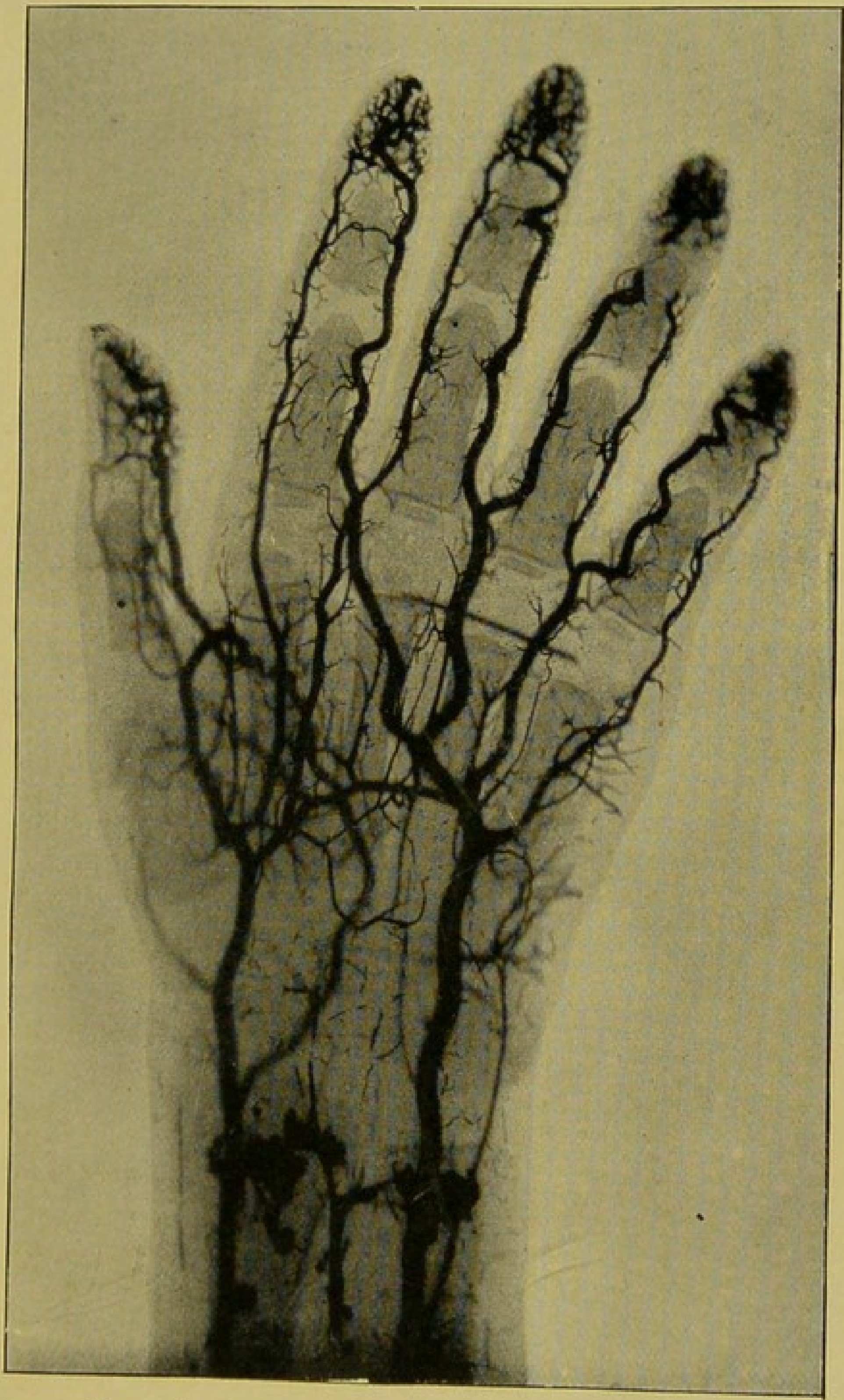
the plate. The tube is then shifted from the medium position by a certain measured distance and an exposure is made. Without removing the plate or the body, another exposure is given with the tube shifted to the other side of the medium position by an exactly equal distance.

After development, the negative, which now shows the orientation cross, the quadrant mark and two shadows of the object, to be localised, is placed upon a glass plate illuminated from below and having two diamond scratches, so that the orientation cross coincides with the latter.



Needle in Upper Arm.

(By Hall Edwards, L.R.C.P., Birmingham.)



HAND SHEWING VEINS INJECTED WITH MERCURY.

(By the Medical Supply Association, 12 Teviot Place, Edinburgh.)

From the points corresponding to the position of the anti-cathode of the tube, two silk threads with fine needle-points attached to them are stretched to the two similar ends of the radiographic shadows of the object, and the point of intersection in space located, and recorded by measuring its distance from the planes of the orientation mark, and from the plate itself. A simple gauge or a pair of compasses may be employed.

