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Contributors

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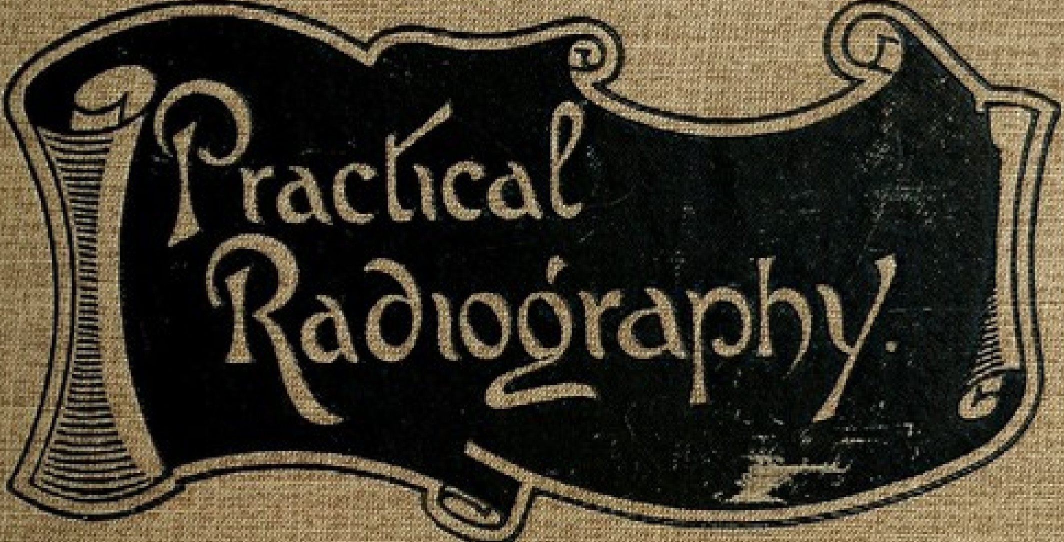

Practical Radiography.

THIRD EDITION

BY A. W. ISENTHAL, F.R.P.S

AND H. SNOWDEN WARD, F.R.P.S.

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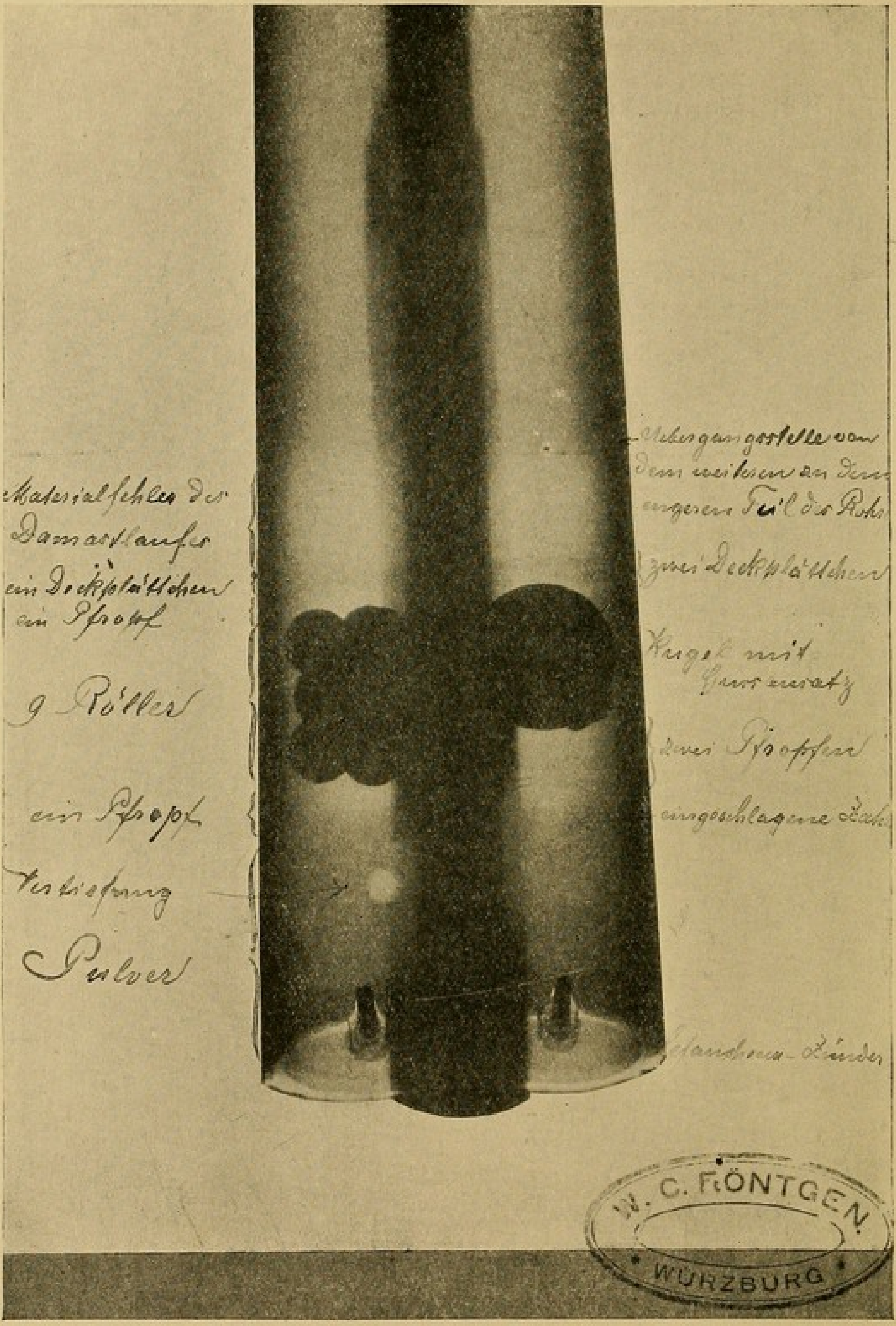

RADIOGRAM THROUGH A DOUBLE-BARRELLED GUN, showing Penetration and Differentiation of Rays.

(Reproduced from Prof. Röntgen's original, presented to one of the Authors.)

PRACTICAL RADIOGRAPHY

A HANDBOOK FOR PHYSICIANS, SURGEONS, AND OTHER USERS OF X-RAYS

BY

A. W. ISENTHAL, F.R.P.S.,

AND

H. SNOWDEN WARD, F.R.P.S.

MEMBERS OF THE COUNCIL OF THE RÖNTGEN SOCIETY)

THIRD EDITION

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INTRODUCTION TO THE THIRD EDITION.

THE first edition of this book,—the earliest handbook of radiography in any language,—was issued in May of 1896, when the subject was less than six months old.

In 1898 the subject had so far grown in importance that a second edition, entirely re-written, seemed necessary.

In this winter, 1901–2, when radiography is recognized as a most valuable aid to the physician and surgeon, when its methods have become relatively permanent, and its apparatus and materials are fairly perfect, a third edition, much larger and more important than the others, seems necessary.

In introducing it the authors wish to acknowledge most gratefully the assistance which has been so cheerfully given to them by radiographers in many parts of the world, but especially by the members of The Röntgen Society and its secretary.

They have also to acknowledge the kindness of many firms and friends in placing electros of their apparatus at their disposal. Among others may be mentioned Baird & Tatlock; A. F. Cossor; Harry Cox, Limited; A. E. Deane of London; T. Ernecke, Berlin; A. W. Hirschmann, Berlin; Max Kohl, Chemnitz; Newton & Co.; Rebman & Co.; The India Rubber Works Co.; and James Wimshurst.

They wish also to urge all who may see these lines to contribute to the sum of knowledge on the subject any advances which they may discover, as freely as did those early workers whose names are honored amongst us.

FIRST EDITION, PRACTICAL RADIOGRAPHY. By H. SNOWDEN WARD; with chapters by E. A. ROBINS and A. E. LIVERMORE. 80 pages. May 1896.

SECOND EDITION. By A. W. ISENTHAL and H. SNOWDEN WARD. 158 pages. September 1898.

CONTENTS.

PRACTICAL RADIOGRAPHY.

CHAPTER I.

HISTORICAL REVIEW.

ALTHOUGH to the physicist the discovery of Professor 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 so successfully applied to practical uses by Professor Röntgen, its announcement came so unexpectedly that absolute incredulity but slowly gave way to scepticism, which ultimately became transformed to awe and wonder. The popular notions about 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 retina 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 color, 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 colors 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 heat, light, photo-chemical action, electricity, magnetism, gravitation, etc.

All these manifestations of ether vibration may be ranged in a sequence which we call the spectrum.

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 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 Professor Langley, with the bolometer, and by Professor 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 Professor 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." Professor Hertz, of Bonn, in 1888, succeeded by his beautiful researches on electric waves in experimentally demonstrating Professor Clerk Maxwell's theory; he showed that these long waves follow precisely the same laws of reflection, refraction and polarisation which govern the infinitely smaller light waves; and Professor Oliver Lodge, and later on Professor Righi most successfully continued these researches, working with shorter electric waves and elucidating the polarisation of such waves.

Examining these electric waves as to their absorption by various substances, we arrive at some remarkable 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, etc., 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 terminals of an induction 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 $\frac{1}{2}$mm., breaks up into various striæ separated by dark bands, their color 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 millimetre, 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 Professor Crookes fully dealt with in his lectures before the Royal Institution in 1879, and again summarized 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 the rotation of delicately suspended wheels with mica vanes in the tube, etc. Another very important characteristic of the cathode rays is their deflection by magnetic forces, the amount of deflection for a certain magnetism 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, etc., 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 Professor P. Lenard, the former assistant of Professor 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 heterogeneity 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 Professor 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.

Professor Röntgen made his discovery whilst following up some of Hertz's and Lenard's investigations by means of a Crookes' 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 photochemical effects, and amongst the various objects interposed between the source of radiation and the sensitive plate was Professor 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.

Professor Röntgen's three 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 from them 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:—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.

SOURCES OF ELECTRIC ENERGY.

THE generation of the X-rays for practical application being at the present stage of our knowledge almost 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 at present their use for the generation of X-rays is still rather limited, they will be described at the end of this section.

PRIMARY BATTERIES.

It does not very frequently happen that the radiographer is called upon to produce his electric current by means of primary or galvanic batteries. Still, their construction and application must be shortly referred to, more especially because the laws governing their combinations and output hold good whatever be the sources of unidirectional current.

A galvanic cell is a combination of metals and solvents, which is able to convert chemical action 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.

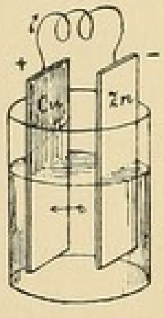


Fig 1

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.

The actual amount of electrical energy which any source of electricity furnishes is obtained by multiplying the current by the E.M.F. Thus: Ampères × volts. The result is expressed in "Watts." It may at once be inferred that a given amount of electrical energy may be presented in various ways—either a very high E.M.F. with a small current or a very large current with a low E.M.F.—since their product in both cases may come to the same amount. It is well to keep this in mind, as a given amount of electrical energy often changes the relative magnitude of its factors in Röntgen work.

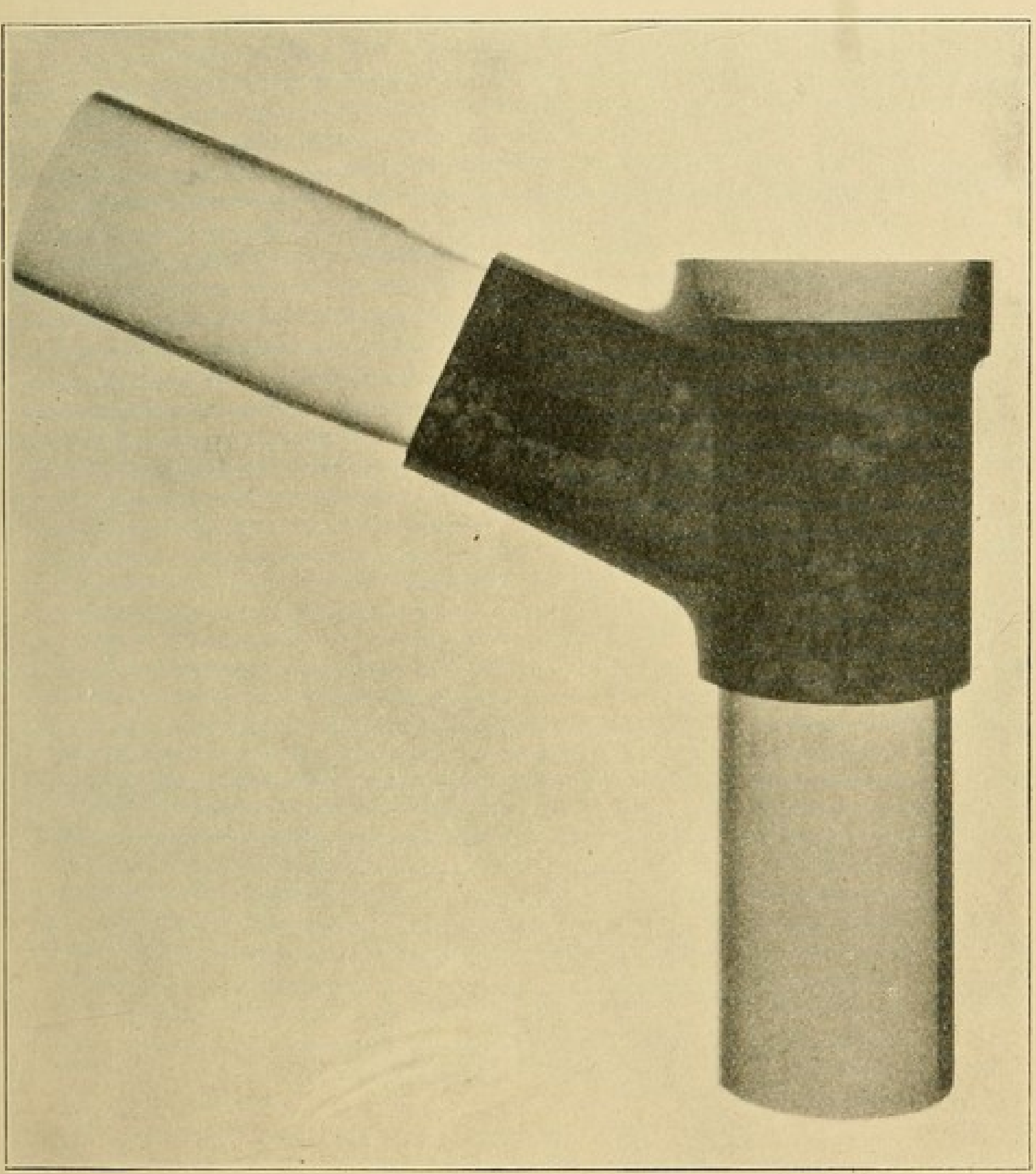
The value of the *electric current* obtainable from a given cell depends greatly upon the area of the immersed part of the electrodes (not upon their shape), and increases with this dimension.

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 free access of the liquid to the metal; so that the resulting E.M.F., and with it the current, rapidly decrease. This polarization 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 is liberated is usually surrounded by some oxidizing material, such as nitric or chromic acid, which easily parts with oxygen, which element combines, combining with the hydrogen to form water.

From a consideration of the above characteristics we may now select those types of galvanic cells which would be suitable for our purpose. It will be best, however, before considering these individual members, to make the reader acquainted with the principal *Units* of the electrical factors—names which constantly occur in the subsequent chapters—and also to introduce a few simple but important laws.

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



RADIOGRAM OF STEEL-JOINT showing extent of Brazing.

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

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 millimetre section and 1·06 metres in length.

The unit of "current" is called an "ampère," and it is present whenever an E.M.F. of 1 volt is acting in a circuit of 1 ohm resistance.

The above electric units stand in a certain relation to each other, which is expressed by Ohm's Law:

$$\text{Current} = \frac{\text{E.M.F.}}{\text{resistance}} \text{ or ampères} = \frac{\text{volts}}{\text{ohms}}$$

The current equals the E.M.F. divided by the resistance of the circuit.

The resistance in the case of a galvanic cell sending current through a circuit is made up of the circuit (outer resistance) *plus* the resistance of the cell itself (internal resistance), which latter decreases with the area of the immersed plates and increases with the distance between positive and negative plates; also with the dilution of the acid or electrolyte.

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

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

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

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

To increase E.M.F. Connect in series.—By connecting each negative electrode with the positive electrode of the following cell, thus 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.

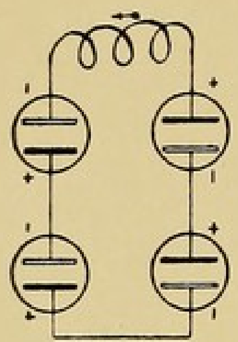


Fig. 2.

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:

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

To increase Capacity or to obtain larger Currents. Connect 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 circuit and obtaining larger currents.

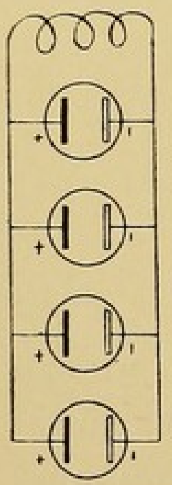


Fig. 3.

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 combination may also be employed when it is desired to increase the capacity of the battery without reducing the working current.

There exist, besides the above, many other arrangements representing combinations of the two fundamental connections, but since, as a rule, suitable cells may be purchased in the first instance, we need not go further into this matter.

Although the number of existing types of cells is immense, our choice of a suitable type is greatly limited, as few constructions comply with the conditions of effectively running an induction coil, namely, high E.M.F., large currents, and great constancy and capacity.

The following types are most frequently used :—

Bunsen Cell.—A carbon plate is immersed in nitric acid, or saturated solution of sodium nitrate and nitric acid, contained in a cylindrical porous pot. The latter is surrounded by a cylinder of sheet zinc immersed in dilute sulphuric acid (1 : 20 by volume) E.M.F. = 1·9 volt.

Bichromate Cell.—Carbon and zinc in various shapes immersed in a saturated solution of bichromate of potassium and sulphuric acid, E.M.F = 2·1 volt.

(To prepare 1 litre of the solution, gradually add 70 gr. of powdered bichromate of potash to 80 c.cs. of sulphuric acid, mix well and finally fill up with 0·85 litre of water in a thin stream.)

Edison-Lalande Cell.—Zinc and oxide of copper in solution of aqueous caustic potash (1 : 3 by weight) covered with oil to prevent evaporation, E.M.F. = 0·85 volt. Of these, the first type is rather objectionable, on account of the noxious fumes given off during working and the trouble of recharging. The third type, although very constant and free from fumes and local action, is in most cases impracticable owing to its low E.M.F., since from 12 to 16 cells would be required to run a coil. We are thus practically bound to the use of the bichromate cell, which, although not constant in the true sense of the word, permits of satisfactory working, provided the plates are of sufficient area.

Fig. 4 represents a very convenient form of bichromate battery, in which the zincs may be lifted out of the jars or immersed to varying depth. For small coils or for running separate motor interrupters, the jars should have a capacity of 1½ quart. This will furnish a current of 1½ ampères for 20 hours. For larger coils the jars should be capable of holding 5 quarts, furnishing a current of 5 ampères for 20 hours.

The effect of polarisation is to reduce the working current. This may be ascertained by observing the ammeter or—if the battery is working a coil—by noting any drop in the pitch of the contact breaker.

At this stage some improvement may be effected by immersing the zincs to a greater depth in the electrolyte, but if the solution assumes a dark green colour, it will have to be renewed.

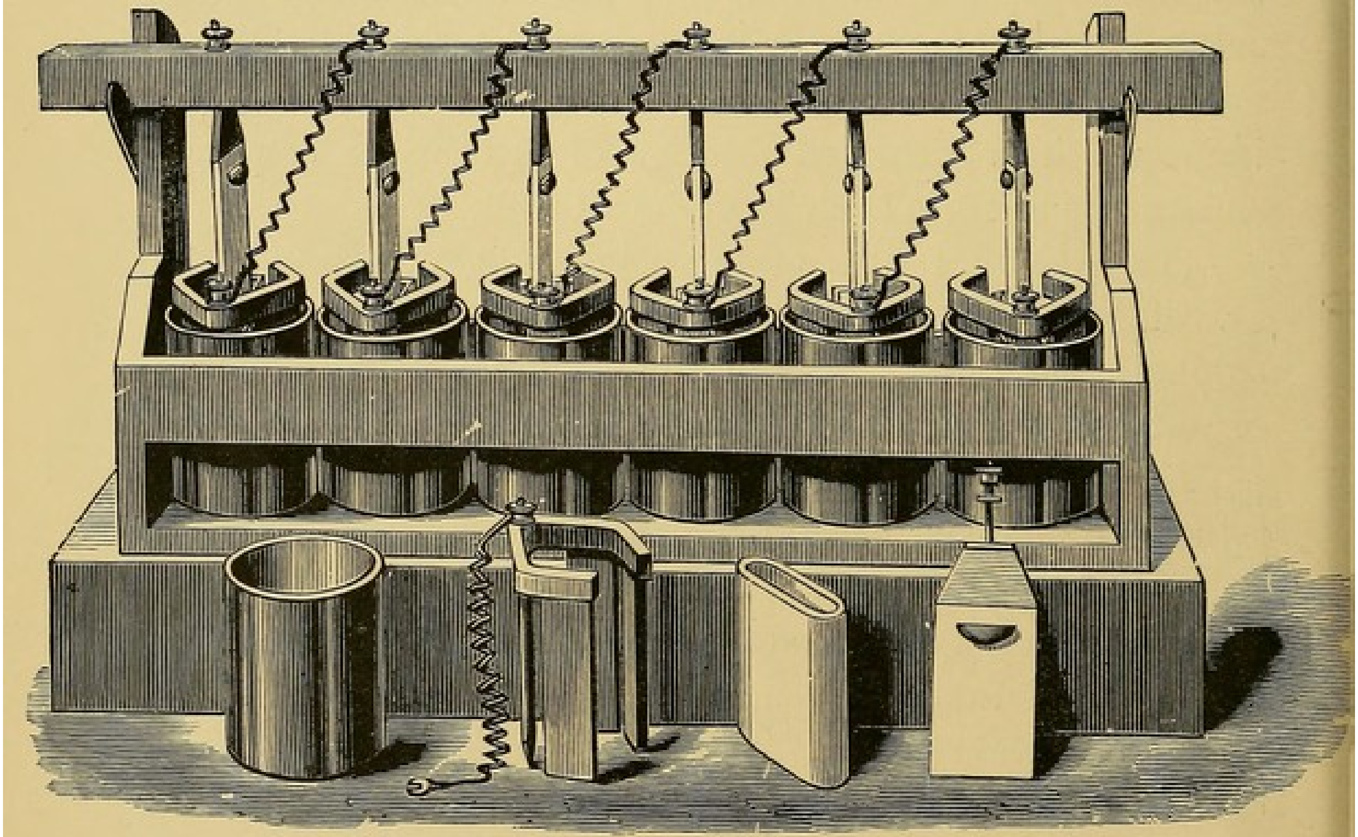


Fig. 4.

Before doing so, all the bright, metal parts, where contact is made, must be carefully cleaned, the carbons washed in hot water and the zincs carefully amalgamated. To do this, the zincs are first thoroughly cleaned under water with a stiff brush, then placed in a shallow tray containing dilute sulphuric acid (1 : 15) and a little mercury. When uniformly covered with mercury the plates are washed and dried.

In order to arrive at the proper number of cells to be used for the coil or the interrupter, we should remember that the initial E.M.F. of 2 volts or more per cell will not, in the majority of types, be maintained for long, whilst the battery is working, but will soon drop. We have therefore to assume a mean working E.M.F. of about 1·6 volt per cell, rounding off the resulting number of cells upward; *i.e.*, a coil requiring 12 volts at its terminals ought to be run from $\frac{12}{1 \cdot 6} = 7 \cdot 5$, or, say, 8 cells.

Finally, let us remark that even the very best primary battery, however carefully constructed and maintained, is inferior in convenience and certainty to other sources of current, and should only be chosen where no other means of generating an electric current is available.

ACCUMULATORS.

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 utilized 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—preferably lead—are substituted for the zinc and copper, a chemical action will be produced, resulting in the formation of brown peroxide of lead ($Pb\ O_2$) on the plate to which the positive pole of the primary battery was connected, and of hydrogen at 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), and the negative plate is converted into spongy lead. The combination then 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).

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.

In the Faure system the active material is prepared beforehand, and spread on a suitable support or grid—mostly 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 (PC_3 O_4) and sulphuric acid (50 per cent.), and, for the negative plates, either litharge (PCO) and sulphuric acid or porous lead. This system almost dispenses with the necessity of preliminary "forming."

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 the whole discharge, is practically maintained at 2 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 product of the maximum discharging current and the duration of discharge in hours. 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.

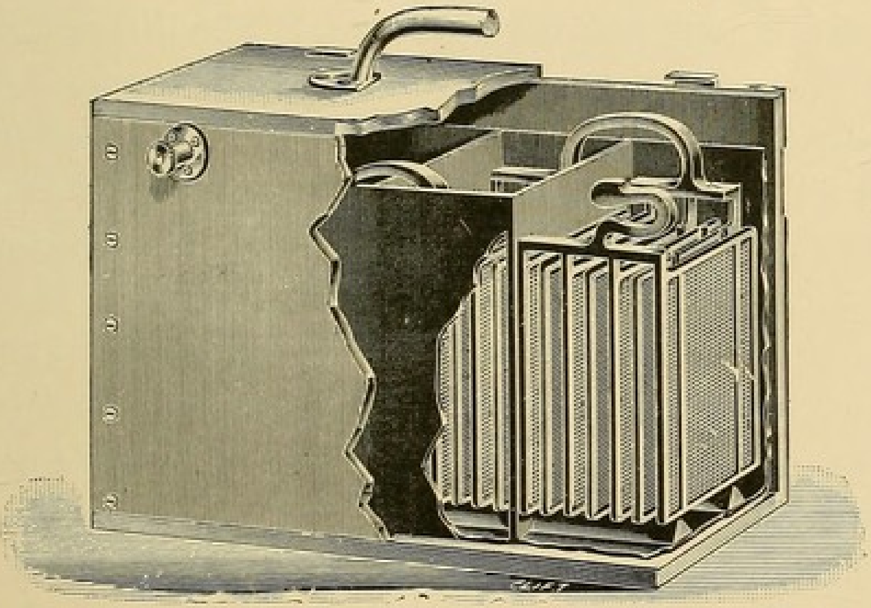


Fig. 5.

If the guaranteed capacity of a certain type of accumulator be, for instance, 32 ampère hours at the maximum discharge of 8 ampères, then we may use the battery at one charge:

With 1 ampère for 32 hours	*at least*, though usually a 32-hour capacity will allow of 40 hours' discharge with 1 ampère and about 18 hours with 2 ampères, etc.
„ 2 „ „ 16 „	
„ 4 „ „ 8 „	
„ 8 „ „ 4 „	

A well constructed accumulator will not suffer permanently if discharged for *a very short period* at a higher rate than the maximum discharge current, though the capacity will be somewhat reduced.

Although the number of types of accumulator construction is exceedingly great, yet there is much less difference between the various patterns than between the various primary batteries; these types differ chiefly in details of construction, such as insulation, support of active material, etc., whilst the essential principle remains unaltered. The choice of a suitable type is thus greatly facilitated, and centres chiefly round one factor, viz., greatest capacity for a given weight.

A light accumulator is, of course, in almost every case a great consideration, but it should be borne in mind that the attainment of minimum weight is not always compatible with durability, and in those instances where the accumulator has to be taken about a great deal, either by rail or in some other way, a type should be selected which will withstand the deleterious effects of vibration.

The capacity of the accumulator, again, must depend upon the specific requirements, since a fully charged accumulator loses its charge spontaneously, even if no useful discharge has taken place. It would be a mistake to choose the capacity too great, as the accumulator has in any case to be charged up every three weeks or so. Supposing that the accumulator has to run a coil taking 5 ampères current every day for half an hour altogether, a capacity of $\frac{5}{2} \times 3 \times 6 = 45$ ampère-hours would be about right, assuming six working days per week and a three-weekly charging. If, however, the accumulator is not stationary, and the weight at the above capacity is too great, then a smaller capacity must be selected and the charging done more frequently.

Charging Accumulators.—As a rule it will not be difficult to find an electrician willing to charge the accumulators at regular periods, but there are also many instances in which such an arrangement either cannot be made, or where for other reasons it becomes necessary to do the charging at home.

Leaving aside as impracticable the charging by means of primary batteries, there are three ways of replenishing an accumulator, viz., by thermopiles, dynamo current and current from the mains of an electric supply station.

The first of these three methods, on account of the small currents which are obtainable from a thermopile, should only be employed where no other means of charging is available, and only when the accumulator is of small capacity, or when only short discharges have to be compensated for.

We shall deal with the construction of the thermopile in a subsequent chapter, but for the present purpose we must remember that the E.M.F. of the best type only amounts to 2 volt at 3 amp. current. In order, therefore, to charge a 4- or 6-volt accumulator by this means we should either have to employ several thermopiles connected in series, or we should be able to alter the series connection of the accumulator cells to a parallel connection, so that only 2 volts would be required at the terminals of the accumulator battery. Thermopiles being costly instruments, we seldom find more than one or two employed for charging, but to easily alter the grouping of the accumulator cells, some automatic device — often called "pachytrope" — is added to the battery, so that by simply turning a handle various combinations of the accumulator cells may be made to suit the conditions of charging and discharging.

Fig. 6 represents a portable accumulator with its pachytrope attachment, the latter being at the same time so arranged that the connection to the thermopile is automatically established as soon as the position of parallel connection is present, whilst in the series position connection is automatically made with the induction coil.

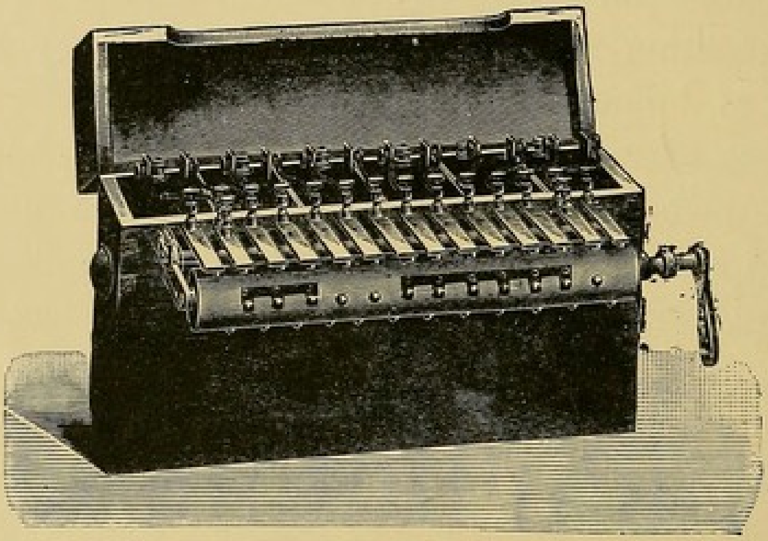


Fig. 6.

The thermopile must have been heated up for some time before it is thrown into circuit, but once set working it will continue to generate current at a uniform rate without any further attention provided the gas burners are all alight and the flames maintained at their proper size.

In order to convey an idea of the time which a thermopile requires to charge an accumulator, we will cite a specific case: A 6-cell accumulator of 18 ampère-hours capacity, when entirely discharged, would require for the attainment of its full charge three days' continuous running of the thermopile. If, however, we start with a fully-charged accumulator, and use it daily on an induction coil, taking 6 ampères for about an hour altogether, then a thermopile is well capable of compensating for this discharge by running for about eleven hours, say, during the night.

The average gas consumption of a thermopile is 6 cubic feet per hour, and the cost is a farthing per hour.

Charging by means of a Dynamo.—This method is practically limited to large accumulators which are used for lighting purposes in country houses or rural districts: it would be too circumstantial to run a motor and generating plant for a small accumulator such as is generally required for working an induction coil. In the former case we may always assume that the engineer in charge of the plant is enough of an electrician to see to the charging of the coil accumulator. Should this, however, not be the case, then the same rules which will be given for charging from the electric light circuit will hold good in charging an accumulator from the dynamo direct, with the following additional precautions. Dynamos wound on the "series" system which are generally employed for running electric arc lamps are apt to change their polarity, especially when—for some reason—their E.M.F. decreases, and an accumulator battery is connected to them. Although on a previous occasion the terminals on the dynamo switchboard may have been determined with regard to their polarity, it will be necessary to ascertain this polarity at every subsequent occasion before connecting up with the accumulator. Further, the connection between accumulator and dynamo must not *be effected before the dynamo is running at full speed* and generating sufficient E.M.F. (as indicated by the voltmeter). Similarly, at the end of the charging or when temporarily discontinuing, the accumulator must be disconnected before the dynamo is slowed down, as otherwise the accumulator would discharge itself rapidly through the dynamo, the E.M.F of which is now below that of the accumulator.

One other case occurs where the accumulator has to be charged from a dynamo direct, *i.e.*, when neither thermopile nor primary battery, nor large dynamo are available, but when animal power alone can be utilized. During the last Soudan expedition Major J. Battersby, R.A.M.C., very ingeniously contrived to replenish his accumulators from a dynamo driven by a tandem bicycle. There is no reason why it should not be possible to dispense with the bicycle and work the little dynamo from a suitable hand-gear with accelerating motion. Two shifts of men will be able to easily work such a gear without serious fatigue. As for the small dynamo itself, it would have to be of the "shunt-wound" type, capable of giving a voltage in excess of that of the accumulators, whilst the current would depend upon the capacity of the accumulator and the time which is at one's disposal for charging, always, of course, keeping within the limits of driving energy supplied by muscular power.

Charging from the electric light circuit.—In speaking of electric light circuits in connection with the charging of accumulators, we, of course, refer only to the continuous current supply.

Quite recently means have been found (apart from the use of rectifiers) to employ the alternating current also for charging purposes. But the efficiency of this method has so far been unsatisfactory, and the construction of the necessary apparatus of a more or less tentative character, so that we may leave it out of consideration.

The first thing we have to ascertain in connection with such a circuit is its voltage and polarity. The former (generally 100, 110, 200, or 230 volts) can be ascertained by applying to the supply company. The polarity, that is to say the positive and negative poles, may be found most conveniently by means of so-called "pole-finding paper," a moistened strip of which, when placed across the two wires connected to the circuit (which must not be allowed to touch each other), shows a red stain at the negative pole.

Having decided (from the instructions sent out with the accumulators by their makers) what amount of curren to use for charging, it is well to insert into one of the wires leading from the circuit a "fuse" (obtainable from any electrician) for that particular amperage, so that if by some mischance or mistake the charging current should unduly increase, the fuse would melt and interrupt the connection between circuit and accumulator. The negative pole of the circuit is then led directly to the negative pole of the accumulator, the positive pole of the latter being connected as shown in fig. 7, through an ampère-meter and an adjustable rheostat to the positive wire of the circuit.

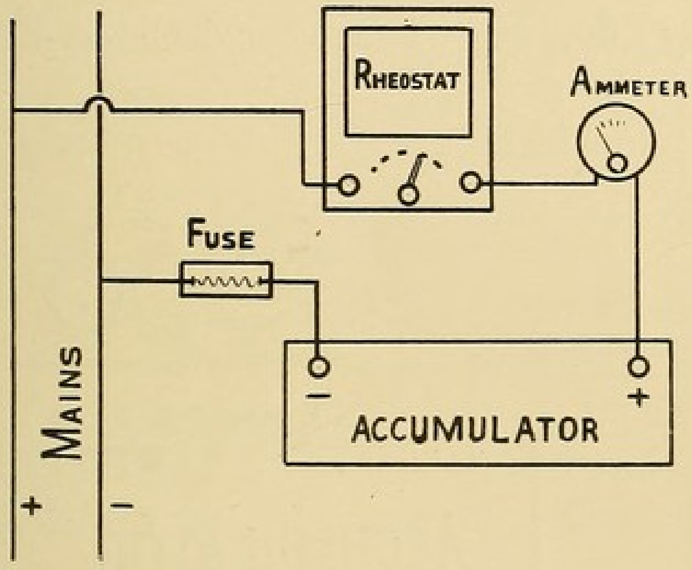


Fig. 7.

On starting, we put the rheostat lever on the stud giving the maximum resistance, and gradually alter its position until the ampère-meter shows the desired current. This current should be maintained until an ample generation of gas-bubbles takes place in the cells, showing that the active material of the plates cannot absorb any more hydrogen. Another means of ascertaining the termination of the charging process is given by the E.M.F., between the terminals of the accumulator, which ought to show, per cell, 2·5 volts on a voltmeter (*i.e.* in a 6-cell accumulator, 15 volts). A third way to ascertain the end of the charging process is to examine, by means of a hydrometer, the specific gravity of the sulphuric acid in the cell, this sp. gr. approximating, at full charge, to 1·23.

During the period of charging, the vent-plugs, or other caps or lids ordinarily preventing the spilling of the acid, must be removed, so as to allow of the free escape of the gas.

In the absence of a suitable regulating rheostat and ampère-meter, we may use a fixed resistance capable of passing a certain current only, and the best way to effect this is to use a bank of suitable incandescent lamps, as indicated by fig. 8. The electrical coefficients and the number of lamps depend upon the pressure of the supply circuit and the pressure of the accumulator as well as its maximum charging current. To take a specific case, let us assume that we have to charge a 16-volt accumulator at 4 ampères from a 110-volt circuit; then the lamps must be ordered for a 110-volt − 16-volt or 94-volt pressure. Since an ordinary 16 c.p. lamp at about 100 volts consumes approximately $\frac{1}{2}$ ampère-meter (when burning brightly), we shall require $\frac{\frac{1}{2}\text{ amp.}}{4\text{ amp.}} = 8$ lamps in

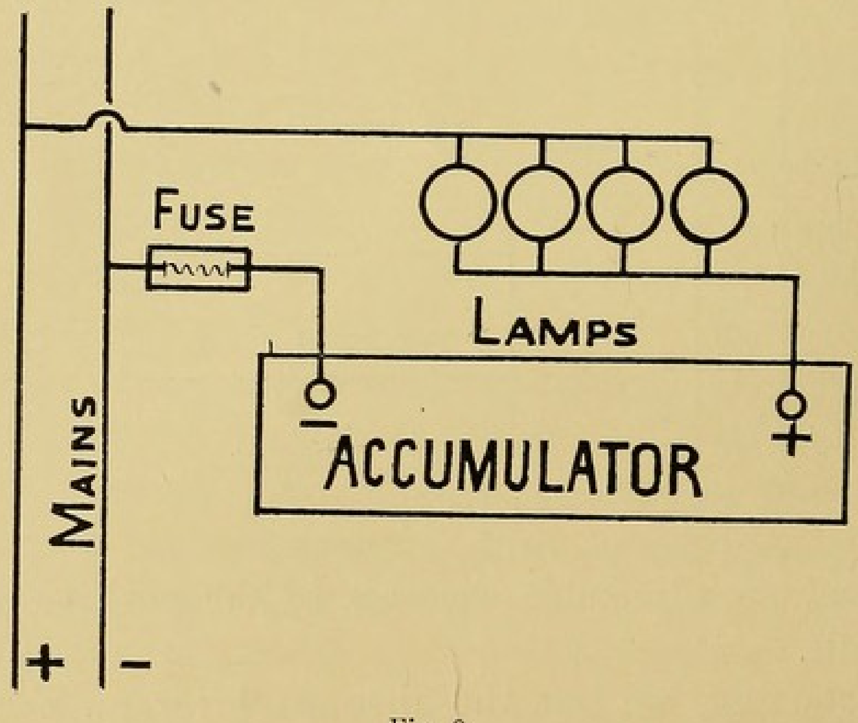


Fig. 8.

parallel. If we wish to pass less current through the accumulator (*i.e.*, when the latter has been discharged too far) we take out, say, two lamps and thus reduce the current to $6 \times \frac{1}{2}$ amp. = 3 amp. : and so on.

There are many convenient forms of "lamp-rheostats" or "charging boards" on the market, but to those wishing to arrange such an instrument for themselves, its construction will be obvious from the above description.

Whether charging through an ordinary rheostat or through parallel lamps, we must not forget to *disconnect the accumulators* at the termination of the charge *before* switching the current off the house circuit, as otherwise the accumulators would discharge through the house installation.

Discharging Accumulators and general working rules.—Although possessing undoubted and great advantages over primary batteries for radiographic work, accumulators require a great 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 1·85 volt ; thus, in the case of a 6-cell battery, 11 volts is the lowest limit for the discharge.

2. Under no circumstances should the discharging current exceed the maximum as specified by the maker for any but the shortest periods.

3. When nearly discharged, an accumulator should not be left for any lengthy period without being previously recharged.

4. 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 1·2 specific gravity.

5. Only chemically pure sulphuric acid should be used for accumulators as well as distilled water.

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

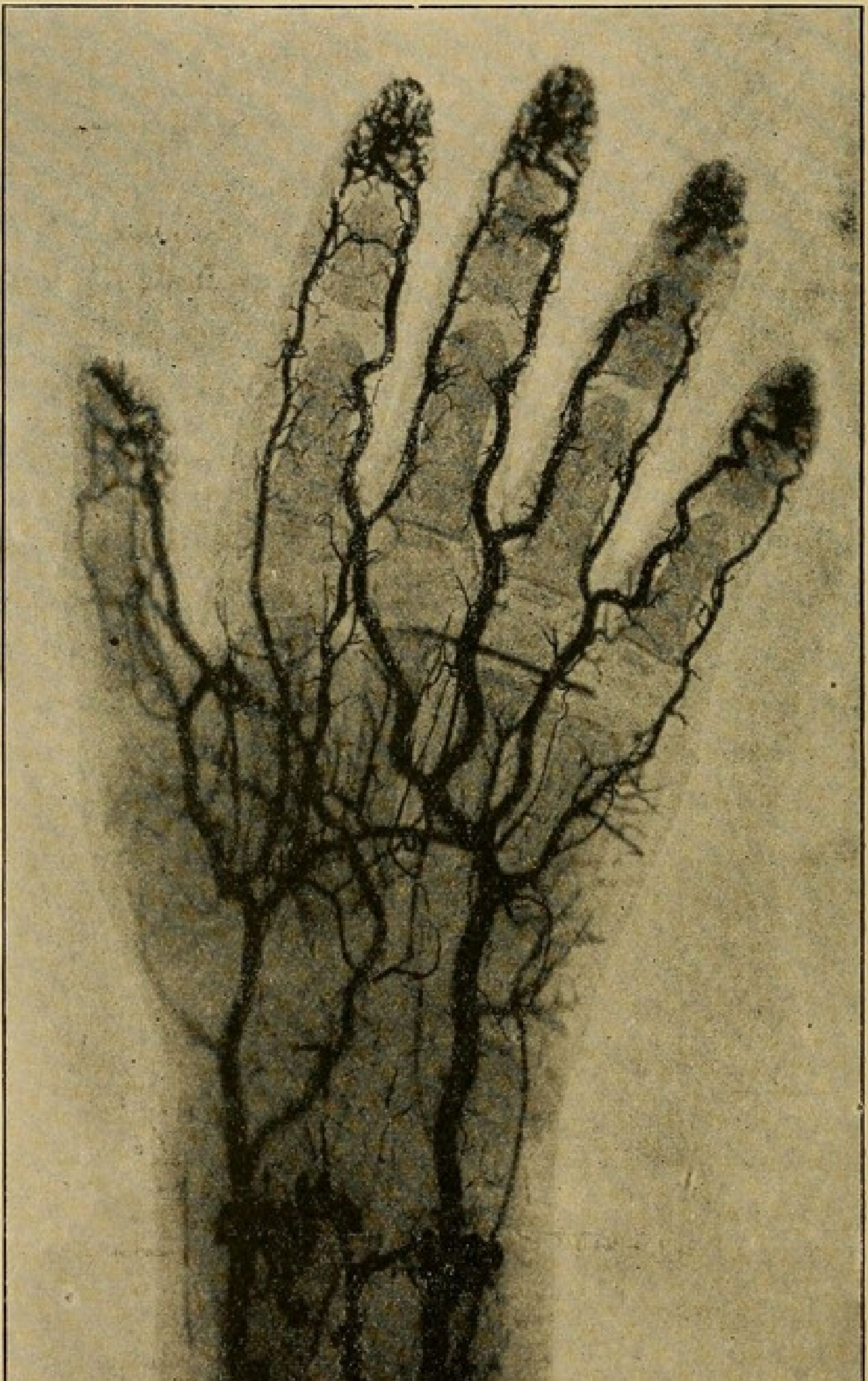
7. Great care must be taken to avoid a "short circuit," that is, a direct metallic connection between the terminals, as this might damage the plates and so ruin the whole accumulator.

In conclusion, we may say that the life of an accumulator depends greatly upon its use, but rarely exceeds four or five years as regards the positive plates at any rate.

