INDUCTION COILS

How to Make and Use Them.

A Practical Handbook on the Construction and Use of Medical and Spark Coils.

BY

PERCIVAL MARSHALL, A. I. Mech. E.

Thoroughly revised and enlarged by

KURT STOYE,

Instructor Baron de Hirsch Trade School.

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INDUCTION COILS

HOW TO MAKE AND USE THEM

With

full particulars, tables of windings and illustrations showing the construction of Coils giving sparks from one-half inch to twelve inches, including

COILS FOR AUTOMOBILES AND GAS ENGINES.

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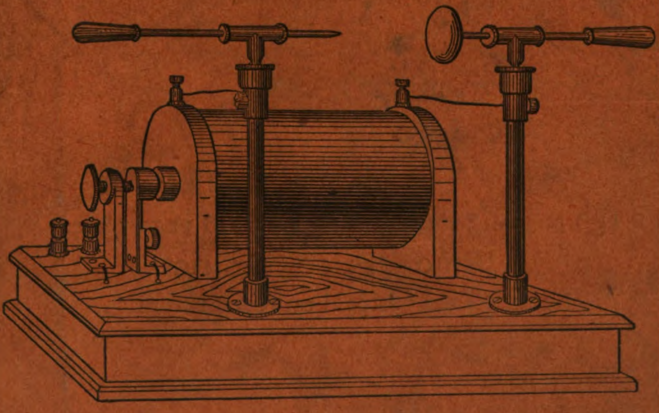

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PREFACE TO REVISED EDITION.

In revising this excellent little English book, one of the *Model Engineer Series*, Mr. Kurt Stoye found it necessary to make many changes especially as to gauges and prices; to add additional matter in numerous places including full detailed instructions for making a new form of Electrolytic Interrupter, with illustration, also two new tables specially compiled for this work showing specifications of materials required for coils giving sparks from ½ in. up to 12 inches, and in every way making this work a most up-to-date and practical American book.

THE PUBLISHERS.

September, 1906.

PREFACE.

The induction coil has always been a popular piece of apparatus with amateurs and students interested in electrical science, so numerous and so fascinating are the experiments which can be performed with its aid. Its practical importance has, moreover, been considerably enhanced in recent years by its application to such useful purposes as X-ray work, wireless telegraphy, and the ignition of the charge in internal combustion engines, such as the petrol motors now so extensively used for cycles and automobiles. In the following pages we have adhered to the lines usually adopted in this series of handbooks, and have commenced by giving sufficient theoretical information to enable the reader to understand the various principles involved in the design and construction of satisfactory apparatus. This is followed by descriptions of the methods of building coils for various purposes, and in a later chapter tables of dimensions are given which will enable the reader to construct a coil of any size, within limits, to suit his own special requirements, if these are not met by the coils described in detail in the earlier chapters. The concluding section on experiments with induction coils will be of interest, as showing some of the methods by which the reader can derive both instruction and amusement from the coil he has made. It is, of course, impossible within the limits of so small a book to deal exhaustively with this portion of the subject, but the hints given will serve to direct the attention of the intelligent student to many opportunities for carrying out attractive experiments and investigations which the possession of a well made coil affords.

PERCIVAL MARSHALL.

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ABBREVIATIONS USED IN BOOK.

B. & S. = Brown & Sharpe wire gauge.
S. C. C. = Single cotton covered wire.
D. C. C. = Double cotton covered wire.
S. S. C. = Single silk covered wire.
D. S. C. = Double silk covered wire.

CHAPTER I

THE PRINCIPLES OF ELECTRICAL INDUCTION.

The action of an induction coil is due to a property peculiar to electricity, the explanation of which is entirely unknown to science. The effect can well be described with the aid of a simple diagram, as in Fig. 1. Here A B and C D are two wires insulated from, but parallel to, one another. Suppose the ends of A B to be joined to the poles of a battery or other source of electricity, the galvanometer G and switch or contact H being interposed in the circuit. The ends of the second

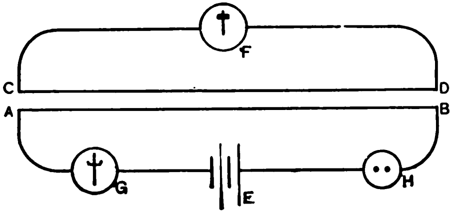


FIG. 1.

wire, C D, are to be similarly joined by a wire which has only the galvanometer F in its circuit. With this simple apparatus two distinct phenomena may be noted.