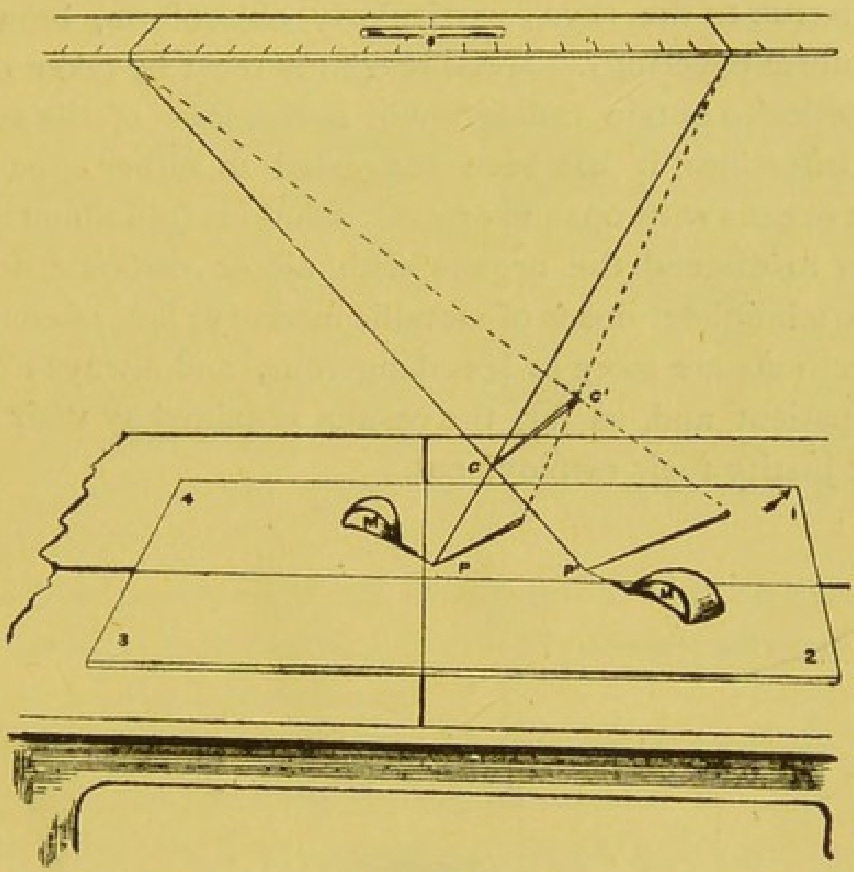


Fig. 51.

The threads are then stretched to the two other ends of the shadows, and the process of recording repeated.

The two ends of the object are thus fixed, and both its length and also angular position may be absolutely determined. Fig. 51 shows diagramatically the locating apparatus.

In some cases, however, none of these methods is directly applicable, since the limb may be contracted, or in an awkward position; the localisation can then only be effected by the surgeon, who must use the sound or probane with the fluorescent screen in a suitable position.

Generally speaking, the radiographic examination of the patient requires no special preparation; it is one of the unique characteristics of radiography, that contrary to the practice in endoscopic and diaphanoscopic methods, clothing, bandages, and splints need not be removed. Frequently, however, it is desirable or necessary to remove some part of the clothing, such as contains buttons, braces, etc. Some aseptic bandages are also rather opaque to the rays, particularly chloroform, bromoform and iodoform coverings. Metallic splints must be taken off.

In order to obtain radiographic indications of the stomach and the intestines, it has been suggested to either expand and fill these organs with opaque metallic solutions (plumbum subaceticum) or to distend the organs with air or carbonic acid, or finally to administer doses of metallic mercury; but, of course, all these methods are more or less dangerous, and always a torture for the patient and, so far, the results obtained by their means scarcely justify their employment.

CHAPTER VI.

DIAGNOSTICAL APPLICATIONS OF RADIOGRAPHY.

THE whole use of the Röntgen rays in surgery and internal medicine is based upon the selective absorption of the rays by the various structures and tissues in the body, which gives us on the screen, or on the photographic plate, the gradated shadow of the more absorptive structures, such as the bony frame and certain other dense organs. Some experiments by F. Batelli, with a view of determining the transparency of the various animal tissues gave amongst others the following results :—

The transparencies of the tissues are in indirect proportion to their densities with the exception of the sinews, which although very dense are fairly transparent.

With increasing thickness of the tissues their transparency decreases, but not at an equal or uniform rate.

The opacity of the muscular tissues is supposed to be due to the iron in the hæmoglobin and to contained alkali; the opacity of the osseous structures, from investigations by Dr. Walsh appears due to the earthy matters forming part of the bones, particularly phosphates of lime.

One of the readiest applications of this principle of comparative opacity of the bones is the identification of fractures and luxations, and the diagnosis of some of the abnormal conditions of the bones themselves.

Every part of the human skeleton has been successfully dealt with, the amount of definition obtainable depending upon the proximity of the osseous parts to the skin, and the absence of dense muscular development. In the case of the metacarpal bones and phalanges of the hand, we thus obtain a most delicate image of the bones, revealing their various structural characteristics, the epiphyses, shafts, small sesamoid bones, &c.

Fractures, compound and simple, as well as dislocations of the several joints, may be in most cases directly observed on the fluorescent screen, and often require no radiographic verification; the proper setting of such fractures, etc., is thus greatly facilitated by constant reference to the screen image, so that proper apposition of the fractured ends should in all cases be secured. Splints and bandages supporting the fracture do not present any great obstacle to the further radioscopic observation of the progress of bony union between the fractured ends, and such irregularities as the presence of bone-splinters, etc., may at once be rectified before ossification has too far progressed.

Fractures of the hip-joint still present some difficulties, so far as screen observation is concerned; and since such cases, on account of their extreme painfulness preclude radioscopic examination, we have always to employ the radiographic method, placing the plate in the most convenient position, which in no way accentuates the discomfort of the patient. The results are frequently satisfactory when using large coils. The particular value of radioscopic methods in cases of accident to such complex joints as wrist and ankle is, of course, very obvious. Most of the diseases affecting the bones result in partial destruction and modification of their density, and in consequence manifest themselves on the fluorescent screen as light and diffuse spots in the usually dense and defined shadows. Tuberculosis, sarcoma and caries may thus be recognised. In the case of osteomyelitis the bones shew greater opacity, indicating additional ossification.

Stiff joints due to fractures or dislocations may be caused either by bony or by fibrous lesion, which may be readily distinguished radiographically.

Besides actual defects and abnormal conditions, the formation and the progress of ossification centres, and of the various epiphysal stages can be carefully studied in the living subject by either radioscopy or radiography.

Dental surgery has equally benefited by introducing radiographic methods. From the peculiar situation of the parts under examination, certain special methods have to be followed, such as placing the affected parts near the plate and sending the rays from the tube obliquely through the opened mouth, etc. ; or placing inside the mouth a small piece of plate or film, wrapped in oil paper or similar protection.

Coming now to the possible application of Röntgen rays to internal medicine and the soft tissues, we find that the greatest progress so far has been made in the diagnosis of the various organs contained in the thoracic cavity. Both screen and radiogram reveal to us in addition to the shadow of the ribs, sternum, and backbone, the approximate outlines of the lungs, which on account of the air with which they are filled appear particularly transparent. Between these light zones and a little to one side of the sternum we perceive the triangular shadow of the heart, and the beating motion of its point. Below the lungs and heart the diaphragm or midriff becomes visible, rising and falling with the respiration and completely separating the thorax from the abdomen.

In the abdomen the passage of the rays is greatly hindered by the intestines and their contents, and so far both screen and photographic plate have failed to clearly indicate any of the abdominal organs, save the upper margin of the liver where it touches the diaphragm, and occasionally a diffused light area corresponding to the gullet.