THERMOPILES.

The employment of a thermopile as a means of working directly an induction coil is most unlikely, since, as we have seen in the preceding chapter, its E.M.F. is very low, and the provision of a number sufficient to produce enough electrical energy would entail an exceedingly heavy outlay. Their use, then, we may confidently say, is limited to the charging of accumulators, as previously described; and although even for this purpose they are but seldom met with, we will give a brief outline of their principle and construction for those whom it may interest.

In 1821 Professor 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 is always from the warmer to the colder junction, and the strength of the current increases with the difference in temperature. The E.M.F. of such a thermoelectric 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



Hand showing Arteries Injected with Mercury.

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

0·000057 volts for each Centigrade degree 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 thermopile. In practice a very great number of couples are joined together, and are so arranged that the heat, which in most instances is furnished by atmospheric gas burners, 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. Of the more successful constructions we will mention but one, that of Gülcher (Fig. 9), which consists of 66 individual couples, heated by about fifty burners in the form of nickel tubes, which serve equally as electrodes.

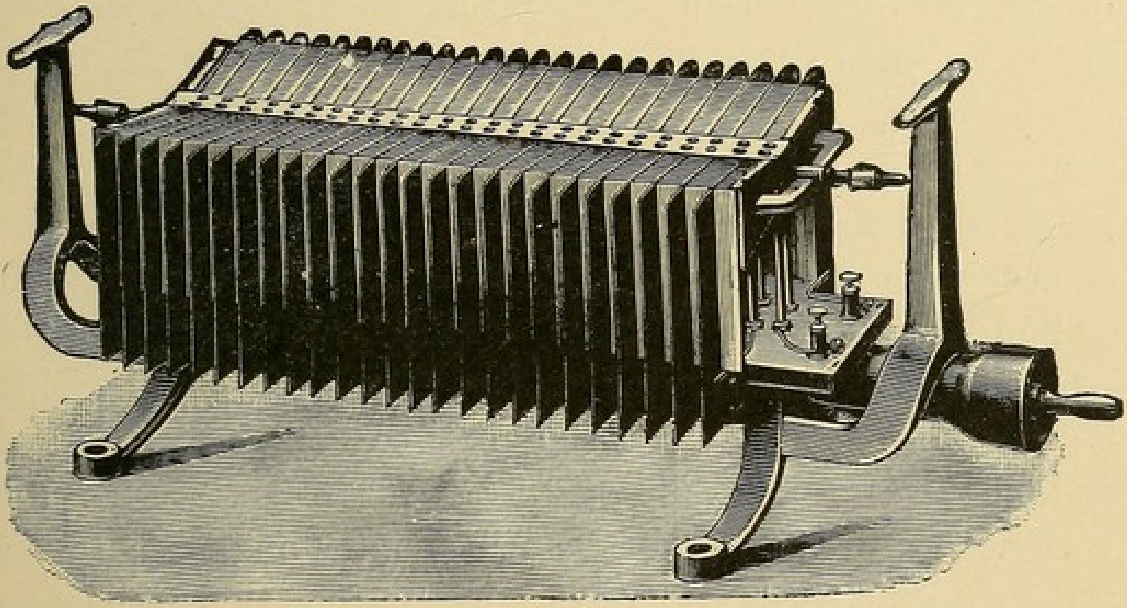


Fig. 9.

The manipulation of such a thermopile is very simple. The gas inlet tube having been connected through a rubber tube with a gas tap, the latter is opened and after about half a minute the gas ignited at the top bar, care being taken that all the burners are alight.

The generation of current attains its full value as soon as the pile is thoroughly heated, and remains practically constant as long as the temperature of the flames remains unaltered. Barring accidents, these piles require very little repair or supervision.

ELECTRIC SUPPLY CIRCUITS.

With the rapid increase in public and private electric lighting from electric central stations, the use of electric supply circuits for working 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 amounts to 100 or 110 volts, and recently to 200 or 250 volts—to the working pressure of the coil, as fixed by its maker, which varies from 6 to 20 volts or more. 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; or a transformer can be used. 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 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 as in the case of a rheostat, and for this same reason any small lamp circuit is sufficient to attach the radiographic instruments to. On the other hand this plan is very expensive as regards first cost, and may also be objected to on account of the introduction of rapidly moving machinery.

(*a*) *Continuous Current.*—In this system the current supplied is generally maintained at a constant pressure and is unidirectional—similar to current generated by a battery (strictly speaking it is pulsating, but so quickly that it cannot be appreciated).

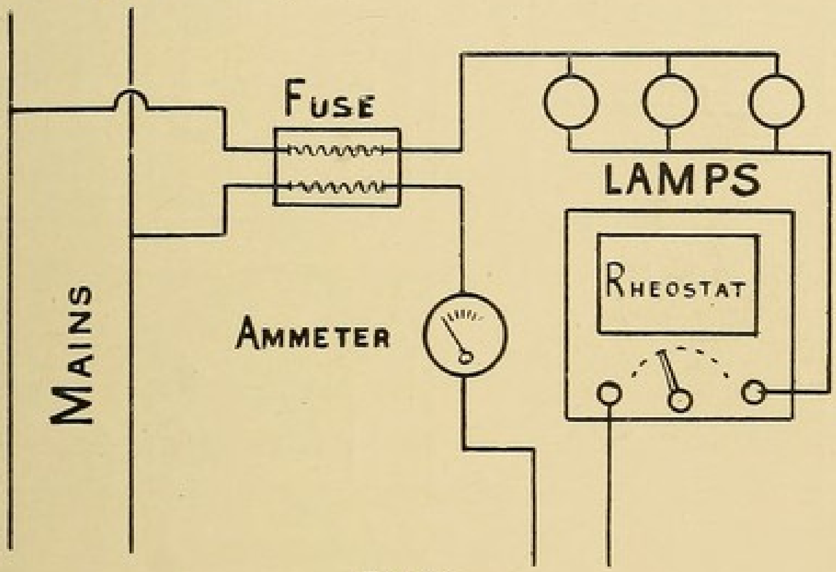


Fig. 10.

It is for this reason that continuous current may be utilized to work any induction coils without being previously transformed in any way, save the usually necessary reduction in pressure by means of rheostats. This reduction of course is equivalent to a certain waste of energy (in heating the wires of the rheostat), and the waste becomes greater as the voltage of the supply circuit is higher, or as, for a given supply pressure, the voltage, for which the primary of the coil is wound, becomes lower. For example, taking a 100-volt circuit and a coil requiring usually only 6 accumulator cells to work it, then 100 volt − 12 volt, *i.e.* 88 volts, must be dissipated in the rheostats, so that the efficiency is reduced to 12%. Coils wound for such low voltages require usually fairly heavy currents (6 to 20 amp.), and it becomes obvious that the rheostats capable of receiving such an amount of electrical energy must be cumbrous and expensive. For this reason the total resistance required is sometimes divided into a fixed and an adjustable part, the former representing the largest amount (as expressed in ohms) and conveniently arranged in the form of a bank of high candle-power incandescent lamps (50 c.p. or so); the rest is contained in an adjustable rheostat, of which figs. 51 and 52 give several types.

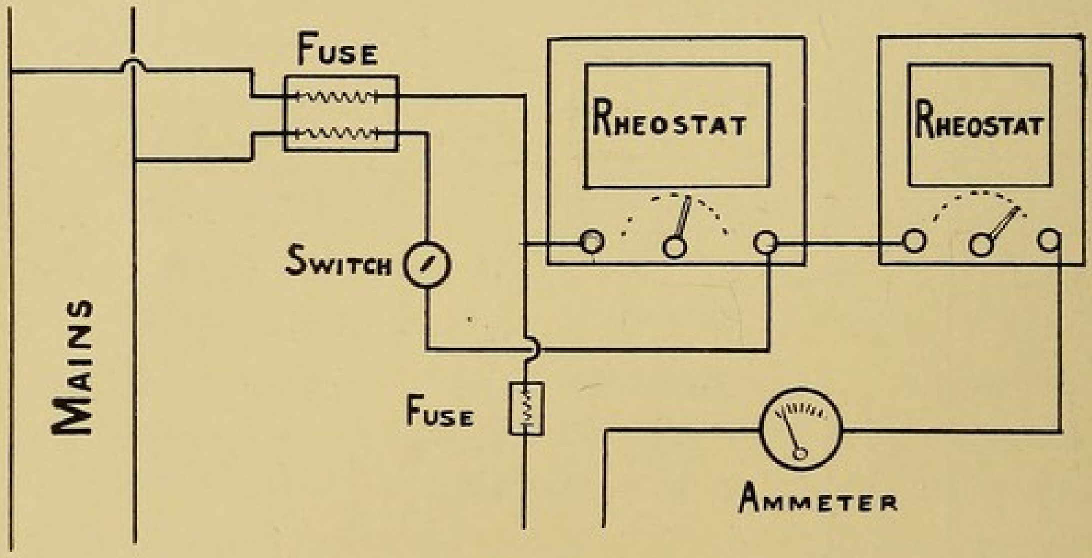


Fig. 11.

Quite recently, however, it has become practicable to connect a coil, wound for any voltage direct (*i.e.* without interposing a rheostat) to the supply circuit no matter what voltage may be alive in the latter. We shall, however, have to postpone the description of this method to a later chapter, as it involves a knowledge of the induction principle and of the construction of the induction coil (see page 49). Similarly, the use of the electrolytic break (see page 75) also permits of the use of ordinary induction coils on circuits of high voltage without previously reducing the pressure of the supply.

Of course, wherever it is known beforehand that a coil has to be connected to the electric light supply, the maker of the coil will take this fact into consideration when winding the primary, and less energy need then be wasted in rheostats.

Diagrams 10 and 11 show various ways of connecting the induction coil to the supply wires.

(b) *Alternating Current.*—This kind of electric supply differs from the continuous current inasmuch as it constantly changes (alternates) its direction, starting from zero to a positive maximum and then falling off through zero to a negative maximum; this rate of change—the "frequency" of the current may be anything between 50 and 120 per second, and it produces entirely new phenomena—necessitating considerable modifications in the apparatus used. The reduction of pressure from that of the mains to the voltage required by the coil can, however, be effected without the great loss of energy which we mentioned when dealing with the continuous current; we need no rheostats which absorb all the superfluous energy, but only a transformer which does not absorb but merely converts electrical energy of a high pressure into electrical energy of a lower pressure. (We shall briefly revert to these transformers in the chapter on induction coils; see page 46.) But even after we have reduced the pressure to the proper amount, the alternating current cannot be used to directly work a coil (except in the case of the electrolytic break, which see).

The reason for this, however, and the means to overcome this inability of the alternating current, can only be dealt with after we have set forth the principle of induction (Chapter III.), and we have to satisfy ourselves at this stage with the mention only of the necessary apparatus.

Either we convert the reduced alternating current into a continuous current by running a "motor generator" from the supply wires, or we use some form of "rectifier."

A motor generator consists of a combination of a suitable motor—taking alternating current and driving a dynamo which supplies continuous current; the objection to it being, again, the introduction of high speed machinery, besides the difficulty of starting small alternating current motors (Fig. 12).

A rectifier such as would be employed for our purpose consists of an arrangement whereby, of the alternate phases of the original current, one only is picked out and utilized, the other being either entirely or greatly suppressed. The disadvantage attendant upon such an apparatus is the delicacy of adjustment and the sparking at the contacts, besides the inefficiency of the method. Still it is sometimes the only possible solution, and we will therefore describe one form of it later on (page 84).

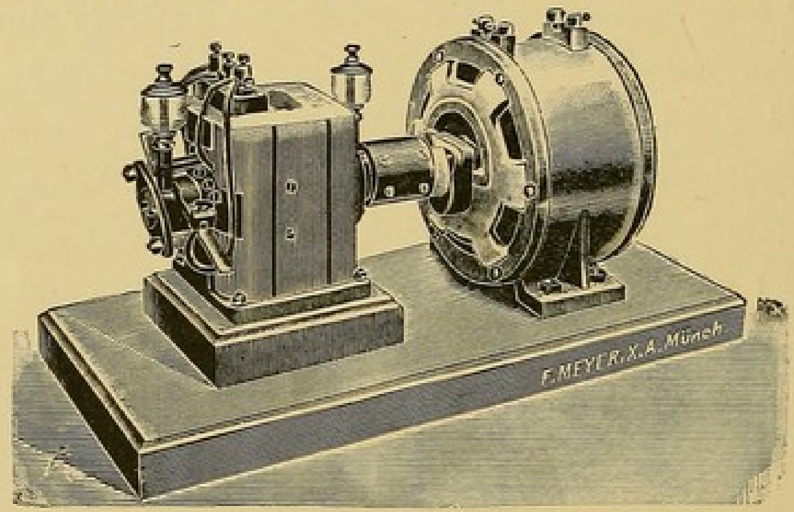


Fig. 12.

STATICAL OR INFLUENCE MACHINES.

In all the preceding cases we produced electrical energy, the E.M.F. of which was so low 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 pressure *direct*, and on this score offers certain considerable advantages for X-ray work, especially in the direction of simplicity of apparatus and the almost entire absence of the maintenance factor.

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 completely neutralize each other, so that as a rule a 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. 14, 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 $\frac{1}{4}$ 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 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.

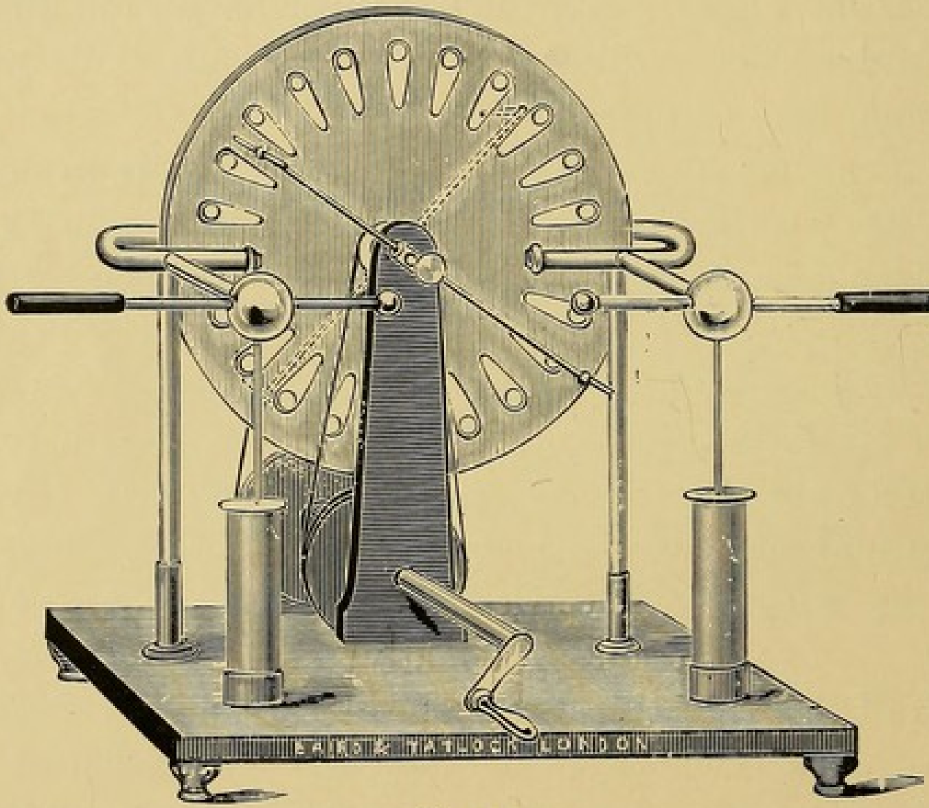


Fig. 13.

As the theory of the action of these machines is rather complicated, we will not attempt to record it here, particularly as the management of the machines does not presuppose such knowledge.

In the modification of the Wimshurst machine known as the "Pidgeon" type, the sectors are embedded in paraffin-wax, only the semi-globular contact knobs of the sectors being exposed to the air. At each of the four "earthing" brushes, a fixed inductor is arranged in such a way that when a sector is connected to earth, this sector stands between the opposite disc on one side and the fixed inductor on the other. Hence a double charge is induced.

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, 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 to 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 oxidized, 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 now and then 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 (Fig. 14).

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 neutralizers. The latter must be so bent that the brushes touch the discs during the whole period of rotation; keeping one neutralizer 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 neutralizers are at right angles to each other and equidistant from the collectors.

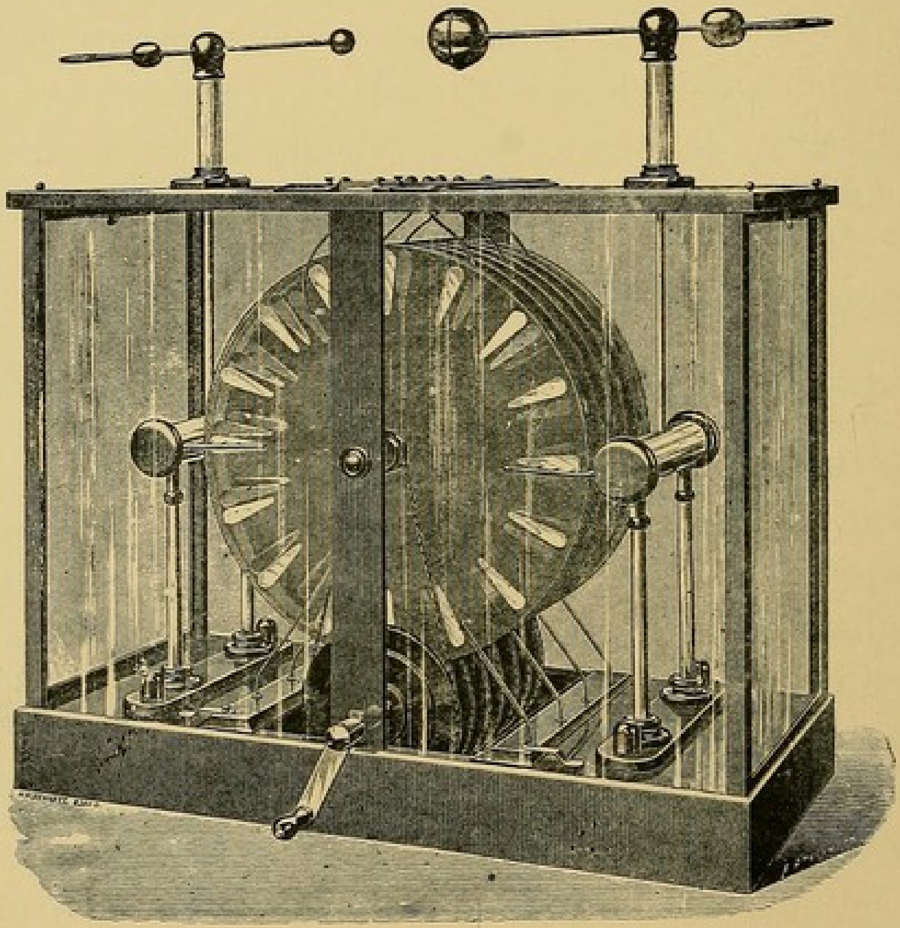


Fig. 14.

It is of course important to determine 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 the horizontal position.

The *advantages* of statical machines for X-ray work may be stated as follows:—

(1) *Simplicity.*—Dispensing entirely with batteries, accumulators or current from the mains, the statical

machine may be said to be essentially mobile and to make the operator independent of local circumstances and difficulties. The further absence of induction coils, measuring and controlling instruments and accessories both cheapens the installation in first cost and also minimizes the risk of breakdowns inseparable from more complicated arrangements.

(2) *Maintenance.*—Very little—if any—attention need be given to the machine when not in use, and it is always ready—without previous preparation—to generate electrical energy.

(3) *For Radioscopy.*—The potential (electric pressure) generated by a statical machine is almost perfectly continuous, producing a most steady discharge through the X-ray tube and consequently a very quiet illumination of the fluorescent screen which is most conducive to certainty in diagnosis.

(4) *Range of Radiation.*—By the insertion of air-gaps between either one or both tube terminals and the positive and negative leads, and by altering the lengths of these gaps, the radiation of a given tube may be largely modified, *i.e.* a tube may be made to give "hard" or "soft" images on the screen (see Chapter IV.). Further, tubes which have become so attenuated in vacuum as to be unfit for use on a coil may be "broken down" with a statical machine, or, in other words, may be regenerated for reasons which are not very clear at present.

Against all this we have to set off the following *disadvantages* of influence machines :—

(1) *Construction.*—The employment of such fragile material as glass—especially in the shape of thin discs—renders the machine unfit for rough handling or for transport when fitted up. The substitution of ebonite for the glass discs is an improvement from the mechanical point of view, but the efficiency of the machine soon falls owing to a peculiar surface oxidation taking place in the ebonite.

(2) *Reversal.*—Although good modern machines excite easily and under all conditions of climate, yet their polarity is apt to change in the most erratic manner as often as the rotation of the discs is discontinued. This is both annoying and a factor of failure, especially when using the machine for radiographic work, since it makes the proper timing of exposures very difficult, to say the least.

(3) *Prolonged Exposures.*—Probably owing to the very small amperage of a statical discharge, it has been found that the exposures necessary to obtain good skiagrams are considerably longer than when using an induction coil; to counteract this deficiency machines with many pairs of plates must be used, thus increasing again first cost, weight, bulk, and liability to disorders. To be more specific, we have found that a machine having four pairs of plates 28 inches in diameter is only equal to a good 6-inch induction coil in this respect.

(4) *Leakage.*—The tendency of statical electricity to leak through imperfections in the insulation and to form "brush discharges" introduces many new and partly undesirable features. Apart from the comparatively harmless (if no Leyden jars are in circuit) though startling physiological effects of the discharges upon the human body, the brush may mark the photographic plate and give rise to subsequent "peculiar diagnoses," or it may play upon the X-ray tube and cause same to become perforated and useless. Again, the brushing seriously interferes with the proper function of the tube and necessitates keeping the leads between the tube and machine as short as possible.

(5) *Motive Power.*—Of course, to obtain uniformity of generation, the machine should be rotated at a uniform speed, and this—in the case of exposures exceeding a few minutes—is rather fatiguing. An electrical or thermal motor is therefore often geared to the driving axle of the machine, although by so doing one of the chief

advantages of statical machines, viz., their mobility and independence from outside sources of energy—is again sacrificed.

Summing up, we may say that, as yet, the best statical machine is not able to dislodge a good induction coil, and that for their adoption to become more general, the statical machines will have to be improved in several ways. Especially should they be made more robust in design, more efficient in current (without increase of bulk), and the tiresome reversal of polarity must be overcome.

CHAPTER III.

INDUCTION COILS AND INTERRUPTERS.

PRINCIPLES OF INDUCTION.

THE induction coil, sometimes called the Ruhmkorff coil, after its first constructor, is the converter of electrical energy which is most frequently used for the generation of the high electrical pressures which X-ray work requires.

The principle underlying its function is that of electromagnetic induction, discovered by Michael Faraday in 1832. It 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. A similar induction of a secondary current takes place when we *interrupt* an existing primary current. 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 several things:—

(1) 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.

(2) 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. Such an iron core becomes highly magnetized whilst the primary current is flowing, and the importance of this magnetism becomes apparent when we express the principle of electro-magnetic induction in the following manner:—

If we have a metallic circuit suitably disposed in a magnetic field, then an E.M.F. is induced in such a circuit with every change in the magnitude or direction of the magnetic field.

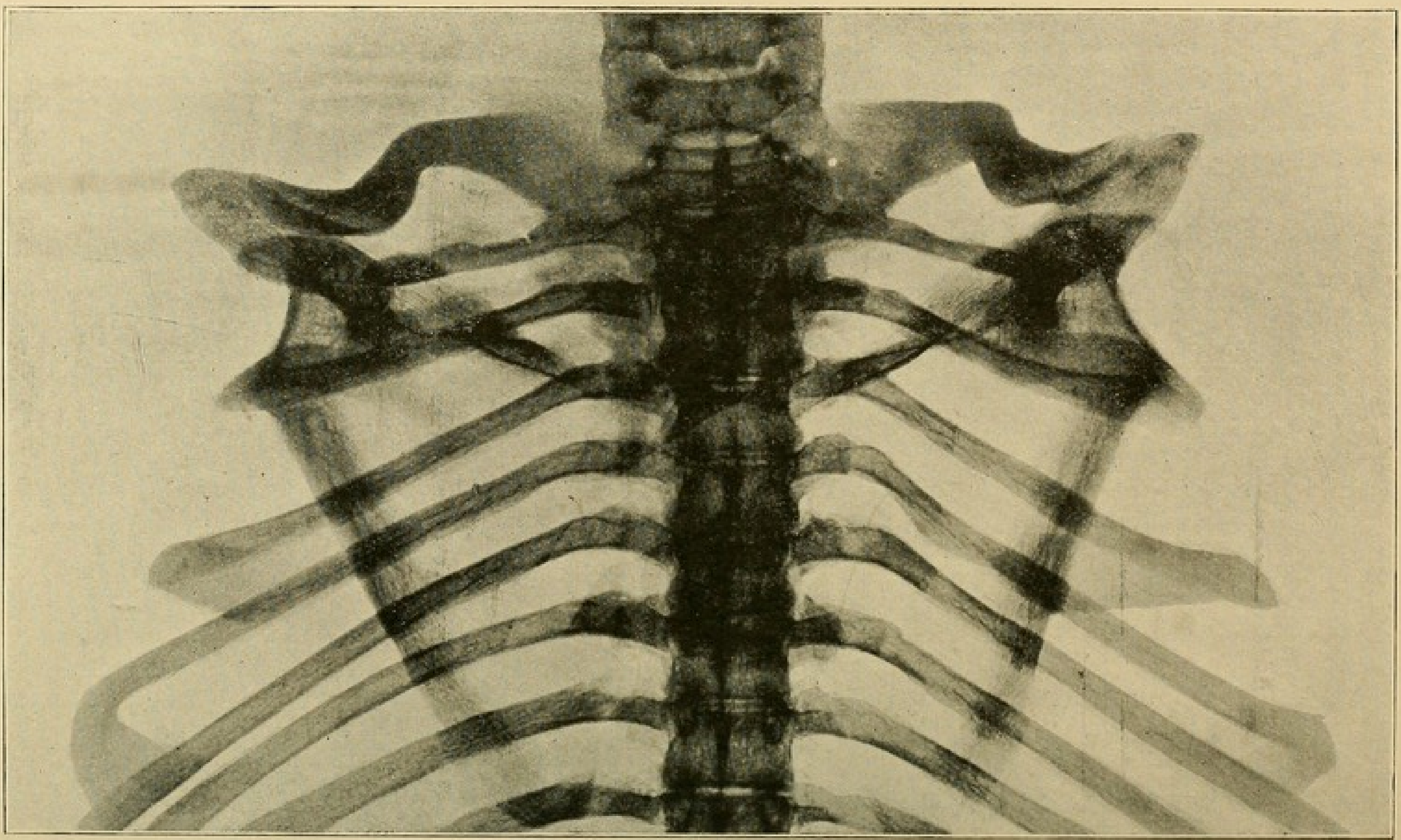
(3) The induced E.M.F. is proportional to the time rate of this change in the magnetic field, or, in other words, the more rapidly and completely the change from one magnetic condition to the other takes place, the higher will be the E.M.F. induced thereby.

The efficiency of an induction coil depends thus upon the three essential parts of it:—It must be wound in its secondary circuit with a great number of turns (of fine wire, in order to not unduly increase the bulk); it must possess a core of soft iron capable of being rapidly magnetized and demagnetized by the primary current, which—as is usual for electro-magnets—circulates round the core along the primary turns of wire; and there must be a device by which the primary current may be rapidly and very completely broken and re-established—a so-called break or interrupter.

It will be seen that this arrangement, in which the make and break 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.

The secondary currents from 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 react 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 therefore 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 uni-directional 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 minimize the opening sparks which take place between the contact points of the interrupter; 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 interrupter. 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



RADIOGRAM OF THORAX. Skeleton only.

(By the Voltohm Company, of Munich.)

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 necessity that the iron core quickly follows the magnetic changes to which the primary current subjects it. Practice has shown that only very soft iron can do this; besides, induction also takes place in the mass of the core itself, resulting in the flow of "Foucault" and "eddy" currents which would heat the core and thus waste energy.

To overcome these currents, or rather to prevent them as far as possible, the iron core of an induction coil or transformer is not made in one solid piece, but is subdivided in a direction vertical to the flow of the "eddy" currents.

With the foregoing theoretical considerations in mind, it will be easy to intelligently appreciate the constructive details of an induction coil, as described in the following pages.

(*a*) INDUCTION COILS.

Every induction coil is made up of the following essential parts :—The core, the primary, the secondary, the condenser and the interrupter. Leaving the description of the latter, on account of the variety of types, to a separate section, we find that the other constituent parts are more or less identical in all types of coils.

The core is made up from a cylindrical bundle of thin, well annealed iron wires, bound together, and, for good insulation against eddy currents, thoroughly impregnated with paraffin wax, the whole wrapped round with tape.

Upon this core is wound the *primary*; it consists of two or more layers of stout silk-covered copper wire, the whole also being insulated by immersion in paraffin wax and enclosed for further insulation from the secondary in a stout tube of ebonite, closed at both ends.

The secondary consists generally of a large number (40,000 to 150,000) of turns of very fine silk-covered copper wire, wound upon the primary tube.

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, to 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, should always be adopted. It consists of subdividing the secondary winding in the axial direction of the coil into sections of such lengths that 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 until each section is only a fraction of an inch in width (down to $\frac{1}{8}$ in.), and represents a flat disc. Each section is wound separately with

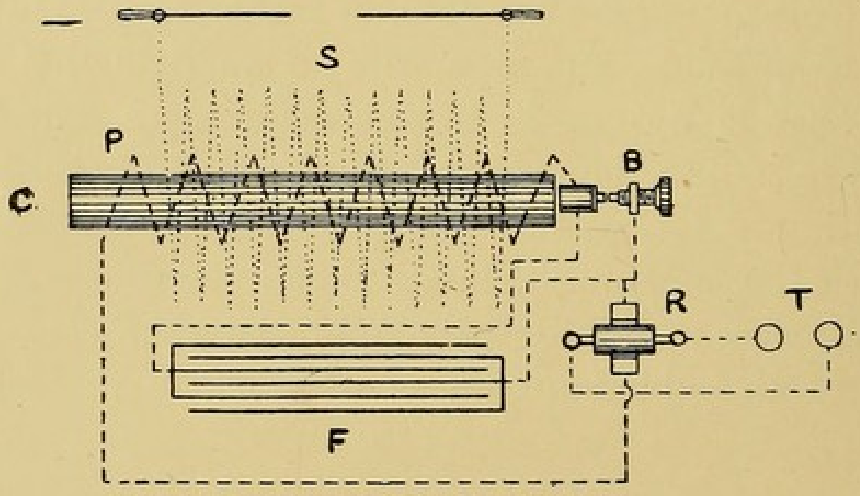


Fig. 15.

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 or several discs of paraffined paper are placed between each two sections for further insulation; the wire ends are soldered together, and the whole coil is waxed in, placed between ebonite flanges, and finished with an ebonite cover. The ends of the secondary wire are generally brought to two brass terminals mounted upon the ebonite cover or flanges. This finishes the coil proper, which must be mounted in some suitable way upon the box base of the whole apparatus.

For smaller coils the cheeks or flanges may be firmly screwed to the base. For larger instruments it should be preferable to rest the coil upon suitable supports only, as this facilitates transport and obviates the risk of breakage and mechanical damage which with such brittle material as ebonite and with comparatively large weights is very frequent.

The condenser generally contained in the base box is usually built up from sheets of paraffined paper or mica, sandwiched between sheets of tinfoil which are smaller all round than the insulation. Each tinfoil sheet is furnished at one end with a narrow strip so placed as to project alternately at each end, and the two lots of strips are each clamped together and fitted with connecting terminals so that they may be joined either to separate terminals on the outside of the base or direct to the contacts of the interrupter.

The base of the instrument also bears a few further appliances, such as connecting terminals for the wires coming from the source of current, terminals (in larger coils), for the attachment of the wires coming from the interrupter and some form of "commutator" or "current reverser" which also serves as a switch.

Another useful accessory, which may be conveniently mounted upon the instrument itself, is the "discharger." A pair of stout ebonite pillars (suitably set apart) carry at their upper ends metal fittings through which two dischargers (brass rods) may slide, so that the ends of the dischargers may be brought to any distance within the admissible spark length of the coil. One of the dischargers terminates in a fine point, the other in a plane disc, and connection is made between the spark pillars and the previously mentioned end terminals of the secondary by means of fine silk-covered wires.

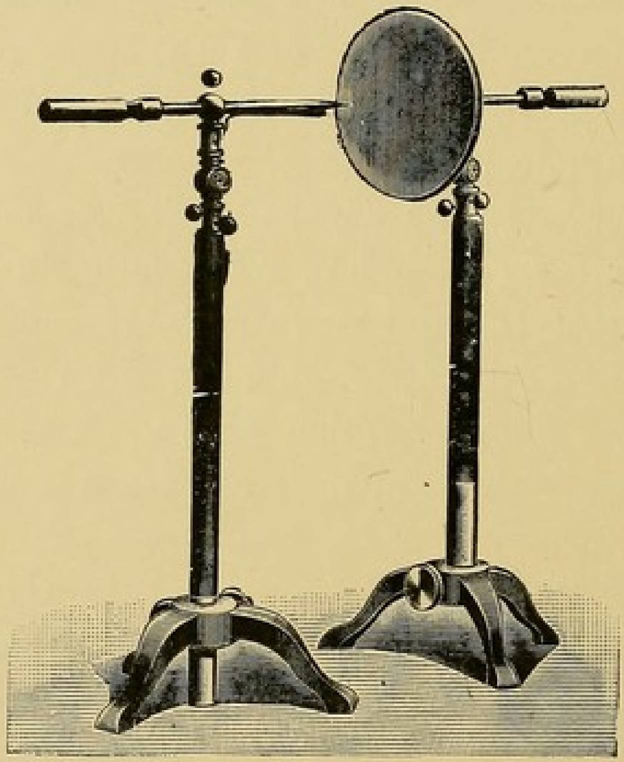


Fig. 16.

The reason for the point and disc is to find the polarity of the secondary. At a certain position of the reverser the sparks given by the coil run (more or less irregularly) from the point to some part of the surface of the disc (Fig. 17). In this case the point is positive and the disc negative, and the coil works more smoothly. At another position of the reverser the sparks fly between point and edge of disc, when the latter is positive and the point negative.

Lastly, each coil ought to be provided with a fuse, the lead wire or foil of which may be easily renewed, and which is so dimensioned as to prevent any accidental excess of current which might damage the coil. Especially when using vibrating interrupters, the contact studs of which are liable to "stick," or when working coils from the mains through an electrolytic interrupter, such fuses may be instrumental in saving costly repairs to the coil.

Some makers also provide means to cut out either the whole or part of the condenser; the former arrangement is useful in many ways: the partial exclusion, however, of the condenser is of no great use to the practitioner, except in the case mentioned on page 57.

Before describing some other forms of transformers, and the various interrupters, it may not be amiss to briefly consider the question how to judge the efficiency and output of a coil.

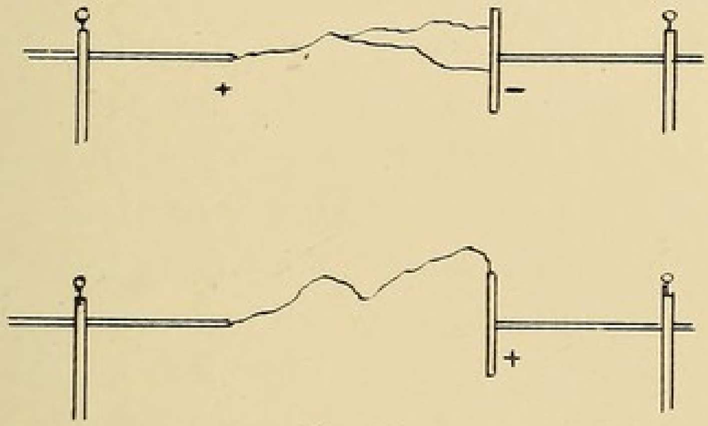


Fig. 17.

In the vast majority of cases the only factor mentioned when specifying a coil is its maximum spark: this is, however, quite insufficient and erroneous. Just as we always consider in every machine (thermal or electrical or otherwise) the energy which it is capable of producing or of transforming, so we ought to study the amount of energy (electrical) which may be transformed with a given coil.

The electrical energy, as we have seen, is the product of current and E.M.F., the latter bearing a certain proportion to the spark length of the secondary. The increase in current furnished by the secondary of a coil manifests itself in the brightness and number of individual sparks in the stream playing between the ends of the secondary. Of two coils giving equal spark lengths, the one which supplies the brighter and thicker sparks is the better one. To make matters quite clear we will assume that a certain coil giving a ten-inch spark furnishes a secondary current of ·002 ampères, and another coil giving a twelve-inch spark a secondary current of ·001 ampères. The former secondary gives us (roughly speaking) an output of *·02*, the other an output of *·012*. Thus, in this case, the larger coil is inferior for Röntgen work, since the efficiency of a tube depends upon the energy available for it.

The very feeble strength of the currents in the secondary which we have assumed in the above numerical example will be explained when we examine the transformation of the primary energy sent into the coil.

Presuming for the moment that no loss occurs in the transformation, and starting with a primary current of 5 ampères at a pressure of 12 volts, we send into the primary an energy of $12 \times 5 = 60$ watts. This energy at the outside can be expected from the secondary, and assuming every inch of spark length between the secondary terminals to require 50,000 volts pressure, then the secondary E.M.F. in a ten-inch coil would be about 500,000 volts. Thus the current $= \dfrac{60 \text{ watts}}{500{,}000 \text{ volts}} = \cdot 00012$ ampères.

In so far as—for theoretical and constructive reasons —the transformation by a coil is below 60 per cent. in efficiency, the above secondary currents will be found smaller still, unless we wind the primary with extra heavy wire and use very strong primary currents (for spectral analysis); or use special forms of magnetic circuits (see page 57).

Further, the maximum spark length of a coil and the volume of spark must be attainable with a fairly high number of interruptions (1,000 per minute) if the coil is to be considered efficient for our purpose. The size of a coil, its bulk and weight are by no means to be taken as a criterion of its efficiency. It is often pointed out that for a given spark length the smaller coil is the better one. Nothing could be more misleading, for with the insulating materials at our disposal, a certain safety against break-down of insulation requires a certain bulk of insulating material, which can only be reduced at the cost of reliability. Again, by increasing the self-induction of the coil and relying upon slow interruptions, the coil may be made smaller, but still possessing the distinct drawbacks of being debarred from using certain forms of high frequency interrupters and of using more energy.

Unless a coil is to be selected for portability only, there is no real advantage in reduction of dimensions.

Quite recently, owing to the introduction of the electrolytic break, some makers have arranged the primary portion of the coil interchangeable, so that different primaries may be inserted into the coil to make it suitable for various interrupters, or better still, the primary is wound in several portions which may be used singly or combined and so give varying self-inductions to suit both interrupter and tubes.[1]

Figs. 18 and 19 show a very convenient constructive realization of this principle as introduced by Kohl of Chemnitz.

The ends of the various layers of the primary are fitted with sockets into which a series of plugs may be inserted, thus effecting various combinations of the layers.

Before proceeding to the description of that very

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[1] The transformers mentioned on page 37 as necessary to reduce the pressure in alternating circuits are essentially induction coils without interrupters, the alternation of the current itself being sufficient to cause induction and to convert the high pressure of the primary into the lower pressure of the secondary.

important part of a coil, the contact breaker, we will—for the sake of completeness only—refer to some other forms of induction coils or transformers, which, although very little used at present in actual radiographic practice, claim our attention from their intrinsic interest.

A modification of the ordinary type of induction coil which purports to reduce the weight and material used for a given capacity is due to Messrs. Rochefort and Wydts, of Paris. Starting from the assumption that the low efficiency of the ordinary type of coil is to be ascribed to the great resistance of the secondary windings and to leakage taking place in the coil itself, they have invented a new insulation consisting of some special hydrocarbon in the shape of a paste, which is claimed to be free from the disqualifying peculiarity of carbonizing after use.

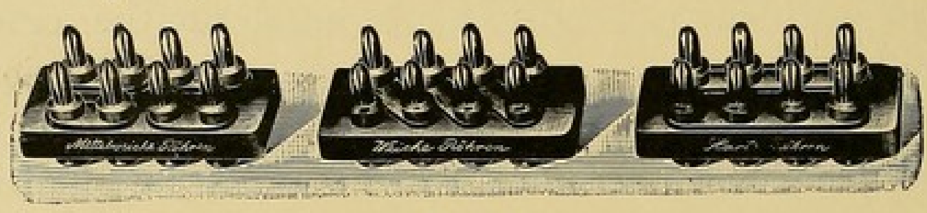


Fig. 18.

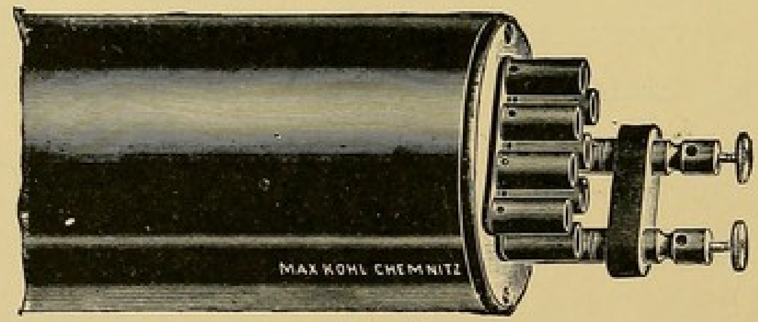


Fig. 19.

Fig. 20 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 1½ 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. Owing to the small resistance of the secondary, this coil gives very fat sparks, which would materially aid in obtaining short exposures, but for some reason or other the instrument has come little into use, especially since some of the new interrupters have enabled us to attain high efficiency with ordinary coils.

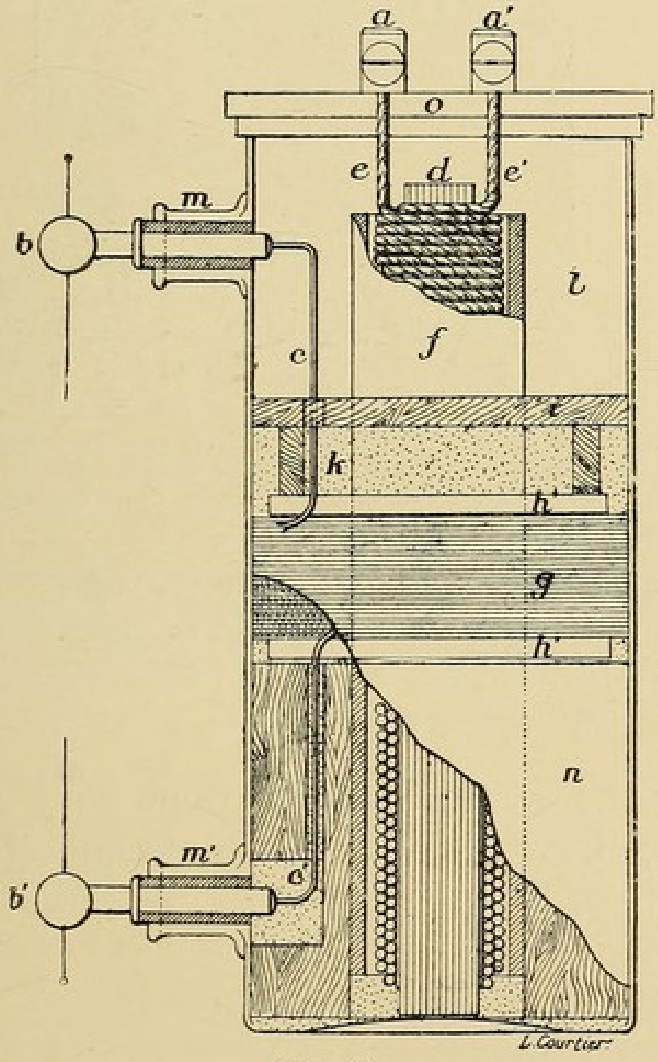


Fig. 20.

Closed Magnetic Circuit Coil.—This latest type of transformer aims at higher efficiency by producing from a given primary current a more powerful magnetic field, a greater inductive effect being obtainable thereby without the necessity of employing an immense number of fine wire turns in the secondary. This is effected by carrying the magnetic lines of force for practically the whole of their path through soft iron instead of providing—as at present

—only a small length of iron and completing the magnetic circuit through air (a bad magnetic conductor). Owing to the reduction in the resistance of the secondary circuit the quantity therein generated is very greatly in excess of anything we are obtaining from coils of ordinary construction, but no very high frequencies may be employed.