The switch H being 'off', and no current therefore flowing in the wire A B, the needles of both galvonometers will, of course, stand at zero. Now suppose the switch H to be suddenly moved to the 'on' position. The needle of galvanometer G will move to another position, where it will remain as long as the current is allowed to flow. It will, moreover, be found that the needle of the second galvanometer F is also diverted at the moment of contact, but that this movement is immediately followed by a swing back to the original position occupied, namely, to the zero point. Obviously, although no metallic connection exists between the wires A B, C D (these being electrically insulated from each other), a current has momentarily passed in the circuit of which C D forms a part, but has very quickly ceased to exist.

The switch H is now to be moved back to the 'off' position. The movement of the needle of galvanometer G is back to the zero position, but again that of the other galvanometer shows a momentary deflection—indicating the passage of a current—and this time, it will be observed, the movement of the needle of F is in the reverse of its previous deflection, indicating the important fact that *the currents in the wire C D are in opposite* *directions when the circuit in A B is closed and opened.* It is obvious that the making and breaking of the circuit through A B has the result of 'inducing' a current in C D,—how, we cannot say, but this is the fact.

By means of suitable apparatus it can be determined that at the 'make' of circuit the current induced in C D is in the opposite direction to that in A B. At the break the current in C D is in the same direction as it was flowing in A B.

Since the current in A B is the cause of the phenomena just described it is called the primary current, and A B is called the primary wire. The current in C D is the secondary—or induced—current, and C D is the secondary wire.

Currents are induced in the secondary wire only at make or break of primary circuit, or when the current in the latter is fluctuating in intensity. The most marked results are observed when the make or break is sudden, and the action is strongest at the *break* of the primary current.

The inductive effect of the current in a wire on another wire parallel to it is not very great under the conditions already given.

Reverting to the diagrammatic circuits shown in Fig. 1. If we imagine the wire A B to be covered with insulating material and wound on a hollow bobbin in one or two layers, it can easily be seen that the secondary wire C D can be wound on top of it to any desired number of turns. The two sets of wires will still be parallel throughout their lengths, and the whole will form a compact apparatus. Indeed, two of the essential parts of an 'induction coil' have now been described, and these are illustrated, diagrammatically, in Fig. 2 where the thick line, P, encircling the tube T, is the primary, and the fine lines S, two layers of the secondary wire. It does not matter in which direction the winding is done, but in each wire it must be continuously in the direction in which it is begun.

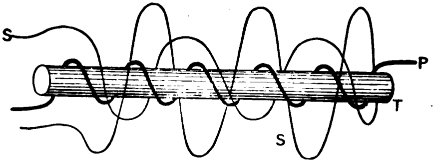


Fig. 2.

Although the coil so far described is a more powerful apparatus than Fig. 1, it can easily be made still more energetic. If the tube T, which must be constructed of some good insulating material, be filled with an iron core, the inductive effect of the coil is vastly increased. There is an intimate connection between the magnetic lines of force and the inductive action of electric currents, and the introduction of the magnetic iron core results in the concentration of these lines of force into a powerful 'field,' surrounding and penetrating both the sets of wires. It has been found that the highest possible effects can be obtained from any given induction coil only when the iron core is of the softest possible iron. This core must not be of a solid bar of iron, but must consist of a bundle of wires. The finer these are the better; the tighter they are packed and the closer they fill their allotted space, the better will be the result of the coil's action.

One more important phenomena must be observed. This is called the self-induction of the primary wire. It could not be discovered in the simple apparatus indicated in Fig. 1, where the primary wire (A B) consists of a single strand only. When this is wound into a coil as at P P, Fig. 2, however, it is found that every single turn acts on its neighbors just as though they were independent coils of secondary wire, and it even induces secondary currents in them in the same way. This is very important, as will be understood if one is reminded of the directions taken by the induced currents at make and break of circuit.

It will be remembered that at the instant of closing the circuit (*starting* the current in the primary) the direction of the induced current in the secondary wire was in the opposite direction to that in the primary wire. The same is the case with the current induced in the coils of the primary wire by the action of its own turns of wire. This has the effect of weakening the current in the primary wire, since it is impossible for opposing currents to traverse the same wire without affecting one another. Incidentally, it may be observed that the very weak current at 'make' has a correspondingly weak effect on the true secondary winding.