Turning from the normal anatomy to certain abnormal conditions, it may be said that much has already been accomplished in the diagnosis of the various abnormal conditions of the heart. The movements, as regards their amplitude and direction, are clearly marked and may be traced in some way upon the skin ; thus making possible the verification of the observations by other diagnostical methods. Enlargement of the pericardium, aneurisms of heart and aorta show themselves as zones of medium opacity and by irregularities in the shape of the heart's shadow. The changes which certain diseases introduce in the lungs become clearly expressed in the radioscopic image. The presence of esudation due to pleuritis asserts itself as a darker zone in the normally very transparent area corresponding to the lungs, and may also be shown to displace the heart in some cases. In like manner pulmonary abscesses and tumors may be recognised, and various abnormal conditions —such as union of the pericardium with the diaphragm— detected. The different degrees of movability of the halves of the diaphragm, the displacement of the one side by enlargement of the lung, and the connection between asthmatic troubles and partial paralysis of the heart are matters which may be most instructively and usefully observed.

Another exceedingly important and fruitful field for X ray work, is the detection and location of foreign objects and abnormal deposits in the various parts of the body and extremities. The material already on hand is so ample and diversified, and our methods of manipulation so well understood, that this particular branch of radiography very seldom presents any real difficulties to the worker. It is, of course, quite impossible to enumerate all the actual cases, but they include the detection of widely different articles such as bullets of every calibre, pins and needles, glass fragments, splinters of iron, aud other metals embedded in the muscular tissues. The location of metallic objects even in such encased and dense structures as the skull, has been successfully accomplished, and many curious and valuable results have been arrived at.

The oesophagus, particularly of young persons and infants, has proved a veritable mine for radiographic research, in so far as we have an astounding number of successful cases in which swallowed objects like coins, bone counters, whistles, buttons, and so on, have been radiographically traced, and subsequently removed before having time to ulcerate into the trachea. In adults several instances are reported where false teeth and sets have thus been detected.

Very much more difficult is the location of such foreign objects in the abdomen, the gullet and intestines of adult subjects, but it is to be hoped that very soon success in this direction will be the rule rather than the exception.

As regards the location of the various abnormal deposits in the abdominal organs, the net result of the large amount of work done in this particular direction is by no means very encouraging. There are various rather different deposits, or calculi, which behave widely different when exposed to the rays. We distinguish gallstones (biliary), stones in the kidney, and stones in the bladder; the first named, on account of their greater transparency to X rays, are the most difficult calculi to record on a sensitive plate, and wherever success has been reported, the results were of the vaguest description, the negatives which can be obtained from abdominal exposures being always so veiled and diffuse that no prints on paper could be obtained.

Stones in the kidneys are somewhat easier to deal with, although the results are generally very indefinite, and almost make the previous knowledge of their presence or absence by some other mode of diagnosis a necessity.

Quite different results do we obtain, however, when radiographing the same cases post-mortem, but although of some interest, such experiments are not likely to prove of great practical value.

On the other hand radiography has already done very good service in the detection of uric calculi in the bladder, and some very clear cases have from time to time been brought forward.

Another class of deposits which are much easier to detect are the gouty formations, which latter especially manifest themselves in the phalanges of hands and feet, replacing the opaque phosphates of lime by the more permeable urates.

In the case of chronic rheumatism, however, these transparent parts are absent, or even replaced by portions of greater opacity, so that the rays here give us a means of distinguishing between the two forms of disease.

Yet another great and promising field remains to be explored, namely, the radiographical study of Obstetrics. Up to the present very little has been accomplished, so far as the detection of the living human fœtus is concerned. The reason for this lack of success may be sought in the diffusion of the rays during their passage through the intestines, the muscular nature of the uterus, the resistance of the amniotic fluid and the plentiful supply of blood to the vessels leading to the fœtus. Moreover, the various movements of the pregnant subject, voluntary and involuntary, and of the fœtus itself introduce the greatest difficulties.

CHAPTER VII.

THERAPEUTIC VALUE OF THE X RAYS.

WHEN the powerful penetration of the Röntgen rays became first known, it was quite natural to conclude that they might be directly, or might be made, the vehicle of physical action upon those deep-seated organs which are inaccessible to ordinary therapeutic methods. It was thought that since the new radiation is in some respects similar to ultra-violet light, it might show a destructive action upon bacteria, wherever these microbes might be present in the body. This speculation had so far been a failure, since the very numerous experiments in using powerful radiations upon cultures of bacteria, both direct and also when inoculated into small animals, have led to no convincing result.

Quite recently however, Dr. Hermann Rieder, of Munich, took up the experiments to prove or disprove the effect of X rays upon bacteria, and arrived at the following results. Bacteria suspended in agar, bloodserum or gelatine were destroyed after about an hour's continued exposure to Röntgen rays ; cultures of the cholera bacillus in bouillon require for their destruction a longer time (over two hours). Dr. Rieder believes that even if it should prove impossible to entirely destroy the bacteria in the human body, a partially destructive effect upon them by the Röntgen rays should greatly assist the organism in its natural protective struggle against the further development of the intruding microbes.

There is, on the other hand, ample evidence that the rays do exert a certain, but little understood, influence upon the epidermis, at times causing acute dermatitis and depilation.

The latter has been frequently observed when placing the tube very near the back of the hand or close to the head and exposing for considerable time; more exact in its bearings is the case described by Freund, who exposed a hairy and pigmented naevus on the back of a child for a certain period every day to the rays, at the same time screening part of the naevus by a leaden plate. The result was a perfect depilation of the unprotected part; but it remains to be seen whether this effect is permanent, or whether the hairs will grow again.

Although the majority of X ray workers enjoy immunity from ill effects, yet as already said, a great many cases of dermatitis following upon prolonged radiographic exposures are recorded; in several instances the symptoms are strangely like those produced by sunburn, and have led to the assumption that X rays are present in the sun's rays.

It seems, however, that some other circumstances (not well defined) and individual predisposition greatly influence the nature of such cutaneous irritations. Moreover, according to Dr. Foveaux and de Commelle, this trouble is only caused when the contact breaker works slowly; when the tube is not covered and gives off cathode rays as well. During radioscopic examinations, where, as we have seen, a rapidly working interruptor is a *sine quâ non*, and where usually the tube is in some way covered, ill effects have been rarely noticed.