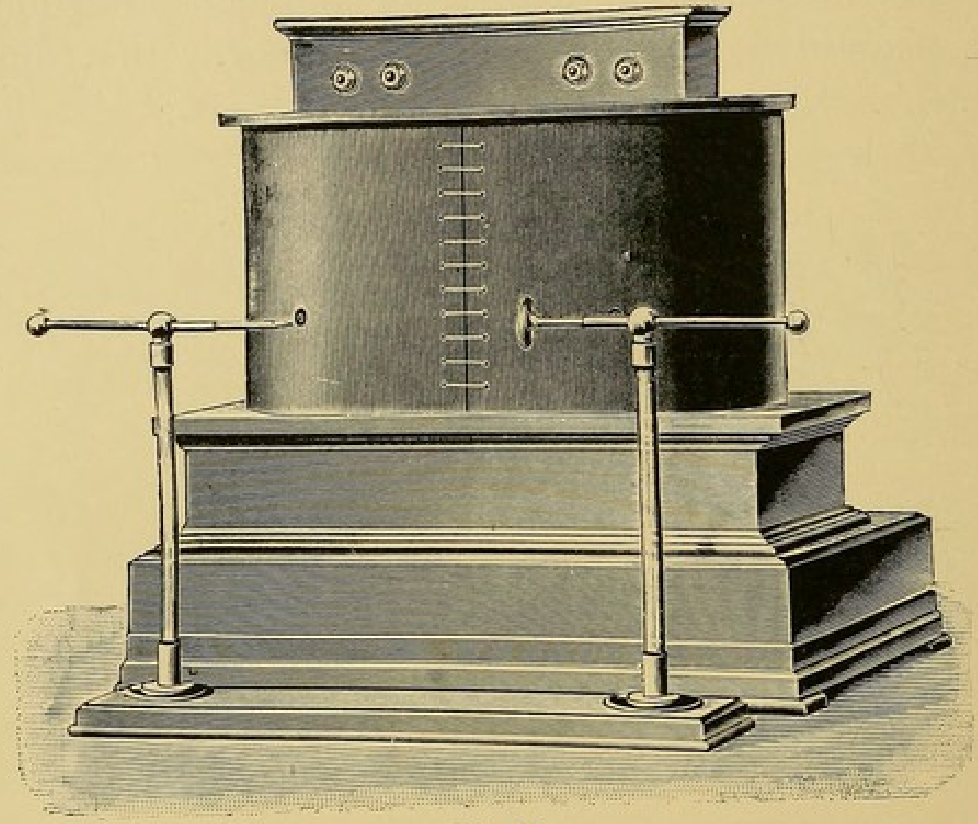


Fig. 21.

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 quâ 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.

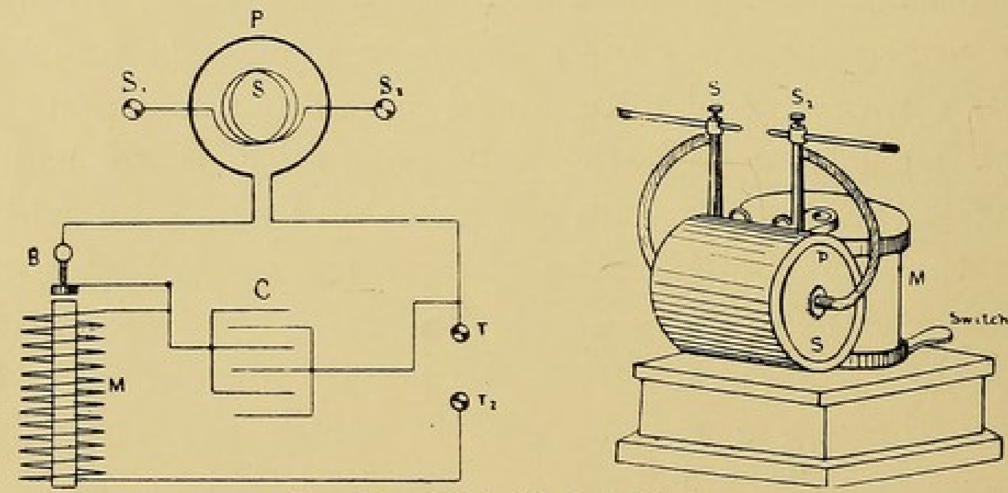
The essential characteristic of Tesla alternating currents is their exceedingly high frequency, attaining to about ten millions per second as compared with the 200 or 300 obtainable in the case of Ruhmkorff coils with mechanical contact breakers, and the induced secondary E.M.F. of a Tesla coil runs 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 non-conductors like paraffin wax and ebonite would be quite inadequate to effect insulation, 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 be passed through a transformer, T, which raises it to a pressure of about 6,000 volts. The discharge of the condenser manifests itself as an exceedingly bright and snappy spark in the adjustable spark gap, G.

The intensity and frequency of the resulting sparks are extraordinary, and with suitable tubes very fine radiographic and radioscopic results are obtainable.

On the other hand, owing to the inclusion of a Leyden jar, the primary circuit must be made inaccessible, since shocks from it would be most dangerous to the human body. Sparks taken from the secondary of a Tesla coil are harmless, and scarcely excite the sensory nerves at all owing to their extreme frequency.

A further very serious drawback to the use of a Tesla coil for radiographic purposes is the very intense crackling sound caused by the primary spark-gap, which makes the arrangement very unsuitable when weak or nervous patients have to be examined.

Tesla Oscillator.—This arrangement was brought out by Tesla about two years ago, and though having been demonstrated before various scientific bodies in Europe, is even now a laboratory instrument only, its commercial form not existing for some reason. Still, the following particulars, given by Professor S. P. Thompson to the Physical Society of London, may be of interest, since, owing to its compactness and economy, the oscillator may come into use for Röntgen work. It consists essentially of three parts : a vertical electro-magnet (M), Fig. 22, 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 micro-farads capacity, which is charged by the self-induction of the electro-magnet 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.



Figs. 22 and 23—Tesla Oscillator.

The action is probably as follows :—The current from the terminal, T_2, magnetizes 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 or 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; but, since it furnishes an alternating current, special tubes are required when using it for Röntgen work.

INTERRUPTERS.

From a consideration of what was said on page 48 about the working of an induction coil, we are led to the following conditions which a good interrupter should fulfil:—

Uniformity of interruptions, high frequency, accuracy and completeness of interruption, adaptability for large currents and high pressures; also—though this does not affect the efficiency of the coil—absence of noise.

It is perhaps well to classify the very great number of good interrupters, as it is impossible to describe every little variation in detail.

There are the interrupters in which contact is made between two solids, usually platinum; another class in which one contact is solid, the other a conducting liquid, generally mercury; further, those constructions in which certain physical phenomena are made use of to attain most rapid and exact breaks, *e.g.* the electrolytic interrupters. Some of these constructions are applicable to both continuous and alternating currents; the majority, however, only to continuous current.

Certain designs are automatic, others require a separate means of driving them.

(1) *Platinum Interrupters.*—The 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 armature and contact fly back to their position of rest, re-establishing the current and so continuing the play. The fault of this primitive form is that it does not allow of much adjustment in either frequency or suddenness of interruptions.

Passing over the "Deprez" break, which yields from 15 to 40 interruptions per second, we come to the English type illustrated (diagrammatically) by Fig. 24.

H is the iron armature or hammer, fixed to the flat spring, S; the contact pieces are of stout platinum wire, and are co-axial with the core. Besides the screw adjustment, B, there is an additional tightening screw, 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.

In using this break, the contact screw is turned towards the armature until a spark passes between the points of the discharger, placed at about one-half of the maximum sparking distance of the coil. After switching off the current and setting the dischargers at the desired spark-length, we again turn on the commutator in the right direction (previously ascertained) and turn the bottom screw backwards until the resulting tension of the contact spring and the subsequent higher magnetization 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.

The proper adjustment having been effected, the position of the contact screw must be fixed by tightening the lock-nut. When the interrupter 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.

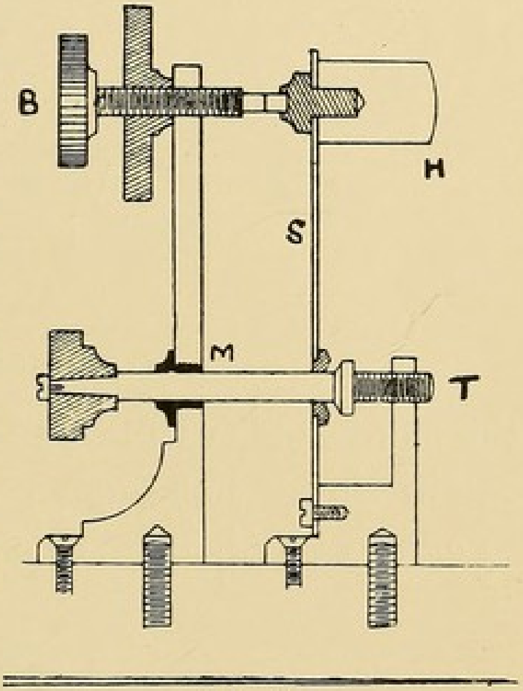


Fig. 24.

A modification of the above break illustrated in diagram 25 and Fig. 26 allows 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 very marked, 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. It is provided with yet another adjustment screw, which, when screwed right in contact with the vulcanized fibre plate, simply converts the interrupter into the 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 the tube and the kind of work in hand.

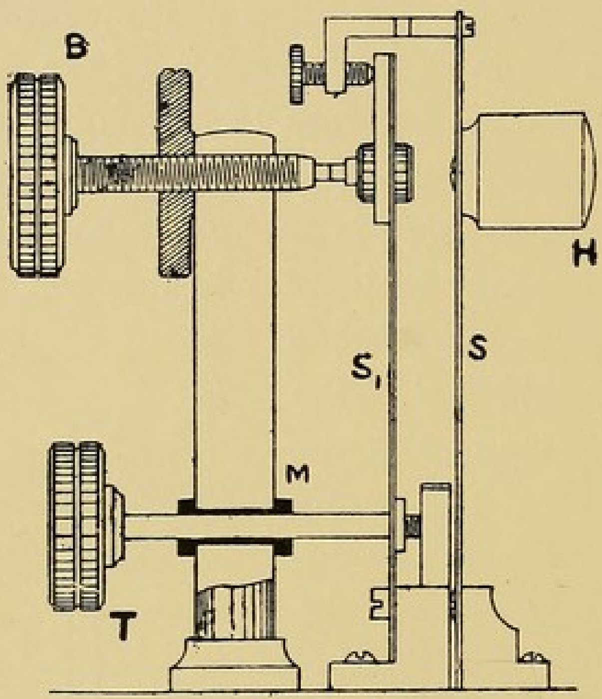


Fig. 25.

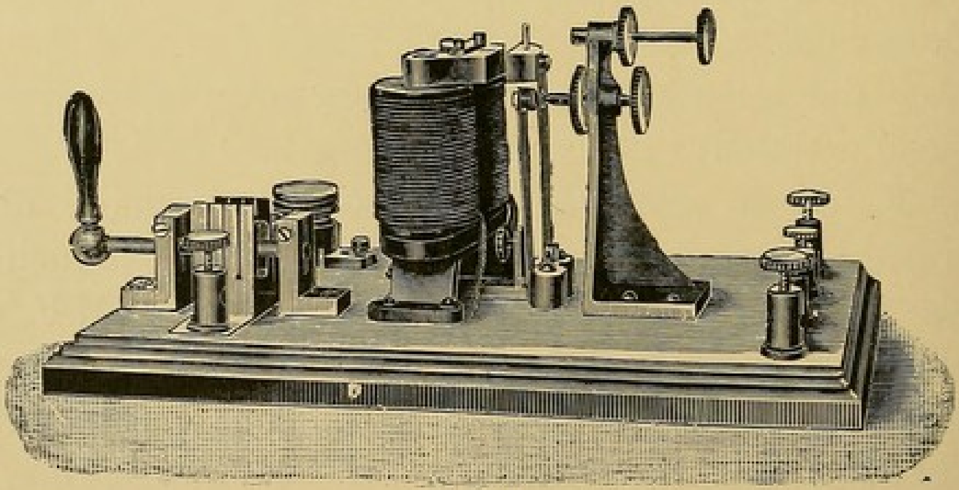
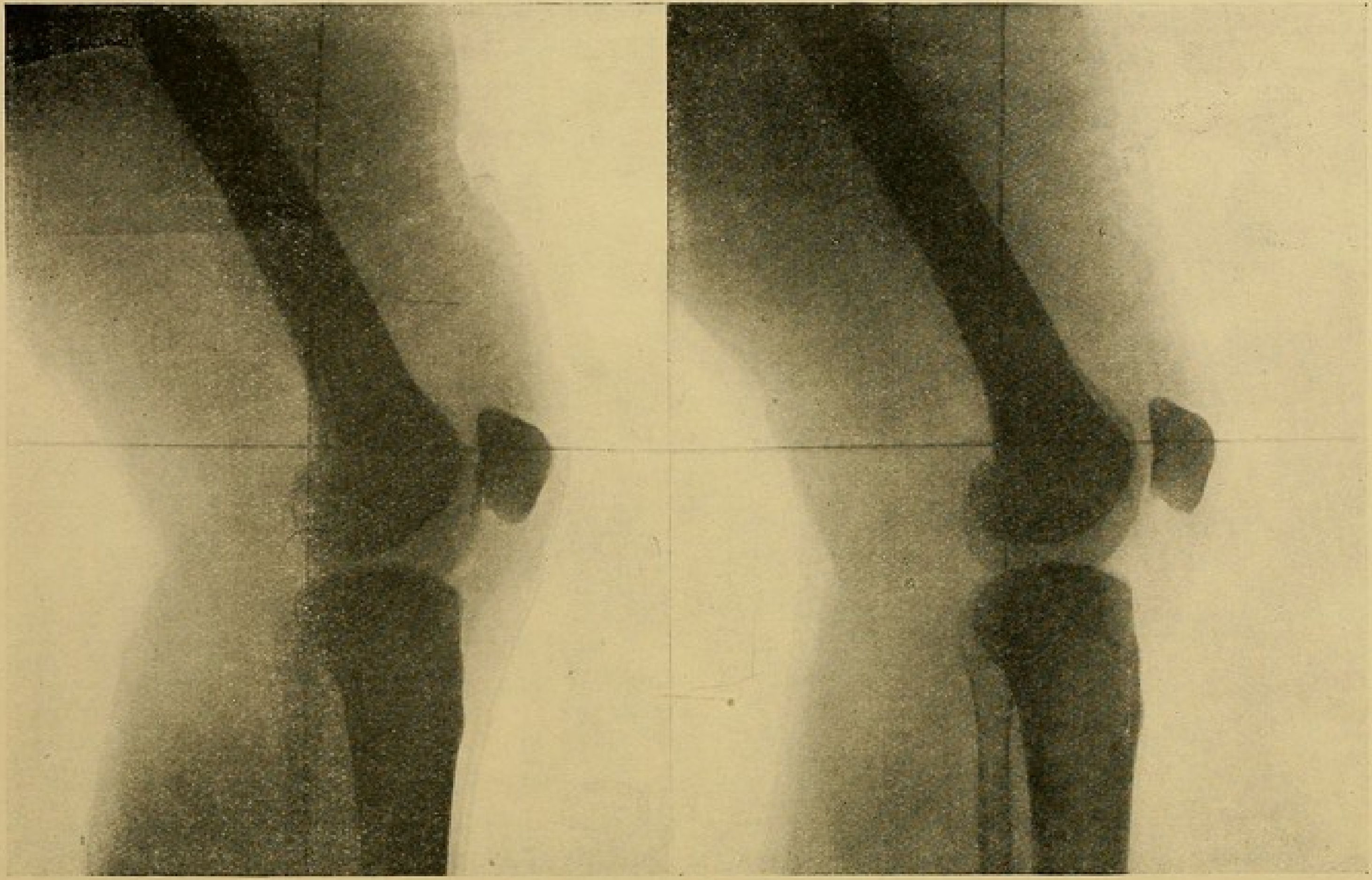


Fig 26.

One of the disadvantages of such platinum breaks is the irregular wear of the contacts, particularly in the case of large coils with heavy currents. Gaiffe tried to secure

PLATE V.]



STEREOSCOPIC RADIOGRAM OF AN ADULT KNEE-JOINT.

(By A. W. Isenthal.)

more uniformity in wear by rotating one of the platinum studs slowly by means of a small electric motor, but the subsequent gain is too small to warrant the complication. Before starting the coil we have to see that the contact surfaces are smooth and in touch all over, if necessary ensuring this by drawing a sharp flat file across the studs. In some constructions the contact is so arranged that the break takes place under water or petroleum; this reduces the deteriorating sparking.

Various other designs of interrupters belonging to this first class embody revolving discs or drums with suitably arranged contact segments against which contact brushes are pressing; the sparking must be minimised as far as possible either by immersing the contact in paraffin oil as above or by employing an air blast directed against the contacts.

(2) *Mercury Interrupters.*—In the majority of instruments belonging to this class the stationary contact is represented by mercury or an amalgam contained in a suitable vessel, and the movable contact by a pointed rod to which a reciprocating motion is imparted by mechanical means or automatically by the magnetism of the coil core, or finally by an electric motor run from the source of current. In a recent type the vibrating rod is replaced by two rotating blades of copper. In order to prevent oxidation of the mercury, the latter is covered with an insulating layer of alcohol, petroleum, or water over an inch in depth, which, being a better insulator than air, also makes the interruptions more complete.

Care must be given to let the dipper enter the mercury quite vertically; otherwise the mercury is stirred up and the accuracy of the interruptions impaired.

In every form of mercury break two adjustments should be 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).

The earliest forms of mercury interrupters were of the rocking type, actuated by the core of the coil itself, and although marking a distinct advance over the platinum breaks, share with these the comparative slowness, which unfits them for use with the fluorescent screen. To increase this low frequency various manufacturers have arranged two mercury cups with two dippers which alternately make contact on one side or the other, so that for each swing of the lever we get two contacts. Such interrupters, as well as most of the following types, being comparatively bulky, are mounted separately upon a board which frequently also carries the necessary connecting terminals, the current reverser, a switch and fuse. This arrangement, besides simplifying the coil and keeping down its size, commends itself for the reason that it is wise to avoid close proximity to the coil in adjusting the contacts, and this tendency is (in large coils, at any rate) now carried to such an extent that the coil consists very often of the condenser box and the coil only, both the former and the primary fitted with terminals. Even the dischargers have been carried out as separate parts, connected by fine wires only with the secondary terminals of the coil.

Figs. 27 and 28 illustrate various constructions of mercury motor breaks, embodying various adjustments and movements.

Every interrupter of this type which is actuated independently, *i.e.* by separate motor or by mechanical means, requires to be started before the current is switched on to the coil. Otherwise it may happen that the dipper is immersed in the mercury, and that in consequence an excessively heavy current would rush into the coil on closing the circuit, an occurrence which may, as we have seen, seriously injure the coil.

Although this condition can be easily fulfilled, and, as a matter of fact, is done quite mechanically after a short time, many workers consider it a certain drawback. In the type of mercury interrupters which we shall now describe this drawback is absent. This, together with the wide range of working pressure which they permit, make them perhaps the most desirable breaks—at any rate where small prime cost is not of primary importance.

Mercury Jet Interrupters.—The fundamental idea underlying the construction of jet breaks is the substitution of the dipper by a jet of mercury, whilst the mercury surface is replaced by solid metallic contacts. The jet is maintained either by centrifugal force or by mechanical means, or by gravitation, but in every instance the existence of the jet is dependent on the rotation or movement of the break, so that there exists no jet, and consequently no contact, until the break is working, whether the circuit through the primary of the coil be closed or open.

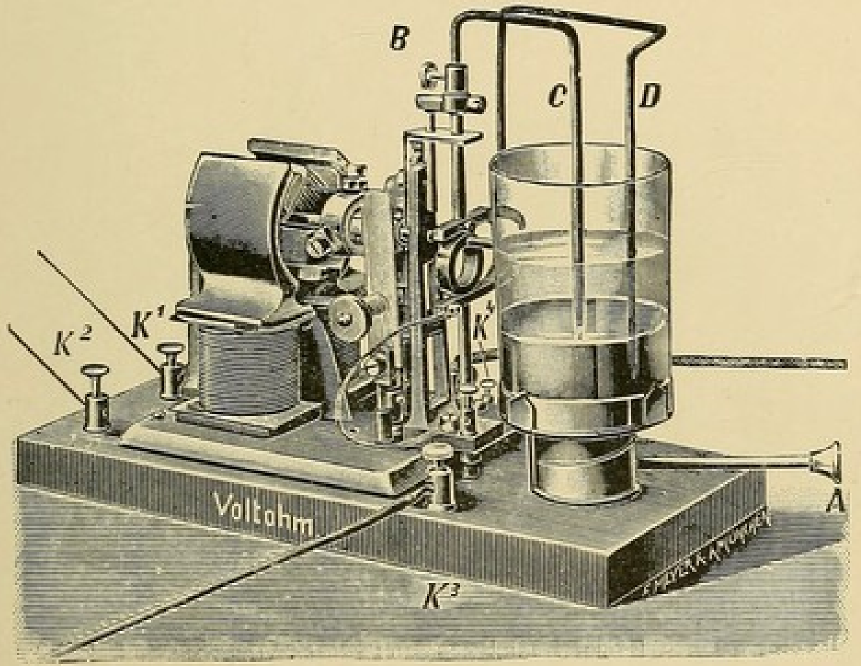


Fig. 27.

A reference to the individual types will make this quite clear.

The earliest form of these jet interrupters consists of a suction tube bent at right angles, rapidly rotating round its vertical axis and with the lower end permanently dipping in a quantity of mercury. The mercury rises by centrifugal force, and is forced out of the horizontal branch of the tube in the shape of a fine stream, impinging against the inner surface of a contact cylinder. If we connect the mercury with one end of the coil primary and the contact cylinder with the other terminal, and if, further, the contact cylinder is fitted with sectors of insulating material, then, on rotating the bent tube, we obtain a series of interruptions, the frequency of which is proportional to the number of contacts and the revolutions of the spindle. Replacing the contact pieces by others of various shapes and widths we have it in our power to vary both the number and relative duration of the contact periods. After establishing contact, the mercury falls to the bottom of the containing vessel in order to be again sucked up, and so on.

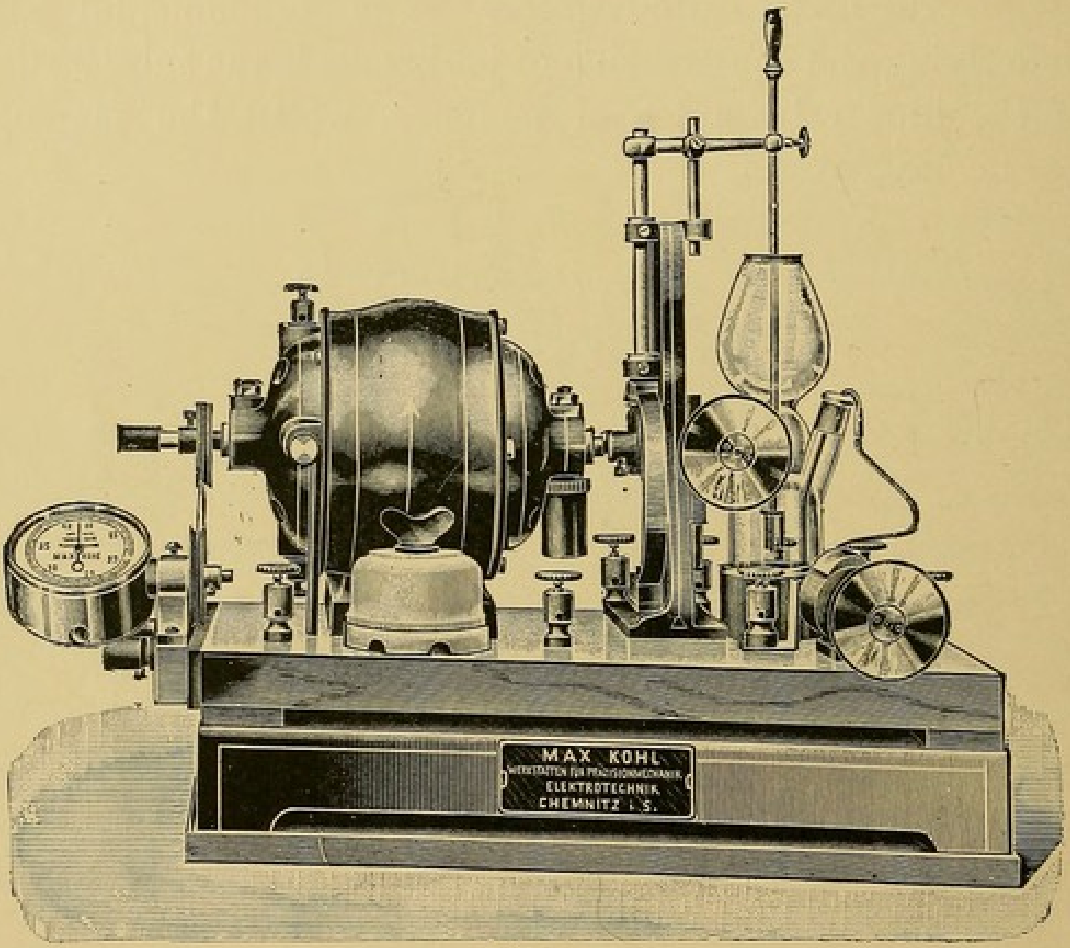


Fig. 28.

A vastly more convenient modification of a jet break is represented by a construction of Dr. Max Levy (Figs. 29 and 30). Its novel features are a stationary mercury jet and the method adopted for adjusting the duration of contact. The stationary jet is obtained by a simple displacement motion, such as a couple of geared pinions rotating in a closely-fitting case. By this means a jet is produced at very low speeds to begin with, and as it is stationary the splashing of the mercury is greatly reduced. Apart from the fact that it is better balanced, much higher speed and consequently greater frequencies may be attained. The nozzle from which the mercury jet issues can be raised or lowered from the outside, which property, in conjunction with the triangular shape of the contact pieces, enables us to obtain very great variations in the duration of the contact. The metallic contact pieces are fixed to the circumference of a revolving drum and are easily interchangeable. Their bases are on top and their apices point downwards.

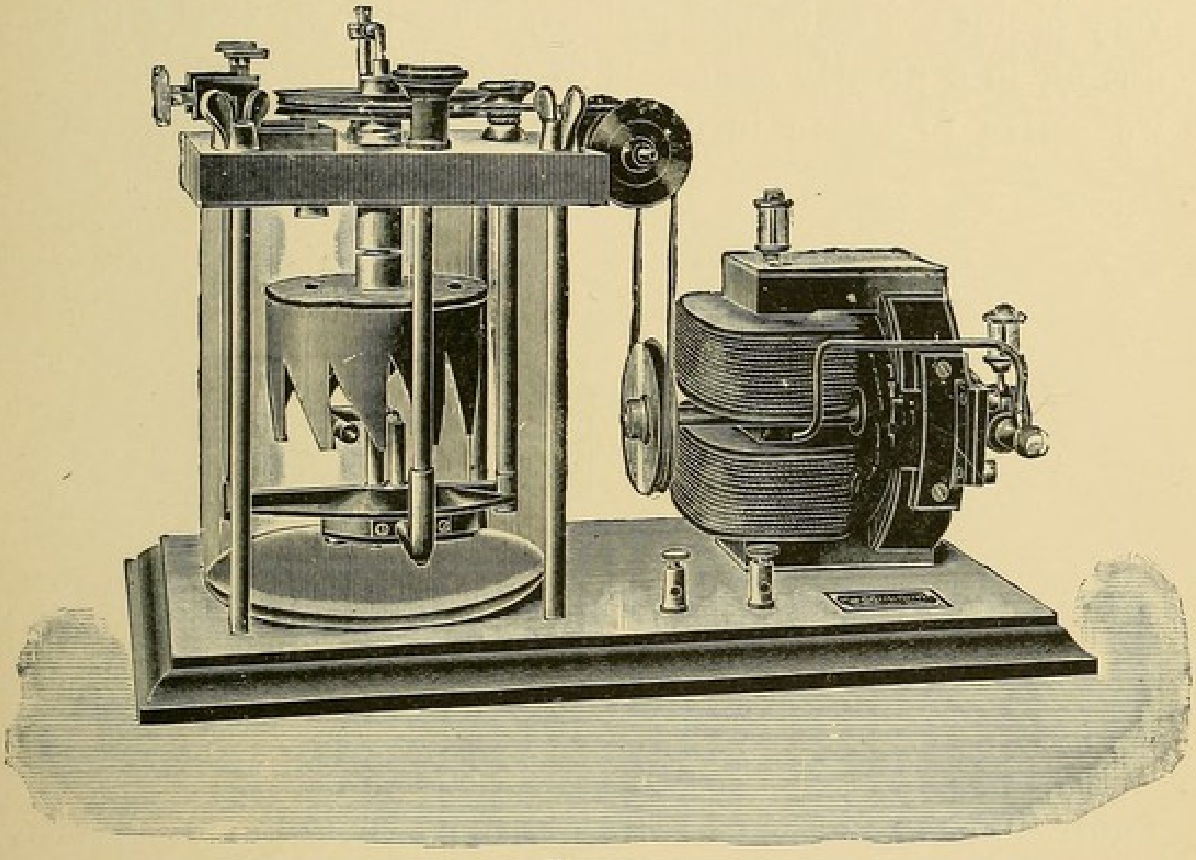


Fig. 29.

On reference to fig. 30, it will be seen that on rotating the blades past the nozzle (thus cutting the jet) contact is made for a shorter or longer period during each revolution according to the level of the jet. If the latter is at its lowest position, the jet can only impinge for a very brief period on the contacts, and as we raise the nozzle, larger and larger segments of the triangular contacts present themselves, until finally, at the highest elevation of the nozzle, we have a very prolonged make and a short, sharp break, thus reproducing in a greatly enhanced degree the conditions which we strive to attain in the case of platinum breaks by tightening the vibrating spring, and in the ordinary dipper mercury break by raising the level of the mercury.

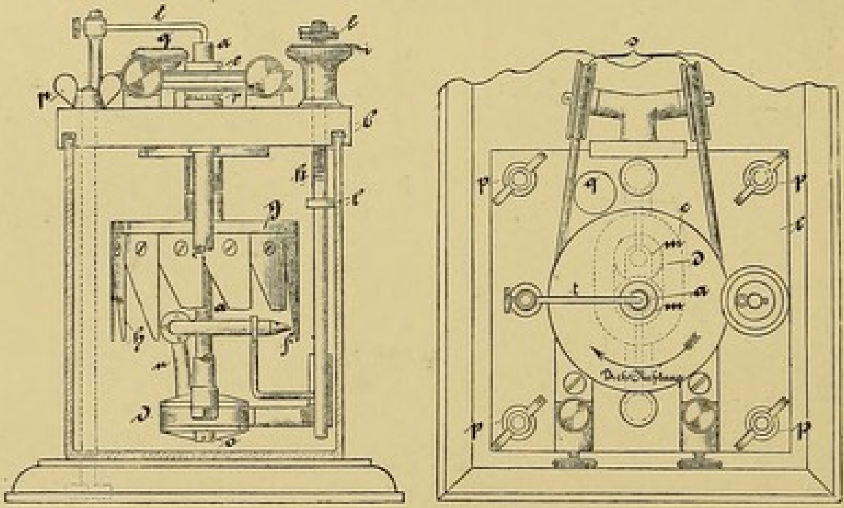


Fig. 30.

As the instrument contains no reciprocating mechanism and is perfectly balanced, we may run it at a very high speed without fear of unduly increasing the wear or the attendant noise.

This is further minimised by the introduction of ball bearings where essential, and by immersing the contact drum in paraffin, which acts both as a lubricant and also as an insulator (to extinguish the opening spark at the contacts more rapidly).

The motion is imparted to the interrupter by a small electric motor, running at about 1,000 revolutions per minute, so that with 24 contact pieces on the drum we obtain as many as 400 interruptions per second.

A very striking advantage connected with this and the preceding form of break has not yet been touched upon; it concerns the connection of a coil to electrical sources of widely differing pressure.

If we remember what was said about the induction principle, we shall readily understand that the duration of contact greatly influences the magnetization of the iron core and the induced secondary E.M.F., chiefly on account of the magnetic inertia of the core. Diagram 31 illustrates graphically the interdependence of magnetization (degree of saturation) and energizing current (for a given sample of iron) or—what is very closely related to it—between magnetization and contact-time. The higher values of magnetization, and with it the higher values of induced E.M.F., are only attained after the lapse of a certain time. If we regulate the number of interruptions so that each contact only takes a very short time (say $\frac{1}{1000}$ of a second), then, as diagram 32 shows, we do not utilize the full magnetic capabilities of the core; the magnetism only attains a small intensity and is then destroyed again. In order, therefore, to increase the magnetic saturation of the core, we must either cut down the interruptions (to, say, $\frac{1}{500}$ of a second) or—what will have the same effect—prolong each individual contact (Diagram 33).

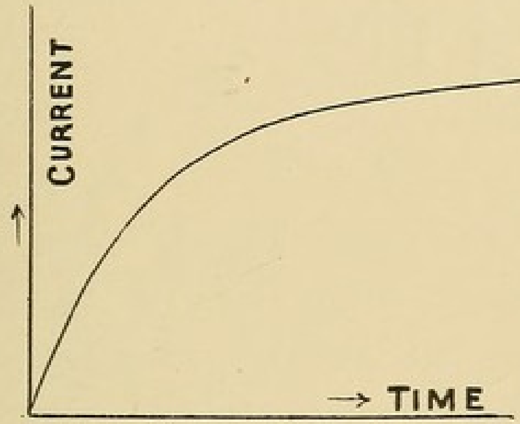


Fig. 31.

There is, however, still another way in which we may force up the magnetization, and consequently the induced E.M.F., without unduly curtailing the frequency of the interruptions, and that is by applying a higher voltage to the magnetizing winding of the iron core.

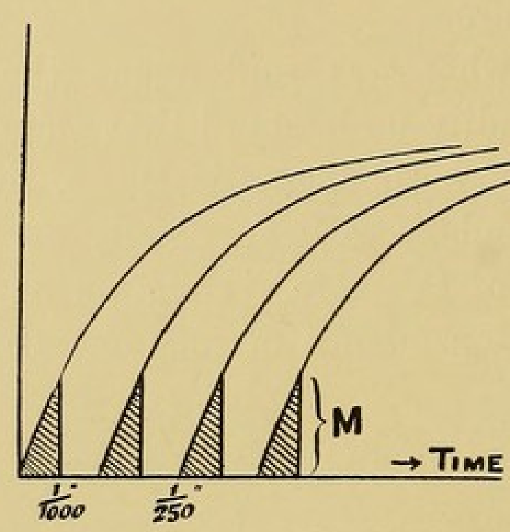


Fig. 32.

Diagram 34 shows for the same sample of iron as above the corresponding magnetic curve, and it is obvious that for the same period of contact as above $(\frac{1}{1000})$ we obtain a much higher magnetization.

The first of the above methods, *i.e.* reducing the

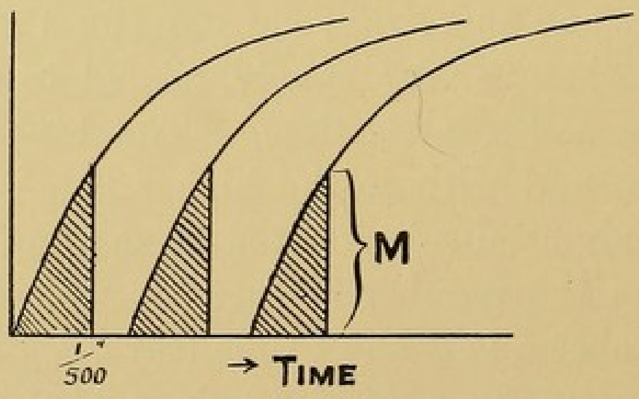


Fig. 33.

frequency and prolonging the contact (by raising the level of the mercury against the dipper), has often to be resorted to when working large coils from a few cells, and it is one of the advantages of mercury breaks that this can be effected within wider limits and much more reliably than is the case with vibrating platinum breaks, where the prolonging of the contact periods can only be effected (in most instances) by applying undue tension to the spring, thus causing the platinum studs to "stick" or weld together when heavy currents are passed; the springs also get hot and change their elasticity and vibration period. In both cases also the slowness of the interruptions seriously interfered with the steadiness of the shadow on the screen. On the other hand, owing to excessive sparking between the contacts and to the formation of arcs between the dipper and the mercury surface, the application of higher pressures to coils has been but very rarely recommended, and where coils had to be run from the 100 or 200 volt supply circuits, some form of rheostat was always interposed, which, of course, consumed energy and cut down the pressure at which the coil was actually worked.

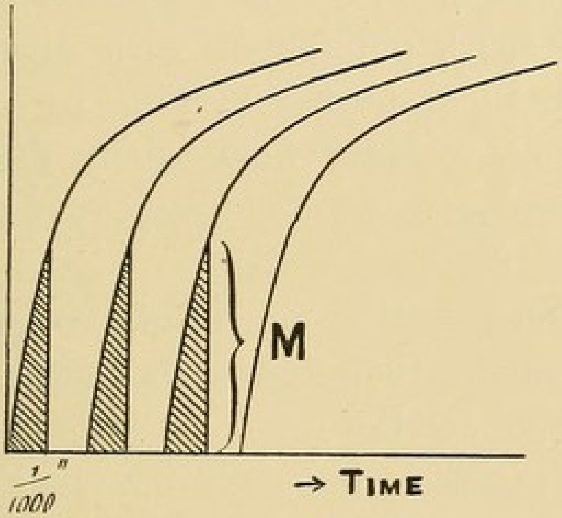


Fig. 34.

The jet interrupter made it feasible to run coils direct on circuits having potential differences up to 250 volts, because we have it in our power to so arrange frequency and duration of contact that even with such high pressures there will be no undue increase in the primary current, whilst at the highest frequencies the magnetization of the core will be sufficiently high.

To illustrate this, the authors can point to a case where a coil was run with a jet interrupter from a 100 volt circuit direct without any resistance between coil and house-wires, the primary current reading 1·5 ampères when taking a 12-inch spark and 2·5 ampères when taking a 16-inch spark—in both cases with the break running at 150 interruptions per second.

Moreover, with the Levy type of jet break, it is easy to change over from running a coil on a battery of 6 cells (12 volts) to running it off a circuit of 230 volts, simply by depressing the nozzle of the jet, without altering the frequency of the interruptions. The resulting discharge across the spark-gap is surprisingly brilliant, and very much like the spark obtainable with electrolytic interrupters. After this short reversion to the theoretical working of a coil, we may now briefly describe the last type of jet break, in which the jet is maintained by gravity.

The instrument consists chiefly of two metallic vessels, insulated from each other and each containing mercury; from the upper vessel the mercury flows in a thin stream into the bottom vessel, but is intersected by a rapidly rotating vane which, since each vessel is connected to one terminal, makes and breaks contact in rapid succession. Centrifugal force lifts the mercury from the lower to the upper vessel. There is, however, no special advantage in this type, for the claim that both contacts are stationary does not signify a gain, and no adjustment is possible, as in the preceding types.

A few words on the renewal or cleaning of the mercury may be useful. Where water is used as a covering, the mere rinsing of the containing vessel under a tap will be sufficient to wash out the mud and to obtain a metallic surface of mercury. The dipper should be kept finely pointed so as to prevent the formation of ripples on the surface, when it is entering it.

Where paraffin oil is employed, the paraffin is first decanted, then the mercury covered with benzine, and after a time washed with a hot solution of soda. Finally the mercury is filtered in the well known way through wash-leather.

ELECTROLYTIC INTERRUPTERS.

This class of interrupters, differing radically in design and action from any of the preceding types of mechanical break, is of very recent date, though the principle involved in their construction has been known, and indeed practically utilized, in other directions for years past.

Early in 1899 Dr. A. Wehnelt, of Charlottenburg, announced the discovery of a new arrangement whereby the current from a continuous source of supply could be automatically interrupted in a surprisingly rapid and complete fashion, with the result that when applied to the ordinary induction coil the latter yielded most remarkable quantities of energy in the secondary circuit.

The construction of this original apparatus, which is still being used by many workers, was very simple. In a vessel filled with dilute sulphuric acid are immersed two electrodes of dissimilar proportions, a large surface of lead being faced at a short distance by a small length of platinum wire suitably introduced through an insulating sheath. If such an arrangement is inserted in a circuit containing self-induction in some form or other (the primary of an induction coil, for instance) and a sufficiently high E.M.F. is acting in the circuit (from 24 volt upward), then the normal electrolytic action taking place at the positive electrode—(the platinum wire)—gives place to a violent reaction, manifesting itself by the appearance of a reddish arc at the wire and a rhythmic noise, which, of course, is indicative of a regular and rapid interruption of the current flow. It has been further observed that these interruptions are sufficiently complete and rapid to allow of the abolition of a condenser, thus further simplifying and cheapening the installation.

The frequency of the break and the amount of current passing through may be adjusted within fairly wide limits by altering the conditions of E.M.F. Self-induction and area of the positive electrode and their interdependence may be briefly summarised for practical purposes as follows :—

Keeping the area of the anode (wire) constant, we may increase the current in the circuit by diminishing the outer resistance, thus increasing the current density (current per unit of surface); this results in a higher frequency, as evidenced by the higher pitch of the noise.

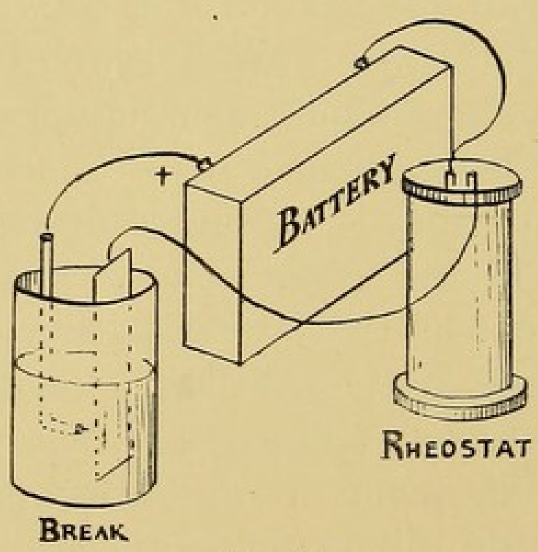


Fig. 35.

Keeping the resistance of the circuit constant, but increasing the current by enlarging the area of the anode (reducing the current density), we obtain slower vibrations.

Keeping both the resistance and the area unaltered, and using a higher E.M.F., we again raise the frequency because we increase the current density.

So far frequencies up to 1,700 and even 3,000 per second have been attained with this form of break.

The frequency also greatly depends upon the self-induction of the circuit, which is natural, seeing that the phenomenon is largely one of resonance. With too little self-induction, the current will be continuous; with too much, the interruptions will likewise disappear and give place to the third stage, in which the anode becomes incandescent. With new induction coils the self-induction may, of course, be chosen to suit the peculiarity of the electrolytic interrupter; with existing coils, the proper amount of self-induction in the circuit may be secured by interposing between coil and break a rheostat with variable self-induction (unless indeed there be already too much self-induction in the windings of the coil itself).

Many theories have already been advanced to explain the action of this new break, though they are greatly divergent. The one hypothesis which seems to us most feasible is that suggested by Mr. W. Jamieson of Glasgow (in the November number of the *Archives of the Röntgen Ray*), and which we reprint herewith.

"When the current is turned on, the back E.M.F. of self-induction prevents it attaining its full value instantaneously. Attaining this value, however, an arc of peculiar nature, which we might term an electrolytic arc, is formed at the anode. The great heat of this generates steam, which—because of the inertia of the liquid—quickly attains a very high pressure. This pressure becomes so great that there is not sufficient E.M.F. to maintain the arc, which promptly goes out. Meanwhile the steam overcomes the inertia of the liquid and drives it violently away from the anode, completely rupturing the circuit, this superheated steam being a poor conductor. The liquid, however, being driven away from the point of the anode, produces a stream in that direction, which quickly condenses the steam, and the operation starts over again. The sole purpose of the self-induction in the circuit seems to be to form a temporary resistance, so as to give the state of instability a start."

As regards the practical application of the break,

Fig. 36 represents one form of such a break, in which the anode (platinum wire) is introduced through a gland in the side of the containing vessel and made adjustable by being pushed through a nozzle of steatite or ebonite. This form of break, however, very soon showed considerable drawbacks in actual use, chief amongst which was a kind of "fatigue," *i.e.* a state of inactivity when the break had been working for some time. Various remedies, such as heating the platinum wire or providing several anode cones instead of one, failed to materially improve matters, and thus led to the adoption of modifications of Wehnelt's original design.