Attention should now be turned to the condition of things at ' break ' of circuit. In the secondary coils, a current is induced similar, as regards direction, to the inducing current. In the primary wire the same effect is found, and since the two currents (the initial and the induced) travel in the same direction in the same wire, they add together to form a powerful rush of current which results in a much greater effect on the secondary coil.

This ' extra ' current in the primary wire has the effect of producing a flashing, bright spark at the contact breaker, and also of prolonging the period of demagnetization of the core. This is a great disadvantage, since on the rapidity of magnetization and demagnetization depends to a large extent the power of the coil. To reduce the effect of the ' extra ' current, as it is called, a condenser is introduced, which stores the rush of current until the circuit is again ' made,' when it augments the battery current to some extent. Thus the principal action of the condenser is to reduce the destructive sparking at the contact-breaker, and to shorten the period of demagnetization of the iron core; its secondary effect is the great increase in length, thickness, and brilliance of the spark from the secondary coil. Condensers for coils usually consist of sheets of tin-foil insulated from one another by sheets of paper soaked in paraffin wax. Their construction and method of connection will be described in due course.

CHAPTER II

PRACTICAL HINTS ON THE CONSTRUCTION OF INDUCTION COILS.

Induction coils may be divided into two distinct classes—those for the purpose of giving brilliant and powerful sparks for experiment, and those used solely for shocking and medical purposes. It is, of course, possible to make a coil serve both ends, but this is an exceedingly bad plan, as any coil capable of giving even quite a small spark might produce serious results if the whole shock were taken by anyone of somewhat sensitive nerves. Generally, coils for medical or shocking purposes require less careful workmanship than the others, and an induction coil of this character is most suitable for the amateur's first attempt in this direction. A sparking coil must be constructed with scrupulous regard to insulation, and since also the greatest effect is obtained when the secondary wire is closest to the primary, practical experience is essential in its making.

Materials. The following hints on the materials to be used and the methods of connecting up will be of use in the construction of a coil of whatever size. The various parts may be taken in a definite order, commencing with the core.

The core of an induction coil, whatever its size or purpose, should consist of soft iron wires. They should be of small size, Nos. 21, 22 and 23 B. & S. gauge being usual and very good sizes. This wire is bought in coils and can be cut up into pieces the required length after the wire has been straightened. This is done by drawing it between two rows of nails fixed in a board, as in Fig. 3, so arranged that a very slight kink is given to the wire as it passes each nail.

Fig. 3.

The bundle of wires having been thus prepared, it should be annealed even if *soft* wire has been employed. To anneal, place the bundle in the fire the last thing at night, so that the wires become thoroughly red-hot and then slowly cool out with the fire. If kept red-hot in the fire for long, the thin wire will oxidize or burn away and become useless. It will be found that the wires have slightly warped during the annealing process. The wires can be straightened again without any trouble by simply rolling them between two hardwood boards 3 or 4 at a time. The further treatment of the core depends upon the purpose of the coil, and may therefore be left for the present.

The primary wire in ordinary induction coils is always thicker than that employed in the secondary winding, and both primary and secondary wires are of copper, the purer the better. Primary wire is usually double-cotton-covered (D C C), and as cotton is a somewhat poor insulator, should always be soaked in melted paraffin wax either before or after winding on the coil.

The secondary wire should be silk-covered if the greatest possible effect is to be obtained, as a greater length of wire can thus be wound in a given space. It is, however, very expensive, and ordinarily its use may be confined to the making of large, highly finished, and expensive sparking coils, or small, neat, medical coils, when, if the layers of wire are very carefully wound, it need not be soaked in paraffin wax, a course which is essential if cotton-covered wire is used for the secondary winding.

Sizes of wire. As to the sizes of wires, the following will serve as a guide (B. & S. gauge is employed.) For shocking or medical coils, No. 20 or not larger than No. 17 wire may be used for the primary winding. For sparking coils up to ½ in., No. 16; up to 1 in., No. 14, up to and including 4 in., No. 12; and No. 10 for larger coils will be found suitable primary wires. The secondary wire might be set down once for all as No. 36, this wire giving with good workmanship, nearly

1-in. spark for every pound used, and being of sufficient sectional area to produce a thick, snappy spark well suited to most purposes. If a much thicker spark is required, at a sacrifice of length, No. 34 wire may be used; similarly, No. 38 or No 40 may be employed to produce long, thin sparks. For shocking coils, No. 32 or 34 is recommended.