In every instance the affected parts were those nearest the tube, and it seems, therefore, reasonably certain that since the X rays penetrate to the plate and must pass the other side as well, which remains intact, the real cause might be looked for in some other influence emanating from the tube, such as electric action.

One peculiarity of this cutaneous effect consists in the comparatively long time (a fortnight or so). which often elapses between the cause and the actual appearance of the trouble. The prevention of the action, whatever it be, is obvious. The tube must not be placed too near the skin, and some experimenters also advise the interposition of a thin sheet of aluminium between tube and skin, which only slightly interferes with the X-rays, but would cut off the cathode rays, supposing these to be the real cause of the trouble.

Any proved beneficial effect of the rays upon malignant growths inside the body, such as tumors, cancer, or upon consumption would, of course, be of surpassing importance. Some spontaneous cases of alleged successful treatment are dispersed throughout the medical Press, but it is yet too early to rush to any conclusion respecting ultimate possibilities and new methods of treatment.

The much-debated question whether the rays are able to stimulate the retina, or the optic nerve, or certain optical brain centres has recently been revived by the description of a case in which the patient who was absolutely unable to perceive even the strongest light could make out the colour of the fluorescence and the shape of an X-ray tube; the fact, however, that the interposition of a piece of cardboard destroyed this perception, seems to point to the fact that the active rays were not identical with the Röntgen rays, since the latter would not be obstructed by the cardboard. Another report concerns a man who twelve years ago suddenly lost his sight, and who, by continued treatment with the rays recovered part of his sight.

Of course, in extreme cases where the optical nerve is completely destroyed or permanently paralysed, no hope of any beneficial effect can be entertained.

CHAPTER VIII.

GENERAL APPLICATIONS OF THE RAYS.

ALTHOUGH the extent and importance of the surgical and medical applications of the Röntgen rays have so far completely overshadowed their other possibilities, yet the latter are fairly numerous, and some of them have already passed into every-day industrial routine.

Closely connected with their medical sphere of usefulness are their applications to veterinary surgery, to the army and navy medical service, and as evidence in legal cases.

As regards the first-named, there are obvious limitations, although good work has been done by Mr. V. E. Johnson, Prof. Hobday, and others; the necessity of employing very large sensitive plates in order to obtain radiograms of parts of the larger animals, as also the restlessness of the animal, introduce certain practical difficulties, which, however, have been partly overcome by the expenditure of great perseverance and ingenuity.

Anaesthesia must often be resorted to in prolonged exposures on animals, or such mechanical arrangements must be made that both plate and tube are immoveably fixed to the part to be examined so that, even should spasmodic movement take place, the relative position of the parts, and consequently the distinctness of the outlines would be maintained. The most frequent examination, so far, is that of the extremities of horses with a view of detecting the cause of lameness, of spavin, and the presence of foreign objects in the hoof.

The application of the rays in the military and naval services may be twofold; namely, in the ordinary hospital routine, and on the field. In the latter case the use of the screen alone is feasible to deal with the most urgent cases, and to decide whether it is possible to remove the wounded to the base hospital. It is during the hours of actual engagement, and those immediately succeeding, that the certainty of the new diagnosis is of such immense help to the surgical staff, permitting them without slow, painful, and perhaps incomplete asceptic probing, to ascertain, and perhaps rectify the presence of shots, splinters, fractures, etc., and thus do away with a great deal of suffering and unnecessary or faulty amputation and bone-setting with their fatal consequences, which, of course, with the former methods of diagnosis were inseparable from the stress and circumstances under which the first aid to the wounded is necessarily given. Such cases which absolutely require to be radiographically dealt with, have to be disposed of at the base hospital.

The success and absolute scientific exactness of the new diagnosis led almost immediately to its introduction as legal evidence. The law demands, as a rule, that there should be an anatomical basis or evidence to substantiate the case for the plaintiff in cases of alleged injuries; and in countries where the extensive liability of the employer in cases of accident is legally accepted, or in claims upon accident assurance companies, the production of a suitable radiogram considerably simplifies and clears the proceedings. It also greatly tends to prevent simulation, and consequently must in time discourage perjury; moreover, since the modus operandi of radiography does not cause physical pain or injury, or in any way clash with the dictates of morality, the plaintiff cannot judicially refuse to submit to the examination.

Some other medico-legal cases in which radiography may eventually be of the greatest value can only be enumerated here. They refer to the decision as to pregnancy in doubtful cases, the determination of the age, by means of the stage of the ossification of the epiphyses, in half-charred bodies perished in the flames, and the identification of bodies by looking for radiographic evidence of known former injuries, such as shots and fractures.

Leaving now the medical sphere of application and turning to the industrial possibilities, the selective penetration of the rays for the detection of various enclosed objects was naturally the first peculiarity to be practically exploited. The postal authorities introduced the radioscope to detect illicit enclosures of coins and articles of value in letters and parcels; the French Customs at the present time employ the same means in the examination of passengers' luggage, but since many contraband articles, such as lace, tobacco, etc., are quite transparent to the rays, the value of the new system of examination is not very apparent, besides, the risk of damaging by these means photographic preparations, such as plates and papers which may be contained in such lugguage, will in all probability cause the discontinuance of the practice. Much also has been expected from the radiographic examination of suspicious parcels during the recent dynamite scares in Paris, and one or two successful radiograms of the contents of such infernal machines have been obtained, but in so far as really dangerous consignments are usually encased in metal boxes or iron shells, the practicability of radiographic examination is limited.

In those cases where letters or documents are written with specially prepared inks made from opaque metallic solutions or other equally opaque ingredients, it is possible to radiograph the contents. The obvious remedy against such indiscretion is to fold the letter several times, or better still to enclose it in metal foil before placing in the usual envelope.

Ordinary photography has frequently done splendid service in detecting forgeries, and is now worthily supplemented by radiography, which permits of discovering any alteration in the thickness of the paper or parchment, such as may have been caused by erasion.

The authenticity of old paintings which have become darkened by age, may be established in certain cases, without in any way injuring the painting, by taking a radiogram which brings out the monogram of the master. Such a case, in which a valuable oil painting by Albrecht Dürer was identified, has just been recorded.