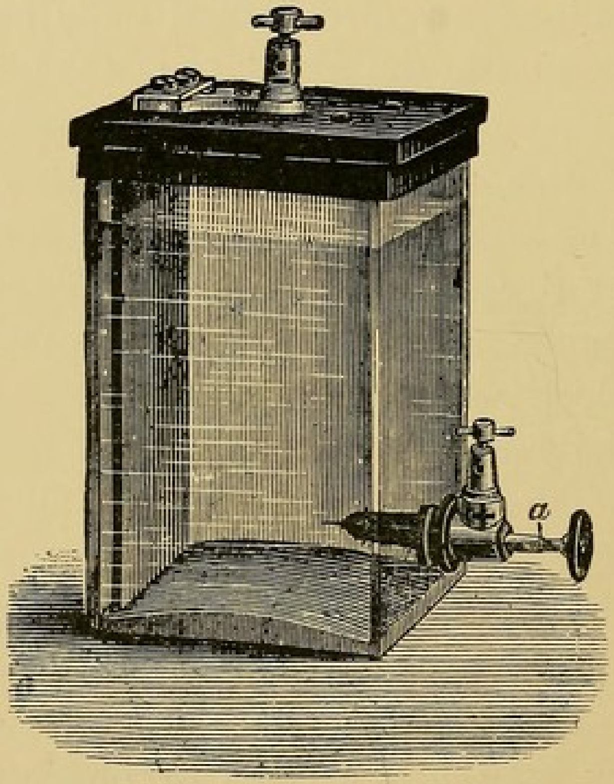


Fig. 36.

Dr. H. T. Simon and Mr. Caldwell published simultaneously, though quite independently, another form of electrolytic interrupter, in which both electrodes consist of lead plates, the high current density indispensable to the action of the break being transferred to the electrolyte, which in passing from one electrode to the other has to squeeze through a very small aperture.

Three forms are described by Dr. Simon in the June number of the *Elektrotechnische Zeitschrift.* An outer leaden vessel filled with dilute sulphuric acid contains a glass or porcelain cylinder with one or more small holes in it, the latter containing the second lead electrode; or a glass jar is divided into two compartments by a partition of glass, which again is pierced with small holes whilst each partition contains its lead plate.

The third modification has at present chiefly a theoretical value. An inverted U-tube is filled with the electrolyte, save at the top, where an air-bubble constricts the cross section and where the interruptions take place.

The element of adjustment has been introduced by Mr. A. A. C. Swinton. The inner cylindrical glass vessel has a small hole of about four millimetres diameter at the lower end, the size of this hole being made variable by means of a conical glass rod fitting into this aperture and being arranged so as to be conveniently raised or lowered. Such a construction is illustrated by Fig. 36, and it may be said for it that its action is not perceptibly altered by prolonged use, that the polarity of the electrodes is no longer of vital importance, and that the wear of the electrodes is much slower than in the original "Wehnelt" construction.

One great drawback, however, is the liability of the perforated glass vessel to become damaged during the working of the break, causing (owing to the sudden increase of the cross section of the liquid) an instantaneous rush of current through the coil and then a sudden stoppage; possibly by substituting a more reliable material for the glass the continuity of working may be eventually secured.

There is also a very considerable heating of the electrolyte during the working of the break, which necessitates the adoption of certain means whereby the temperature of the liquid may be kept within workable limits, as when for purposes of prolonged screen examinations, for instance—

the break must be kept in the circuit for any length of time. Amongst the methods employed to ensure this condition we mention: Surrounding the containing jar with a jacket; causing water to circulate in the space between the two vessels: or forming one electrode of a spiral of lead tubing through which cold water is circulating: or providing a containing vessel of such capacity that the heating of the electrolyte and the consequent "fatigue" of the interrupter only occur after very long periods of working (Fig. 38).

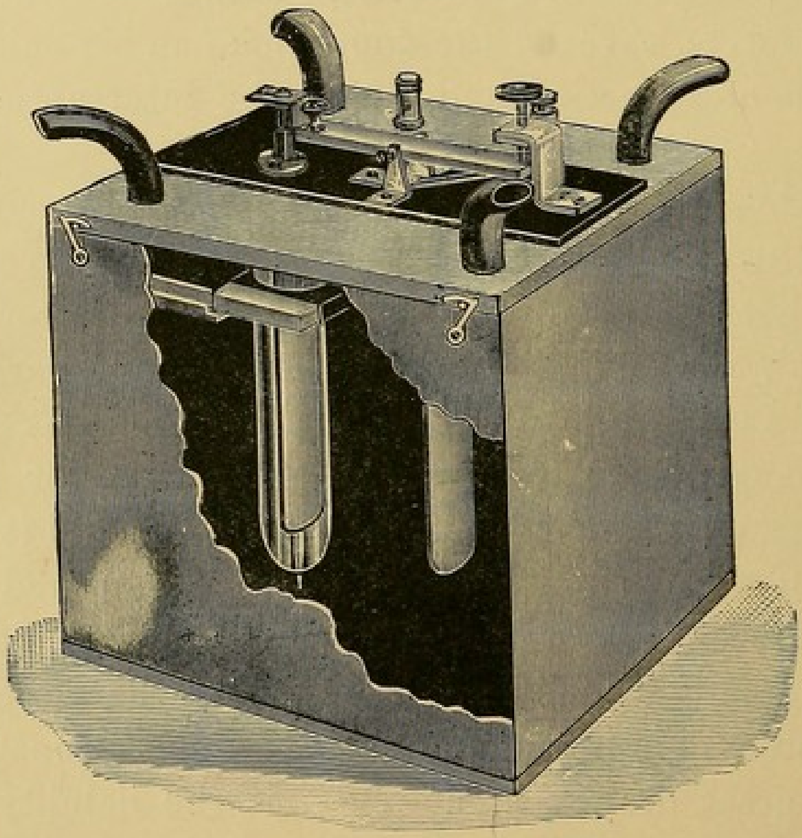


Fig. 37.

The various attempts to substitute different metals and electrolytes for the orginal lead and sulphuric acid have not been productive of any appreciable advantage, and generally require higher voltages.

The electrolytic interrupter produces considerable noise when working, which is apt to be disagreeable to some patients; for this reason, and also because acid fumes are given off, the break may be placed in some other room.

Fetlock of Horse.

(Radiogram taken by A. W. Isenthal. Exposure 45 seconds.)

To obviate the necessity of leaving the operating room in order to regulate the length of the platinum wire, an interrupter with two or three platinum anodes of different dimensions may be employed (see Fig. 39), and connected with a switching arrangement in the X-ray room, so that the operator may, at will, employ either of the anodes or their combinations (seven in all).

So far we have only given prominence to this type of interrupter on account of its simplicity and theoretical interest; it possesses, however, even now, in spite of some technical imperfections and drawbacks, some marked advantages over other forms of break, so that we may safely predict for it an important position amongst interrupters for X-ray work, if only we succeed in producing tubes which will stand the resulting strain. Thanks to the immense number of interruptions which it yields, the character of the discharge between the ends of the secondary is unlike any other spark discharge; instead of a

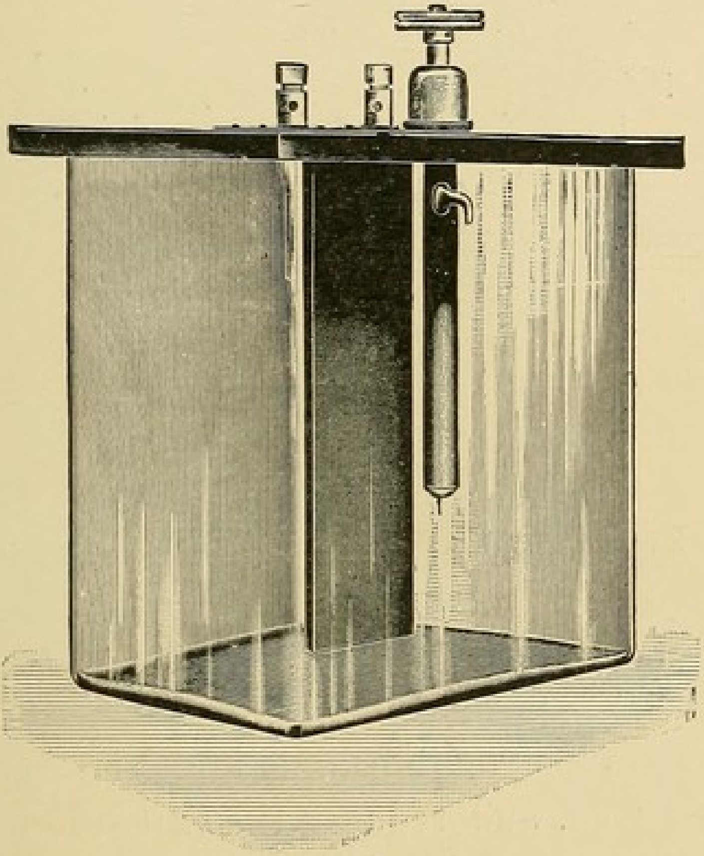


Fig. 38.

single spark or even a stream of sparks we obtain by its means a veritable torrent of sparks, which—at shorter gap-lengths—develops into a flaming discharge, indicative of great energy. The result of such a discharge through one of the typical X-ray tubes will be fully dealt with in a later chapter (page 103), but we may briefly state here that it ensures perfect steadiness of the image on the fluorescent screen, and reduces the exposure necessary for a radiogram to a small fraction of the time usually required for this purpose, when an ordinary platinum or mercury break is employed.

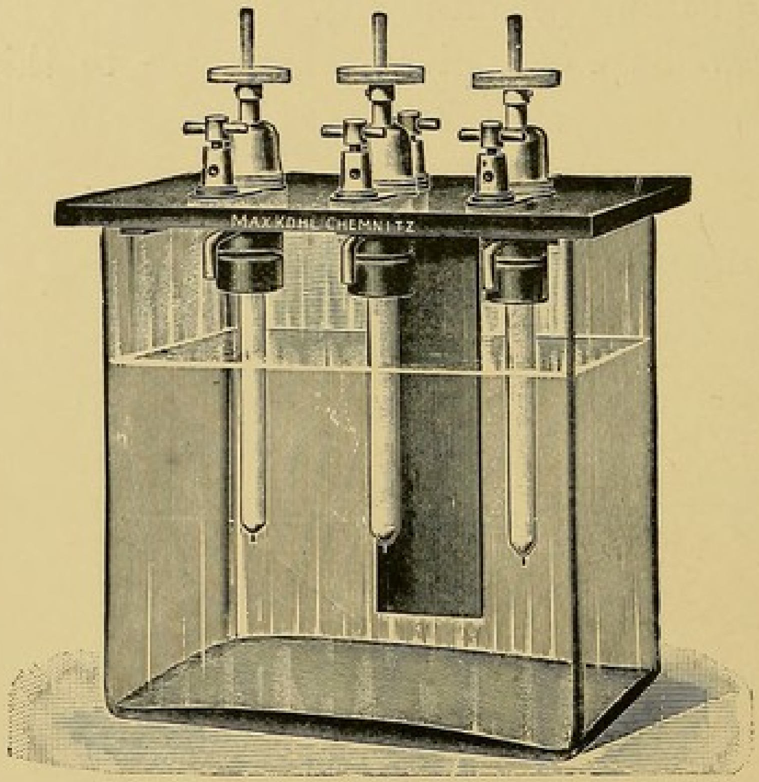


Fig. 39.

INTERRUPTERS FOR ALTERNATING CURRENTS.

On page 37 we explained the character of an alternating current, and defined the meaning of frequency, etc. It seems, from what we learned in the chapter on induction, that such an alternating current should be suitable—without the employment of any additional interrupter—

to produce the phenomenon of induction in a suitably arranged secondary circuit. This indeed is the case, and the ordinary type of transformer for electric light and power transmission is an important practical application of the principle, converting alternating current of a certain voltage into alternating current of any other desired voltage.

For the purposes of X-ray work we require, however, not an alternating, but practically a uni-directional current in the secondary (and in the tube), a condition which we strive to attain as nearly as possible by the construction of the interrupter and the provision of a condenser (see page 48). If therefore we wish to employ the alternating current to run a coil, we must either entirely suppress or at least greatly weaken one or the other series of impulses. In other words we must only utilize the positive or the negative phases of the current.

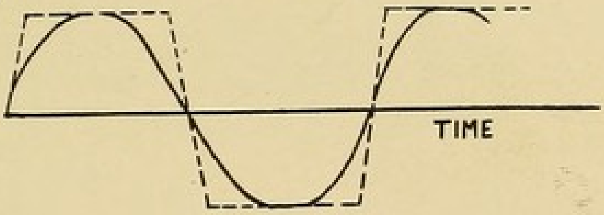


Fig. 40.

Besides, in order to obtain the greatest possible inductive effect we should so modify the shape of the current curve that the time rate of change becomes considerable. Diagram 40 will make this clearer.

The full line indicates the orginal character of the alternating current, from which it is clear that the change from the maximum to zero is too gradual for induction purposes.

The dotted curve shows how the ordinary sine curve should be modified so as to give better inductive effects.

The simplest plan to suppress the negative phases, for instance, has only recently become feasible by the introduction of the Wehnelt break, since the latter only furnishes the peculiar discontinuity of the current when the platinum wire is the anode. We may, of course, expect that on sending an alternating current through it, only those phases will be interrupted (or inductively employed) during which the wire is positive, whilst the negative impulses of the current—though actually flowing—do not come to an expression as far as inductive effect is concerned. There has been no difficulty in the authors' hands in obtaining very nearly the full spark length from coils run under these conditions, provided only that the coil did not contain in itself too much self-induction; with coils, the primaries of

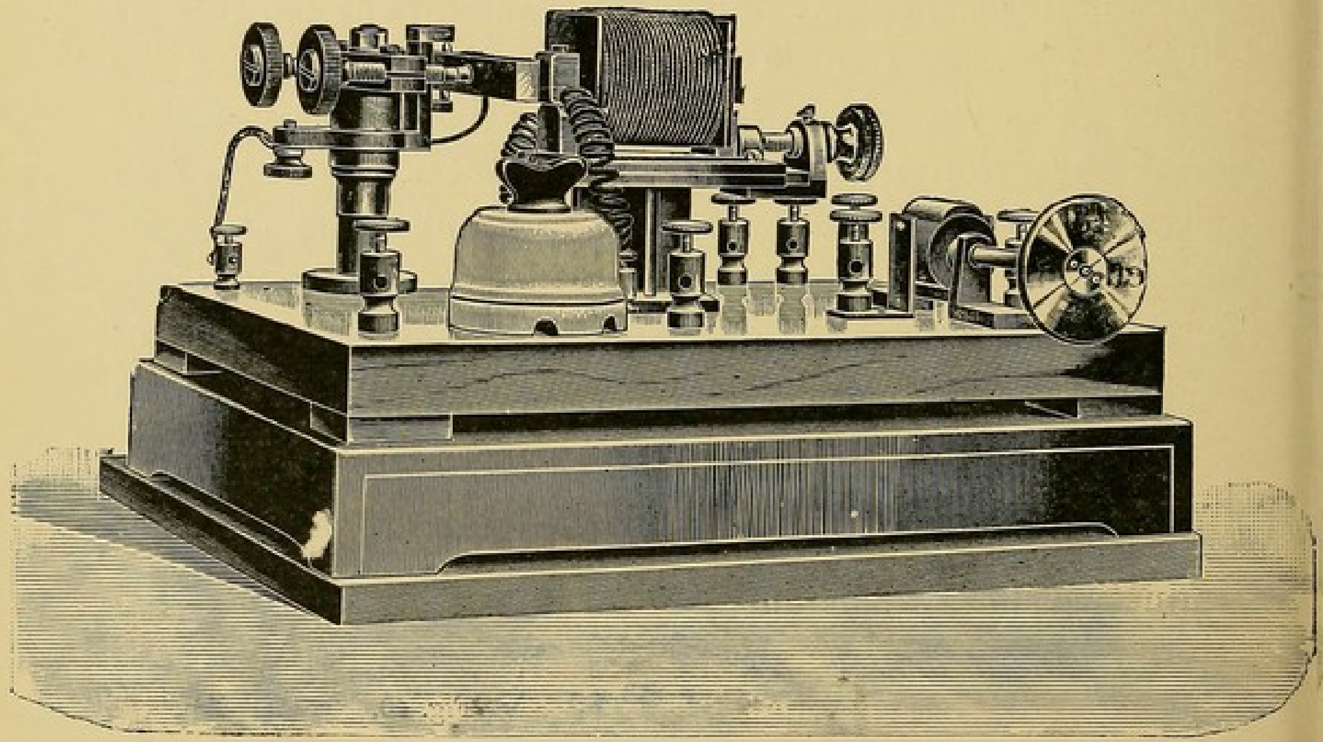


Fig. 41.

which are suitably wound, the full spark length as above may be obtained.

In cases where the electrolytic break is not desired, the only means to utilize the alternating current is offered by some form of synchronous interrupter which will effect the above described modifications of the original current curve; we will first describe the more usual type which belongs to the class of platinum interrupters (Fig. 41).

An electro-magnet through which the alternating current is flowing is mounted opposite one pole of a vibrating bar-magnet, causing the latter to be attracted as often as the polarity of the electro-magnet is opposite to that of the bar-magnet; that is to say, the bar-magnet will swing in synchronism with either the positive or the negative phases of the alternating current; a tension spring which permits of adjustment usually keeps the bar away from the electro-magnet. The bar and the upright supporting it carry the platinum studs, between which the interruptions of the primary circuit take place, and the action may be summed up as follows:—Suppose the positive phase of the current produces a north pole in the electro-magnet opposite the north pole of the bar-magnet; then the latter, both by

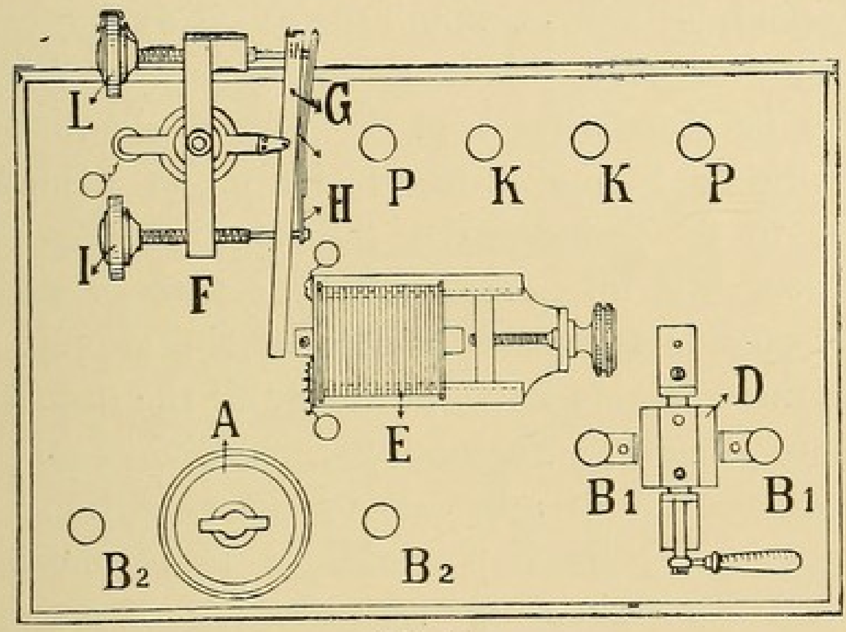


Fig. 42.

magnetic repulsion and by the tension of the adjusting spring, is pressed back against the contact screw, and the positive phase of the current passes through the coil, without, however, acting inductively. When, on the other hand, the negative phase is traversing the electro-magnet, there will be the opposite polarity—and consequently attraction between bar and electro-magnet—with the result that the former swings forward and in so doing breaks contact. In this way the negative phase will act inductively in the coil. To ensure the highest possible inductive effect, the contact screw and the tension screw must be so adjusted that the attraction and consequent break takes place when the negative phase is exactly at its maximum. When the adjustment has been correctly carried out, the secondary of the coil will yield currents which are as nearly uni-directional as those of a coil worked from batteries or from continuous currents. If, however, the tension of the spring be not sufficient, or if the permanent magnetism of the swinging bar has for some reason or other become weakened, it may happen that attraction takes place between bar and electro-magnet at every phase of the alternating current, so that we obtain inductive effects, but of an alternating character, in the secondary coil.

This fact, of course, manifests itself by the behaviour of the tube or even the spark gap (see page 53), but it may also be recognized from the pitch of the interrupter: when working normally the latter emits a note corresponding to the periodicity of the supply: when breaking both phases this pitch rises to the octave of the former and corresponds to the frequency of the supply.

Such interrupters have, however, all the disadvantages of platinum-breaks. To modify the ordinary dipper mercury break so as to adapt it to the conditions of synchronous working is impossible, as it is mechanically impracticable to keep up reciprocating motion of the requisite frequency.

There only remains the rotary, or, better still, the jet interrupter, which, when driven by a synchronous alternating current motor and provided with an adjustment whereby the moment of break between jet and contact may be brought into step with the maxima of one phase, would certainly offer great advantages.

CHAPTER IV.

THE VACUUM TUBES FOR THE GENERATION OF X-RAYS.

In the preceding chapter we have not given much consideration to the spark which is produced between the ends of the secondary of a coil. We, however, noticed quite briefly that there is a difference in the appearance of the discharge, according to the polarity of the discharger points, and also that under certain conditions of working the apparent quantity of the spark is considerably increased.

If we enclose the secondary terminals of an induction coil within a glass tube and gradually exhaust the air from this tube, the visible electric discharge between the terminals undergoes a series of changes, its appearance of a bright and well defined spark or stream changing first to a broad luminous ribbon which, when the gas pressure within the tube sinks below half a millimetre, breaks up into various striæ separated by dark bands, their color 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 1-2,000th of a millimetre, 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.

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 the sensation of light. If we bring the cathode rays to a focus, by forming the cathode surface as a semi-globular hollow, we are able to produce a strong thermal effect at the focus. The chemical effects of the cathode rays can be demonstrated by the blackening of a sensitive photographic film placed in their path; the mechanical effects by means of delicately suspended wheels, with mica vanes, mounted inside the tube.

There is finally one other effect, which of course concerns us more exclusively than any other property of these cathode rays, namely, that whenever they come into collision with any solid, whether conducting or insulating, a new and entirely different kind of radiation or form of energy is called into existence—the X- or Röntgen Rays.

We cannot within the scope of this chapter enlarge upon the properties of these rays, but will merely put on record some features which have a direct bearing upon the manufacture and design of the tubes :—

(1) Various materials placed in the focus of the cathode stream show different degrees of emissivity, *i.e.* the higher

the atomic weight of the material, the richer is the yield of X-rays emitted from it (other conditions, such as electrical energy, etc., remaining the same).

(2) Metals (with one exception) and glass containing heavy metallic oxides are fairly opaque to the X-rays.

(3) Aluminium is the only metal which, when used in a high vacuum as the cathode, does not become appreciably disintegrated.

(4) Röntgen rays cannot be refracted or reflected, therefore it is impossible to bring them to a focus.

(5) The penetration of the Röntgen rays increases with the vacuum from which they emanate.

Turning now to the description of the tubes themselves, it is obvious that, both on the score of transparency and also on account of the high pressure obtaining between the electrodes, only an insulator can be used as the material from which to make the body of the tubes, and with one or two experimental exceptions glass has been employed, in so far as it may easily be blown or moulded into any requisite shape and is both light and inexpensive. Of the three kinds of glass which are available, the so-called German or sodium-glass is the one most universally employed, chiefly on account of its transparency to the X-rays. The color of its fluorescence under the stimulus of the cathode or the X-rays is a bright apple green.

Less suitable, although frequently used on account of the ease with which it can be worked, is the English soft lead glass, which fluoresces with a pale blue color.

Another glass mixture containing phosphates has lately been employed in one or two instances, but besides the peculiar purple color of its fluorescence there is nothing to recommend its use.

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 must be made of aluminium, since this metal does not appreciably disintegrate under the influence of the electric discharge. Owing to the difference in the coefficient 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 stems of the electrodes, too, should be of stout aluminium wire which must be suitably supported in the neck of the tube in one way or another, so that the electrodes, once sealed into the tube, cannot change their position (unless specially desired) as regards their distance apart and centrality. We know that cathode rays exert a mechanical force upon their target, and unless the latter is well fixed it will shake and vibrate under the impact of the rays, and possibly mar the definition of the image (owing to the source of the rays vibrating). As regards the anti-cathode, we may say that the old method of soldering a piece of platinum sheet to a thin aluminium stem has now almost disappeared; the platinum which in most cases forms the emitting surface is now fixed (by riveting or plating) upon a suitable backing of aluminium or copper, which prevents the too rapid heating of the target under the impact of the cathode rays.

We may here say that the additional mass of metal thus introduced into a tube entails considerably more work in its exhaustion and adds to the expense. Some care should also be given to the terminals of the tube which have to bear the strain of the connecting cables: the early form of simple platinum wire loops is quite insufficient, and owing to the fragility of the latter is a source of constant annoyance as well as of danger, since, in the event of their giving way, the connecting wire may drop upon the patient and give rise to some undesirable physiological effects. The platinum wire as it comes through the glass should be soldered to substantial brass caps and these 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.

Although the majority of radiographers, as represented by medical men, may be assumed to buy their tubes, as they do other instruments needed in the exercise of their profession, from a reliable manufacturer or dealer, and although those who prefer to exhaust their tubes themselves are in the minority and would consult for their instruction in this particular art some specific treatise, we think it necessary to give our readers at least an outline of the process of exhausting a tube, since it may help them to understand some properties of these tubes with which they are constantly confronted in practical work.

We all remember the mechanical air-pumps of our school days, with which many phenomena occurring *in vacuo* may be successfully demonstrated. These vacua, however, are very far from the mathematical or even the Crookes vacuum, and owing to their construction the ordinary mechanical air-pumps are not capable of exhausting a tube to such a high degree of rarefaction.

A modification of these mechanical pumps, the "Geryk" pattern, however, marks a great advance and furnishes a very high vacuum. Yet in the process of X-ray tube-making only the initial stage of the exhaustion is attained by mechanical pumps, whilst the latter stages of rarefaction are obtained with some form of "mercury pump." These instruments are modifications of the "Sprengel" air-pump, invented in 1865, in which a jet or several jets of falling mercury suck the air from the space to be exhausted, the air showing in the form of beads between the falling drops of mercury. The pump is furnished with a "McLeod gauge," which shows the pressure still obtaining in the exhaust vessel, and with a suitable drying tube, filled with sulphuric acid or phosphorus pentoxide to keep the air perfectly free from moisture. Fig. 43 shows one of the many forms of mercury pumps in the market.

When the exhaustion of a tube has reached a certain degree (as registered by the gauge), the electrodes of the tube are connected to an induction coil, and the secondary current passed through; the effect of the electric discharge is to heat the residual air in the tube, and to assist in driving it off. It also enables us to judge, by the appearance of the discharge itself, the degree to which exhaustion has progressed.

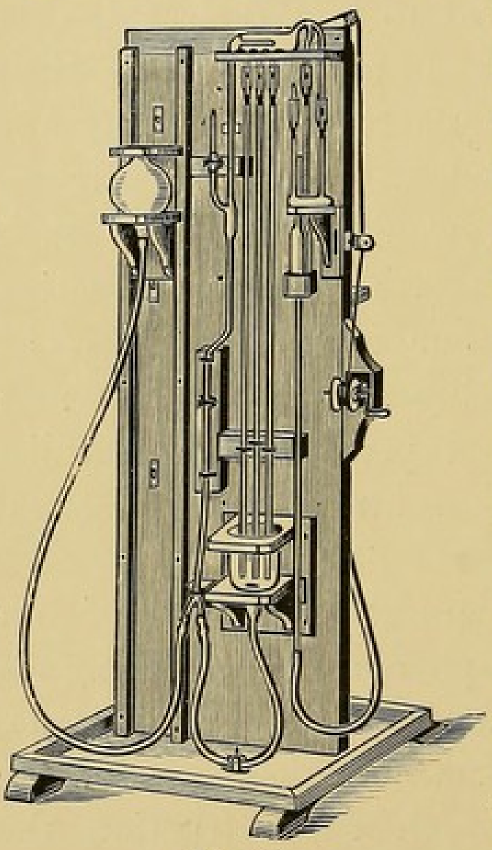


Fig. 43.

The air which is in contact with the inner walls of the tube, and also that portion which is occluded in the metal of the electrodes, can only be got rid of by strongly heating the tube whilst it is on the pump, and by prolonging the pumping process.

Tubes which have not thus been treated may show at the start (when taken in use) the characteristics of a well exhausted tube, but as soon as the discharge heats the interior, the occluded air is set free and the vacuum falls, as indicated by the "anode light."

The larger the tube and the more metal it contains the longer must it be on the pump. As the rarefaction proceeds, the characteristic fluorescence of the glass makes its appearance, and by repeated examination of the tube with the fluorescent screen, that moment may be determined when the tube should be sealed off from the pump.

We shall show in the course of this chapter how the vacuum thus obtained influences the properties of the rays emitted, how the initial vacuum changes under working conditions, and how it may be temporarily restored.

Turning now to the various forms of tubes that at one time or other have been constructed, their number is so enormous that a description would fill a good-sized volume. By far the greater number of these forms, however, were constructed during the early days of radiography, when the essential conditions which go to make a good tube were not 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 differs only 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.

The earliest tubes were not specially designed for X-ray work, but were those which could be found in every physical laboratory for the demonstration of certain Crookes experiments. They were plain cathodal tubes (Fig. 44), in which both the cathode and anode were flat discs of aluminium, so placed with respect to each other that the cathode stream was free to impinge upon the glass wall opposite the cathode and to produce there the fluorescence, and, as was subsequently found, the X-rays. This type, though capable of yielding

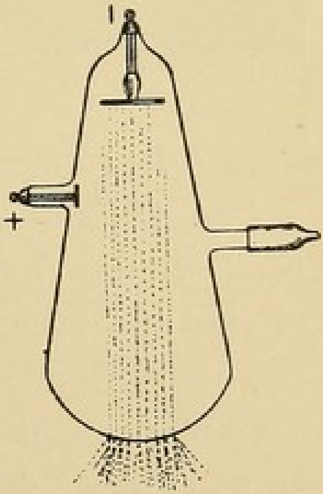


Fig. 44.

fair results when judiciously arranged and manipulated, soon 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 causes the latter to become intensely heated, and eventually to collapse through the atmospheric pressure, so that the tube could only be worked intermittently.

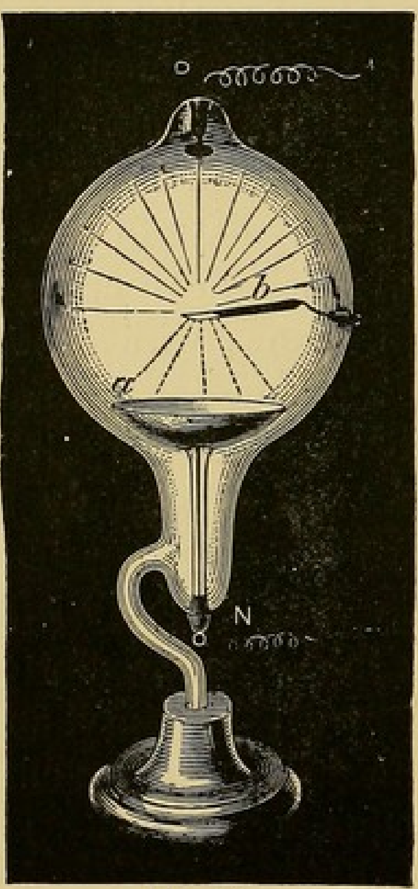


Fig. 45.

As, furthermore, the fluorescent patch of glass is the source of the X-rays in this pattern, it follows that there is a considerable amount of diffusion, and that in order to counteract the resulting penumbra of the radiographic outlines, the distance between tube and object had to be increased—meaning, of course, longer exposures.

Cathodal tubes are to-day only of historical interest.

The next and most important step forward in the development of X-ray tubes was the introduction of what is now generally called "the focus tube."

Fig. 45 is the prototype of this form, though Sir W. Crookes, who first designed it, employed it for a totally different purpose.

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 quite 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 Professor Silvanus P. Thompson to denote that 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 types, particularly of Continental origin, the tube is provided with a separate anode, which may be connected to the anti-cathode at will, and permits of a certain degree of regulation, as we shall see later on.

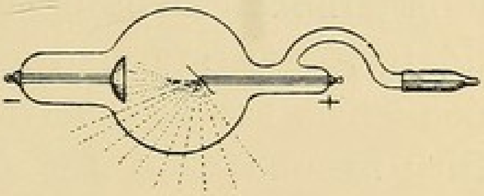


Fig. 46.

Fig. 47 represents the bi-anodal German tube, which, under various names (Excelsior, Record, etc.), has been widely adopted in this country.

The modification of the focus tube for alternating currents as well as some other variants cannot be gone into, since they likewise have no practical importance; they are, however, represented on page 99 (A, B.)

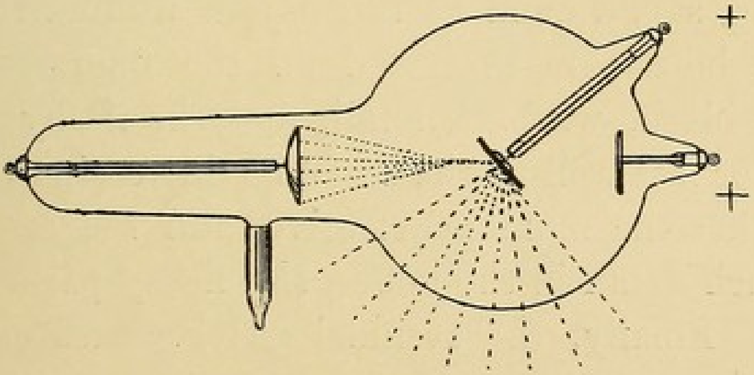


Fig. 47.

The life of a vacuum tube, barring such accidents as breakage and perforation by sparks, is largely influenced —apart from the conditions of use—by a peculiar phenomenon, which may be observed more or less in all types, and which asserts itself in the gradual rise of the vacuum with continued use.

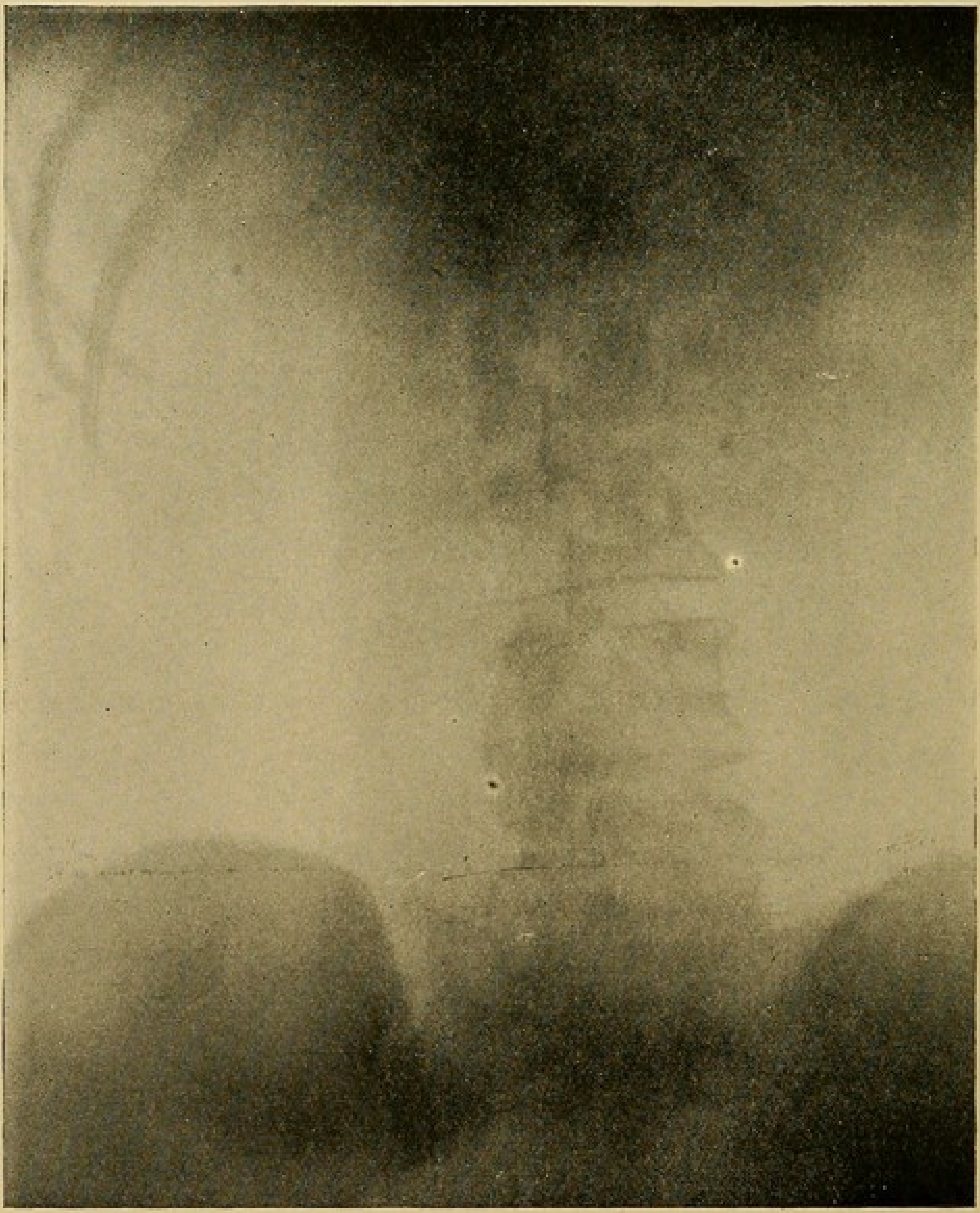
This rise is, of course, accompanied by a corresponding rise in the resistance of the tube, and continues until a stage is reached when the electric discharge is no longer able to pass through, but preferably passes round the tube from terminal to terminal in the form of a spark, and no Röntgen rays are generated. The most feasible explanation which has been advanced to account for this peculiarity assumes that the platinum anti-cathode and other platinum parts become disintegrated 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 various properties of the X-rays can be expected, a most serious disadvantage, which makes our work largely empirical.

Starting, for instance, with a comparatively low vacuum, and taking, say, a hand as test object, 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.

Although the absolute prevention of this change in the emissivity of a tube is, for obvious reasons, an impossibility, yet much has been achieved in securing greater constancy and introducing certain compensating factors; such tubes are termed "regenerative tubes."

PLATE VII.]



Radiogram of Lumbar Spine and Region of Kidneys (female, age 48).
(By A. W. Isenthal.)

REGENERATIVE TUBES.

Many ways are open to us by which the vacuum of a tube may be altered, though the tube itself be hermetically sealed. The following are some methods :—

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 anti-cathode gets incandescent; the former is the more usual method and easier to apply.

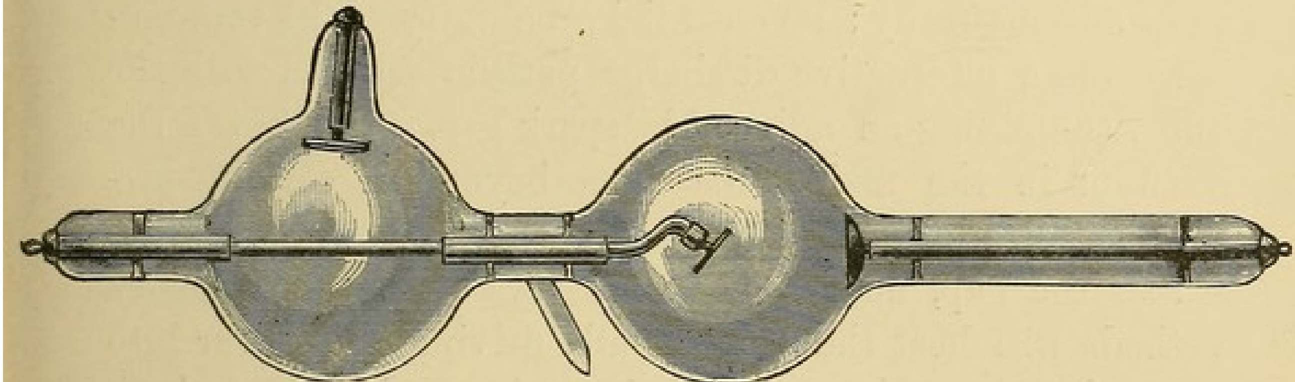


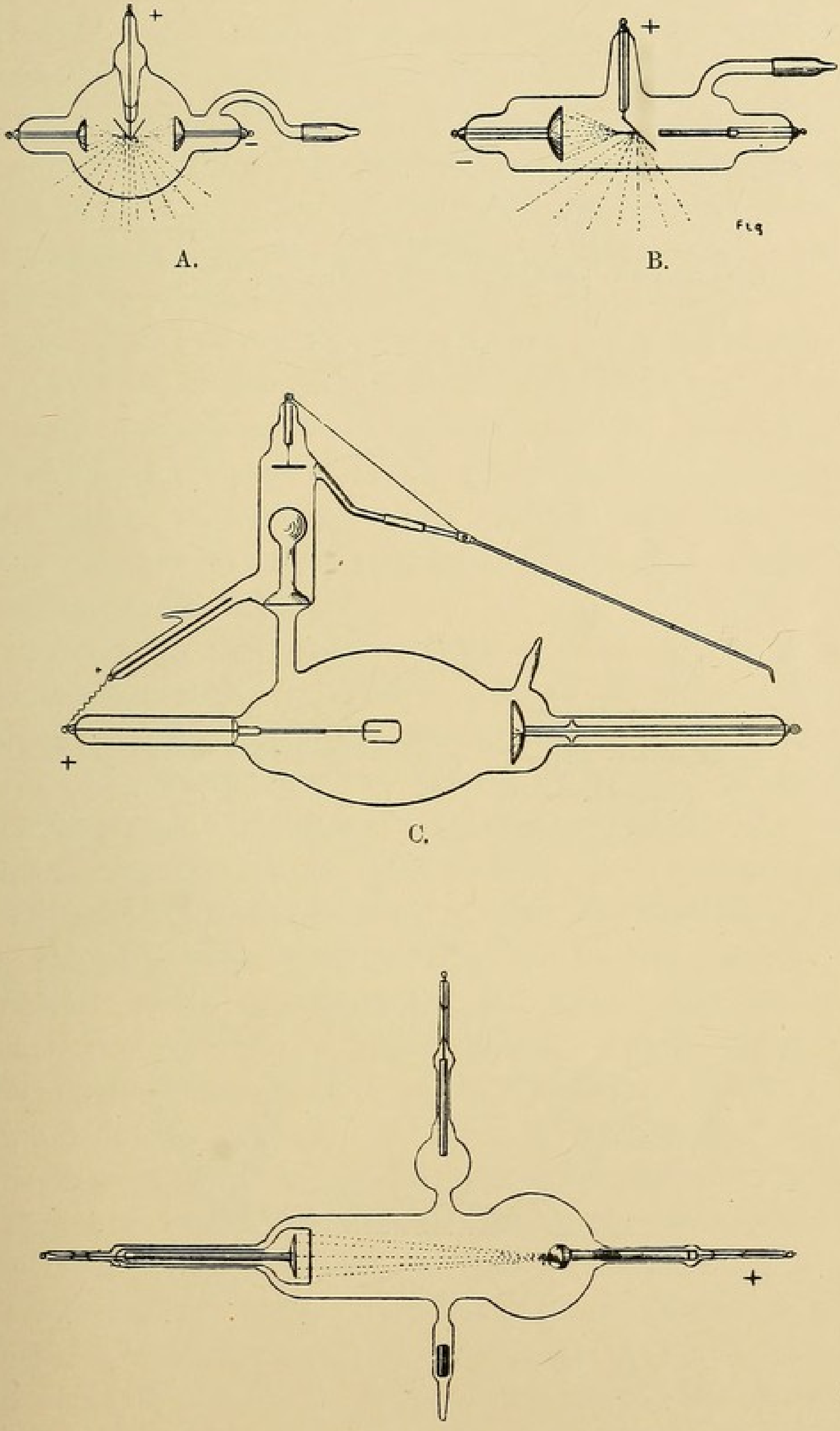
Fig. 48.

This treatment, of course, does not presuppose any particular design of the tube, and may therefore be universally employed with all types. In this class may be ranged the "*Double Bulb" tube*, shown in Fig. 48.