Paraffin wax is used almost exclusively nowadays for coil insulation. It is better than resin, shellac, etc., and is practically only second to mica. The wax should be hard, clear, pale (not yellow), and perfectly clean. Pure beeswax is best, but is much more expensive. Great care must be taken when melting the wax not to burn it, as that detracts from its excellent insulating properties. The best plan is to melt it always by suspending the vessel containing it in another which can be boiled—like a glue pot, in fact. The wax can never be overheated when that method is adopted.

Woods. In all spark coils it is essential to have good sound construction, and the wood used must be perfectly dry, clear grained, and carefully varnished or polished. Ebonite must be used in many parts, especially of large coils, but where 'appearance is no object,' good sound wood soaked for a long time in molten paraffin wax will be found a very efficient substitute. Points must be rigorously avoided in every part of the apparatus (except, of course, the discharging point or points).

The condenser is usually fitted in the base of the coil in a box-like space provided for it, and is unnecessary for a shocking coil. Its position determines the dimensions of its leaves. It is composed of tin-foil sheets interleaved with larger sheets of waxed paper. In the smallest sparking coils there should be a margin of ½ in. at least all around the tin-foil sheet, and in larger sizes this margin should be proportionately greater. In a 6-in. spark coil the margin should not be less than 1½ ins.

The paper for the condenser should be moderately thin, not too heavily sized, and must be flawless; each sheet should be examined in a good light, and if it contains the minutest pin-hole, or any thin places, must be rejected, or that part at any rate, must not be used. It is cut to suitable sizes and soaked for a few seconds in melted wax, then allowed to drain and cool off. The tin-foil may either be cut oblong and have separate connecting lugs, or these may be cut out all in one piece, and with a little planning there need not be much waste by this method. It has the advantage that the condenser can be made more compact.

The condenser is built up in the following manner. A base of several thicknesses of paraffined paper is first laid, and one of the tin-foil sheets placed on it centrally, as in Fig. 4 (A). On this is placed a single paraffined sheet, and on this again a second tin-foil sheet with the lug at the other end (Fig. 4 B). Next, a paraffined paper and a third tin-foil sheet with lug as in A; another paper, and a fourth tin-foil sheet as at B. This is continued, tin-foil and paper alternating, and alternative tin-foil sheets with lugs at opposite ends, until all are used up. A warm iron can be used to press down the condenser and make it compact and secure. All the lugs at each end can then be clamped by means of a thin piece of springy brass to which is soldered a wire. The usual conventional representation of a condenser is as Fig. 5, the paraffined paper being omitted to simplify matters.

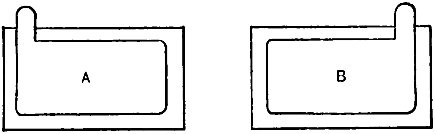


Fig. 4.

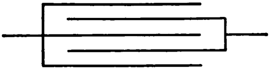


Fig. 5.

Primary Coil. It is quite possible to obtain a strong shock from a coil consisting of a primary winding only, with the usual core and contact-breaker. A simple form is shown diagrammatically in Fig. 6. Here the core is represented by C, and consists of a bundle of soft iron wires about 4 in. long and ⅜ in. in diameter. The wire wound on this core may be about four layers of No. 24, although only one layer is represented in the drawing. One end of the wire is joined to the support of the contact spring S, and the other end to a terminal W. Another terminal, X, is joined to the contact-screw T. A wire is taken from T to terminal Y, and one from S to terminal Z. None of the wires may touch one another at any part. If a battery be joined to terminals W and

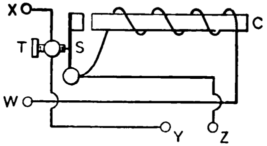


FIG. 6.

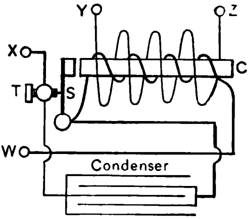


FIG. 8.

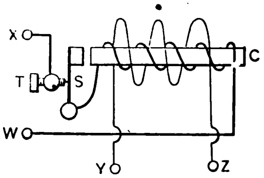


FIG. 7.