Similarly many valuable antiquities and curios present certain problems which may be cleared up by radiographic methods; for instance, the amount of bone ash, which is radiographically opaque, in a given piece of crockery, may allow us to classify the object as old china or ordinary porcelain.

Another often-reported case is that in which a valuable mummy, about which professional opinion was divided, was subjected to the rays, without removing any of the bandages, when the contents were recognised as the remains of the sacred Ibis.

Although most metals are very opaque to the rays from a Röntgen tube, yet by either employing very powerful radiations and sufficiently long exposures, or by examining the metal in very thin sections, several problems may be successfully approached; the two principal questions so far concern the homogeneity of castings and weldings. and the physical composition of alloys. The latter problem has been taken up by Mr. Heycock, of Cambridge University, who alloyed two metals of widely different X-ray opacity—to wit, sodium and gold,—and then radiographed a thin section of the alloy.

The sodium, by its transparency, was found to be crystallised in long thin masses, whilst the gold was pretty evenly distributed.

This result is likely to be very much extended, and to be the starting point of some very curious and valuable metallurgical discoveries.

The presence of flaws and hollows in castings, particularly of steel, and in armour and boiler plates, girders, &c., is at present only very imperfectly ascertained by weighing or tapping. Radiographic examination, however, if applicable, would afford an absolutely certain means of detecting such disqualifying defects. Of course, the opacity and thickness of the metals which would chiefly have to be examined, so far greatly limited such experiments; but there is no fundamental reason why the process should not pass eventually into industrial use.

To the mineralogist and geologist much valuable information may be conveyed by radiographically sifting various ores as to their opacity. It is by now well known that true gems—such as diamonds, jets, etc.,—show considerable transparency to the X rays, whilst their imitations, consisting generally of lead, glass, and other glass coloured with metallic oxides, are more or less opaque.

Caryl Haskins suggests the radiographic comparison of samples of coal (of equal thickness) which, by fixing the relative percentage of ashes and earthy matter, would prove a simple and effective method of physical analysis.

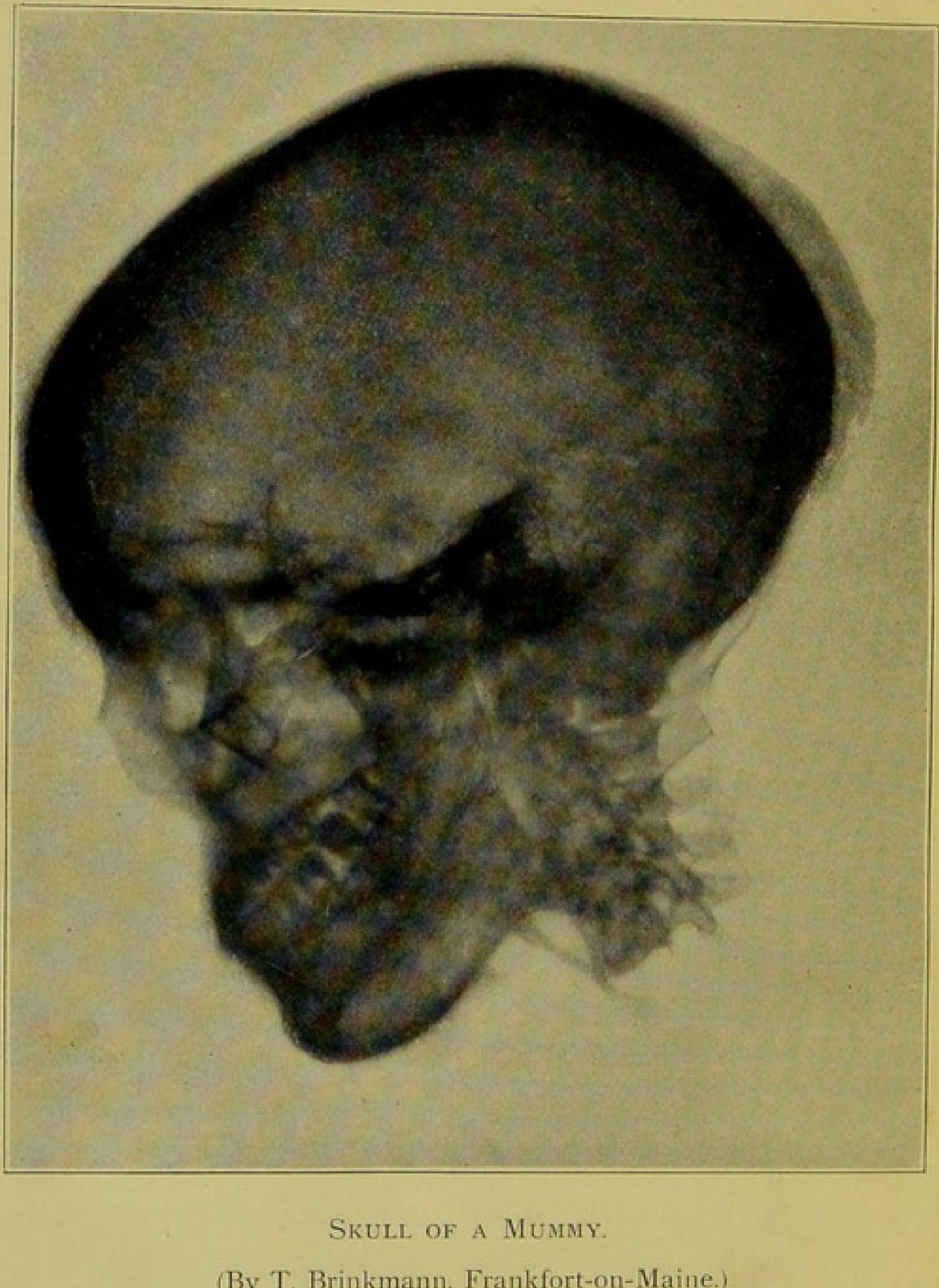
We have also found a great difference in the opacity of various qualities of manufactured rubber, due to different proportions of admixed chalk and similar matters. In the same line of business, a radioscopic examination of the raw product previous to its introduction into the masticators, would be exceedingly useful in order to detect stones or other objects which are often enclosed in the raw lumps to increase their weight, and which cause trouble in the machinery.