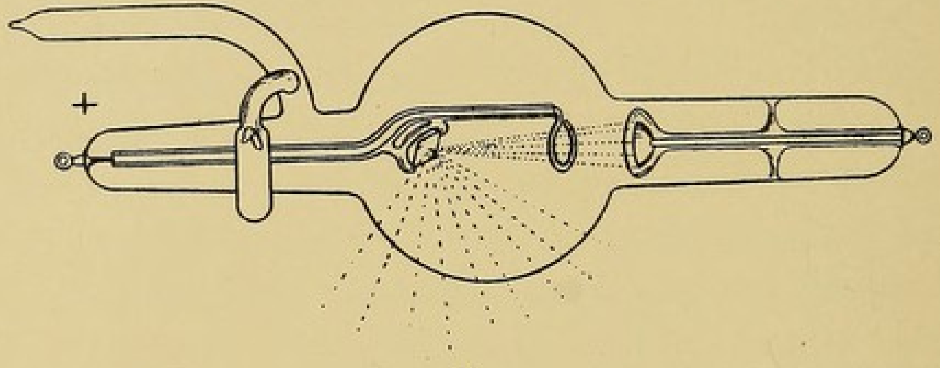
The distinguishing feature of this type is the bulb arranged behind the working bulb; when the tube is on the pump, the requisite heating of the walls is only applied to the working bulb, with the result that after sealing off, there is a certain store of condensed gas clinging to the inner walls of the small bulb, which may either be driven off into the main bulb (when the vacuum has risen above the useful degree) by the application of heat to the small bulb or preferably by the passage of the discharge itself through the tube.

2. *By the introduction of certain absorbent substances into the tube.*—The reserve of gas is furnished by some such substance as caustic potash, palladium, carbon or permanganate of potash, which at ordinary temperatures occlude gases but yield them up when being heated. Usually this substance is placed in a small auxiliary branch, and heated from the outside—care being taken to effect this heating very gradually and carefully, as otherwise too much gas may be given off or may lower the vacuum below the X-ray stage. In the type C, page 99, this heating is done automatically; 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 prearranged 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 (Types C, D, E, on pages 99 and 100).

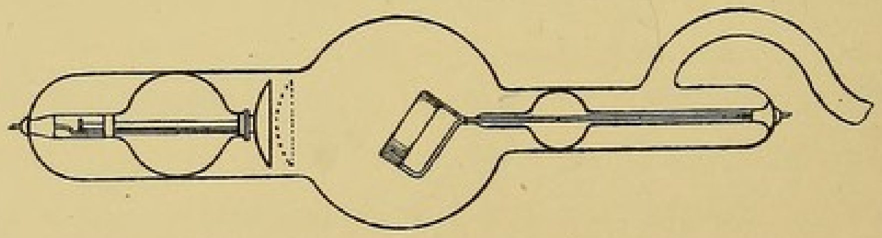
3. *Mechanical regeneration.*—Although mechanical means are employed to vary the radiation emitted from tubes of this class, the immediate cause of the variation is electrical, inasmuch as we really alter the resistance of the tube. According to Mr. A. A. C. Swinton and Dr. Dawson Turner, the penetrative value of the rays depends for a given vacuum upon the area of the cathode disc and upon the linear distance between cathode and anti-cathode. Mr. Swinton designed two types of adjustable tubes: in one, four concave aluminium cathodes of the same curvature but of different diameter focus the cathode rays upon an anti-cathode, which may be rotated by mechanical vibration from the outside and so made to face either cathode at will; the smaller the cathode used the higher



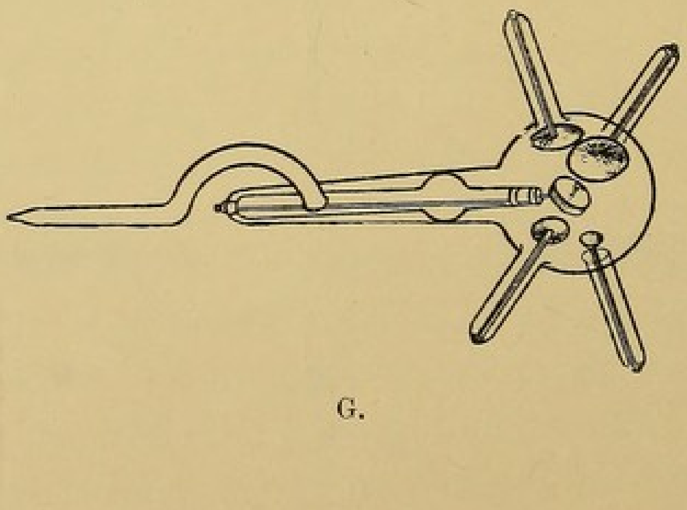
Various types of tubes.



E.



F.



G.

Various types of tubes.

the penetration. In the other type the cathode may be brought into various positions as regards distance from the anti-cathode, and the penetration of the tube increased by lessening this distance (Types F and G on page 100).

Nowadays but very few of these tubes are in practical use, since their manipulation is by no means easy but sufficiently circumstantial to prevent their more general adoption, at the hands of medical men at any rate.

4. *Electrostatic regeneration.*—It may be shown that the increase of the tube resistance is partly due to the fact that the outside of a working tube becomes electrostatically charged and reacts upon the dynamical discharge inside the tube. In order to draw off this outer charge some connection must be made between the inner and the outer surfaces of the tube.

A ring of plain copper wire round the neck of the tube (but not touching it) in the plane of the cathode edge is separated by a very small distance from an earthed copper wire. Between these two wires a very rapid intermittent discharge takes place, and the resistance of the tube seems to fall considerably, as evidenced by the increase in fluorescence. Similar results are obtained by coating the neck of 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. On the other hand this arrangement facilitates the passage of sparks round the tube and increases the risk or perforation; 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 to wrap 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 may be varied.

Recently Hirschmann has patented a method providing for the arrangement of a metallic screen above the anticathode, but outside the tube and connected to the anode (Fig. 49).

The latest and most promising method of regenerating a tube is based upon the phenomenon of osmosis. Platinum, when at red heat, becomes permeable by hydrogen. If we thus provide a tube with a branch terminating in a small narrow tube of platinum or a platinum alloy, and if we carefully heat this narrow tube in a Bunsen or spirit-flame until red heat is attained, then the hydrogen from the flame passes into the bulb and reduces the exhaustion. It is obvious that this method is far superior to all other means of regeneration, since there is no limit to the supply

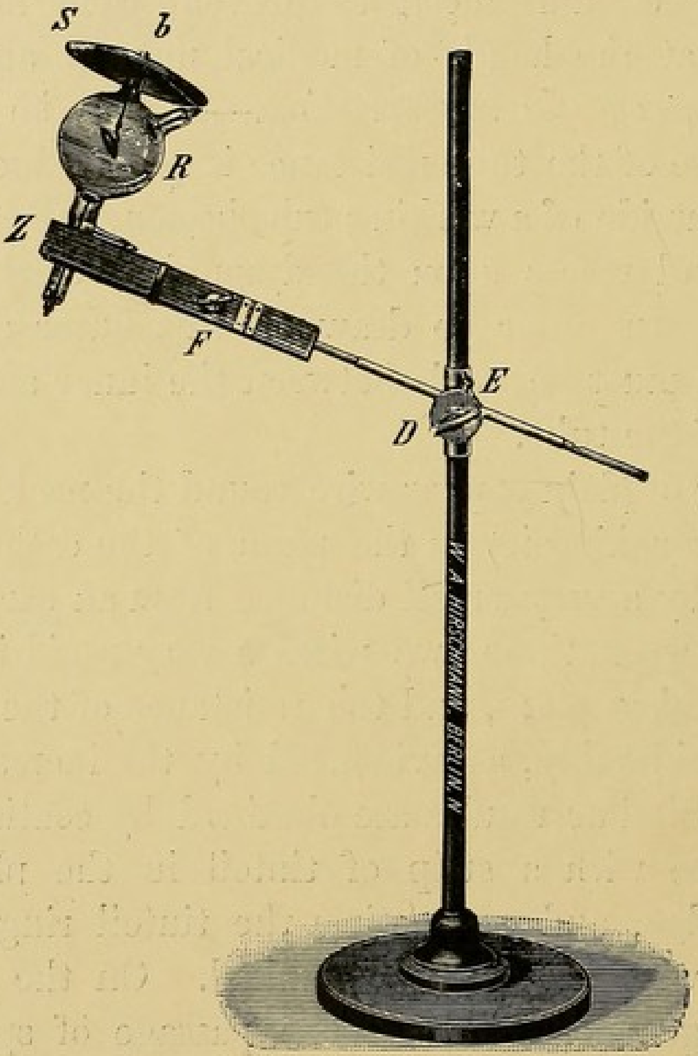


Fig. 49.

of hydrogen as in the case of absorbent substances introduced into an auxiliary vessel and heated either electrically or from the outside. The joint between glass and platinum, however, requires to be effected with very great care so as to prevent any tendency to leakage.

It must, however, be borne in mind that all these various means of regenerating will only serve temporarily, and that a time will come when the only remedy lies in the complete re-exhaustion of the tube. This again presupposes that the tube to be thus treated has not, during its period of actual work, become too much blackened, *i.e.* if the inside of the bulb has become coated with a deposit of disintegrated metal from the electrodes, it is not worth while attempting re-exhaustion.

Before we deal with the manipulation of tubes in general, we have to consider several additional modifications, the construction of which has been dictated by the recent introduction of mercury-jet and electrolytic interrupters.

As we have seen, such interrupters produce exceedingly powerful discharges across the terminals of the secondary of an induction coil, and it is obvious that in order to withstand such quantities of energy the ordinary tube must be greatly modified.

One of these modifications had indeed been in extensive use previous to the application of heavy discharges : even with the ordinary forms of contact breakers it had been found impossible to place the platinum anti-cathode into the exact focus of the cathode rays, as the heat effect was so great as to immediately perforate the platinum. On the other hand, in order to reduce the source of the X-rays in a tube to a point, which is a condition essential, as we shall see, to the exact localization of tiny foreign objects, this focal position of the anti-cathode had to be adhered to. The remedy lay in the provision of anti-cathodes made of highly refractory metals such as osmium or even an alloy of osmium and iridium ; a small lump of this material, suitably clamped between platinum discs and mounted in the exact focus of the cathode will not only withstand the heat of the ordinary cathode stream but also those vastly more powerful discharges obtained by the employment of the above-mentioned new breaks. Against the general use of such tubes must, however, be placed their very high initial expense and their liability to rapid deterioration of vacuum.

Another construction is based upon the idea to keep the anti-cathode at a low temperature by causing either a stream of cold water to circulate through a tubular anti-cathode or by making the anti-cathode hollow and filling it with a quantity of water, making suitable provision for the escape of the steam generated during working.

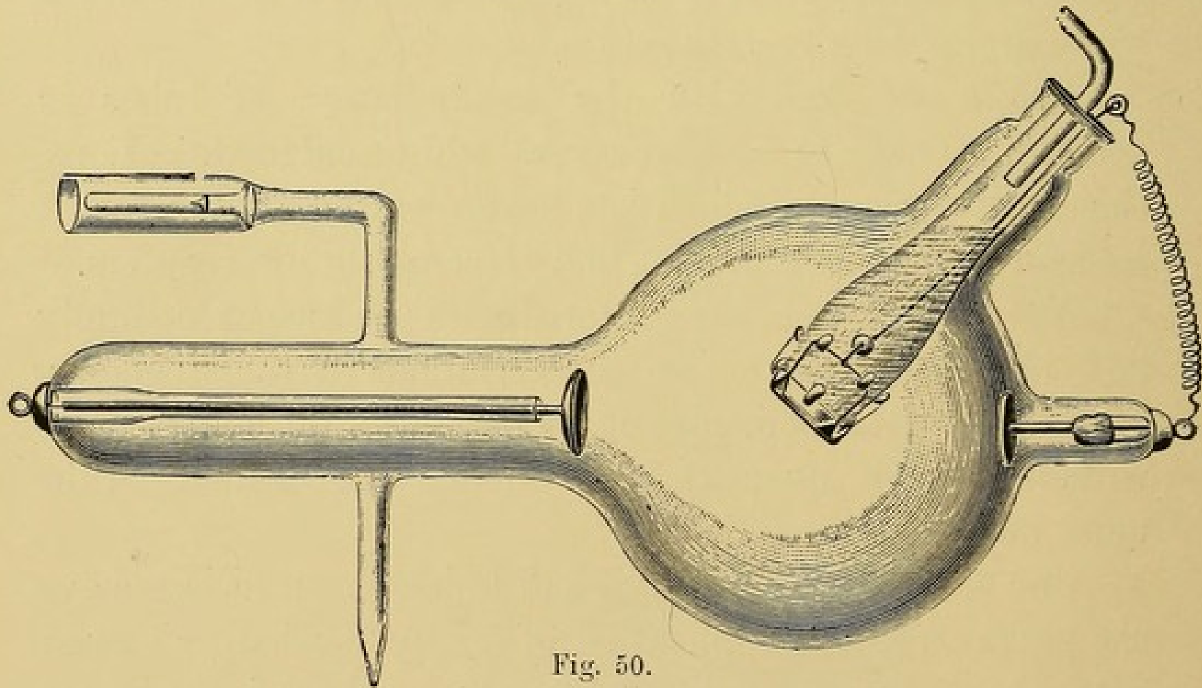


Fig. 50.

The earlier form in which the anti-cathode itself was made hollow suffered from the liability of developing leakage where the anti-cathode was joined to the glass tube. Fig. 50 shows an improved form without a joint; the anti-cathode consists of the usual flat disc, which, however, is fastened by means of platinum wires to the flat bottom of a cylindrical glass vessel fused into the main tube. Between the two a disc of porcelain or steatite is clamped: it absorbs the heat generated on the anti-cathode and conveys it gradually to the cooling vessel, the water in which, even if the anti-cathode be brightly incandescent, does not attain a very high temperature.

Apart from these special designs, we now possess very useful heavy discharge tubes, which only differ from the ordinary tubes in the substantial construction of the electrodes and especially the heavy backing and support of the anti-cathode; these alterations, of course, requiring special care and thoroughness during the exhaustion of the tube, so as to prevent the liberation of occluded gas in the finished tube under the influence of the heavy current passing through.

The construction of coils shown in Fig. 19 gives us also a convenient means of securing for a given tube the best conditions of working with electrolytic breaks. Connecting all primary layers in series, we reduce the spark length, and by employing at the same time a very short anode we reduce the current and are able to use soft tubes.

Connecting the primaries in groups and employing a somewhat longer anode the combination is suitable for medium tubes.

Connecting all the primaries in parallel and using long anodes, we increase the primary current and have the best conditions for working hard tubes.

MANIPULATION OF TUBES.

Some of the conditions which have to be observed when using tubes really follow from their peculiarities and constructions as above described; in addition we give a few other rules which may be of advantage to the beginner.

The tube should be perfectly dry and free from dust, which is apt to quickly settle upon it when working (due to the electrostatic charge of the tube). The wires or cables connecting it with the secondary terminals of the induction coil should be so arranged that throughout their length they are sufficiently far apart to prevent sparking across; they must not touch any conductor, and, most important of all, they must be kept clear of the walls of the tube, as otherwise there is every chance of the latter becoming perforated by a spark passing through the glass wall.

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, whilst the proper appearance is that of a semi-globe strongly fluorescent in front of the anti-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 resorted to in almost every instance, 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, possibly injuring the latter. If, however, we provide a spark gap between the secondary coil terminals, then in the foregoing instance the discharge would pass by preference across this gap.

Again, when the vacuum of the tube rises, as it always does after a time, sparks will begin to pass across the spark gap, leaving the tube itself practically inert, and thus indicating the necessity of resorting to one or the other mode of regeneration in order to restore previous conditions.

In some cases, especially when working with a Wimshurst machine, a double spark gap must be provided in series with the tube, *i.e.* one on either terminal. It has often been observed, and recent investigations by Mr. Gardiner have proved, that by means of such spark gaps a soft tube excited by a Wimshurst machine can be made to give out hard rays at will, almost to as great a degree as by increasing the vacuum.

The heating of tubes for the purpose of lowering their vacuum should be performed with caution, so as to effect just the right amount of regulation. The best place to apply the flame is somewhere behind the cathode; it is a bad plan to force a tube which has become very high by too frequent or too intense heating, since the alteration in vacuum is then only slight and temporary and since the glass may become sufficiently softened to enable the outer atmospheric pressure to crush it.

In conclusion, it should be remembered that the vacuum of a tube, and consequently the nature of the rays emitted from it, are by no means constant, even though the tube may not have been working.

The temperature and amount of moisture in the air greatly influence the above characteristics. So does the period of rest elapsing between two periods of work, and that to such a degree that tubes which are found to be almost spent and past the ordinary help of regeneration, may, if left unused for some considerable time, be found most serviceable on being again tested.

CHAPTER V.

ACCESSORIES.

Besides the instruments proper for generating and utilizing the new radiation, there are several accessories which go to complete the radiographer's outfit or to facilitate his work.

Some of these, such as measuring instruments, rheostats, etc., we have already touched upon in Chapter II.; of the others we will now describe only some typical constructions, since the variety of design would make any attempt at completeness a useless task.

To start with the simplest, we must mention the "pole finder." In most cases it is based upon the electrolytic decomposition of a solution by the electric current.

In one form the solution is enclosed in a short glass tube, into which platinum wires convey the current. As soon as the connection with the source of the current is established, the liquid at one of the platinum wires turns pink, indicating that this wire is connected to the negative pole; by shaking the tube, the color disappears again. Less expensive and equally convenient is Wilke's "pole-finding paper." Strips of absorbent paper are saturated with the above solution and dried; the solution being non-poisonous, the strip may be moistened with the tongue, and on applying two wires, leading to the poles to be tested, the appearance of the red spot indicates that the respective wire is negative.

Such pole-finders will be found invaluable when attempting to charge accumulators from the mains or when using an electrolytic break. In their absence, however, an ordinary compass needle will serve to indicate the direction in which the current flows in a circuit. If we lay the compass on the wire in such a way that when the needle is at rest the wire is in the plane of the needle, then the current is flowing in the direction south to north when the north pole turns to the right.

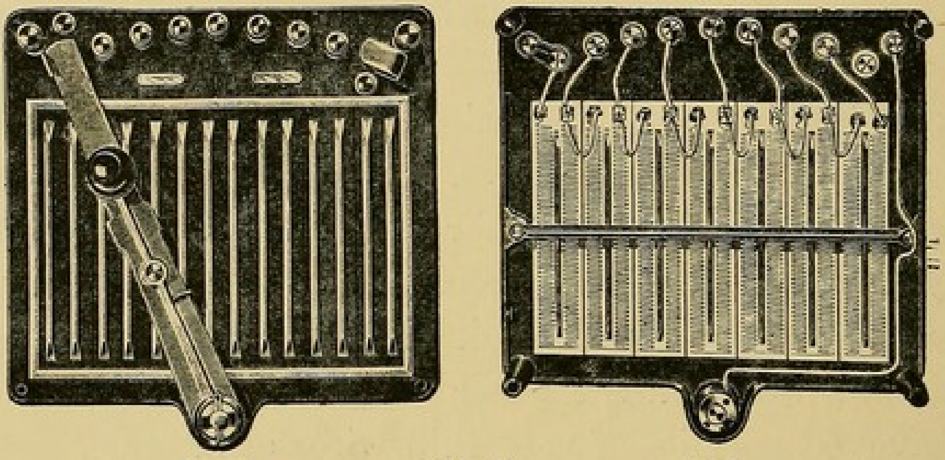
The metallic connections between the various instruments comprising the electrical outfit are effected by copper wires; all the connections in the primary circuit should be stout enough to carry the heaviest current which may be used without getting warm; the insulation need not be very effective (double cotton covering) if care be taken to prevent any crossing of the wires. As a rule, however, good electric light wires are used for the purpose.

Quite different conditions obtain in the secondary circuit of the coil; its very high E.M.F. requires the highest insulation, whilst on the other hand the small current to be conveyed permits of very thin wires or strands.

If the distance between tube and coil is only a matter of a few inches or so and the wires do not touch any object, gutta-percha-covered wires will do; if the tube (as is generally the case in practical work) is several feet or yards from the coil, a very carefully insulated cable should be used to prevent stray discharge between the poles and to avoid brush discharges into objects which are in contact with or support the cables. But even the best insulation is far from perfect, and the operator should make it a rule never to permit the cables to touch any metal or to touch the cable with the body whilst the coil is working. It is a good plan to keep the cables throughout their length a certain distance (maximum spark length of the coil) apart by means of stays or bridges made of insulating material.

Rheostats consist essentially of suitably disposed lengths of wire (of a metal possessing high specific resistance) subdivided into sections and provided with a means of placing one or more of these sections into circuit. Figs. 51 and 52 illustrate two of the most modern types in which the resistance wires have been replaced by resistance bands embedded in an insulating layer of enamel or arranged at the back of iron plates; this arrangement secures compactness and protection from fire.

Better still are the rheostats on the "Jenny" system, in which the wires are embedded into fireclay, round which metal frames are cast. This construction is practically indestructible and mechanically stronger than enamel rheostats.



Front. Fig. 51. Back.

Besides a rheostat of some form or other, each installation on the supply circuit must contain a single or double pole "fuse." This very simple apparatus consists essentially of a piece of wire or strip made of an easily fusible metal and of such cross section (or thickness) that if the current through it exceeds a certain pre-arranged amount the fuse gets heated and eventually fused, and in so doing interrupts the circuit.

Fig. 52.

This is a most important point, as, in running coils from high-voltage circuits, many circumstances may arise under which the coil would be damaged or over-strained if not protected by a fuse. Provision is generally made whereby the burnt-out fuse may be readily replaced by a fresh one without the help of tools.

Every installation should also be provided with an *ampère-meter* (Fig. 53), an instrument measuring the amount of current flowing in the circuit, by the deflection of a pointer on a scale. It consists essentially of a coil of insulated copper wire, which, when current is passing through it, acts upon some form of magnet, pivoted on its centre, and thus rotating or deflecting the light pointer connected with it; the ampère-meter is wound with comparatively few turns of wire (heavy enough to carry the maximum current to be measured), whilst the "*volt-meter*," which measures the E.M.F. or the pressure, is wound with a great many turns of fine insulated copper wire, being in other respects constructed exactly like the ammeter. In addition, some form of *switch*, by means of which the current may be turned on or off is generally inserted in the circuit.

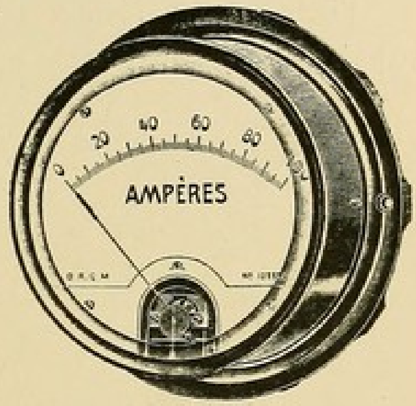


Fig. 53.

Tube holders.—For experimental work, an ordinary wooden Bunsen retort-holder (Fig. 54) 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 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 may be dangerous to the patient and also to the tube, which gets easily perforated. Figs. 55 and 56 show good holders having all necessary movements.

Except in those cases where a radiogram has to be obtained whilst the patient is in bed, or where we only require to examine or radiograph the extremities, some suitable table or couch should be provided. There are a variety of excellent constructions which show more or less the same principal features: A strong wooden frame over which sailcloth or thin leather or some equally strong yet radioscopically transparent material is tightly stretched; the tube is then placed below the couch, and the patient reposing on the couch may be very conveniently examined

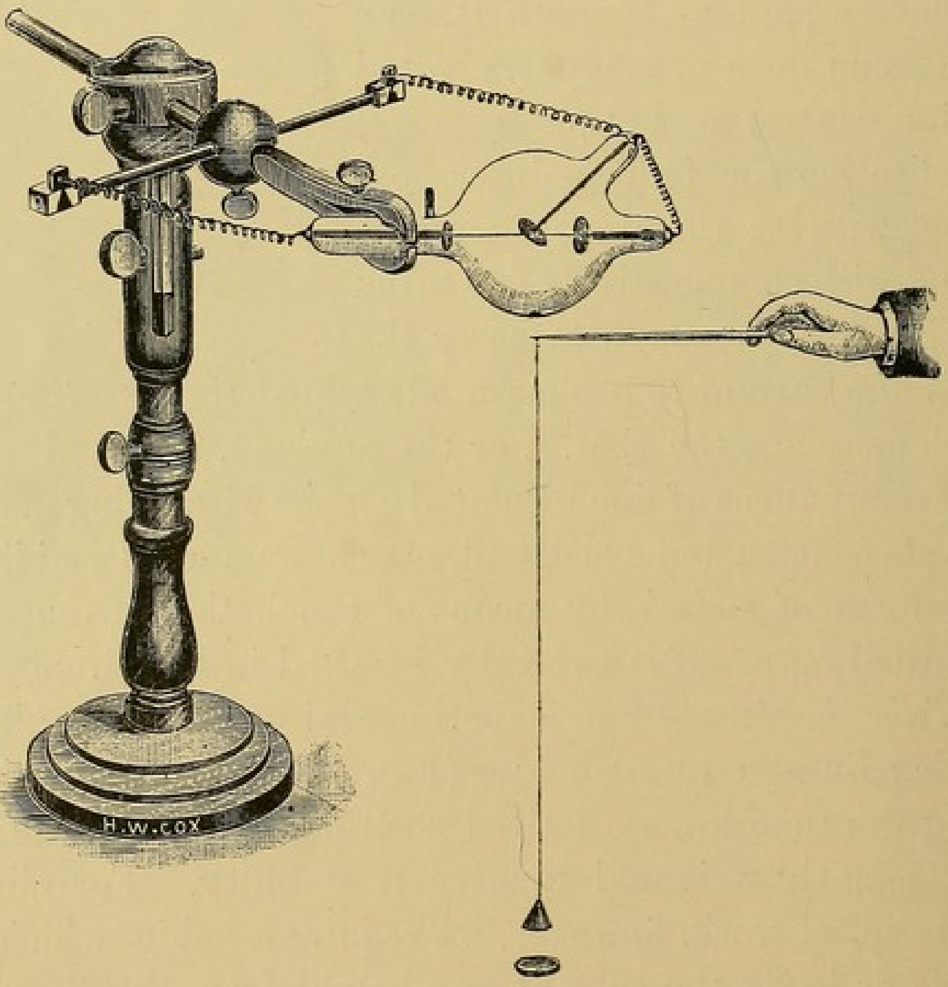
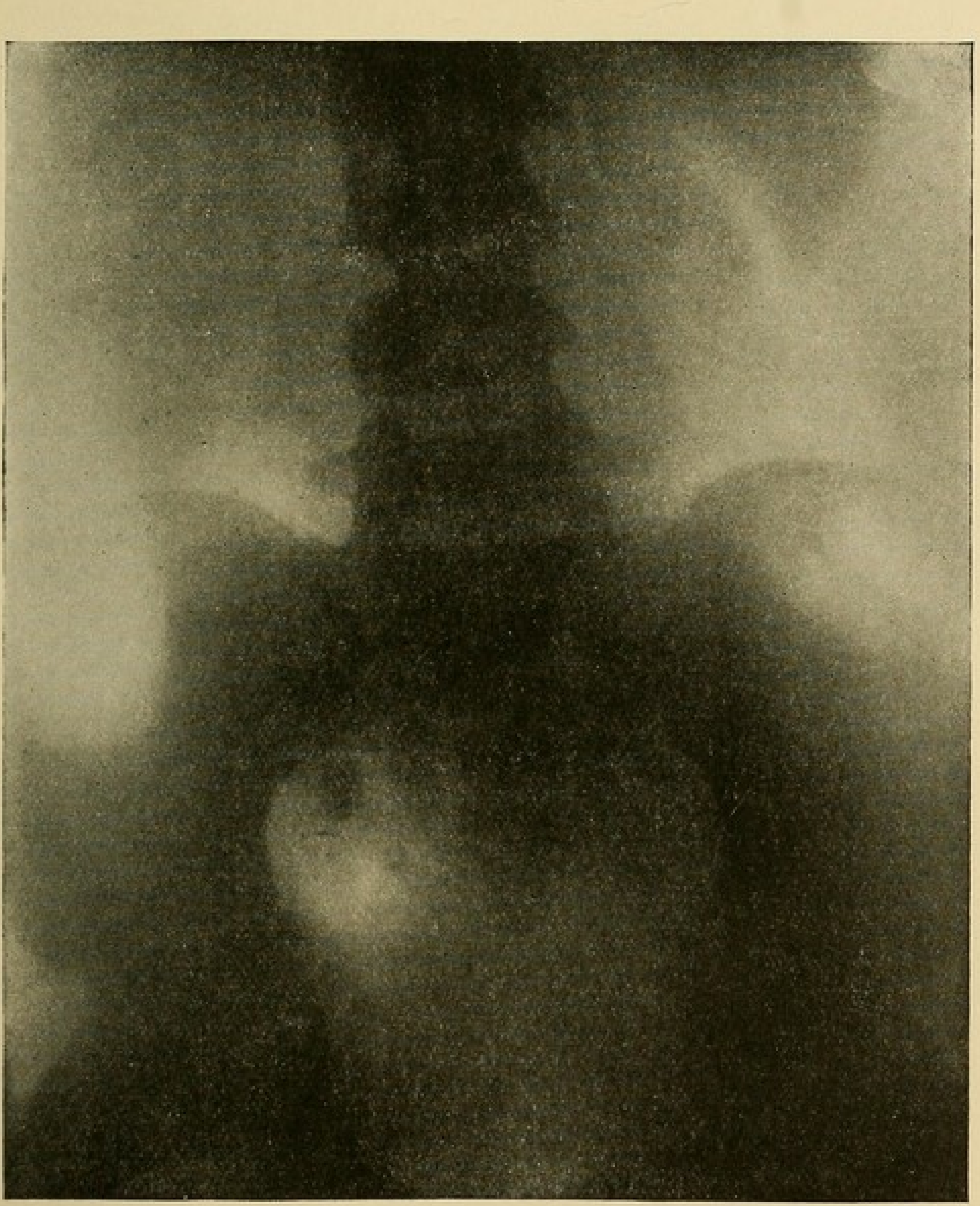


Fig. 54.



Radiogram of Stone in Ureter.
(By Dr. C. Lester Leonard, of Philadelphia.)

with the fluorescent screen. When taking radiograms the transparent material may be covered over with a board (resting on the sides of the frame), which affords the necessary support to the photographic plate, and the tube is placed—as usual—above the patient. Frequently the

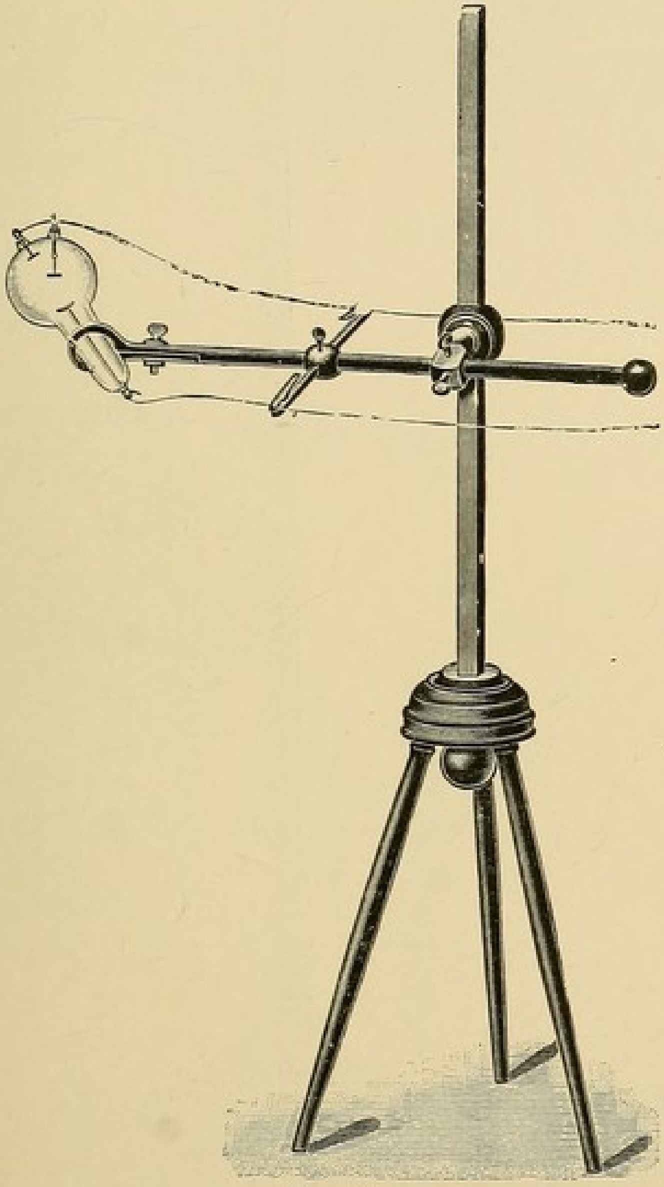


Fig. 55.

couch is fitted with a plate-holder so that the tube may remain below and the plate-holder can be brought in contact with whatever part has to be radiographed. This is rather an advantage, as after examining with the fluoroscope the patient need not alter his position and the tube need not be moved in order to take the radiogram. It is impossible here to enumerate the special forms of supports, etc., designed for the purpose: a glance through the various makers' lists will show what is best for one purpose or the other. We must, however, briefly allude to those couches which are employed to obtain stereoscopic

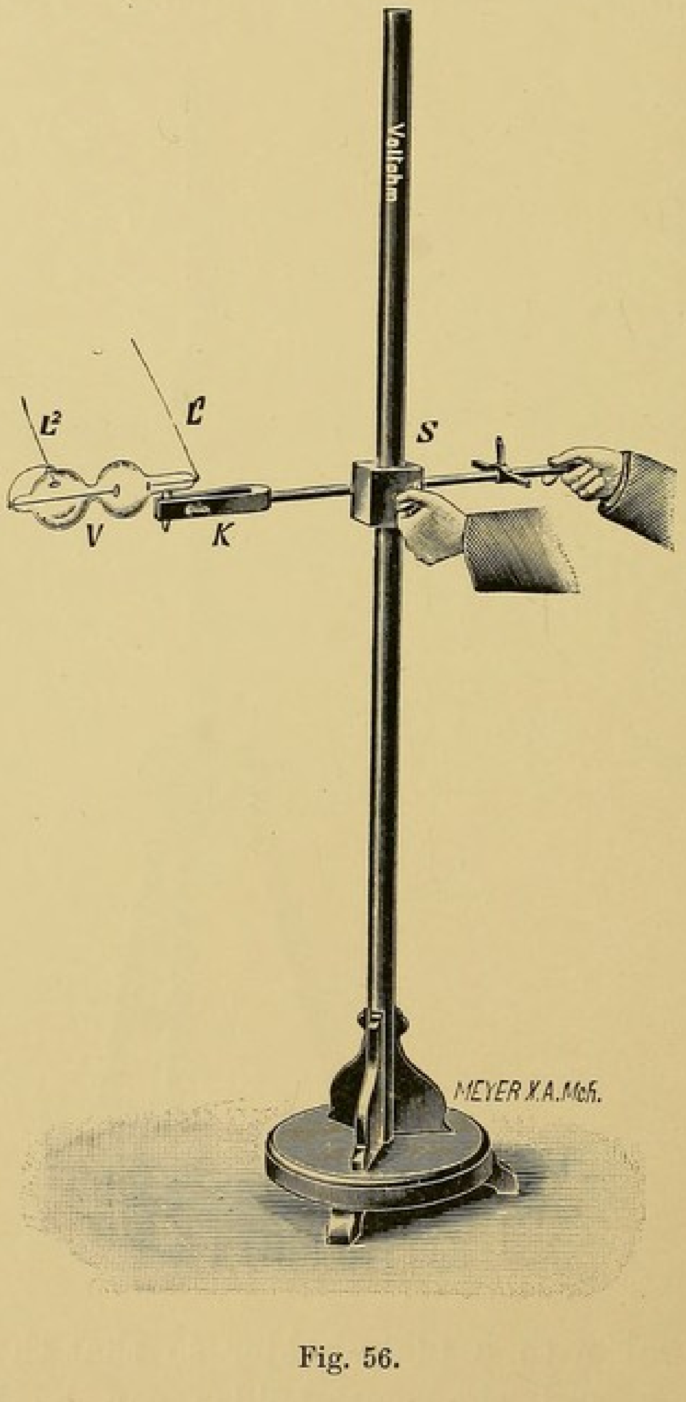


Fig. 56.

radiograms and for localization (see page 161). In this case it is essential that the tube-holder and the plate-holder should be firmly (yet adjustably) connected to each other in order to secure certain relative positions between tube and object. The plate-holder must be so constructed that it is easy to substitute fresh plates without moving the patient, and the holder must possess cross and orientation

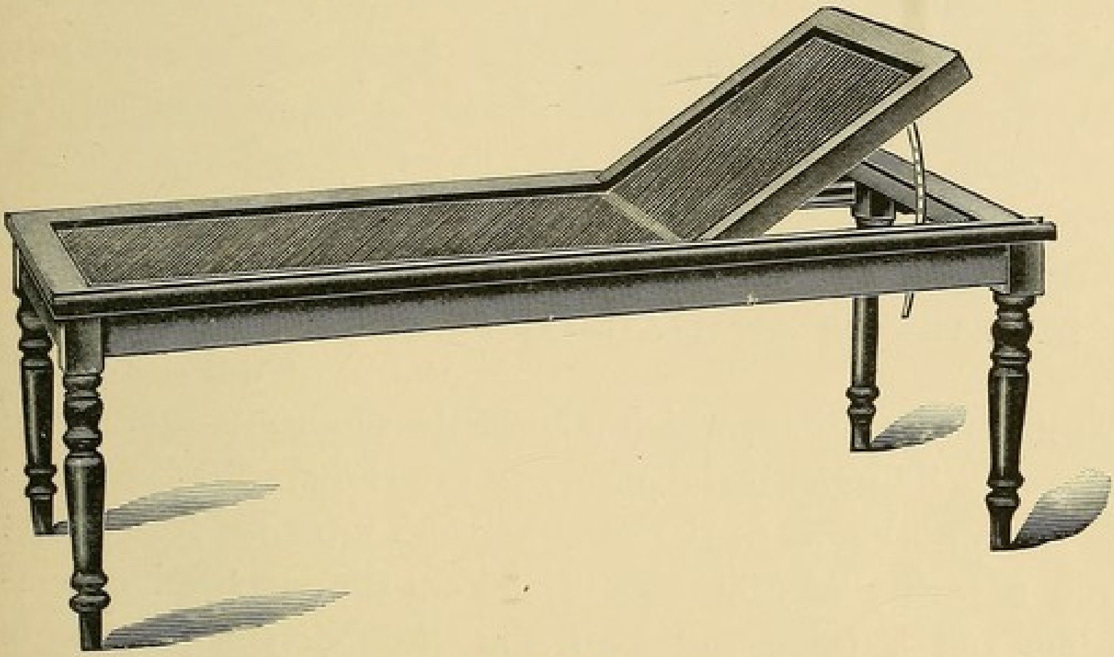


Fig. 57.

wires as set forth on page 162. Tube-holder and plate-holder move simultaneously, should it be required to bring

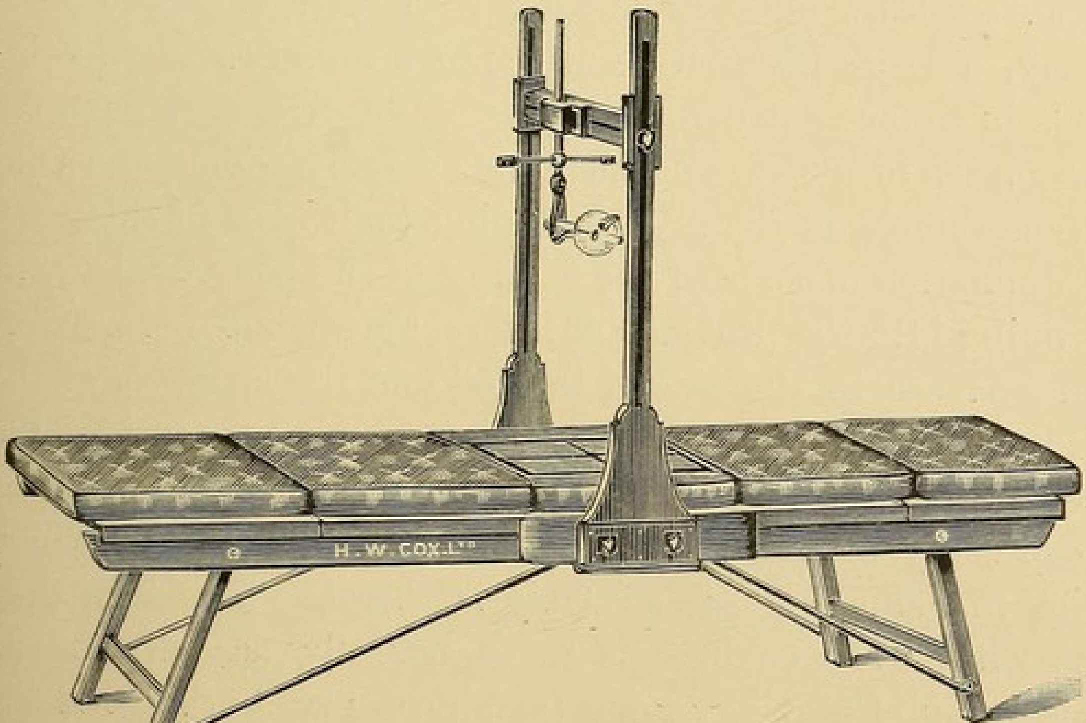


Fig. 58.

the latter beneath (or above) some particular part of the body.

CHAPTER VI.

DIAGRAMS OF INSTALLATIONS: DETERMINATION OF SIZE.

THE considerations which govern the determination of the size of a Röntgen installation are threefold. Firstly, there is the question as to the scope of work intended; secondly, the necessity or otherwise of making the installation portable, and last but not least, the all-important question of initial outlay. When speaking of the scope of the work intended, we have to bear in mind that although even a small coil with its simple accessories may be sufficient to deal, at least radiographically, with all the parts of the body, a large installation will prove infinitely more valuable in so far as it permits of the application of radioscopic diagnosis to a degree which considerably widens the field of usefulness of the rays, including, as it does in this case, examination of some of the cavities of the body, and so extending into the province of internal medicine. Moreover, an increase in the size of the coil and the inclusion of the most perfect forms of accessories permit of considerable reduction in the time of exposure, and in some instances (especially when utilising those powerful discharges which the introduction of electrolytic breaks has furnished us with) even enables us to successfully accomplish the recording of moving organs (respiratory system). Besides, the possession of a powerful coil, in particular, is getting more and more imperative, since such coils are destined to be most extensively employed in connection with some of the latest developments of physical therapeutics (high frequency treatment and therapeutic X-ray action), and thus the installation can be more economically utilised than would be the case if X-ray work only were to be occasionally practised. Broadly speaking, then, unless portability be an essential, the installation should centre round a 12-inch (or at the least a 10-inch) coil; for hospitals which can boast of a special X-ray room, and which are on a continuous-current circuit, the provision of a 16-inch, or, if possible, a 20-inch coil is strongly recommended.

Wherever the X-ray apparatus has to be frequently moved, be it to patients' houses or for campaigning purposes, portability is of course the most important factor, to which all other considerations have to be sacrificed.

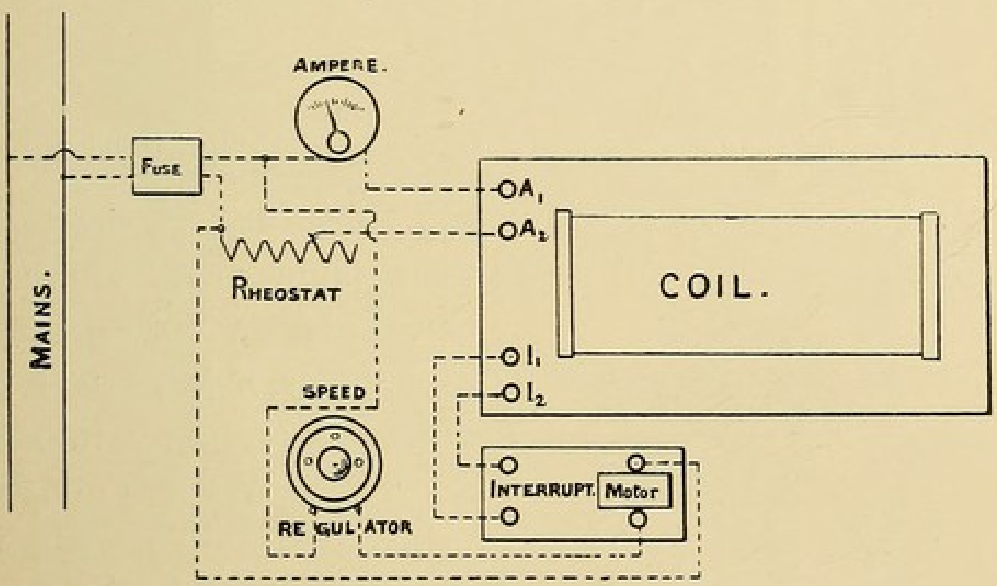


Fig. 59.—Connection of coil with mains using independent interrupter.