X, and a metal handle to each terminal Y and Z, a person holding the two handles will receive a fairly strong shock. The effect is due to the self-induction of the coiled wire, as already explained. A condenser must be not used with such a coil, as it will absorb the ' extra ' current which is the cause of the shock.

A diagram showing the simplest form of primary and secondary induction coil, without a condenser is shown in Fig. 7. The same references serve as in the last case, but, of course, we now have the secondary coil (shown by the fine winding) to deal with. Its ends are simply taken to the terminals Y and Z, which in this case have no electrical communication with the primary current. Fig. 8 is the same coil *with* the condenser, and it will be seen that one set of tin-foil sheets is connected to the contact-spring, and the other to the contact-screw.

CHAPTER III

How to Make a Powerful Shocking Coil.

A good coil for shocking or medical purposes should be easily regulated so that a current of any required strength may be administered. This can be effected in various ways, but the best method is perhaps the regulation by sliding the secondary coil on or off the primary wire. With a coil made as follows, this is easily accomplished.

The baseboard may first be made. It should be of good hard wood—say mahogany—planed perfectly flat, 12 in. long, 4½ in. wide, and ½ in. thick. It should be fitted with two rabbeted pieces of wood at the sides, as in Fig. 10.

The core is next to be made. This is formed of a bundle of soft iron wires of about No. 22 gauge, 4½ in. long. Select a piece of thin brass tubing 4½ in. long and ½ in. in diameter, and pack this tightly with the iron wires. Then force the bundle out an inch or so and bind the protruding end tightly with wire; push the bundle a little farther and continue binding it and pushing it out until the whole bundle has been secured. The ends may then be filed up flat and dipped in soldering fluid. The ends only should then be secured by dipping them in some molten solder contained in a ladle, when the binding wire may be removed and the core washed in water to get rid of the remaining soldering fluid. File over the surface of the core a little, when it should slide freely inside the ½-in. brass tube.

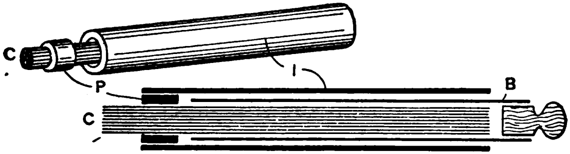


FIG. 9.

Brass tube. Now take this brass tube and a sheet of stout paper, brown paper or cartridge being very suitable. Cut the paper 10 in. × 4 in. and paste it with good flour paste or mucilage until it is thoroughly soaked and quite limp. Wrap the tube with two turns of clean, dry, thin paper, and on this proceed to roll the pasted strip, rubbing it down well all the time. Allow it to dry, when the brass tube and the paper lining can be withdrawn, and the result should be a hard paper tube.

Another narrow strip of paper, ½ in. wide, is now to be wrapped round the core ½ in. from its end, and is to be well pasted or glued in place. It must be made just thick enough for the paper tube to fit over it, and if made too large in the first place, can be shaved or filed down to a suitable size when dry. The paper tube can now be fixed in place by glueing it on the collar, making it flush: The brass tube should be slipped in over the core while the joint is drying, the arrangement being shown in Fig. 9 in which B is the brass tube, C the core, P the collar, and I the outer paper tube. When dry, withdraw the brass tube and soak the complete core and paper tube in hot paraffin wax. Then cut a square piece of mahogany 3 in. each way and ½ in. thick, find the centre of this and bore a hole just large enough for the paper tube to fit in (at the collar part). At the top of the wood fit terminals *a* and *b*, Fig. 11, and fit the core in the wooden square so that it projects by the amount left outside the paper tube, namely, ½ in. Glue in place very firmly, the arrangement being shown in Fig. 11.

The primary wire is to be wound on the paper tube, the ends being joined to the terminals *a*, *b*. About 4 or 5 oz. No. 18 D.C.C. wire will be required, but a little more should be provided, and it should be soaked in melted wax before use. Commence by baring one end of the wire, scraping it clean and bright, and twisting it round under the terminal *b*, which may then be screwed down tight. Wind evenly and closely nearly to the other end of the tube and then return, finishing the second layer at the wood end. Again wind to the other end and back, and secure the remaining end, after cleaning it, under terminal *a*; the primary winding is now finished.