Some very interesting and beautiful results attended the radiographic examination (by Prof. Goldstein and by Dr. Wolfenden) of various zoological (marine) and botanical specimens, which brought out a much greater abundance of detail than was obtainable with ordinary photographic methods.

Marangoni radiographed plants and wood with a view of detecting the presence of larvæ of destructive insects.

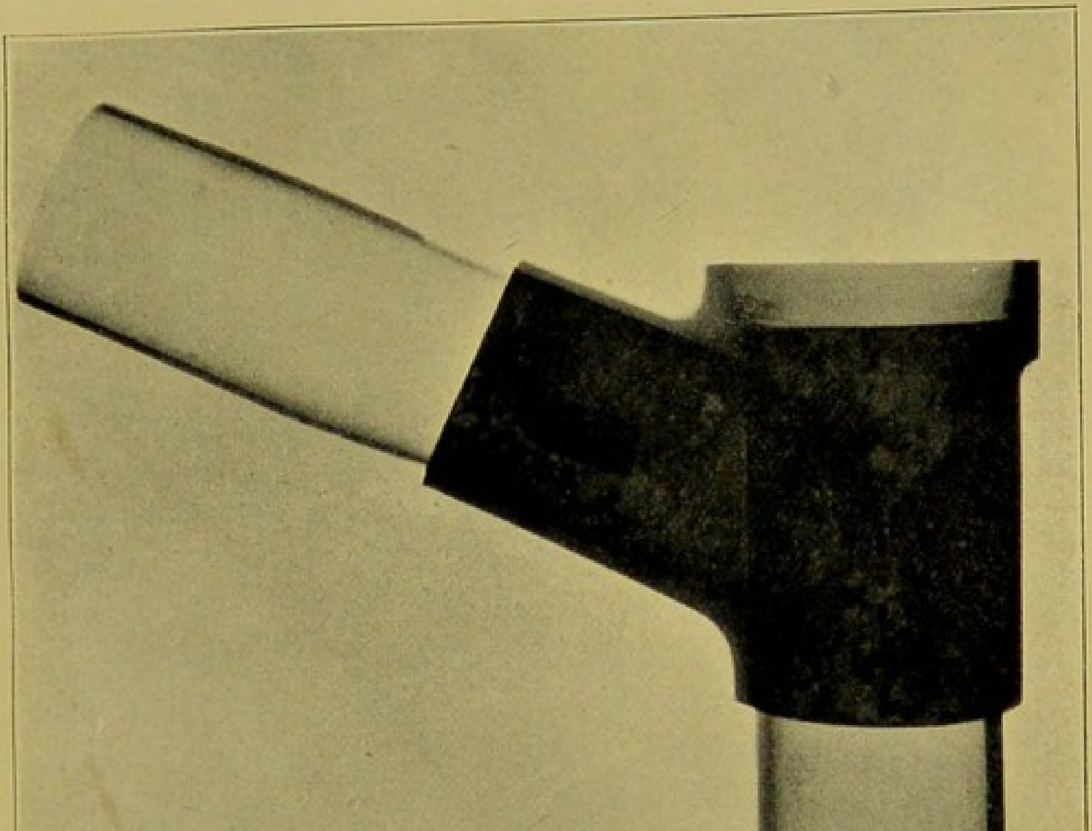
Ranwez employed the rays to detect adulterations in food stuffs, such as the admixture of sulphate of barium with saffron. Bussard and Condon, of the National Agronomic Laboratory of France, by studying the radioscopic density of potatoes, concluded that the increasing opacity near the skin pointed to the prevalence of fecula in these parts, which was confirmed by chemical analysis.

Objects of varying thickness, when radiographed, yield a graduated shadow, so that it would be possible to radiographically reproduce coins and embossed metalware. In order to reduce



SKULL OF A MUMMY.

(By T. Brinkmann, Frankfort-on-Maine.)



Radiogram of Steel-joint Showing Extent of Brazing.

(By Hall Edwards, L.R.C.P., Birmingham.)

the necessary exposure, Count Turati produces first a plaster cast of such objects, grinding the back of the cast perfectly plane, and exposes this replica to the rays. The resulting negative is then copied on a thick layer of bichromated gelatine.

One other use for the propagation of Röntgen rays across space, somewhat akin to the Lodge system of wireless telegraphy is suggested by Dr. Hall Edwards. Since the rays from a very powerful source act at considerable distances upon a fluorescent screen, it would be possible by means of a system of alternative fluorescent flashes to signal across space and even through intervening obstacles, like walls, without the aid of wires. On the other hand, the absorption of the rays in air increases with somewhat like the square of the distance, so that it is not very likely that X ray telegraphy will enter into competition with Hertzian wave transmission.

One great problem, namely, the isolation of the various radiations emitted from the tubes which we are at present using, requires to be solved before we can effectively and with certainty deal with the many industrial and also medical possibilities. At present, the heterogenous nature of the rays necessarily obscures and modifies some of the effects, and explains the practical impossibility to repeat the exact conditions of any radiographic experiment. We say that a certain result, therapeutic or other, is produced by the X rays, yet we are by now quite aware that really only one particular set of rays are effective, and that the other rays are not inactive, but partly blur the phenomenon under observation. A great deal should, we think, be eventually accomplished, both by screening the radiation by interposed media and also electrically and magnetically.

CHAPTER IX.

THEORETICAL CONSIDERATIONS.

HAVING now at some length described the practice as well as the applications of Prof. Röntgen's discovery, it behoves us to devote the remaining chapter to a consideration of some theoretical data, which, although not directly bearing upon our present working methods, yet are desirable to know, as they teach us something about the limitations and possibilities of the new power which we already handle so freely.

First, as regards the nature of the X rays, it is significant of the difficulty of the problem, that whilst the application and working details have been vastly extended and greatly improved since Röntgen's first publication, our theoretical knowledge concerning the new radiation itself, in spite of the incessant work of so many able investigators, has so far not yet been placed upon a firm basis, and scientific controversy is still concerning itself with the question: What is the nature of the Röntgen ray?

The attempts to satisfactorily account for the various phenomena of the X rays have been mainly carried out upon three distinct lines, which found their first adherents in Germany, England and America respectively. Prof. Röntgen in his original paper expressed the belief that his newly discovered radiation were the long expected and theoretically predicted longitudinal waves in the ether, waves which produce alternate zones of compression and rarefaction in the ether, similar to those produced by sound waves in the air. The proofs for this theory, however, have so far been rather wanting in conclusiveness, and the number of its adherents is now very small.