Unfortunately the weights of both coil and battery (whether primary or secondary) cannot be reduced below a certain minimum unless durability and capacity are endangered, so that a 12-inch coil becomes unpleasantly large, and generally speaking we have to content ourselves with a 10-inch or an even smaller coil. As regards the question of initial expense, it should be remembered that although the expense of the coil proper increases disproportionately with the output of the latter, the outlay

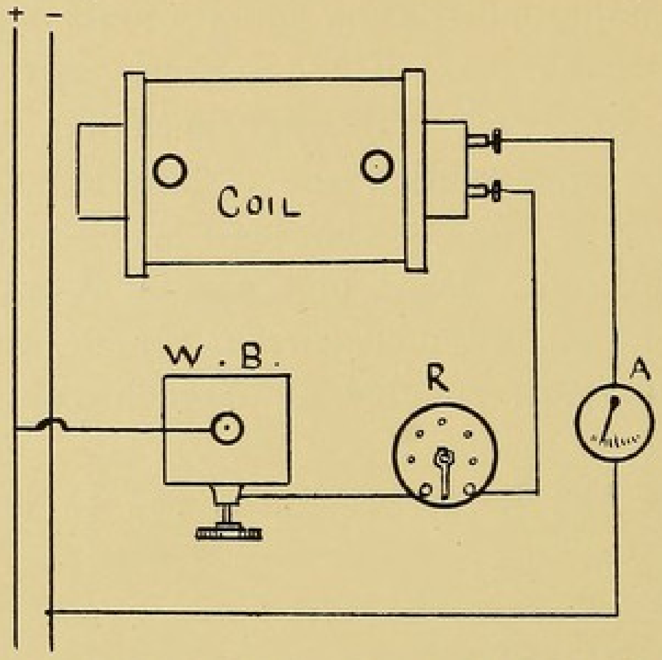


Fig. 60.—Connection of coil to mains using electrolytic interrupter.

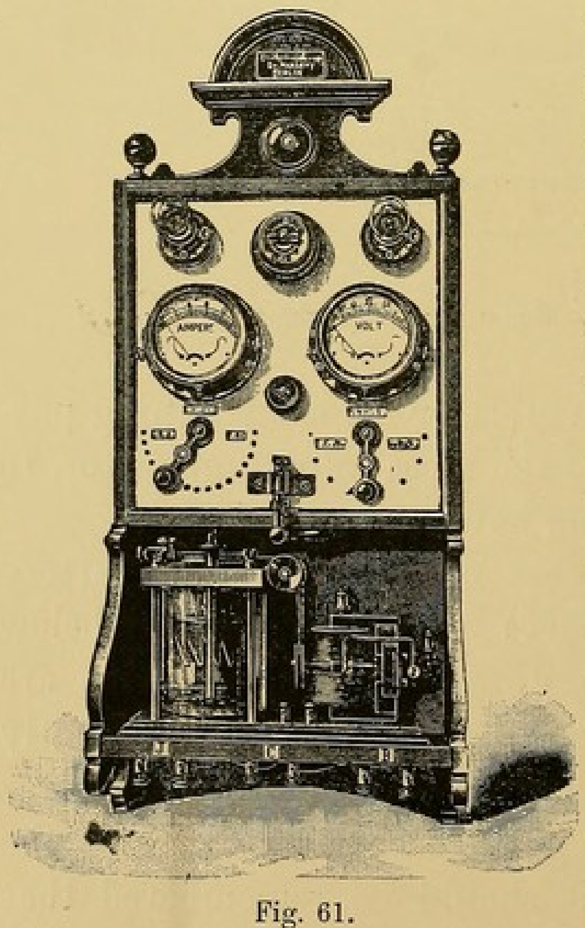


Fig. 61.

for the remaining accessories, such as interrupters, measuring and controlling instruments, tubes and photographic accessories, remains practically the same whatever be the size of the coil selected; moreover, a large coil permits of economy in many ways. We are enabled thereby to utilise a given tube for a much longer period, because if the vacuum has risen with age and use, the large coil will be able to force the secondary discharge through it when on a smaller coil the tube will no longer respond; the reduction in the time of exposure which a large coil permits, of course signifies a considerable saving both in the amount of energy taken from the source of the current, and also in the wear and tear of the apparatus, more especially the tube; lastly, this reduction in the time necessary for, say, the taking of radiograms of the trunk cannot fail to appeal to the busy practitioner, and also strongly impresses the patient who is certain to consult that medical man whose tools are the most perfect and who gives his patient a minimum of inconvenience. The size of the coil decided upon and the selection of accessories made, it becomes necessary to electrically connect the various items, and we give in the following pages a number of typical diagrams illustrating the various ways of effecting these connections. Where the installation is a permanent one, such as in the consulting room or the hospital X-ray room, it is a matter of both convenience and appearance to arrange the wires

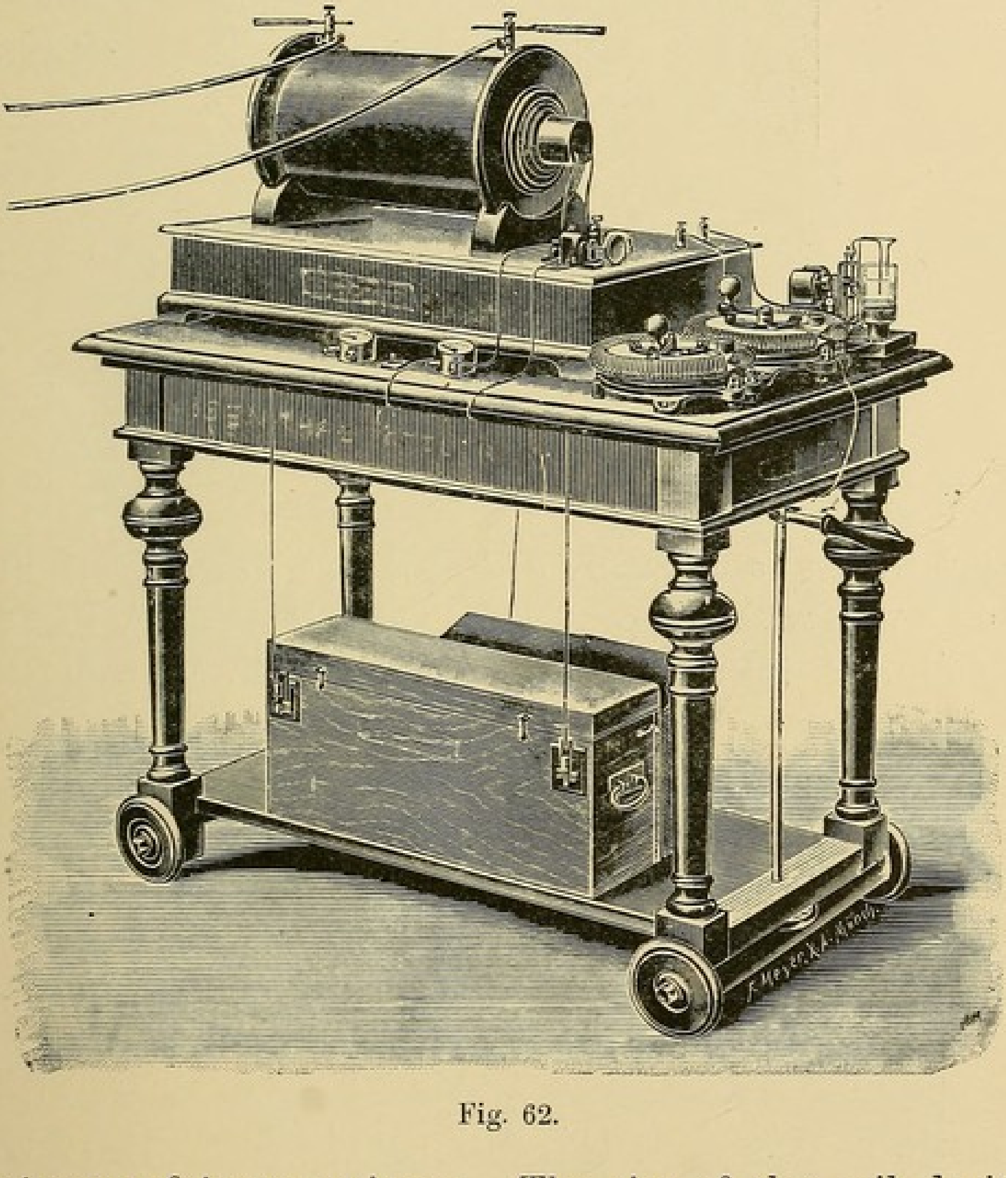


Fig. 62.

connecting the apparatus as well as the instruments themselves, so that a certain amount of manipulative simplicity and neatness is secured. In such cases all instruments except the coil are usually collected on a switchboard hung up on a wall with the connections at the back (see Fig. 61), or coil and instruments are fitted inside a cabinet or on a table (Fig. 62). The latter arrangement has the advantage of enabling the whole installation to be moved about, as through the various wards of a hospital. If the

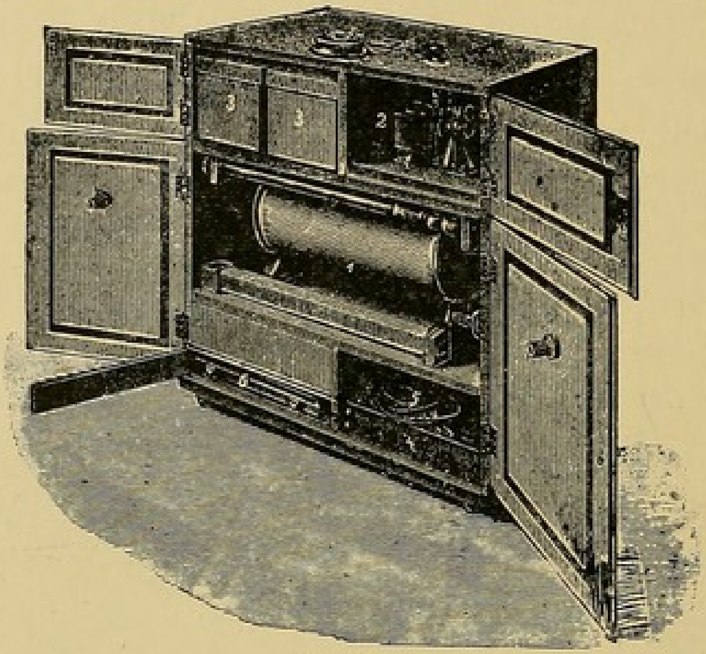


Fig. 63.

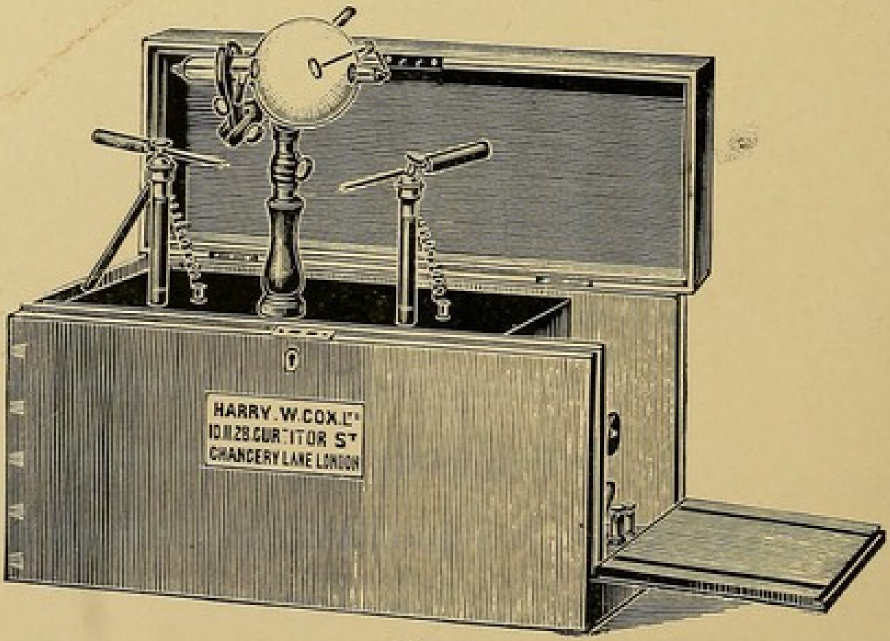


Fig. 64.

installation is worked from the mains then—in the latter case—several current plugs should be provided in the various rooms where it is intended to use the switch-board table.

The separation of coil and switching gear such as is represented in Fig. 61 is to be strongly recommended, especially when we are dealing with very large coils, as it minimises the danger to the operator arising from close proximity to the high voltage of the coil itself. Installations which have to withstand a great deal of rough usage and frequent transport may be advantageously arranged in strong cabinets, with all the necessary adjustments and manipulations to be effected from the outside by means of special keys (Fig. 63); this prevents unauthorised persons from tampering with the instruments and affords a certain amount of protection against mechanical damages.

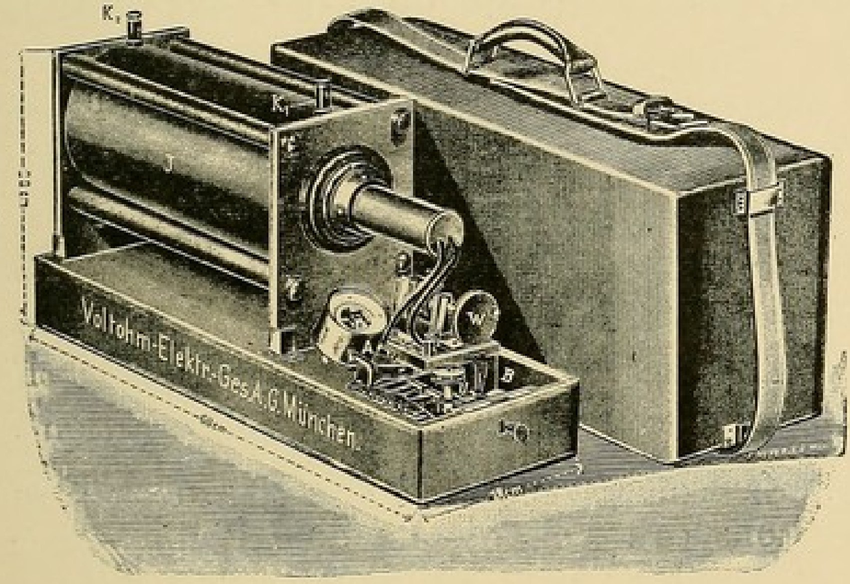


Fig. 65.

Figs. 64 and 65 show two forms of "Portable Coils."

CHAPTER VII.

MEANS OF DETECTING AND UTILISING X-RAYS.

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 physical and the chemical effects of the rays, corresponding with which the practical application of Professor Röntgen's discovery has been developed in two distinct directions—Radioscopy and Radiography.

I. Physical Effects.

The physical manifestation of the rays is twofold:—Ionisation of air and other insulators, and fluorescifient action. The former—although of no direct practical applicability—is by far the more sensitive means of detecting the existence of X-rays. An insulated and electrically charged body loses its charge when Röntgen rays impinge upon it.

As an explanation of this phenomenon it has 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. Professor 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, hydrogen sulphide, chlorine, and mercury vapour. Solids, such as paraffin and ebonite, also become for a short time conductors of electricity.

For purely physical experiments and quantitative determinations as well as for standardisation of the radiation given off from a tube under certain conditions, this effect is always resorted to (Electroscope).

The second physical effect of X-rays, *i.e.*, their ability to produce fluorescence and phosphorescence in certain compounds, is of immense importance, and as a matter of fact we owe the discovery of the rays to an accidental observation of the fluorescence of a piece of prepared paper.

Now fluorescence is another form of physical energy having its origin in several kinds of primary energy. It has been produced—like phosphorescence—in suitable substances by stimulation by ordinary light rays, by the invisible ultra-violet rays, by electrical stimulation, by heat, and now lastly by that radiation with which we are immediately concerned in this book—X-rays. Whenever a new form of energy is derived from another (primary) form, as in the present instance, the efficiency of the conversion—that is the intensity of the new manifestation of energy—becomes greater the more completely the old form of energy disappears or, rather, becomes absorbed in the process of conversion. In other words, if for some purpose we wish to produce a new effect from a given primary cause, we must endeavour to make the conversion a thorough one, choosing such methods that, if possible, the old effect entirely ceases. This point is rather important, as it refers in our case both to the fluorescifient action of the rays and to the chemical (or photographic) action. Whatever be the nature of the fluorescent preparation we employ, it is evident that it should be the more suitable, the more opaque a given thickness of it is to X-rays or—what is equivalent to this—the higher its atomic weight. This condition pointed to the use of compounds of the noble metals, and, as a matter of fact, for purely fluorescent purposes we use compounds of platinum nowadays almost exclusively.

Platinocyanide of potassium was first employed for radioscopic purposes by Mr. Herbert Jackson. It is 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 color.

Platinocyanide of barium, the substance originally employed by Professor 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 color of its fluorescence is a bright greenish yellow.

Tungstate of calcium, as first suggested by Edison, is, as a rule, inferior to the cyanide salts. Much, however, depends upon the method of peparing it, and for the sake of the photo-active color of its fluorescence (pale purple) combined with its comparative cheapness it is being much used for intensifying screens (see p. 147).

The double fluoride of uranium and 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, or linen, 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 is generally backed with thin ebonite or black paper for better protection against mechanical injury and to exclude ordinary transmitted light. The barium or tungstate screens are protected from atmospheric influences by a coating of varnish.

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 more further screens, even at considerable distances.

This fact suggested to Dr. Macintyre the use of coarser crystals for screens, which indeed produced greater brilliancy in the image, but, unfortunately, at the expense of definition. Another, rather better, plan, is to retain the fluorescent material in its minute crystalline form and to apply two or three layers to the screen ; but even then the absorption of the Röntgen rays is far from perfect, and considerable improvement in the brilliancy of the screen image may only be looked for when a fluorescent preparation more opaque to X-rays can be found, although early American experimenters seem to have already subjected an enormous number of likely chemicals to experiment.

Another direction in which, possibly, improvements may be looked for, is indicated by the combination of fluorescence with phosphorescence. Fluorescence, as we know, is a form of luminous energy subsisting only whilst its primary cause lasts, *i.e.*, it is energy with practically no inertia. We turn on the tube and the same instant the screen lights up ; we switch off the coil and practically at the same moment the screen becomes dark again. (We say "practically" advisedly, because for a very brief period after the emission of X-rays from the tube has ceased, the platinocyanide screen remains fluorescent, or, strictly speaking, phosphorescent.)

Phosphorescence, however, is energy with considerable inertia; when we start the exciting cause (light, heat, mechanical or chemical energy, or X-rays) the luminosity which results does not at once attain its normal intensity; sometimes considerable insolation is required before this intensity is attained; likewise, when shutting off the primary cause, the phosphorescence does not subside, but continues for an appreciable time (with, of course, ever diminishing intensity).

Here, then, we have the chief difference between these forms of luminous energy which are so frequently confused. Now as to the bearing on the question of improvement in fluorescent screens:—With a purely fluorescent material the illumination of the screen is independent of the time during which the tube acts upon the preparation; with phosphorescent material we add to the stimulus given by the tube in a certain time another stimulus by the next impulse, and since the luminosity due to the former has not completely subsided at the moment when the second impulse is given, it follows that the luminosity must increase and thus become a function of time up to a certain maximum, which depends upon the character of the preparation and the rapidity of the stimulations or interruptions in the coil.

Sulphide of zinc is a useful phosphorescent material, but attempts to use it alone for the production of a screen have led to no satisfactory result, since the initial luminosity is insufficient, and for the radioscopic examination of moving organs in the body (such as the heart and diaphragm) would probably introduce errors in the direction of apparent enlargements (due to the after-glow of the material).

Possibly a combination of fluorescent and phosphorescent substances in the proper ratio and giving out light of approximately the same color will therefore ultimately be employed for the preparation of our screens for diagnosis.

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 decided 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 Daguerreotype 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 bromo-iodide and gelatine chloro-bromide, all with alkaline development.

But here, again, we must confess that our methods are barbaric, so to speak, and that the efficiency of this chemical conversion is deplorably low.

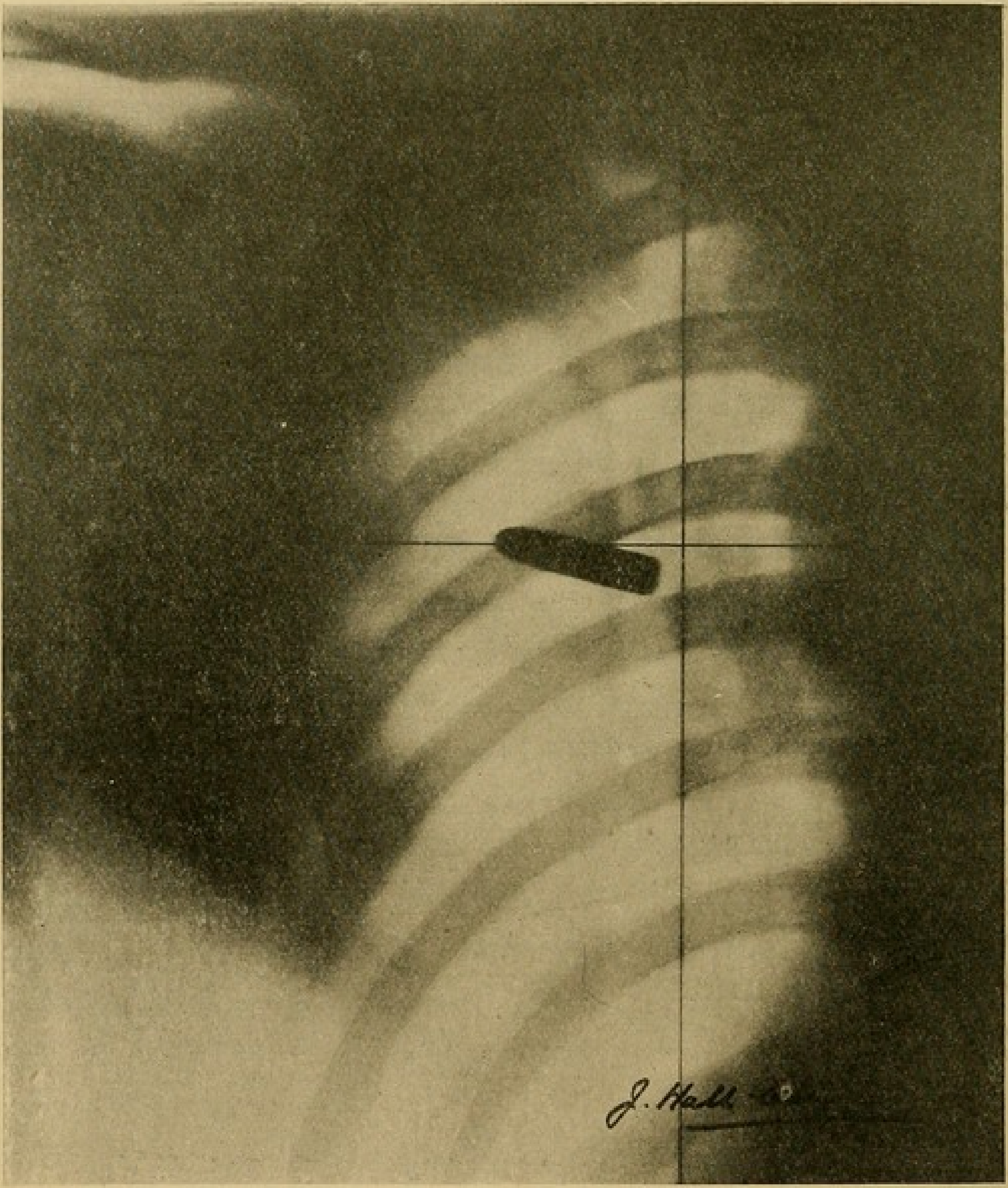
On page 123 we have shown that to obtain efficiency, the primary energy or cause should be absorbed as completely as possible. The fact, however, is that the X-rays suffer but very little absorption in the emulsion, but pass through in sufficient intensity to affect other emulsions. This can be shown by superposing a dozen or more films without substrata (Sandell films) and exposing to X-rays. On development all the films will be found affected. It may not be amiss to refer here briefly to an important chapter in ordinary photography which formerly presented a striking analogy to our present day difficulty of efficiently registering photographically the X-rays.

Until the year 1870 it was practically impossible to photographically reproduce a large portion of the visible spectrum; only green, blue and violet rays were able to produce an effect upon the plate. This peculiarity Dr. H. W. Vogel explained by showing that only these colors were more or less absorbed in the cream-colored emulsion, whilst the non-actinic rays, such as red, orange and yellow, passed right through. In order to absorb these, with a view of their exerting chemical action, he dyed the film with the complementary color. Thus, for the reproduction of red, the dye employed was a suitable green, which absorbed all the red rays and forced them to do chemical work in the film. The particular dye used, however, entered into a new light—sensitive combination with the colloid base of the emulsion. For orange and yellow colors, blue or violet dyes were employed. Thus the proper rendering of colored objects in monochrome as well as the foundation of photography in colors became at once an accomplished fact.

Now, what we require for efficient X-ray recording is an emulsion which will absorb the rays—or the equivalent of a dye. Possibly immersion of the plate in some X-ray-opaque solution will solve the problem.

Quite early in the history of radiography attempts were made to embody certain fluorescent substances into the emulsion in order to increase its sensitiveness to the X-rays, but the results were not at all encouraging, since the negatives showed a coarse grain and the gain in sensi-

PLATE IX.]



MAUSER BULLET IN CHEST.

(Radiogram taken at the Imperial Yeomanry Hospital, Dulfontein, South Africa, 1900, by J. Hall-Edwards.)

tivity was not very appreciable. Increasing the thickness of the film (as tried by Lumière) gave better results, but such plates are more tedious to manipulate, as the various reagents penetrate the film more slowly. In this category we must also include the plates and films with emulsions on each side, introduced by Dr. Max Levy: the photographic manipulation, although fairly speedy, is rather inconvenient. Of other so-called X-ray plates and papers we will mention the "Cathodal" plate, by Edwards & Co., Eastman's X-ray paper, Carbutt's films, and latterly, Cadett's X-ray paper.

Mr. Wilson Noble, in his presidential address to the Röntgen Society in July 1900, threw out an interesting suggestion which we quote verbatim. "What we want is an emulsion—whether of silver-chloride or of another salt I care not—that shall be at once sensitive to Röntgen light and more opaque to it, and so retain the rays and make them do chemical work. If silver will not do as a base, probably some other metal will, or another salt than the bromide or iodide may be tried. Considering that we have in this country some of the best plate-makers in the world—men of scientific training, who thoroughly understand the chemical basis on which they are working, men who are never satisfied unless they can bring out something better than what has been done before—it is surely not beyond the bounds of possibility that a plate should be introduced that should be as good for Röntgen light as other plates are for ordinary light. An ideal plate would be one that was insensitive to ordinary light and which could, in consequence, be developed by daylight. I see nothing theoretically impossible in this, but I fear we shall have to wait some time before it is accomplished."

CHAPTER VIII.

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, fitted with a suitable eyepiece (to adapt itself to the contours of the face) at the narrow end, and containing the fluorescent screen at the wide end, either permanently fixed or removable. In a more perfect form the stiff body of the box is replaced by camera bellows and stiffening guides so that we may adjust the distance between screen and eye (Figs. 66, 67, 68).

These instruments, however, when used for larger screens than 10 by 12 inches, 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 anti-cathode pointing towards the observer, and should be in a suitable box, or be otherwise covered so as to exclude its fluorescent light.

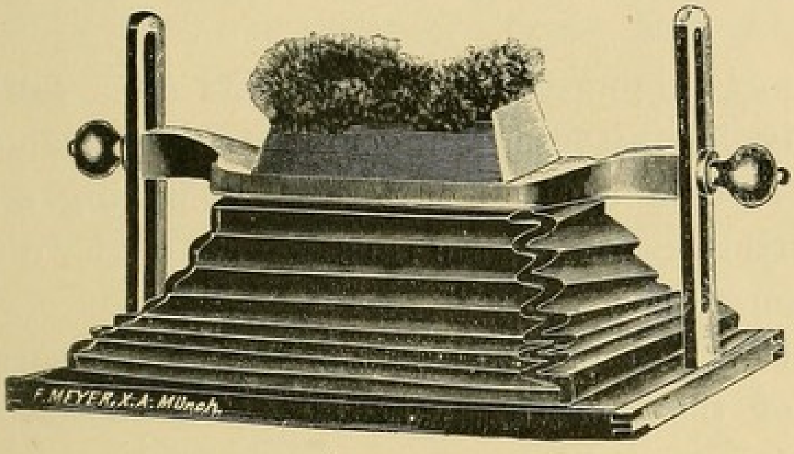


Fig. 66.

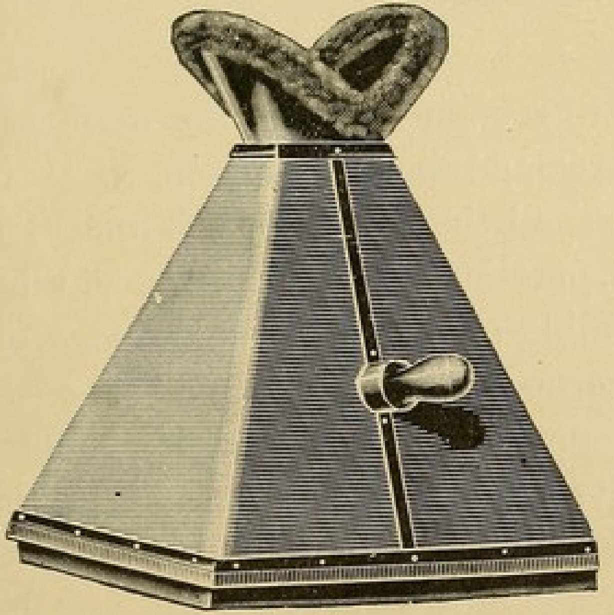


Fig. 67.

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 anti-cathode. 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 interrupter spark by encasing the interrupter in cardboard or paper.

When examining very small objects on a fairly large screen (say, for instance, a finger) it is a good plan to cover the screen with a piece of cardboard having a suitable small aperture cut in it; we thus get rid of the disturbing lateral fluorescence.

In all radioscopic examinations it is important, on account of the comparatively faint luminosity of the screen image, to remain for some few minutes in complete darkness, before studying the screen, so as to be able to fully appreciate all the details of the image, a matter calling for great practice and perseverance, especially where the proper reading of the radioscopic image of the internal organs is concerned. The centre of the screen should be opposite the anti-cathode of the tube, and the distance between the two depends, as we shall see later on, upon the nature and thickness of the parts we wish to investigate.

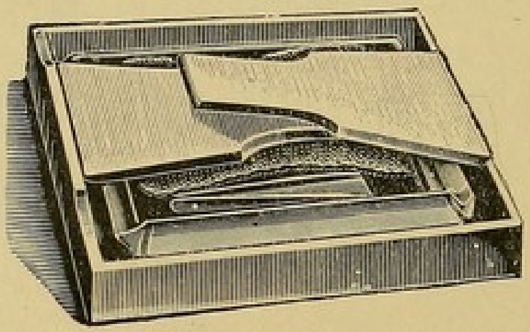


Fig. 68.

The present possibilities of radioscopic examination are very satisfactory, since practically every part of the body may be thus explored; its special field of usefulness is in the study of the respiratory and heart movements which generally cannot be recorded radiographically. Latterly, by the introduction of the electrolytic break and other forms of high frequency interrupters, the utility of the screen has been wonderfully extended. The steadiness of the screen image is now absolute, and this together with the higher luminosity (caused by more powerful discharges through the tube) has removed a great deal of the former uncertainty from this method of diagnosis.

A most important factor in order to secure success in this direction is the condition of the tube; the ideal tube is the one which combines penetration and contrast, two properties which are generally more or less opposed to each other. Penetration (as we have stated in Chapter IV.) increases with the resistance of the tube or the degree of vacuum; contrast, as a rule, however, is only found to be present in soft tubes. Generally speaking, then, the combination of these two desirable qualities—at least to a certain extent, may be looked for in medium tubes, *i.e.*, tubes of such a degree of exhaustion that their resistance is equivalent to about a 6-inch spark between the dischargers. But there exists a condition, the causes of which have not yet been sufficiently studied, when the tube emits rays of great penetration and withal yields a vigorous image both on the fluorescent screen and on the plate. The characteristics of this stage of maximum efficiency are an incandescent anti-cathode with some traces of blue anode-light in the tube. Unfortunately this state of affairs is always more or less transient and the tube soon becomes perforated. Again, the tube has to be selected with a view to the special purpose which it has to serve, unless, indeed, it be of a type which permits of regulation or unless we can influence the character of the emission by modifying the conditions of the supply of current to the tube. For the examination of the thin extremities, or for use on children, whose bones are still somewhat transparent, a tube of low vacuum is better than a highly exhausted one. On the other hand, for the examination of difficult articulations, such as the shoulder joint, tubes of high penetration are indispensable. One tube will seldom meet all the varying conditions which occur in practice, and a selection of tubes of different vacua should always be available. A further reason for this is the opportunity given to other tubes, laid temporarily aside, to recuperate. With the modern types of interrupters we may greatly influence the screen image by altering the "dip" of the contacts or, what amounts to the same thing, by regulating the induced E.M.F. in the secondary of the coil and with it the current passing through the tube; the shorter the contact, the less penetrating—in general—are the rays emitted from a given tube. This control may be made still more pronounced when we use a statical machine as generator. In this case the connection between machine and tube includes one or two adjustable gaps; the longer the gaps, the more penetrative will be the rays, and *vice versa*. Some experiments giving numerical particulars of this phenomenon have been given by Mr. Gardiner in a paper read before the Röntgen Society in March, 1900.

CHAPTER IX.

PRACTICAL RADIOGRAPHY—PHOTOGRAPHIC.

When a photographic plate has been exposed to the X-rays its condition is, so far as is known, similar to that of a plate which has been exposed to light. At any rate, the methods of developing and fixing the image, to make a "negative," and of making prints, lantern-slides, or other transparencies from the negative, are the same as in ordinary photography. For this reason, it is wiser to refer the reader who knows nothing of photography to a good first hand-book * than to attempt to deal with the subject exhaustively here. Still, we propose to treat the subject sufficiently fully to enable a careful worker to learn the developing process without the aid of a skilled photographer or a special hand-book.

The choice of a photographic plate or film must be decided by many considerations. The easiest thing to obtain, and the simplest to manipulate, is the ordinary photographic dry-plate, having a sensitive emulsion of gelatine and silver coated upon glass. Its glass support is convenient to handle in all the operations; and plates are so enormously used for photographic purposes as to ensure uniformity of manufacture, and certainty of always obtaining them from stock and in fresh condition.

Celluloid films have sensitive emulsion similar to that used on the dry-plates, but coated upon a basis of celluloid

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

instead of upon glass. They have the advantage of flexibility, so that they can be placed in close contact with a curved or uneven surface (as a human body or limb), and in the large sizes they may be safely used, say, immediately under a patient lying on a soft or uneven bed, where glass would be broken. The disadvantages of these films are their cost, the fact that they cannot be obtained of the same extreme sensitiveness as the most sensitive dry-plates, and that they do not keep so long.

Double-coated films, with a thickness of sensitive emulsion on each side of the celluloid support, have had some vogue, and in certain cases have enormous advantages: also double films (gelatine only) have been used with much success. As will be seen later, the double-coating has, practically, the effect of doubling the sensitiveness of the film—or enabling the exposure to the X-rays to be reduced by half. Such films, however, need very special handling, and somewhat more complex apparatus in development than are necessary for ordinary plates or films.

Paper films, with the sensitive emulsion spread upon translucent paper, have considerable advantages. They are cheaper than celluloid films; the paper is a chemically inert support, so that the keeping quality and the attainable sensitiveness are probably quite equal to those of glass plates. The paper support is usually not quite so transparent and structureless as glass, so that there is a slight loss in printing from the negatives unless the developed film is "stripped" from its support. If this is done, it may be mounted on a final support of transparent structureless gelatine or celluloid, which makes it sufficiently stiff and tough to stand much handling without danger.

An advantage of films (both celluloid and paper) is that, since they are practically transparent to the X-rays, half-a-dozen or more may be exposed behind each other at the same time, with the result that on development a number of practically identical negatives are obtained.

This introduces the idea of using ordinary bromide paper of great sensitiveness in place of either plates or films. The paper has the advantage of cheapness, and where only a few images are needed (unless the "negative" image is objected to) they may just as well all be made by the original exposure as by making a negative first, and a series of prints therefrom. In the early days of radiography it was found that practically identical images, as regards strength, were obtained on each sheet of a packet of one hundred bromide papers exposed to the X-rays at a single exposure. This gives some idea of the very small extent to which the rays are absorbed in producing the radiographic impression and in passing through the sensitive films and their paper supports. It must be noted, however, that the objects used in these early experiments had strong contrasts (coins in leather purses, etc.), so that the conditions for obtaining equal images through a series of papers or films were much better than they would be in the case of an object with but very slight contrasts.

Ferrotype plates (sensitive emulsion on sheets of black lacquered iron) have been strongly recommended, and brands of British and of German manufacture have proved very sensitive to the X-rays, giving strong, definite images with short exposures. They are reasonably flexible, not easily breakable, and lighter than glass plates. The image produced upon them is a positive, instead of a negative; but as the iron support is practically impervious to X-rays and entirely so to light, these plates cannot well be used when more than one radiogram of a subject are desired. Images on these plates can best be multiplied by copying, and making a negative with a camera, after which the printing is easy.

The development and fixing of ferrotype plates are much the same as with ordinary plates or films, but as the resulting image is in practically black silver, on a black support, an extra operation of "bleaching" is needed to render the picture visible.

Whether plates or films are used, the beginner will find a difficulty in selecting one from the many brands offered. Unfortunately, perhaps, there is no "best" plate or film; and between the products of various makers there is *far less difference* than is often claimed by partisans of this or that brand. It is an absolute fact that at the time of writing there are no bad or unreliable plates on sale, and that the films of the best makers are almost, if not quite, equally good and dependable. This fact is emphasised because in the early days of radiography (1896–7) several brands of "special" radiographic plates were placed on the market without sufficient trial and experiment by the makers, and proved bad and useless in practice. Further, it is well to emphasise this same fact, that the beginner who makes failures may search for the causes in his own manipulation, and not blame, or change, his plates.

Whatever brand is selected for a beginning should be continued until the worker is fully proficient—in spite of all statements by friends or dealers that some other brand will give better results.

Plates (and films) vary greatly in sensitiveness (which is commonly called "speed" or "rapidity") and within certain limits the sensitiveness to X-rays corresponds with the light-sensitiveness. How far this holds good has not been finally demonstrated, but in the only quantitative investigation made on the subject* it appeared that photographic and radiographic sensitiveness ran in parallel up to 80° or 100° on the Hurter and Driffield scale, but that the still higher sensitiveness to light gave no corresponding increased sensitiveness to X-rays. The Hurter and Driffield scale here mentioned is the method adopted by some plate-makers of signifying the sensitiveness of their

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* Paper before the Royal Photographic Society in 1896, by H. Snowden Ward and E. A. Robins.

different batches of emulsion. Many of the boxes are marked with "H. and D. speed numbers," and for comparing the sensitiveness of different batches *by the same maker* they are reliable. Unfortunately, however, some makers take a different basis from that recommended by Hurter and Driffield themselves, with the result that plates of one maker may be double the sensitiveness of those marked with the same speed-number from another maker.

Generally speaking, therefore, for most radiographic work in which it is desirable to make the exposures as short as possible, it is well to use a "rapid" or "extra rapid" plate of some good make, without going to the extreme of light-sensitiveness. All other things being equal, better negatives can be made on relatively slow than on very rapid plates, so that if the most perfect possible work is aimed at, medium rapid, or even "ordinary" plates should have preference whenever their use does not prolong the exposure too much.

If plates of the one brand are used, and of "H and D" numbers less than 100, the rule for X-ray exposure may be taken as for light-exposure, namely, that the exposure is inversely proportionate to the speed-number. Thus if a given subject, with given conditions of tube, current, etc., requires one minute's exposure on a plate of 100° H. and D., it will need two minutes on a plate of the same make, marked 50° H. and D.: always subject to the proviso in the next paragraph.

"Speed" of a plate, in radiography, practically means the reduction of a given density of silver in a longer or shorter time of exposure. The plate in which the greatest quantity of silver is reduced to the metallic state by a given exposure and development, is held to be the most rapid. It has been shown above that the sensitive film is transparent to the X-rays, and that when a paper film is used, several images can be made at once. In the same way, if a given sensitive film is doubled in thickness, the amount of silver reduced under given conditions is doubled, and the "speed" is doubled, also, from the radiographic point of view. The increasing of film-thickness would not, however, affect the photographic speed-testing; and it is well to remember this, as explaining certain apparent discrepancies which may occur. In comparing two plates of equal sensitiveness photographically, the one with the thicker film (or film richer in silver) will appear more sensitive under the X-rays.

Whether films or plates are used, it is necessary to protect them much more carefully than in ordinary photographic practice, for the card-board boxes which are perfectly safe against light are pervious by the X-rays. Even when the plates are stored at some distance from the working apparatus they may need special protection, for wooden cupboards or brick walls are not sufficient safeguard. The best way is to have a box of zinc or of wood with a covering or lining of stout sheet lead, in which the plates (in their cardboard boxes) should be kept. Only one plate at a time should be in the operating room.

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 a cover for exposure. This cover, usually of black paper without any pinholes, must be quite opaque to light, but permits the X-rays to pass unaffected. Very convenient are the envelopes sold by Marion & Co., London, and Wm. Tylar, of Birmingham. In order to always know the position of the film side (which in the dark room is readily ascertained by its matt 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 plate-holders such as those illustrated by Fig. 69, 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, either of 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.

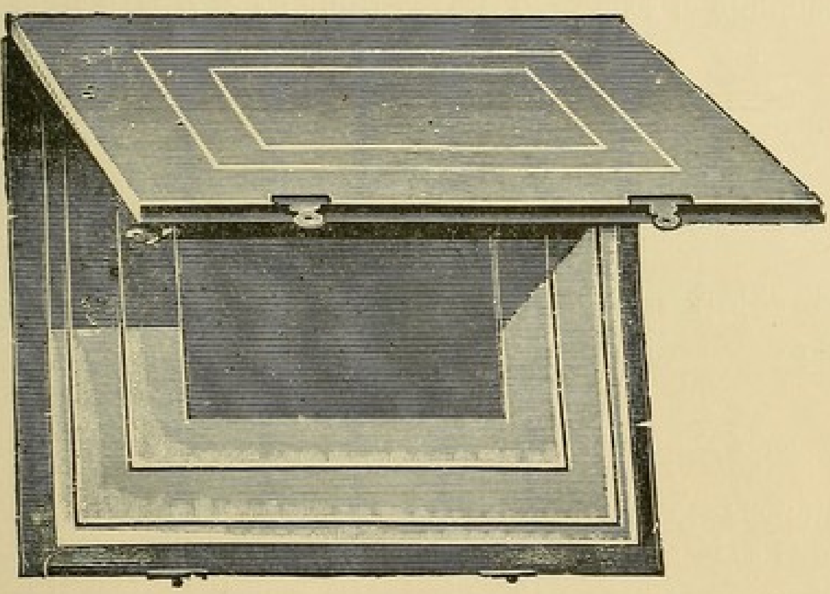


Fig. 69.

For developing radiograms, almost any of the usual developers may be employed, although it is advisable to use the formulæ suggested by the 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.

Potassium bromide . . .	1 oz.
Water	9 oz.

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

Or

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

C.

Potassium 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 hydroquinone formula, although slower in action, yields clean negatives with plenty of contrast.

The following one-solution developer is 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 solution of

Rodinal	1 oz.
Water	1 oz.
Bromide of potassium	½ oz.

will accelerate the appearance of the image.

Yet another developer, which has greatly grown in favor until it is perhaps more largely used than any other by the most advanced radiographers, is the metol-hydroquinone. For it many different formulæ are given, and if your plate-maker encloses one with his plates it will be well to use it. The following is very good, and will work well with any plates. It is taken from the Imperial Dry Plate Co.'s instructions.

A.		B.	
Metol	40 grs.	Caustic potash	180 grs.
Hydroquinone	50 ,,	Water to	20 oz.
Sodium sulphite	120 ,,		
Potassium bromide	15 ,,		
Water to	20 oz.		

To develop, mix equal parts of A and B.

The dishes in which development takes place may be of celluloid, vulcanite, papier-mâché, enamelled iron, or porcelain. For larger sizes than 10 × 8 inches, 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 envelope 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; it should be gently rocked to and fro. In about thirty seconds to a minute, the plate should begin to change slightly from its creamy appearance to a grey, wherever the X-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, and no light is transmitted. 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).

Some investigators use exceedingly weak developers, gradually increasing their strength and continually developing for as long as three hours, with very fine resulting negatives, combining a wealth of detail with strong contrasts.

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 hydroquinone 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 hydroquinone development. These special methods are not at all necessary when there is fair contrast between

PLATE X.]

MAUSER BULLET IN THE PELVIS.

(Radiogram taken at the Imperial Yeomanry Hospital, Dulfontein, South Africa, by J. Hall-Edwards.)

the denser and the more transradiant parts of the subject, and when sufficient exposure can be given.

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 :

Fixing bath.

Sodium metabisulphite	2	parts.
Water	100	,,
Sodium hyposulphite	20	,,

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 solution of

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

The black or grey color 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 minims.
Water	1 oz.

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 slowly.

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 the thicker parts of the body, which necessitate long 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 color-sensitive (orthochromatic) plates, or first color-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 color-sensitive plates, according to Gaedicke, is as follows :—

Exposure without screen	1
„ with fluor spar	$\frac{2}{3}$
„ with potassium screen	$\frac{1}{4}$
„ with barium screen	$\frac{1}{9}$

When using the barium screen, the plates are prepared by immersing for four minutes in a bath consisting of

Water	1000 c.cm.
Alcoholic solution of erythrosine ($\frac{1}{380}$)	40 c.cm.
Aqueous solution of silver nitrate ($\frac{132}{1000}$)	16 dps.
Ammonia (·91)	4 c.cm.

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

The fluorescent screen is placed in immediate contact with the sensitive film, and the whole enveloped in opaque paper and exposed so that the rays 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, by Dr. Max Levy, and by others. 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. 69), 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 color-sensitizing and since the price is very much below that of platinocyanide screens.

Another and very good plan, devised by Dr. Max Levy, of Berlin, to 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. By coating the celluloid or glass support on both sides with emulsion, we obtain two images, which, being necessarily in perfect register, give double density to the negative, thus permitting of shorter exposures.

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

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, 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 shall 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 Professor 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.

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 X.

LOCALIZATION.

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 superposition 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 to the respiratory movement, as also the fore-shortening of others, due to their position, introduce certain errors, which can only be avoided in a stereoscopic radiogram. It has often been suggested that a radiographic atlas should be prepared, showing the normal appearance of radiograms of every portion of the human body, taken in certain positions, so as to facilitate the reading of radiograms. But although this idea has been given practical shape somewhere, or at least a start has been made, it is well to remember that the value of such work depends very greatly upon a rigorous process of standardization of all the factors coming into play. To begin with, we must take as the basis of our work a well developed, muscular subject; we must agree upon a standard distance between tube and plate for the various parts of the body; the exact position of the anti-cathode with regard to the main structure of the part under examination must be marked on each plate: and so on. The more complicated the part, the greater is the necessity for exact measurements and for a number of radiograms taken from different aspects.

For instance, an anterior-posterior view alone of the hip-joint will convey no idea of the articulation, and can only be relied upon to detect well pronounced dislocations or fractures.

Besides, an atlas of the utility which we desire must take note of the changes due to the progress of ossification and epiphysal growth and should also include some typical pathological conditions.

The exact localization 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 localize 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 fore-arm; 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 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.

All proper methods of localization depend upon the determination of the three co-ordinates X, Y and Z (Fig. 70), which fix the position of a given point in space.

We find these distances X, Y, Z from the three planes A, B, C by taking radiograms of the point (or object) on photographic plates placed respectively into the positions C, B and A, or rather only C and B, since the former will show the projections of distances Y and X.

Fig. 71 shows how — by keeping the body in one position and shifting tube and plate through 90°—we obtain two co-ordinates, the third being determined from either of the above radiograms by measuring the vertical distance of the shadow from the projection of the orientation plane (a leaden wire laid around the limb or body).

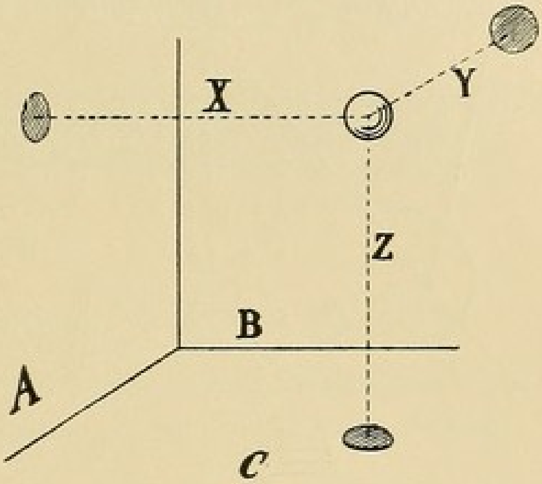


Fig. 70.

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. 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 :

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

Yet another method has recourse to a little model ; two metal buttons are so fastened to the surface of the body

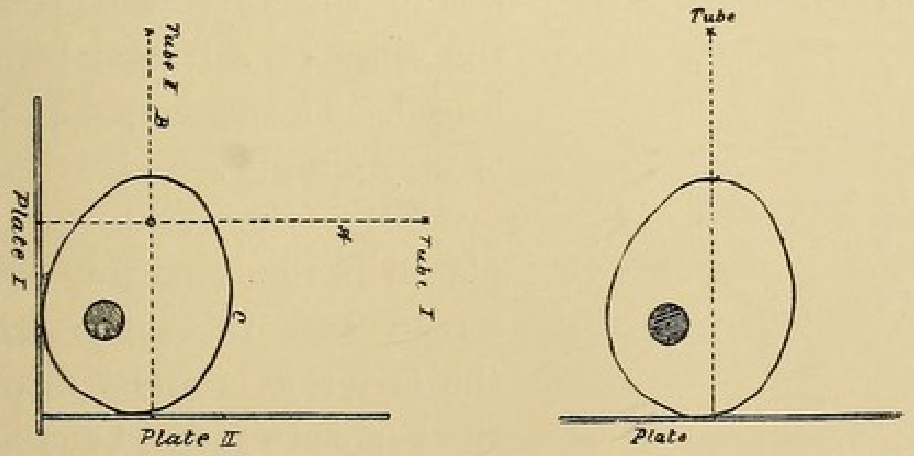


Fig. 71.

that their shadows coincide on the screen with that of the object ; this 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. 73).

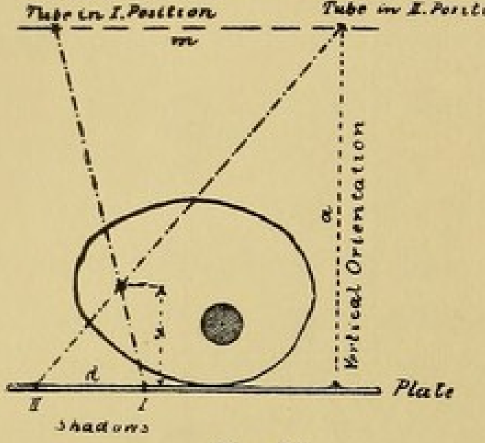


Fig. 72.

The same principle is utilized in a more practical way in the construction of the "Punktograph" (Fig. 74); the buttons are replaced by two metallic rings mounted on ebonite handles (because of their radioscopic transparency) and provision is made to mark the centres of these rings—as soon as they are in their proper position—on the skin of the patient, by means of dermic pencils, which normally are drawn back and out of the way, but spring into the rings on a trigger being released. The mode of application is very simple:—

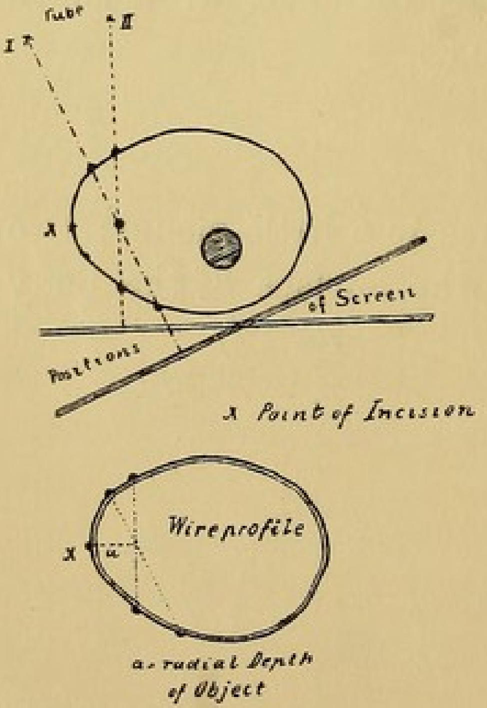


Fig. 73.

With the limb or body placed in the usual way between screen and tube, but so that the latter is laterally displaced, the rings are pressed against the anterior and posterior surfaces of the limb and their positions shifted until the ring shadows as seen on the fluorescent screen appear in perfect register and contain in their inner space the foreign body (or if the latter be large, one of its margins). At this moment the triggers are released and thus two dots marked on the skin. This process is repeated with the limb or the tube showing the opposite lateral displacement and a further two dots are thus marked All that is now required to find the depth, x, of the foreign object, is to measure the distances between the dots on both anterior and posterior surface (a and b) and the thickness (t) of the limb midway between the two sets of dots.

Fig. 74.

By triangulation we obtain $X = \frac{a}{a+b} \times t$ (Fig. 75). It will thus be seen that neither the distance between tube and screen nor the displacement of the tube has to be measured; the only condition being that the displacement plane of the tube be as parallel as possible to the plane of the screen. When the body or the limb under examination shows considerable thickness, so that the rings are at widely different distances from the screen, then it will not be possible to ensure register in the shadows of the rings, but quite easy to secure the shadows being concentric, which will give equally good results.

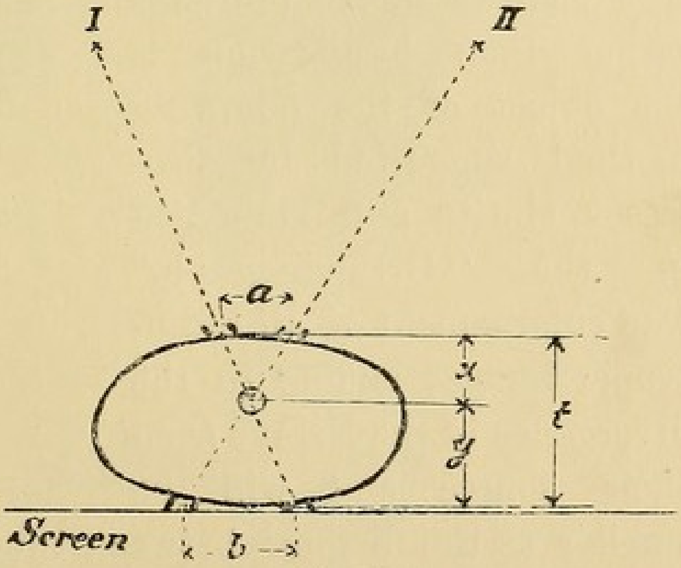
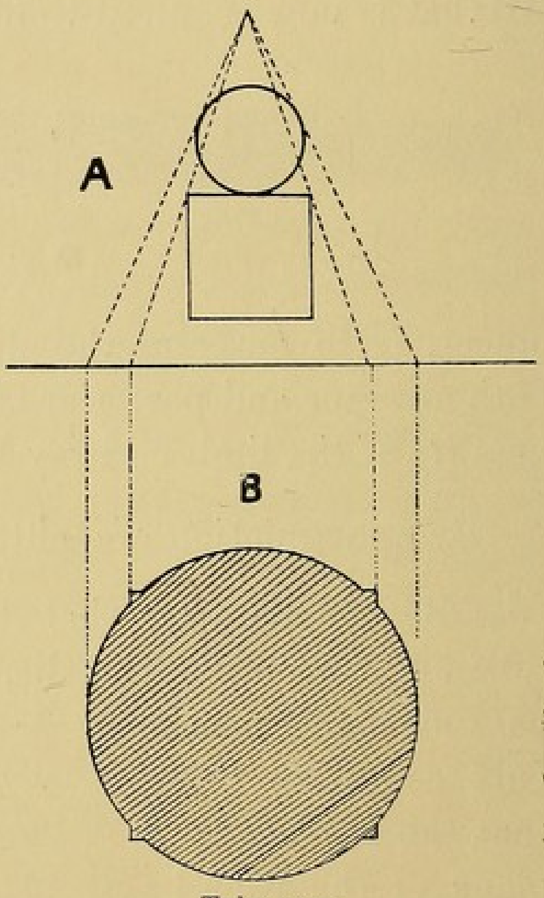
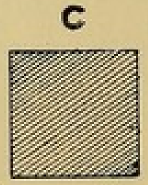


Fig. 75.

Much more complicated as regards apparatus is the system introduced by Dr. Rémy. The principle is to "materialize" those two X-rays which connect the anti-cathode with the foreign body and its screen shadow for two positions of the tube. By means of suitably placed sights and stops, one is enabled to bring the pointed rods (representing the X-rays) always back to their proper plane, so that the latter and the depth of the foreign object may be marked on the patient. It is difficult to convey an adequate idea of the construction of Rémy's instruments without illustrations; we refer those who wish for details to the account given in the *Archives of the Röntgen Rays*, August 1900.



Tube near.



Tube very far away.

Fig. 76.

The determination of the true size of internal organs rather than localization is the object of the following method suggested by Professor Moritz and embodied in the "Orthodiagraph." The enlargement of all radioscopic images is due to the divergence of the X-rays from their source and will be smaller as the distance between tube and screen increases, particularly when the object itself is of appreciable thickness and cannot—by reason of its internal position—be brought near the screen surface. Moreover, the projection of objects upon the fluorescent screen or the photographic plate by strongly divergent rays is deceptive, on the ground that the outlines, thus obtained, are in most cases a combination of the outlines of the lateral and frontal surfaces. A glance at the geometrical figure 76 will make

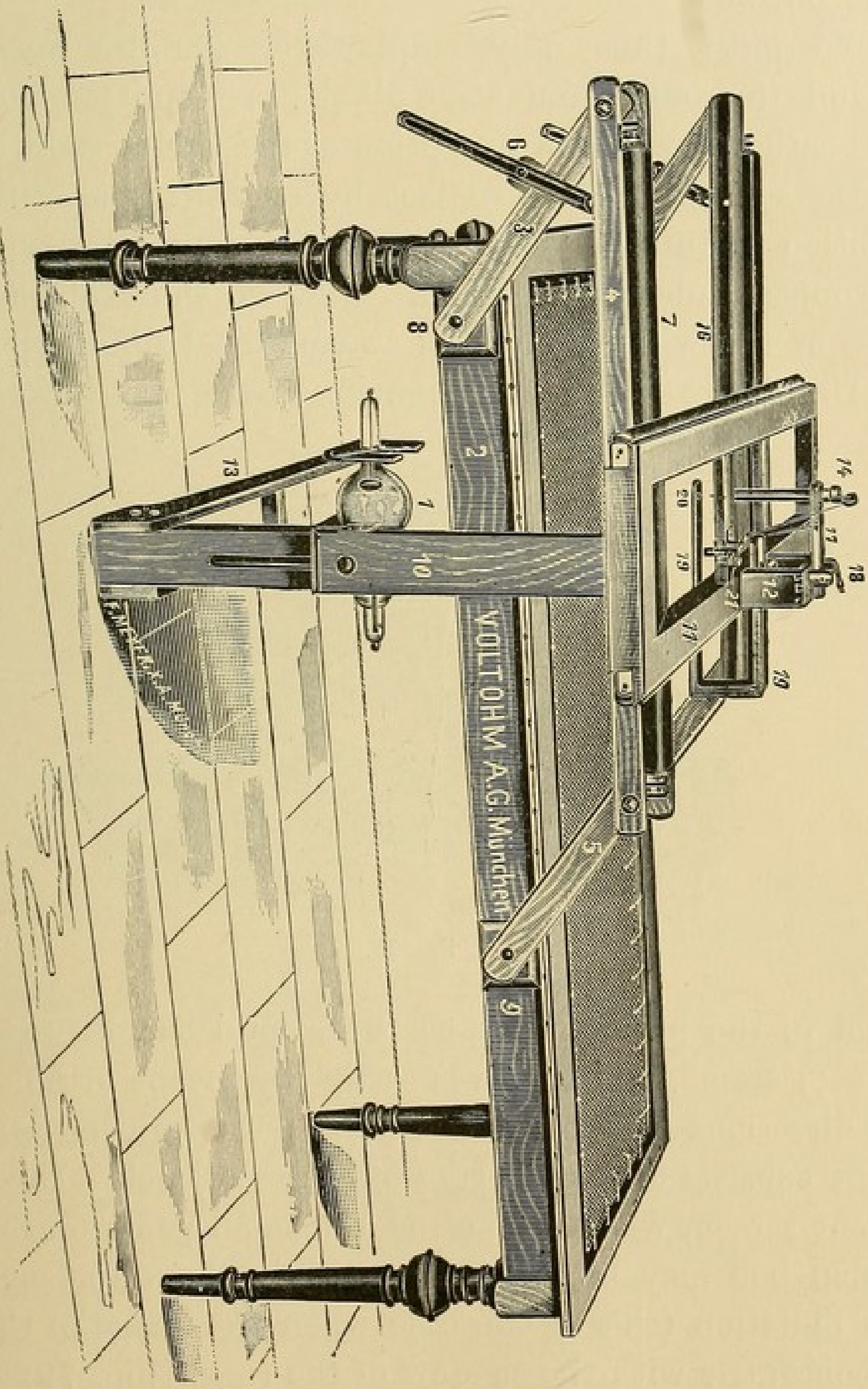


Fig. 77.

this intelligible; with the source of radiation near, the projection assumes a composite character, whilst if the source were at infinity (parallel rays) we would obtain true outlines.

We must thus only employ the parallel rays, *i.e.*, exclude for our examination all the rays emitted from the anti-cathode with the exception of the one at right angles to the screen. This we effect by constantly altering the position of tube and screen simultaneously with respect to the object under examination. Fig. 77 shows the appearance of the whole apparatus as employed for the purpose by Dr. Moritz: Tube and sighting arrangement are firmly fixed to the lower and upper horizontal bar, respectively, of a ⊐ frame, which moves easily (by means of rollers) in all directions in a horizontal plane; the sighting arrangement consists of a small ring of lead (20) below the fluorescent screen, which by means of a small pendulum with a leaden bob may be brought vertically above the source of the radiation (this is the case when the image of the bob is concentric with the shadow of the ring) (Fig. 79). The tube must be fixed in this position. Lastly, there is a capillary inker which permits of marking the centre of the ring shadow (in every position) on a piece of tracing paper laid on the fluorescent screen. By consecutively

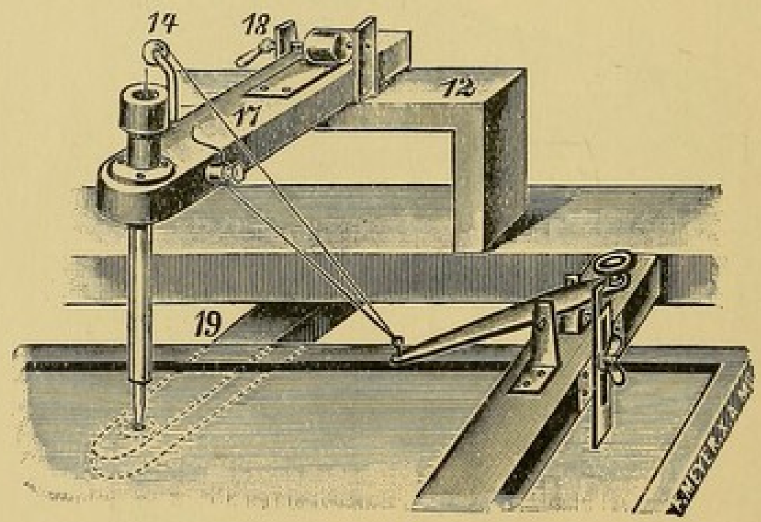


Fig. 78.

moving the whole frame so that the ring-shadow enters into register with all the outlines of the object under examination, we obtain a series of dots forming an outline of the true size and shape of the original (Fig. 80). All lateral X-rays are excluded by means of a suitably arranged lead diaphragm near the tube. The instrument is particularly useful in outlining the cardiac region and its abnormal conditions.

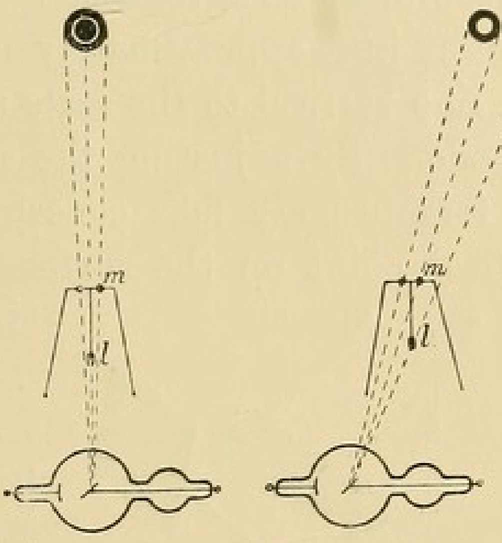


Fig. 79.

The same principle is utilized in Dr. Donath's measuring frame, which, however, does not lend itself so well to the determination of the cardiac outlines.

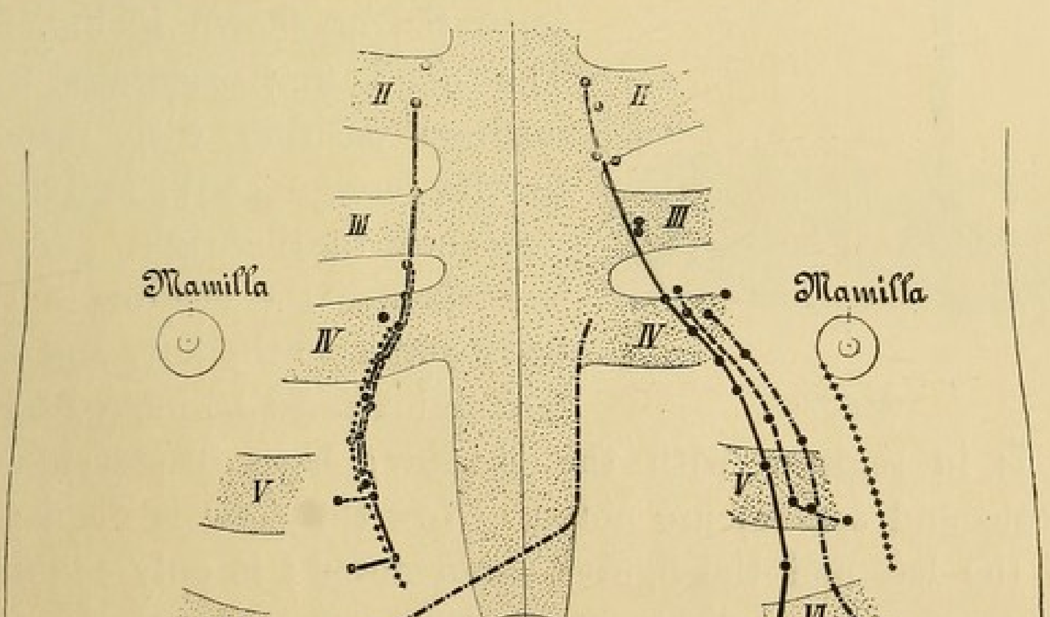


Fig. 80.

It permits the determination of the following four questions :—

(1) The point vertically below the foreign body. (2)

The size of same. (3) Vertical distance of foreign body above screen. (4) Distance apart of two objects (even when above each other). To determine factors (1) the horizontal scale, anti-cathode and middle line of screen are brought into approximately one plane and the lead index in a line vertical to the scale and passing through the anti-cathode. By adjusting the screen so that the shadow of the foreign body falls concentric with the lead index, the vertical point on the surface of the limb may be ascertained (see Fig. 83).

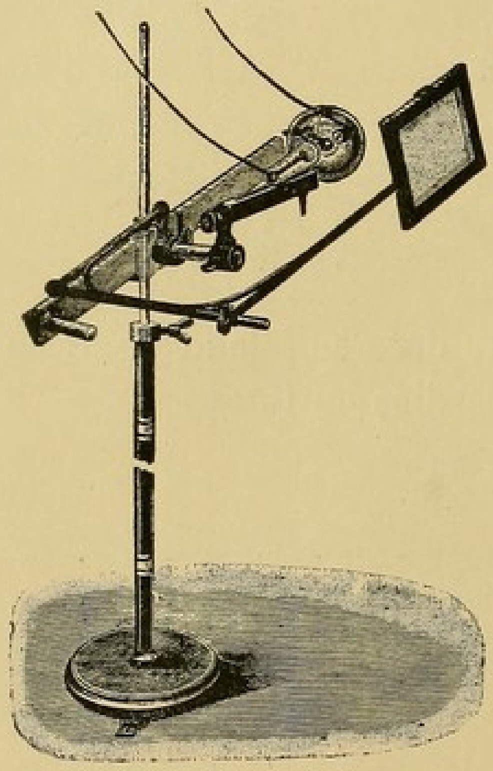


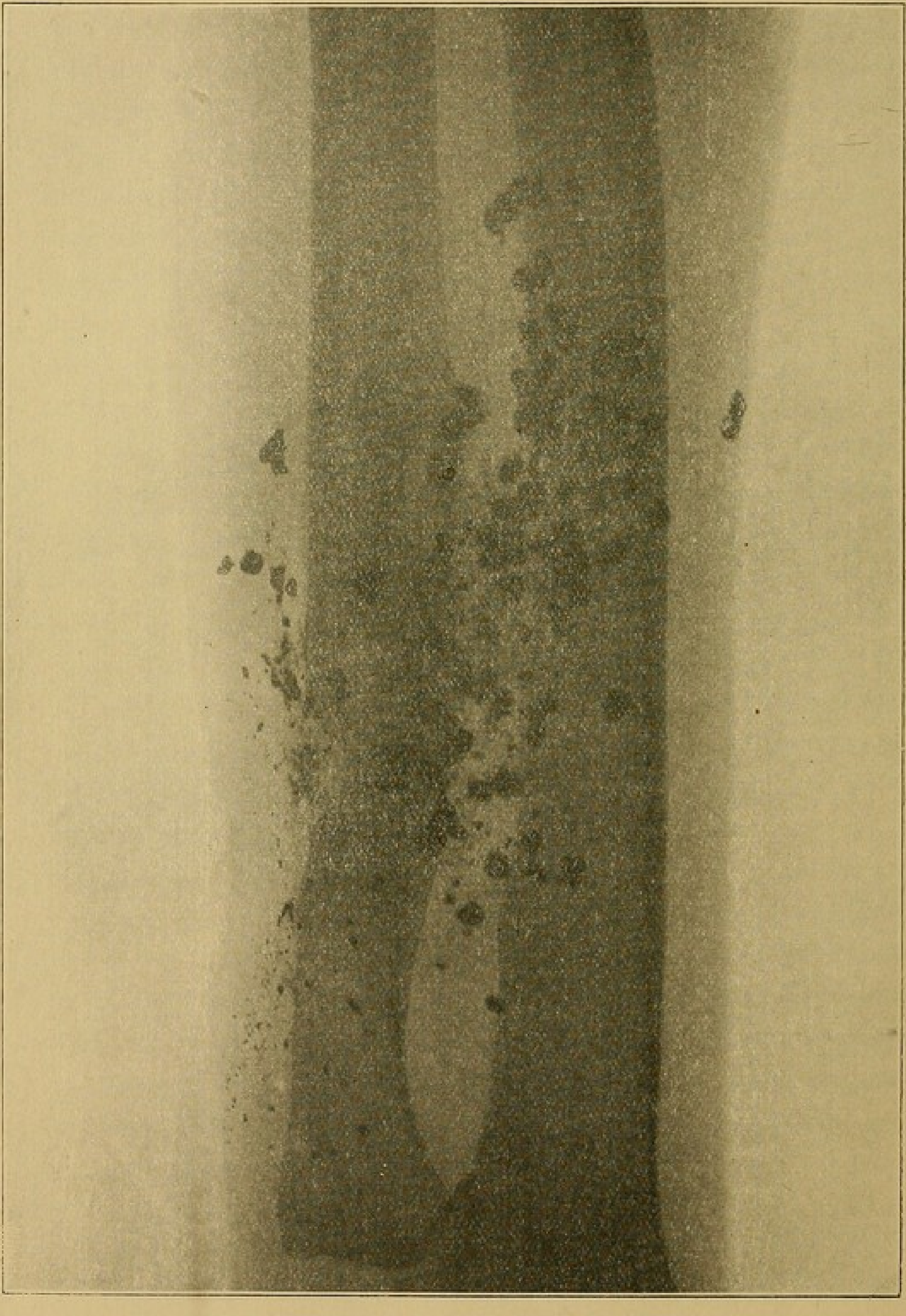
Fig. 81.

(2) The above manipulation is repeated for each margin of the foreign body and the displacement of the tube-holder as shown on scale directly gives the size required.

(3) Tube and screen are separated as shown in Fig. 82. The tube is first orientated to a medium position with respect to the foreign body, and then displaced to the right. As a consequence the shadow of the body shifts to the left, and the lead index must be moved until it is in register with the shadow; both displacements (scale and screen) are noted. Now the tube is displaced to the left and the figures again noted; it only requires to measure the distance, d, between anti-cathode and screen, when we obtain :—

$$x = \frac{b}{a+b} \times d \text{ (where } b = \text{displacement of index on screen).}$$

(4) If the bodies lie side by side, we employ method (2); if one above the other, then method (3) has to be twice followed, and the results subtracted. The degree of accuracy obtainable is from 1 to 4 per cent.



Fracture of Radius and Gunshot in Forearm.

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

A very ingenious method of localization 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 central X-rays by employing fine threads stretched between the position of the anti-cathode and the resultant shadows or images.

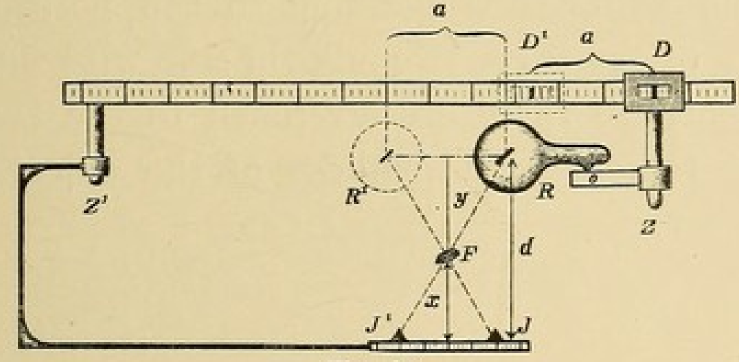


Fig. 82.

In its practical shape the method works out as follows:—The centre of the photographic plate or film is brought exactly vertically under the medium position of the anti-cathode. This centre is represented by the intersection of two thin wires stretched at right angles to each other across the plate-holder; these wires appear on the radiogram, and being previously painted with some dye, they mark themselves on the body of the patient. One of the four quadrants is then marked by placing a coin or similar opaque object upon the plate, the tube is shifted from the medium position through a certain measured distance (as read off on the tube-holder) and an exposure is made. Without removing either plate or body, another exposure is given with the tube shifted to the other side of the medium position to an equal distance.

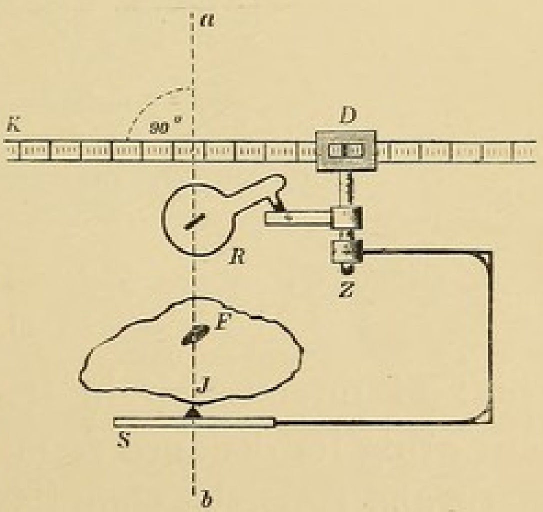


Fig. 83.

After development, the negative showing the orientation cross, the quadrant mark and two shadows of the object to be localized, is placed upon a glass plate, illuminated from below and having two diamond scratches which serve to bring the negative into register.

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.

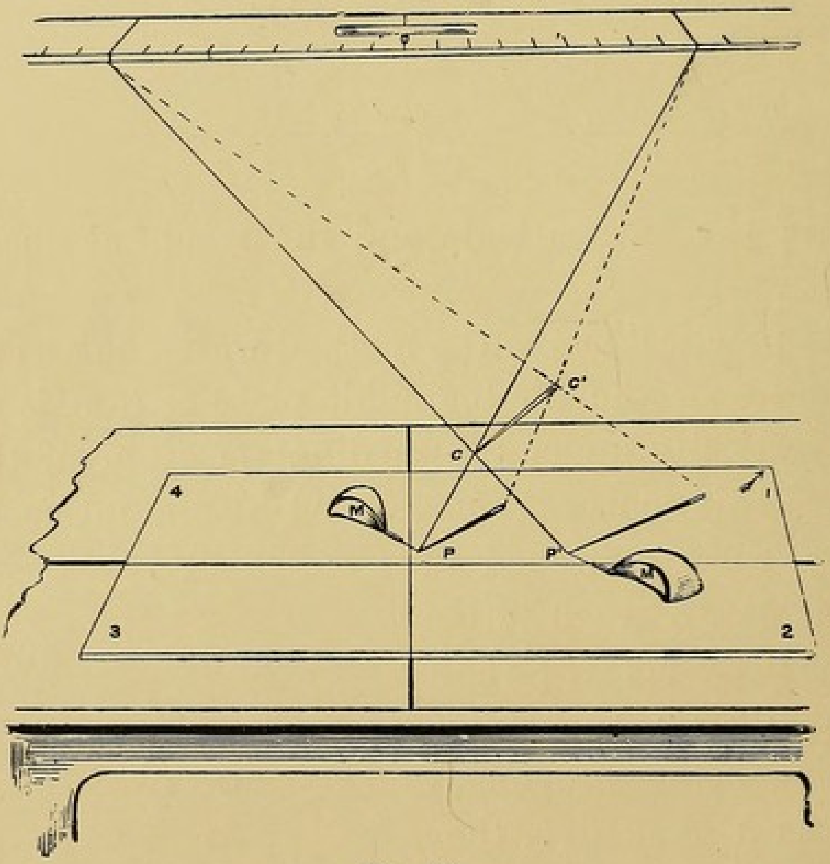


Fig. 84.

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. 84 shows diagrammatically the locating apparatus.

It would carry us too far to enumerate the hundred and one systems and modifications which have been invented and re-invented and which all have one object—localization. Most of them are to be found in the lists of apparatus makers, especially those which require for their employment more or less complete apparatus. However, we will not close this chapter without mentioning two methods of radioscopic determination, both of them dispensing with expensive accessories.

The one, which is due to Professor Barrell, employs two metal cylinders with their ends carefully turned perpendicular to their axes (size 4 inches high and 1 inch diameter) which are placed upright on the photographic plate close to the object under examination, but rather far away from the tube. After the first exposure the tube is shifted as usual, also the cylinders (to the opposite end of the plate), and another exposure is obtained. The resulting radiogram contains four cylinder shadows, and two shadows of the foreign object; by ruling lines along the edges of the two corresponding cylinder shadows for one tube position and producing them until they meet, we obtain that point on the plate which was vertically beneath the tube focus during the corresponding exposure. Connecting the two points thus found with the corresponding shadows of the foreign body we obtain two lines which intersect in a point which is vertically below the actual foreign body at a depth of $x = \frac{a}{a+b} h$, where $a =$ distance between the shadows of the foreign body, $b =$ displacement of tube (equal to distance between tube verticals, as measured on the plate) and $h =$ distance between anti-cathode and plate (Fig. 85).

Even the necessity for such a simple calculation as the above is eliminated in Londe's method. A triangular piece of wood, with a series of metallic pins arranged at measured distances from the base, is placed upon the photographic plate and two exposures with the tube displaced are made. This produces two series of pin-shadows, and from the position of the shadow of the foreign body with respect to the former we arrive at the distance of this foreign body from the plate. For practical work, when the tube can be

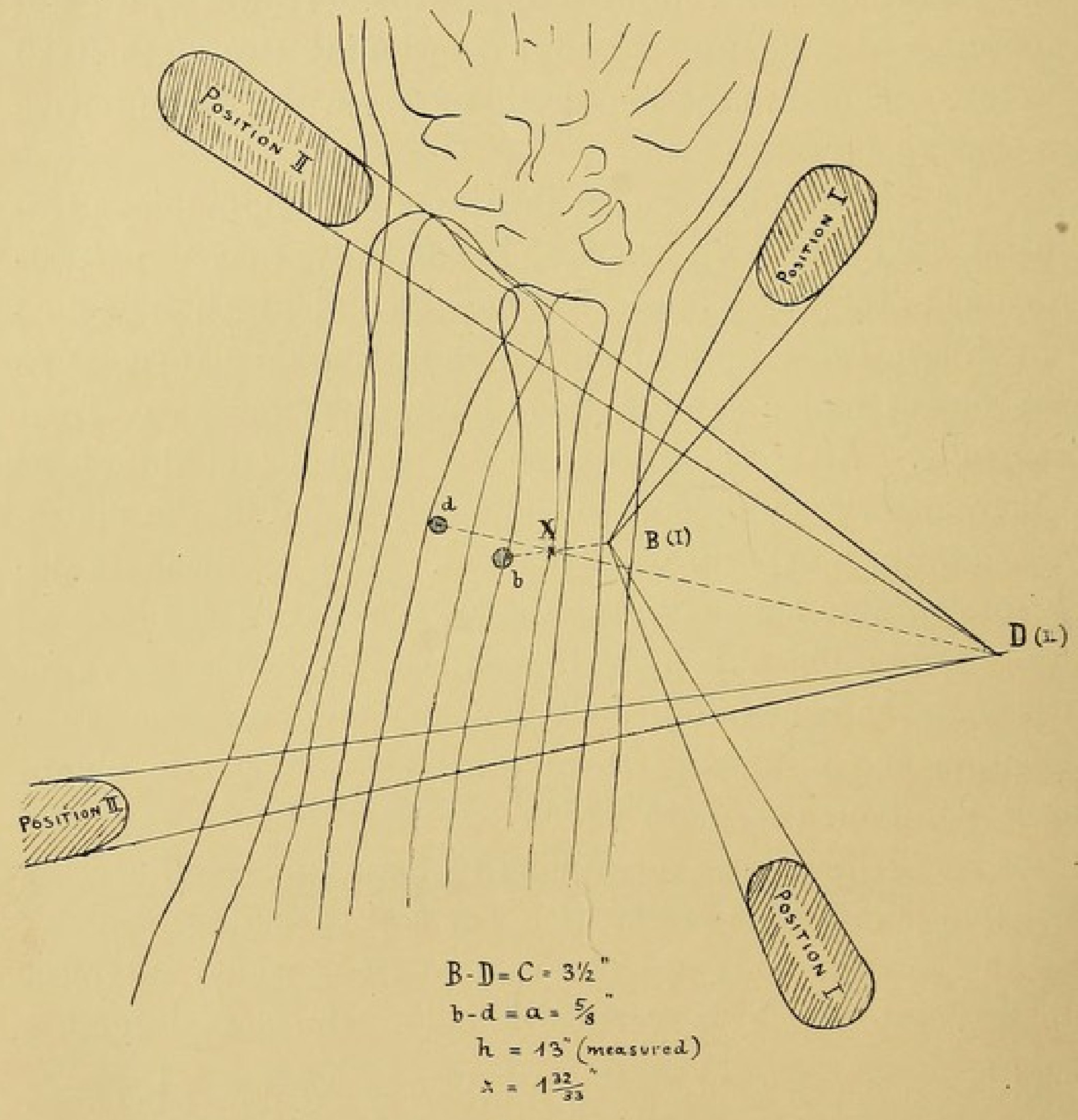


Fig. 85.

always fixed at a certain distance from the plate, a preliminary exposure of the triangle alone and tabulation of the result are sufficient for all subsequent cases. When for different objects the tube distance has to be varied, a test exposure and subsequent tabulation are necessary for each tube distance.

CHAPTER XI.

STEREOSCOPIC PRINCIPLES AS APPLIED TO X-RAY WORK.

In the preceding chapter we have shown that the superposition of the different projections into one plane, such as we invariably find in an ordinary radiogram, necessitates the taking of two radiograms from different aspects in order to arrive at an exact localization of the objects appearing in the radiogram or on the screen. All the various methods of localization there described were either based on graphical or analytical methods by which the two views obtained were brought into correlation. The drawbacks to these methods are, firstly, the necessity of applying certain geometrical methods, and, secondly, the indefiniteness of the process in so far as the true position of the objects is but indirectly conveyed to our senses. It was but natural, therefore, that from the very beginning of X-ray work, attempts should have been made to secure a direct optical method of fixing the true position of objects in the body. The only way in which this can be done is by stereoscopic projection, and according as to whether the result has to be attained on the fluorescent screen or on the photographic plate, the experiments must be classified under the headings of stereoscopic radioscopy and stereoscopic radiography. Taking the latter first, because it was the earlier as well as the easier method, we may say that the principle upon which it is worked is identical with that governing ordinary stereoscopic photography or binocular vision.

STEREOSCOPIC RADIOGRAPHY.

When we look at an object (not too far distant) we examine it from two different points of view, the distance between which corresponds to the distance between the axes of our eyes; the brain combines the two views into the perception of relief. This fact may be easily proved by closing either eye, when the object at once loses this relief. In ordinary photography, therefore, we obtain pictures with stereoscopic effect by taking two views of the same object from different positions (either by shifting the camera between the exposures or by using a camera with two lenses set about 6 centimetres, *i.e.* $2\frac{1}{4}$ inches, apart) and then recombining the two resulting prints (after transposition) by employing prisms or reflecting mirrors.

In stereoscopic radiography we do very much the same thing. We take a radiogram on a plate, then, leaving the object under examination locally undisturbed, we substitute a fresh plate and take a second radiogram, having previously shifted the tube through a distance of 6 centimetres parallel to the plate; the resulting two radiograms, suitably mounted and viewed in a stereoscope, will give us the object in proper relief.

Instead of displacing the tube we may also tilt the object with respect to the tube and thus obtain the necessary two radiograms of different aspect.

These are, in brief, the principles upon which the methods of Hedley, Mackenzie-Davidson, Imbert and H. Bertin-Sans and others are based.

As for the practical realization of these methods it will be sufficient to describe the Davidson process, as the one most frequently used in this country; the apparatus required is identical with the one described on page 161, and the only difference in the *modus operandi* against that followed for localization is, that a separate plate is placed into the plate-holder for every exposure. The plate-holder is so arranged that the exchange of the plates may be effected without in any way disturbing the patient who is lying upon the holder, since the slightest alteration in the position of the former would entirely do away with the stereoscopic effect. The finished prints—when small—may be viewed in the ordinary refracting stereoscope; in the majority of cases, however, radiograms are too large for this purpose and recourse is then had to the reflecting stereoscope, which consists essentially of two plane mirrors mounted at right angles with their apex directed to the observer (Fig. 86). Some adjustment of the mirrors in a direction vertical to the axis of the instrument is desirable in order to compensate for individual differences in binocular vision.

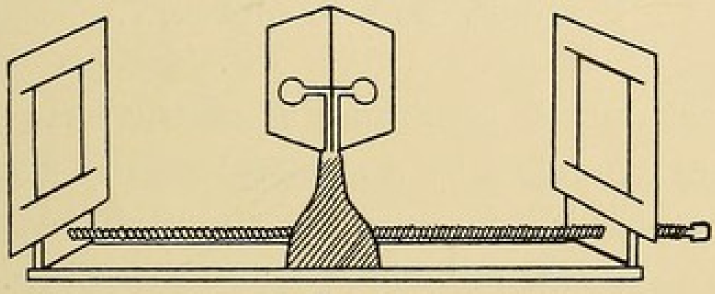


Fig. 86.

Radiographic stereograms differ in one essential point from ordinary stereograms, in so far as the relief is produced in the former no matter which picture is mounted on the right hand or the left hand side of the stereoscope; exchanging the pictures to opposite sides merely produces a different aspect (posterior or anterior view).