The majority of English, and several German scientists, consider the Röntgen rays as transverse vibrations of the ether, somewhat like the invisible light rays of the ultraviolet end of the spectrum, but of tremendously high frequency, and consequently of excessively short wave-length. If it could be shown that the X rays conform to the laws of reflection, refraction and polarisation, and have the same velocity as holds good for any electro-magnetic disturbance of the ether, this theory would be considered proved, and the X rays would then naturally fall into, line with, and form the present extreme limit of those different manifestations of ether vibrations, only differing in wave lengths which we comprise in the spectrum, and which before Röntgen's discovery extended from the electrostatic or Hertz waves through the calorific or heat rays in the infra-red, through the visible spectrum to the ultra-violet or photo-chemical rays. We reprint at the conclusion of this chapter, a table comprising all these vibrations.

The difficulty of bringing forward such proof as above indicated becomes apparent when we know that the phenomena of reflection, refraction and polarisation are so exceedingly feeble in the case of the X rays, that their occurrence for some considerable time has evaded the observation of physicists.

As regards reflection, G. Vincentini and Packer found indications of irregular refléction in metallic parabolic mirrors, but none in glass mirrors. Voller and Walter have also made experiments on the relative degrees of diffuse reflection possessed by different elementary substances; they divided the substances into the following five groups according to their atomic weights:

I.—Carbon as diamond (C=12).

II.—Magnesium (Mg.=24); Aluminium (Al.=27); Sulphur (S.=32).

III.—Iron (Fe.=56); Nickel (Ni.=59); Cobaltum (Co.=59). Copper (Cu.=63); Zinc (Zn.=65); Selenium (Se.=79)

IV.—Palladium (Pd. = 106); Silver (Ag. = 108); Cadmium (Cd.=112); Tin (Sn.=119); Antimony (Sb.=120).

V.—Iridium (Ir.=193); Platinum (Pt.=194); Gold (Au=197); Mercury (Hg. = 200); Lead (Pb. = 206); Bismuth (Bi.=209).

It was found that the elements of group IV. were the best reflectors; those of group III. were a little inferior; and those of group V. very much inferior in reflective power; group II. hardly showed any effect; and diamond none at all.

The refraction co-efficient of the X rays according to Winkelmann and Straubel is for copper 0·9962, but according to Voller 0·999, and for aluminium and diamond 0·9998; this want of sensible refraction is explained by the assumption that such excessively small waves might easily pass between the molecules of bodies. The same reasoning will hold good to account for the absence of sensible polarisation by using crossed Nicol prisms or by Tourmaline, the structure of which, although exceedingly fine, is yet too coarse for the X rays, and would not split these up sufficiently to produce an appreciable amount of polarisation. However, according to B. Galitzin and A. V. Karnojitzki, plates of tourmaline ½ mm. thick gave results which place the polarisation of the rays, and hence their transverse nature almost beyond a doubt.

The only method which we thus have to determine the wave-length of the X rays is that of interference fringes, but without further going into details, we may say that this mode of measurement is so very difficult and uncertain in the present case, and the results are so widely differing, that they permit of grave doubts as to the probability of the wave theory.

Voller calculated the wave-length of the X rays as 0·000001 mm., Dr. Fromm found this length to be 0·000014 mm., and other observers obtained still higher values, and we must conclude that that they dealt with different kinds of X rays.

A modified theory of transverse vibration has been built up by Sir George Stokes, who assumes that the X rays are non-periodic or solitary waves.

The third theory which was started by Nicola Tesla in America assumes that the Röntgen rays are particles of matter, which being repelled from the anticathode with prodigious velocity are able to pass right through the pores of solids. Lately, this corpuscular theory has been greatly advanced by

Professor J. J. Thomson, of Cambridge, who also measured the velocity of the rays, and found it about the thousandth part of that of light.

He further assumes that the impact of the cathode rays is capable of breaking up the ordinary chemical atoms into "hyper-atomic" corpuscles, which would furnish an explanation for the high penetration of X rays, but at the same time rather upsets the established views as to the immutability of chemical elements, and opens up possibilities of tremendous physical importance. Professor J. J. Thomson was led to his theory by extending certain experiments made by Lenard, according to which the ratio of the density (or specific gravity) and the co-efficient of absorption for the Röntgen rays in various substances changes very little, although these factors in themselves vary enormously, so that the distance through which the Lenard rays (at any rate) travel, only depends upon the density of the substance, and not upon the nature of the matter. The "hyper-atomic" theory has been successfully applied to the elucidation of several phenomena connected with the generation of Röntgen rays by Elihu Thomson, but his speculations, though highly suggestive, are of too transcendent a nature to reproduce here.

The discovery of he Röntgen rays has of course led to a great deal of work on other invisible radiations, in the course of which a great many supposed new rays were investigated, such as the Bequerel-Uranium rays and the radiations observed by Dr. Russell, but their consideration falls outside the scope of this publication, and we therefore at once pass on to a study of some characteristics of the Röntgen rays, which directly enter into the practice of radiography.

Transparency of Various Substances for Röntgen Rays.

Batelli and Garbasso have compiled the following table for the relative transparency of equal thicknesses of various substances, taking that of water as unity; we have added for better comparison the specific gravities.