There can be no doubt, that if it were not for the extra time and work required in their production, stereoscopic radiograms would be the rule rather than the exception, and this apart from their beauty, for the following reasons :—

The stereogram conveys a better idea of the articulation of the joints than a series of radiograms taken from widely different positions. In many cases a stereoscopic radiogram alone would be quite sufficient to localize a foreign object, especially when the only doubt about its position is whether the object lies below or above a certain structure; the necessity of taking two radiograms also eliminates the mistakes in diagnosis which are possible if we rely upon one negative only, which may show spots or irregularities which, after all, are only due to defects in the emulsion or to faulty development. The absence, for instance, of a light area in the region of the kidneys on *one* plate out of two taken in rapid succession would be sufficient to discount the possibility of diagnosing this appearance as a renal calculus. Other instances might be cited.

STEREOSCOPIC RADIOSCOPY.

The direct optical combination of the two constituent screen images produced by a stereoscopically arranged pair of tubes is impossible, because the simultaneous working of the tubes would naturally lead to double outlines on the screen.

The only way, therefore, to obtain stereoscopic effects on the fluorescent screen is to alternately use one tube only and so choose the intervals that the continuity of vision may accomplish the fusion of the two images.

The two tubes must be placed with their anti-cathodes about 6 cm. apart, and they may be actuated either by a separate coil each or preferably by one coil; the secondary terminals are connected alternately to one or the other tube by means of a commutator or automatic switch. In addition, we require a rotating, opaque disc with two apertures cut into it on opposite sides of a diameter, and these apertures also must be set apart by a distance corresponding to the space between our eyes.

It is obvious, that if the sector disc and the commutator for the tubes rotate synchronously and are so adjusted that the left hand tube, for instance, is illuminated at the same instant that the aperture for the left eye is passing in front of this eye, we only see one sharp radioscopic image on the screen (which is placed between disc and tubes): the next instant the left eye is obscured, and the right eye aperture uncovered, whilst the right side tube is thrown into action, with the result that we get a perception of another screen image which is the stereoscopic component of the one seen a moment before, and which, owing to the comparative sluggishness of retinal impressions, is still conveyed to our brain, so that the two impressions are unconsciously combined, and we see no longer flat shadows on the screen but shadows which convey the sense of actuality and relief. The constructive embodiment of the principle above described may, of course, be effected in a variety of ways, and several instruments of this type are actually in existence, but they cannot be called perfect at the moment, at least so far as their practical application is concerned. The chief drawbacks or difficulties at present are, firstly, their bulk and cost, which greatly limit their usefulness: secondly, it is very necessary to secure a pair of tubes of practically identical qualities and to maintain this equality during their whole period of action. It is well known to anyone who has used a Röntgen tube that it is almost impossible to get a pair of tubes which show the same resistance and the same penetration on the screen and to maintain a certain vacuum; yet, unless we exclude any dissimilarity in the two screen images, we cannot obtain true stereoscopic effects, since one image will be predominant. Thirdly—since the centres of the tubes (or, correctly speaking, the anti-cathodes) must not be much further apart than 6 cm. ($2\frac{1}{4}$ inches), we have to guard against the possibility of the active tube sparking across to the inert one and thus producing double shadows. We are therefore limited to tubes of low resistance and comparatively little penetration, which obviously restricts the stereo fluoroscope in its present form to the examination of the thinner parts of the body only.

On the other hand, it must be conceded that the stereoscopic screen-image is most instructive and important, that it enables the operator to "touch the spot" as if he were dealing with objects embedded in a transparent jelly. The diagnosis of fractures and dislocations of the smaller joints may be said to be perfect. As regards the use, however, of the apparatus for localization in the removal of foreign bodies, it is doubtful whether it would be possible to effectually observe antiseptic conditions, and whether the operator, who must needs have his eyes at the fluoroscope, is able to make his incision and dissection with the necessary expedition and nicety, since the softer tissues (muscle, nerves, blood-vessels) do not show in the screen image.

CHAPTER XII.

APPLICATION OF THE RÖNTGEN RAYS IN MEDICAL DIAGNOSIS.

THAT property of the Röntgen rays which led to their discovery, namely, their selective absorption, has even now, after six years, remained the most important characteristic as concerns their practical application. It is owing to this difference of absorption that we are able to perceive on the fluorescent screen or the photographic plate the shadows of certain inner parts and organs of the animal body. Again, by far the greatest amount of work done and experience gained have reference to the human organism, to which then the following observations have primarily reference.

Experience has shown that the transparencies of the tissues are in indirect proportion to their densities with the exception of the sinews, which although very dense in structure are fairly transparent to the rays.

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 appears due to the earthy matters forming part of the bones, particularly phosphates of lime.

With the primitive methods and apparatus at first available, only the bones of the extremities and limbs were accessible to radiographic methods; gradually the trunk and the deeper lying parts of the skeleton and finally some of the softer tissues came within the limits of radiographic demonstration.

Nowadays we are able, by employing powerful apparatus and by selecting suitable tubes (as regards their vacuum) to obtain the best results in every specific case.

It may confidently be asserted that the application of radioscopy and radiography in the study of both the normal and pathological conditions of anatomy have resulted in several modifications of former views.

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; but the latter is always to be advised if time allows, as the plate will generally show more than even the best educated eye can see on the screen. 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.

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.

In this connection it should be remembered that recently formed callus does not show in the radiogram, as this has a distinct bearing upon the medico-legal aspect of radiography.

In suspected cases of Tuberculosis, Sarcoma, Osteomyelitis and similar conditions of the bones, we are able to radiographically verify the diagnosis by using a "soft tube," giving as much contrast as possible and showing up the modifications produced by the disease in the density of the shadow.

Such tubes also should be employed for dental examinations, especially when it is desired to show the presence of caries, buried roots, etc., etc.

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 exudation 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 may be directly observed.

Of course, the most popular application of the Röntgen rays is that which covers the detection and location of foreign objects and abnormal deposits in the various parts of the body and extremities; bullets, pins, needles, fragments of glass and iron, etc., are daily traced in the tissues, and coins, artificial teeth, etc., are frequently localized in the alimentary canal or in the gullet. All these foreign objects are more or less easy of detection on account of their great opacity to X-rays, which very much exceeds that of the various tissues of the animal body. The technical and diagnostical difficulties are, however, immensely increased when we have to deal with pathological deposits, calculi in the biliary duct, the kidneys, the ureter and the bladder. These difficulties may be explained from two causes: firstly, the calculi themselves are as a rule fairly transparent and therefore, when embedded in the organs mentioned and surrounded by much other tissue and blood which also possess a fair opacity, become—as it were—lost; more correctly speaking, the ratio of opacities between body *plus* calculus and body *minus* calculus approaches more nearly to unity, the greater the thickness of tissues through which the rays have to pass. From this it will be seen that gall stones are the most hopeless calculi—radiographically speaking. Add to this the transparency of such stones, and the scarcity of radiograms of gall stones is not surprising. The second difficulty lies in the distance which must always intervene between calculus and plate and the movements of the organs containing the former. The greater the distance, the less defined are the outlines of the shadows produced, and this in addition to movement further destroys technical perfection in the resulting radiogram. In the case of the kidneys, the photographic plate can be brought to within about two inches of the kidney; movement of the latter (and of a possible renal calculus) may and should be minimised by ordering the patient to breathe shallow or by turning on the rays only during one period of respiration; a purgative should be given to the patient some time previous in order to empty the bowels as much as possible of their opaque contents. The question whether it is better to place the patient upon his back or upon his belly cannot be answered definitely without having regard to individual circumstances. In any case, as already mentioned in another chapter, two radiograms should be taken so as to avoid a wrong diagnosis which faulty technique or material may cause.

Plate VIII. shows an exceptionally clear case of renal calculus in the ureter.

Small calculi in the bladder are comparatively easy of detection, especially if the bladder has been emptied.

Another class of deposits is represented by gouty formations in the phalanges of the extremities; in this case the deposits are recognised by their transparency in comparison with the denser adjoining parts, the cause being a replacement of the comparatively opaque phosphates of lime by transparent urates.

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

There remains a very important field still to be explored, which unfortunately seems to be quite neglected, although from the difficulties encountered a great deal of patient work is required; we refer to pregnancy. To the inexperienced radiographer it may appear easy enough to detect or radiograph a body of such dimensions and such density as a human fœtus in the abdomen. There are, however, some specific difficulties which make the task apparently hopeless. Chief amongst these are the movements of both fœtus and subject, the opacity of the highly muscular uterus, the opacity of the amniotic contents of the latter and the plentiful supply of blood to this organ. It cannot be denied that much valuable information might be gained as regards development and position of the fœtus in correlation with the architecture of the maternal pelvis, and it is to be hoped that some specialist may be able to devote his time to the problem.

As regards the introduction of radiographic methods into the practice of dental surgery, most of the early work done must be traced to American practitioners, some of whom have been exceedingly successful.

The work done in this country has been admirably summed up by Dr. Goldie in a paper read before the Odontological Society of Great Britain.* According to this authority the conditions in which X-rays are useful include:—

Fractures of jaw and dislocation of teeth in jaws.

Diagnosis of alveolar abscess and of other inflammations giving rise to neuralgia.

Diagnosis of impacted and incoming wisdom teeth, of

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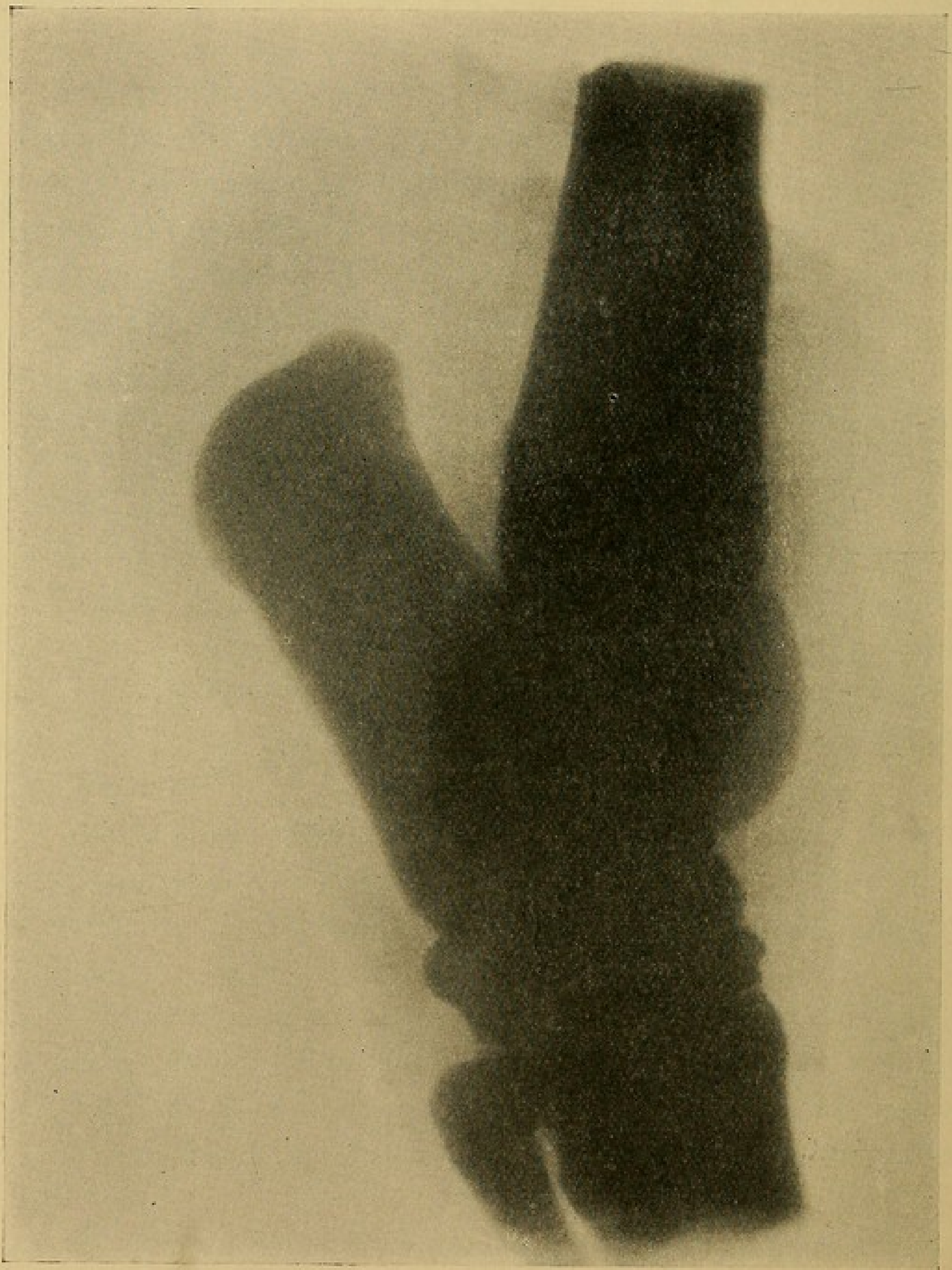
* *Transactions of the Odontological Society of Great Britain*, vol. xxxii. No. 6 (1900).



Hock of Horse.

(Radiogram taken by A. W. Isenthal. Exposure 45 seconds.)

normal and abnormal eruption of permanent teeth, exostosis, and foreign bodies in the antrum of Highmore.

The technique of the application of the X-rays in dentistry has undergone but few changes. After a few unsuccessful attempts to obtain useful radiograms by placing the tube above the face and the photographic plate inside the mouth, unsuccessful because taken under unsuitable conditions, the order of things was reversed and a great deal of ingenuity was expended in constructing a tube which might be inserted into the mouth, whilst the plate or screen was placed outside. We need not dwell upon the difficulties which very soon caused operators to revert to the former method and use ordinary tubes.

Glass photographic plates were first used in the mouth, but owing to their sharp corners and the inability to adapt them to the alveolar curvature they were soon discarded for *films*; these are cut to the proper size, enveloped in opaque paper, and for protection against saliva further wrapped up in either pure rubber tissue or guttapercha tissue.

The proper insertion of the film in the mouth calls for great attention and knowledge of the anatomical details of the mouth; when in position, it is held firmly pressed by the fingers of an assistant whilst the head is placed against an ordinary head rest.

The tube employed should not possess too high penetration, since this would not permit the attainment of sufficient contrast between tooth shadow and gum shadow; a distance of about ten inches between tube and plate gives good results, and from twenty to forty seconds' exposure with a platinum interrupter, or less with a mercury interrupter, is sufficient to produce full details.

Before passing on, we should like to again emphasize the desirability or even necessity (from a medico-legal point of view) of recording in every instance the exact position of the anti-cathode with respect to the subject under examination.

Apart from considerations of tabulation or comparison, this factor must be studied when the radiogram is to lay claim to scientific accuracy such as is required to conform to the demands of legal evidence. By purposely misplacing the tube, almost any distortion or any aspect may be produced, and it is obvious that in actions for compensation in cases of accident every possible or contestable source of error must be eliminated. A great deal of attention has been paid to this point in the United States, where radiograms have frequently been produced in Court and as frequently been rejected for want of standardization in the conditions of experiment.

A few words must be said as to the application of the X-rays in veterinary practice.

The work is in most cases more difficult than in ordinary radiography, partly because the thickness of the subjects is considerably greater than that of human beings, partly and chiefly because special arrangements have to be made to ensure steadiness of the subject.

Good pioneer work has been done by Professor Hobday and Mr. Johnson and resulted in the design of some special holders and appliances.

One of the authors had occasion to continue this work in conjunction with Professor Hobday and Lt.-Col. Smith of the Army Veterinary Department, and the X-rays are now in use by the Veterinary Department at Wynberg near Capetown.

Small animals, such as dogs, cats, etc., when properly hobbled or under the influence of an anæsthetic, are easily dealt with and good radiograms may be obtained.

In the case of larger quadrupeds, chiefly horses, it is not always desirable or possible to ensure steadiness by narcosis or by "throwing" and hobbling; only the extremities are accessible to radioscopic or radiographic examination, and the indications are lameness, spavin, navicular disease, etc. Short exposures have been made feasible by the introduction of the "electrolytic" interrupter, and a radiogram of the hock or the corona may be taken without securing the animal; for the latter joint an exposure of from ten to fifteen seconds is sufficient, and if care is taken to minimize noise, sparking and vibration, the horse will keep quiet for this time. The tubes must not be brought too near the skin, as the electrostatic charge of the outside of the tube would attract the fine hairs of the skin and produce a pricking sensation which would cause so nervous an animal as the horse to become restive. It is advisable to use very penetrative rays from a highly exhausted tube and to place the tube just outside a wooden partition, on the other side of which the animal stands; it is sufficient to hold the plate-holder firmly against the leg of the animal. Of course, the fluorescent screen is very much easier of application than the photographic plate and sometimes quite sufficient; with a 12 or 16 inch coil and a good interrupter, hock, fetlock, elbow and cervical vertebræ may be examined, likewise the teeth.

Much remains to be done, and no doubt will be done as our technical limitations are removed.

CHAPTER XIII.

THERAPEUTIC APPLICATIONS OF THE X-RAYS.

THE idea which first prompted various attempts to utilize the X-rays therapeutically originated in a property of these rays, "penetration," which at the present time we studiously avoid for this very purpose as we shall presently explain.

It was held that these rays, having under certain conditions easy access to the deeper seated organs of the human body, might be made the vehicle of certain physical actions, similar to the method of cataphoresis, in which electric currents penetrating into the skin convey some drugs (like cocaine) into the tissues and there produce local anæsthesia, etc. This hope, however, proved abortive, as did also the expectation that a bactericidal action might be transmitted to infested organs within the body. Neglecting for the moment the highly debatable question, whether any positive bactericidal action of the X-rays exists at all, we now know, that owing to the absorption and modification in character which the rays undergo in passing through media, such expectations were doomed to disappointment.

The experiments and deductions having reference to the action of X-rays upon cultures are still in the embryonic stage, and cannot be gone into here: we refer the medical reader to the work done by Dr. Rieder of Munich and by Drs. Wolfenden and Forbes-Ross of London.

Instances, however, soon became known in which long exposures were followed by more or less complete depilation or, worse still, by severe inflammation of the skin, and many operators and demonstrators of X-rays had to deplore the loss of the fingernails and other inconveniences.

Amongst those who first carefully investigated these effects were Drs. Schiff and Freund of Vienna, Drs. Goch and Albers Schönberg. Their publications soon stimulated English and other practitioners, and the number regularly employing the rays for their therapeutic effects is steadily increasing both in private practice and in hospitals.

But even now it is difficult, if not impossible, to say to what causes, or to what specific rays emanating from a tube, the curative effects on certain diseases of the skin and tissues are to be ascribed.

Some operators hold the extreme view, that X-rays take no part whatsoever in these cases, but that the tube is only to be considered as an electrical instrument (like a condenser) from which certain electrical manifestations proceed, and that the latter alone are responsible for the beneficial changes in the tissues at which we aim ; that the X-rays (such as obtained from soft tubes) are really an undesirable by-product which is responsible for dermatitis, mortification and the like, which more or less interfere with the treatment.

If it were possible to provide a screen of such a description that either all the purely electrical or all the X-ray emissions from the tube would be absolutely absorbed, it would be easy to trace the real character of the agent we are using, but at present such a perfect screen does not exist.

Be that as it may, and even agreeing, as the authors do, that radio-therapeutics are not confined to X-ray treatment only (the high frequency treatment being closely allied, for example), we think that a short exposition of the practice and possibilities of X-ray therapeutics should be included in this handbook, the more so since all the other radio-treatments were stimulated by the original tube practice.

The cases in which X-ray treatment is indicated are: lupus, psoriasis, eczema, rodent ulcer, alopecia, hypertrichosis. As we go to press reports are coming to hand of two cases of cancer of the breast, successfully dealt with by the Röntgen rays.

As regards the apparatus to be employed, any coil above 6-inch spark length, any source of electricity, and practically any interrupter may be used, although on the latter point we shall have something to say later on. Most important, however, is the character of the tube employed, *i.e.*, the degree of vacuum which it shows. It is the experience of practically every worker, that "soft tubes" which show either the cathode stream (purple) or a blue cloud behind the anti-cathode are dangerous, because in this condition they almost invariably produce acute "burns," which are all the more to be avoided, since the first appearance of a reaction may possibly not take place until a fortnight or three weeks after the last application; and all the while we are continuing the "raying" we are accumulating the inflammatory effects, until finally a severe destruction of the tissues results, which is exceedingly painful and difficult to heal. Very high tubes, on the other hand, are apt to introduce electrical influences which most likely produce sloughing, etc. (electric erythema). One has thus arrived at the employment of "medium" tubes, *i.e.*, such, the resistance of which equals a spark length (alternative) of about four to eight inches between a point and a disc. The higher the vacuum of the tube, the greater becomes the penetrative power of the rays from it and the lesser the chance they have of acting by their absorption in the tissues. A modification in the working distance between tube and patient may, however, somewhat compensate for differences in absorption.

The time during which the radiation is acting per sitting varies generally between eight and twenty minutes and is determined by individual circumstances. Frequent and short rayings are preferable to a few continued sittings, because the *doseage* of the current and time may be much easier checked and controlled from certain indications, such as hyperæmia, temperature, etc.

And here we should like to say a word or two as to the errors introduced in the clinical reports of such cases by merely stating the number of minutes during which the apparatus is at work.

It has been shown that the discharge from the secondary of an induction coil—and therefore the emission of X-rays from a tube worked from such a coil—is of a pulsating or intermittent character, the number of current—or ray—impulses depending upon the type of interrupter employed. Assuming that every ray impluse emitted from the tube exerts a certain minute effect upon the tissues, it becomes obvious that the integral effect of a series of rayings depends upon the number of such impluses and not—without further qualification—upon the time occupied for the whole series of sittings.

If every operator were provided with one certain standard apparatus or rather interrupter, working at an absolutely constant speed, then the actual time occupied would be all that it is required to know. But how can we hope to arrive at any useful comparison between the results or working methods of several investigators when their technical data run somewhat as follows: "The strength of current in the primary coil was 2 or 2½ ampères, the duration of sittings 10 to 15 minutes, etc., etc."? Supposing Dr. A. used for the above case a vibrating mercury interrupter giving 200 interruptions per minute and Dr. B., wishing to repeat these data as above given with his apparatus, used a jet interrupter so arranged as to yield 2000 interruptions per minute, the result would in all probability be entirely different (other circumstances remaining equal), because the period of activity of his tube was in reality ten times that of Dr. A.'s, though he may have scrupulously turned off his current after fifteen minutes.

Again, the bare statement of the amount of current passing through the primary of the coil does not aid us at all in comparing the amount of energy radiating from the tube, because this primary current is more or less a peculiarity of the construction of the coil, its self-induction, interrupter, etc.; so much so that whilst one type of coil may register $1\frac{1}{2}$ ampères in the primary, another type may pass 5 ampères, whilst yet the energy produced in the secondary, and *eo ipso* in the tube, may be the same in both cases.

The whole practice of X-ray therapeutics is at the present moment in its infancy; patient work and tabulation of working conditions and results alone can ultimately lead to the establishment of average working prescriptions. The radiation from the tube is heterogeneous and most unfortunately presents the greatest factor of uncertainty, so that it becomes all the more important to correctly and sufficiently record the technical data which we can control.

We suggest, therefore, the following description of apparatus employed in a specific case:—

Size of coil, source of current, type of interrupter, number of breaks per minute, primary current when producing the full spark length at this speed of interruption; primary current registered during exposure, duration of exposure, parallel spark length of tube, distance between patient and anti-cathode of tube.

From the proper source a very flexible lead foil of no great weight can be obtained. A linen—old handkerchief—base is used, on which the area to be exposed is marked, the lead stitched on—the linen overlapping extreme edges and also the edges of the hole cut for exposure. This can be easily moulded to any part of face or body. The edges of the mask require to be free from metallic covering, as otherwise the patient is sure to complain of "pricks," and local irritations may be set up.

It is manifestly impossible to exhaustively treat this important and promising application of X-rays without going into the medical aspect of the matter, and this is beyond the scope of this work. We refer our medical readers who wish to gain a closer knowledge of the changes in the tissues, etc., produced by exposure to the rays to a paper read by Dr. M. Sharpe before the Röntgen Society, and also a discussion on the same subject, introduced by the same author, published in *The Archives of the Röntgen Rays.*

CHAPTER XIV.

GENERAL APPLICATIONS OF X-RAYS.

It cannot be said that the application of the Röntgen rays for general, non-medical, purposes has in any way fulfilled the expectations which were so freely indulged in during the rush of experimental work following upon Röntgen's first and second communications. Indeed, the medical value so completely overshadows every other possible development of X-ray work that the latter is now almost completely forgotten by the public.

For a short time the application of the rays for customs examinations abroad seemed to indicate a vast field of usefulness, but the method was very soon dropped on account of its limitations, uncertainty and complication.

It may be easy enough to detect coins and other metallic enclosures in ordinary letters or postal packets, but it is quite another task to penetrate by means of X-rays the contents of a large travelling trunk or portmanteau, and still more difficult—if not entirely impossible—to discern, say, a box of cigars, or a quantity of lace surrounded by articles of clothing, etc.

The attempts to radiograph the contents of letters or palimpsests or to establish the authenticity of old paintings may be dismissed as interesting laboratory experiments only.

Exactly where the greatest benefit might accrue from the application of X-rays—namely, in the examination of masses of metals—do they fail us most signally.

Except in thin sections or in small dimensions, most metals are almost opaque to even the most penetrative rays which we can produce with the best and most powerful of apparatus. The work of Mr. Heycock of Cambridge University is very beautiful and interesting. He alloyed two metals of widely different X-ray opacity, such as sodium and gold, and took radiograms of thin sections. These radiograms demonstrated the distribution of the sodium in long crystalline masses. It cannot be denied that such experiments are most valuable to metallurgists, and a systematic and comprehensive investigation on these lines is much to be desired.

The presence of flaws and hollows in steel or iron castings, in steel plates and girders may be detected, theoretically, by very penetrative X-rays, but so far no really practical result has been obtained, which could not be arrived at much more expeditiously by weighing, tapping or magnetically examining the object. The use of the fluorescent screen is out of the question, and the photographic plate with its cumulative "memory" is in most cases put out of court through inadequacy as regards size and the questions of time and expense.

To the mineralogist, the conchologist and the geologist much valuable information may be conveyed by the radiographic examination of ores, shells and rocks.

The presence and position of staurolite crystals in pieces of mica-schist have been shown by E. K. Müller of Zürich, and a great many similar uses will readily occur to the geologist; Dr. Rodman has lately produced some beautiful radiograms of mollusc shells, aiding materially their classification by demonstrating the inner architecture of the animal. We also remind the reader of the series of radiograms of marine zoological specimens published by Dr. Norris Wolfenden and others. The delicacy of such radiograms is exceedingly valuable and beautiful.

We are not aware whether Mr. Haskins has followed up the radiographic comparison of various kinds of coal with a view of determining their caloric value from an examination of the amount of earthy matter contained.

Adulterations in food stuffs, such as flour, rice, etc., may be easily detected ; but little has been done in this way, or if any regular practical work is done it has not been published.

The comparative transparency of coal and carbon becomes very clearly marked in the case of chemically pure carbon—diamond. Genuine diamonds and most gems cast no shadow upon the fluorescent screen or the photographic plate and are thus readily distinguished—by the non-expert—from imitation stones. The latter are made chiefly from "paste"—or glass, with a fair percentage of lead or other metallic oxides, and when examined by means of the Röntgen rays show up opaque. Whether this mode of examination offers any advantage to the expert, either as regards expediency or certainty, we are unable to state ; the fact that our leading houses in the jewel trade make no use of the rays seems to indicate a negative reply.

CHAPTER XV.

THEORETICAL.

A BRIEF review of the theoretical ground covered by the X-rays and some similar manifestations of energy cannot fail to be of interest to the practical worker, more especially since the limitations as well as the possibilities of the new form of radiation are thereby defined.

The most important question, What are Röntgen rays? cannot be definitely answered even now, except by the obvious but too general reply that they represent some form of energy closely connected with electrical phenomena.

Every known form of energy consists of oscillations either transverse or longitudinal of a transmitting medium, and according to the rapidity of the vibrations, or conversely to the wave-lengths, the various forms of energy belonging to one kind of manifestation (transverse) are ranged in a series forming the general spectrum.

Professor Röntgen in his original paper expressed the belief that his newly discovered radiation was 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 adherents to this view is now very small.

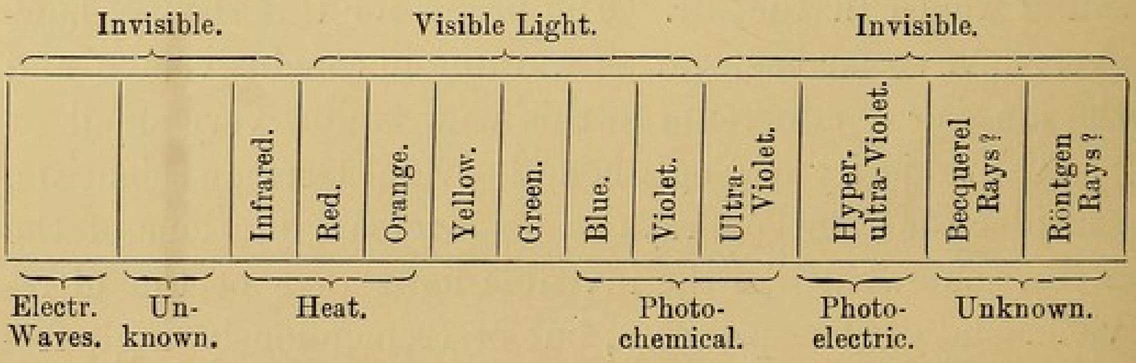
The majority of English, and several German scientists, consider the Röntgen rays as transverse vibrations of the ether, somewhat like the invisible light rays of the ultraviolet end of the spectrum, but of tremendously high frequency, and consequently of excessively short wave-length.

To accurately place the X-rays in the general spectrum would necessitate a measurement of their wave-length in the usual way by producing stationary waves or by observing the refractive index. Now, with the exception of some unconvincing indications of irregular reflection, and doubtful polarisation experiments by various workers, there has been no absolute experimental evidence that the X-rays may be reflected and refracted like other transverse vibrations of the ethers, and consequently no reliable determination of their wave-length has been recorded. For this reason the transverse vibration nature of the X-rays has been often negatived altogether.

However, according to the law of dispersion, the coefficient of refraction for very minute wave-lengths approaches unity, so that the wave-length would fall to something less than ·000001 millimetre, which is practically identical with the figures found by Winkelmann and Straubel (coefficient = ·9962) or by Voller (·999).

In this case, the X-rays would fall into line with the ether spectrum and be ranged some distance behind the hyper-ultra-violet rays (active in the discharge phenomena of electrified bodies).

Anticipating somewhat for the moment, the gap between the hyper-ultra-violet and the Röntgen rays may be conceivably filled by Becquerel rays and glow-worm rays, which show penetration and chemical action in addition to slight reflection and refraction.



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

In Chapter I. we have shown that cathode rays, which are assumed to be the parent rays to X-rays, behave in many respects like Röntgen rays, in so far as they have a certain amount of chemical action, of fluorescifient effect and of penetration, but that they differed radically by their ability to be deflected by magnetic fields acting in a certain direction. Many physicists have thus been led to pronounce that X-rays are only modified cathode rays, and there are indeed many reasons why such a hypothesis has some grounds of probability.

Firstly, we should remember that whenever cathode rays meet some obstacle, X-rays are generated ; now, in all experiments on cathode rays outside the vacuum tube, these cathode rays had to pass through—and consequently to meet—some transparent window, and thus a large proportion of the cathode rays must have been converted into X-rays ; even in those experiments inside the tube where the photo-chemical action of the cathode stream was to be demonstrated by placing small enclosed films into the tube, we do not know whether the blacking of the films was due to pure cathode rays or to the X-rays generated by the striking of the cathode rays against the paper envelope of the film.

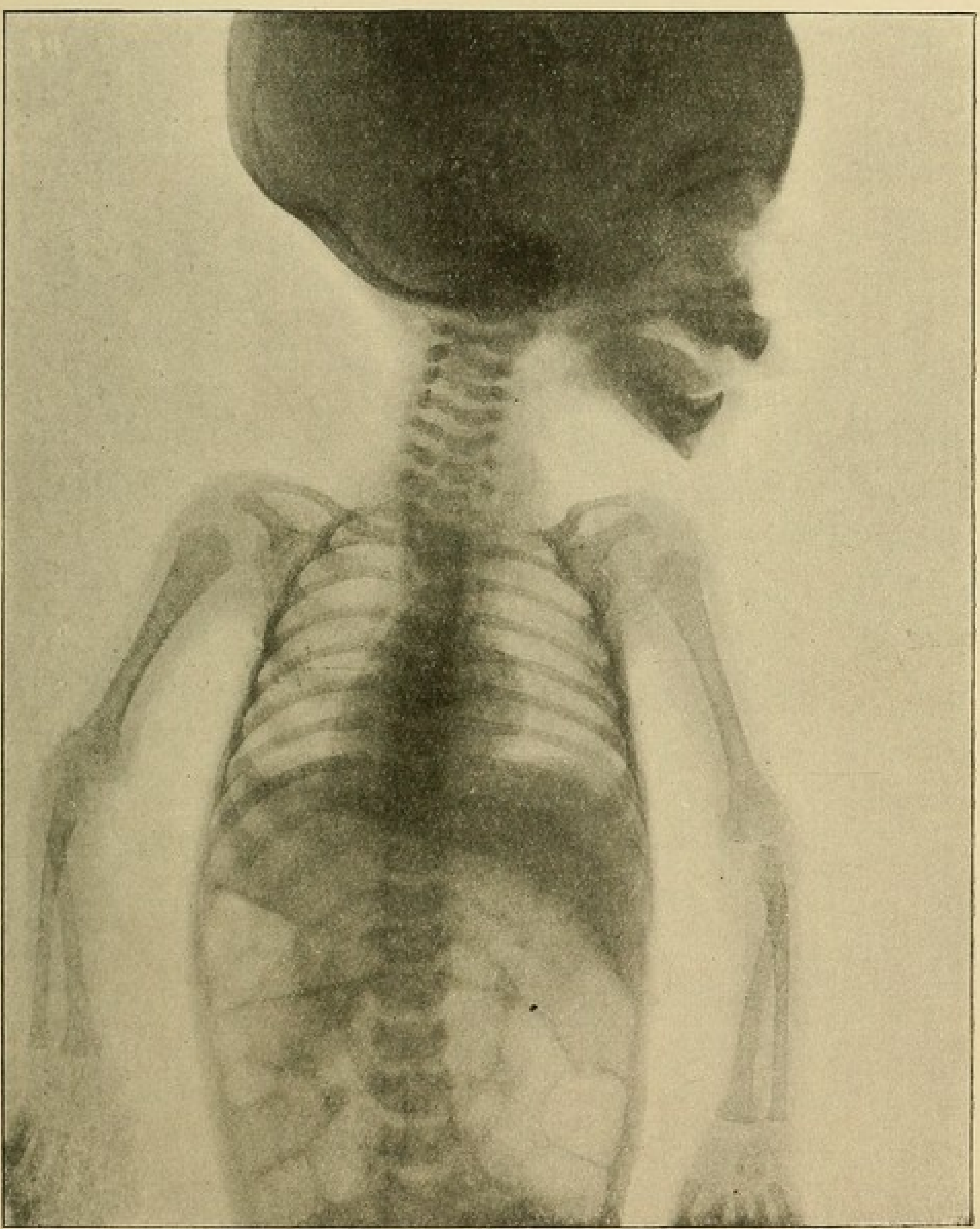
The absence of magnetic deflectibility of the X-rays may be explained in this way. The cathode stream, consisting of negatively charged particles moving with great rapidity (about one third of the velocity of light) behaves somewhat like an electric conductor and naturally is influenced by a magnetic (or electric) field. On striking the anti-cathode or anode, the cathode stream is divested of its electric charge, and in passing onwards (by diffuse reflection from the anti-cathode) as X-rays would, of course, no longer show any magnetic deflection.

We can further conceive, on this basis, that the cathode stream, bereft of its electrical charge—or, in other words, the X-rays—is eager to pick up a fresh electrical charge, when occasion presents itself—-which is quite in conformity with the observed diselectrification of electrified bodies by the X-rays. Moreover, such X-rays show magnetic deflectibility.

This dissociation theory, which was started by Nicola Tesla in America, assumes that the Röntgen rays are particles of matter, which being repelled from the anti-cathode 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.

The latter further assumes that the impact of the cathode rays is capable of breaking up the ordinary chemical atoms into "hyperatomic" 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 coefficient of absorption for the Röntgen rays in various substances change 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.

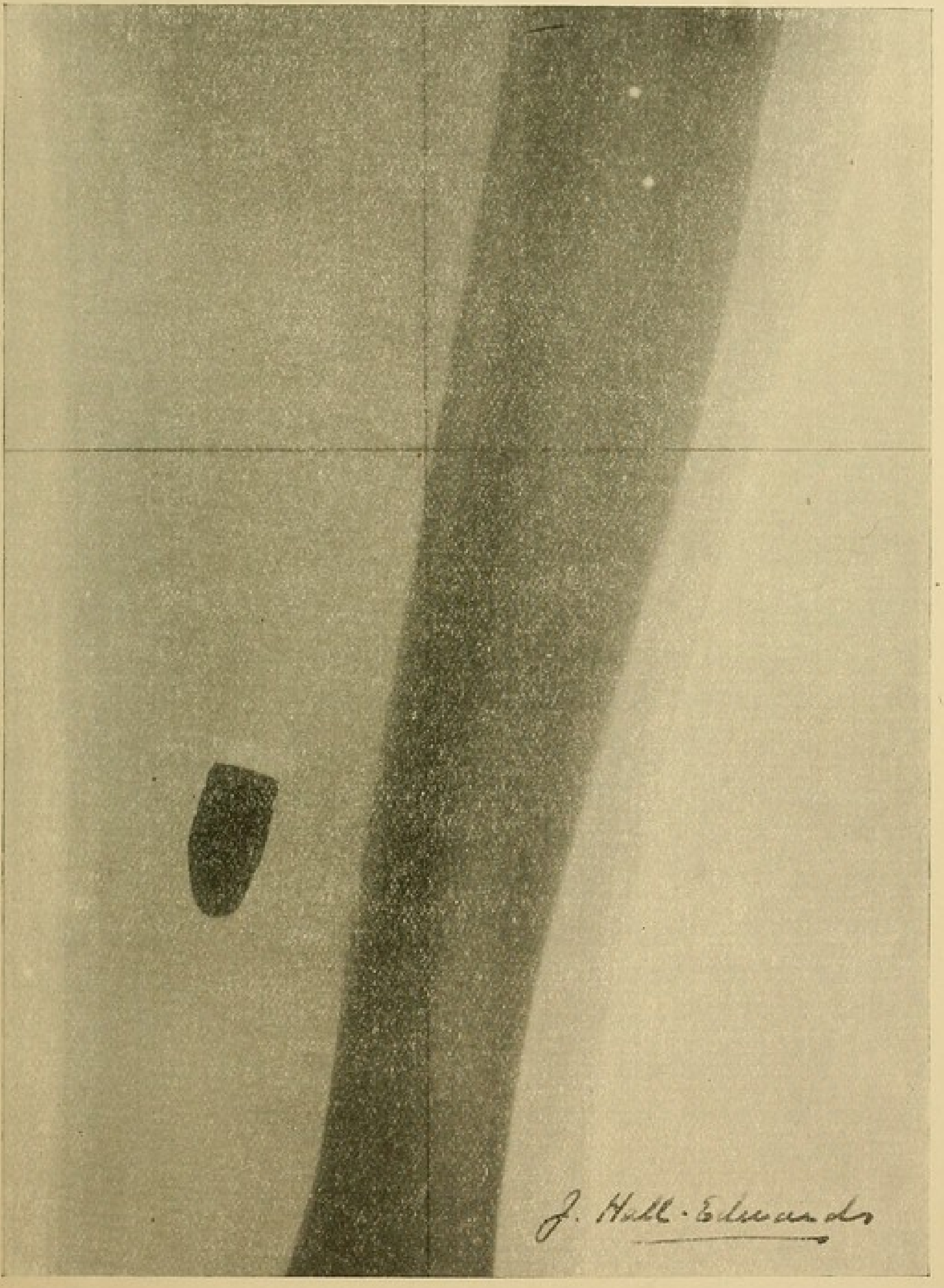
The generation of X-rays, whatever they be, has been considered as dependent upon a certain minimum Electro-Motive force (according to Professor Trowbridge, 100,000 volts). Dr. Wehnelt has gone further into this question and came to the conclusion that X-rays begin their existence even at 7000 volts under certain conditions;



Radiogram of Baby.

(By A. W. Isenthal.)

Plate XII.]



Service Revolver Bullet in Calf.

(Radiogram taken at the Imperial Yeomanry Hospital, Dulfontein, South Africa, 1901, by J. Hall-Edwards.)

generally speaking, the X-ray stage is attained as soon as the "dark space" (see Chapter I.) separating the cathode from the luminous discharge has so far extended as to include the anode; simultaneously, and possibly in some connection therewith, the tube at this exhaustion sends out strong electric waves.

The discovery of the Röntgen rays has, of course, led to a great deal of work on other invisible radiations, especially on the so-called Becquerel rays, which resemble Röntgen rays in many respects, and which—for a time—were believed eventually to supersede the X-rays in medical work on account of the simplicity of their generation.

Uranium, the metal which of all chemical elements shows the highest atomic weight, is capable of emitting invisible rays which affect photographic plates. M. Becquerel was the first to scientifically examine these rays as well as those emitted from various chemical combinations, of which uranium and thorium form the bases; shortly afterwards Mme. Curie succeeded in isolating from certain ores, notably the Bohemian pitchblende, two probably new compounds or even elements which greatly surpassed uranium as regards radio-activity and which were termed "polonium" and "radium." A still higher efficiency of radiation must be awarded to a preparation made by F. Giesel of Brunswick, which preparation, however, is exceedingly difficult to obtain in its state of highest activity.

Such substances, then, show the property of acting by radiation upon a photographic emulsion, even though the rays may have to pass through opaque aud metallic substances. By their agency we may thus produce shadow images of certain more opaque objects; a fluorescent screen is illuminated though but very feebly; penetration and absorption follow the same laws as in the case of X-rays, the difference being one of degree only. Refraction and polarization of Becquerel rays have not been demonstrated, but powerful magnetic fields exert a feeble deflection; the rays have the property of "ionizing" the air—*i.e.*, of making the air and other dielectrics which they pass a conductor, for the time being, of electricity.

All these factors tend to assign to the Becquerel rays a position in the general spectrum close to, but in front of, the Röntgen rays.

TRANSPARENCY OF VARIOUS SUBSTANCES FOR RÖNTGEN RAYS.

The following table for the relative transparency of equal thickness of various substances (water = 1) is due to Batelli and Garbasso :—

Material.	Specific Gravity.	Transparency.	Material.	Specific Gravity.	Transparency.
Pinewood . .	0·56	2·21	Tin . .	7·28	0·118
Walnut . .	0·66	1·50	Zinc . .	7·20	0·116
Paraffin . .	0·874	1·12	Iron . .	7·87	0·101
Rubber . .	0·93	1·10	Nickel . .	8·67	0·095
Wax . . .	0·97	1·10	Brass . .	8·70	0·093
Stearine . .	0·97	0·94	Cadmium . .	8·69	0·090
Cardboard . .	...	0·80	Copper . .	8·96	0·084
Ebonite . .	1·14	0·80	Bismuth . .	9·82	0·075
Woolcloth . .	...	0·76	Silver . .	10·5	0·070
Celluloid . .	...	0·76	Lead . .	11·38	0·055
Whalebone . .	...	0·74	Palladium . .	11·3	0·053
Silk . .	...	0·74	Mercury . .	13·59	0·044
Cotton . .	...	0·70	Gold . .	19·36	0·030
Charcoal . .	...	0·63	Platinum . .	22·07	0·020
Starch . .	...	0·63	Ether . .	0·713	1·37
Sugar . .	1·61	0·60	Petroleum . .	0·836	1·28
Bones . .	1·9	0·56	Alcohol . .	0·793	1·22
Magnesium . .	1·74	0·50	Amylalcohol . .	...	1·20
Coke . .	...	0·48	Olive oil . .	0·915	1·12
Glue . .	...	0·48	Benzol . .	0·868	1·00
Sulphur . .	1·98	0·47	Water . .	1	1·00
Lead ointment .	...	0·40	Hydrochloric acid .	1·240	0·86
Aluminium . .	2·67	0·38	Glycerine . .	1·260	0·76
Talcum . .	2·6	0·35	Bisulphite of carbon	1·293	0·74
Glass . .	2·6	0·34	Nitric acid . .	1·420	0·70
Chalk . .	2·7	0·33	Chloroform . .	1·525	0·60
Antimony . .	6·7	0·126	Sulphuric acid .	1·841	0·50

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.

In his third communication Professor Röntgen deals very exhaustively with this phenomenon.

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 Professor Röntgen's second paper. As an explanation for this phenomenon, 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. Professor 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.

INDEX.

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