Material.	Specific Gravity.	Transparency.
Pinewood...	0·56	2.21
Walnut	0·66	1·50
Paraffin	0·874	1·12
Rubber	0·93	1·10
Wax	0·97	1·10
Stearine	0·97	0·94
Cardboard	—	0·80
Ebonite	1·14	0·80
Woolcloth	—	0·76
Celluloid	—	0·76
Whalebone	—	0·74
Silk	—	0·74
Cotton	—	0·70
Charcoal	—	0·63
Starch	—	0·63
Sugar	1·61	0·60
Bones	1·9	0·56
Magnesium	1·74	0 50
Coke	—	0·48
Glue	—	0·48
Sulphur	1·98	0·47
Lead ointment	—	0·40
Aluminium	2·67	0·38
Talcum	2·6	0·35
Glass	2·6	0·34
Chalk	2·7	0·33
Antimony	6·7	0·126
Tin	7·28	0.118
Zinc	7·20	0·116
Iron	7·87	0.101
Nickei	8·67	0·095
Brass	8·70	0 093
Cadmium	8·69	0·090
Copper	8·96	0·084
Bismuth	9·82	0·075
Silver	10·5	0·070
Lead	11·38	0·055
Palladium...	11·3	0·053
Mercury	13·59	0·044
Gold	19·36	0.030
Platinum	22·07	0·020
Ether	0·713	1·37
Petroleum	0.836	1.28
Alcohol	0·793	1·22
Amylalcohol	—	1·20
Olive oil	0·915	1·12
Benzol	0·868	1·00
Water	1	1·00
Hydrochloric acid	1·240	0.86
Glycerine	1·260	0·76
Bisulphite of carbon ...	1·293	0·74
Nitric acid	1·420	0.70
Chloroform	1·525	0·60
Sulphuric acid	1·841	0·50

E. Sehrwald also examined the Halogens regarding their transparency to X rays, and found that chlorine, bromine, iodine, and their chemical combinations are rather opaque, whilst the cyanides and all organic combinations containing only C O H and N are transparent. According to Meslans, all the carbon derivatives, which, besides carbon, only contain gaseous elements, such as hydrogen, oxygen, and nitrogen, are very transparent, but differ in degree according to their chemical function. Sulphur, selenium, and phosphorus are opaque.

The following results of a series of experiments by Dr. Doelter on minerals are rather important :—

1. The transparency of a mineral is independent of its density, except in the case of very heavy minerals. Such comparatively light minerals as rocksalt, sulphur, potash, saltpeter, realgar are opaque, whilst the heavy corundums, cryoliths, and diamonds are transparent.

2. Replacing the magnesium and alum by iron in their silicates, increases their opacity.

3. Dimorphous minerals show generally but very slight differences as regards transparency, in their various modifications.

4. With the exception of a few crystals like quartz, etc., the transparency of a crystal is practically the same in all directions.

5. The most transparent minerals besides diamonds are: boracic acid, amber, corundum, meerschaum, caoline, asbestos, cryolith.

Returning to the diffuse reflection of the X rays, Elihu Thomson recently showed that, in addition to the diffusion which the Röntgen rays undergo at the surface of such relatively transparent substances as solid paraffin, wood, etc., there is a very feeble, though quite perceptible secondary diffusion from a second similar surface, upon which the first diffusion impinges. This diffusion enters largely into radiographic results, and, as we have seen, asserts itself particularly when radiographing such thick substances as the abdomen. It also explains the emission of feeble X rays from all parts of a focus tube, and their apparent creeping round the edges of interposed screens.

The remaining principal characteristics of the X rays, as mentioned in the Introductory Chapter, are their non-deflectibility by magnetic forces, and their capability of discharging electrified bodies.

That Röntgen rays, when impinging upon an electrified body, are able to discharge same, had been observed at an early date, and has been very fully dealt with in Prof. Röntgen's second paper. As an explanation for this phenomon it had been suggested that, as in the case of the discharge by ultra-violet rays, this may be due to the disintegration of the surface upon which the rays impinge, and that in consequence electrified particles are carried away into the surrounding medium. This hypothesis has, however, been disproved by Mr. Rutherford, who showed that even when the electrified surface is covered with an insulator, the surrounding medium becomes electrified just the same. Prof. J. J. Thomson explains this leakage of the charge under the influence of X rays by assuming that the passage of X rays through any insulator converts it into a conductor of electricity, he found the rate of leakage to increase in the order of the following gases : hydrogen, coal-gas, ammonia, air, carbonic acid, sulphuretted hydrogen, chlorine, and mercury vapour. Solids, such as paraffin and ebonite, also become for a short time conductors of electricity.

As regards the non-deflectibility of the Röntgen rays by the most powerful magnetic fields, the various experimenters who worked in this particular direction are all agreed in the absolute non-existence of magnetic deflection. M. Lafay, however, by first passing the X rays through an electrified metallic plate (silver), obtained slight magnetic deflections.

All these phenomena, ill understood though they are at present, show how greatly the constitution and property of matter may be modified by the Röntgen rays. Apart even from the practical applications as set forth in the preceding chapters, Röntgen's discovery has added a most powerful agent to physical investigations, and been instrumental in stimulating a tremendous amount of research, which must ultimately bear most important fruit, and advance us towards the true knowledge of the nature of the matter which fills the universe.

TABLE SHOWING VIBRATION RATES OF PERIODIC PHENOMENA.

Complete vibrations per second.	oc-taves.	Observations.
288,224,000,000,000,000	58	Rontgen Rays (Voller's figures)
144,112,000,000,000,000	57	
2,251,799,813,685,248	51	Ultra violet photographic limit, in vacuum 3×10^{15} per second (Schumann)
1,125,899,906,842,624	50	Photographic limit of solar spectrum, $1{\cdot}053 \times 10^{15}$ per second (Cornu)
562,949,953,421,312	49	Green light near thallium line
281,474,976,710,656	48	Infra red, photographic limit (Abney)
70,368,744,177,664	46	Heat rays of solar spectrum, lowest direct measurement (Langley)
17,592,186,044,416	44	Heat rays from Substances below 100° C (Langley)
		Eleven octaves unobserved
8,589,934,592	33	Electric oscillations in small spheres (Righi)
67,108,864	26	Electric oscillations in Hertz Resonator, 70 cm. diameter
8,388,608	23	Electric oscillations for flying bullet photographs (Boys)
262,133	18	Electric oscillations in Leyden Battery (Fedderson)
32,768	15	Audible vibrations, extreme upper limit
16,384	14	Electric alternator and turbine (Ewing)
8,192	13	Electric oscillations in Leyden Battery (Fedderson)
4,096	12	Music, highest note
512	9	Electric oscillations in Leyden jar (Lodge)
32	5	Music, lowest note
16	4	Water surface waves of minimum velocity
	1	
	0	
Seconds per complete vibration		
2	1	Second beating pendulum
32	5	Air pulsations in wind (Langley)
65,536	16	Mean solar day, 86,400 seconds

Reprinted from a table by T. H. Muras in the *Electrical Review*, 25th April, 1896, and extended to the Rontgen Ray octave.

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