The core and primary coil may now be mounted on the baseboard, being fitted as seen in Fig. 12,

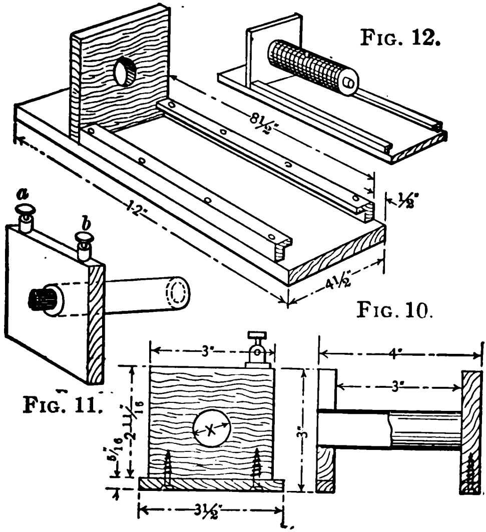


FIG. 12.

FIG. 10.

FIG. 11.

FIG. 13.

the square wooden cheek being glued close against the rabbeted sides and secured by a couple of wood screws from underneath. Care should be exercised in fitting to get the core nice and parallel to the edges of the baseboard.

The secondary portion of the coil now demands consideration. Cut two pieces of ½-in. hard wood to the form of Fig. 13, screwing on the strips at bottom to form the feet which are to slide in the guides shown in Fig. 10. Build up a strong paper tube in the manner already indicated when the primary coil was under discussion. This paper tube is to be of such diameter inside that it will slide freely over the finished primary wire; the inside diameter should not be more than $\frac{1}{16}$ in. larger and the thickness should be about three layers of cartridge paper; it must be thoroughly well pasted or glued. The length is 4 in.

Take the diameter of the tube when dry and make holes just big enough to take it in the middle of each wooden cheek as at *x* Fig. 13. Glue the cheeks firmly and squarely at each end of the tube and set aside to dry. Afterwards fit a terminal at the top of each cheek when the bobbin way be wound full of No. 34 D. C. C. wire. Before actually starting this operation try the bobbin in the slide to see that the feet not only run freely in the grooves, but also that the paper tube clears the primary winding also.

A simple winding machine will be needed if the reader cannot make use of a lathe of any sort. This winder need only consist of two uprights of wood fixed on a simple wooden base as in Fig. 14. The bobbin of wire, which should have been *soaked* in melted paraffin wax, is supported by an axle consisting of a piece of stout wire. The secondary bobbin is mounted on a wooden core, which is also supported firmly on a wire axle, one end of which is cranked to form a handle. The wire should be run through the hand, a fairly long 'bight' being taken as seen at M, and an old glove should be worn during the operation. The beginning of the wire is to be cleaned and passed through a tiny hole in the cheek and secured under one terminal, and to save possible disappointment it should be tested by means of a galvanometer and battery before beginning to wind.

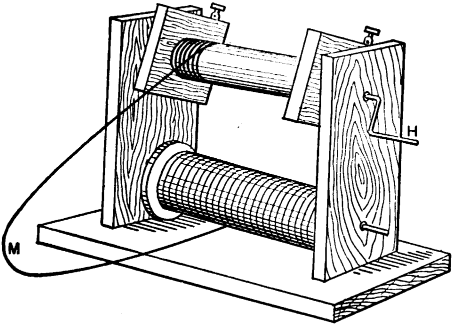


FIG. 14.

Great care should be taken to wind evenly and closely from one end to the other. When one layer is finished it must be covered with a layer of thin waxed paper, and the second layer wound back again to the first end, always turning the handle H Fig. 14 in the same direction. Should the winding of the second layer draw the waxed paper away from the wooden cheek a narrow strip of the same paper should be laid on the uncovered wire (See Fig. 18), as it is at the ends that there is the greatest tendency to spark from one layer to another. For this reason every care must be exercised to prevent the last turn in any layer from sinking down into any space against the cheeks. When all the wire is wound on, or the coil has reached within ¼ in. of the edges of the bobbin ends, the last end of the wire should be bared and secured under the second terminal The last layer of wire should finish at that end; in other words, there must be an odd number of layers.

The coil may be covered with velvet, silk, thin ‘ paper ’ ebonite, or may be left bare as the maker chooses. Similarly the finish of the wood-work is left to his own taste.

Handles should be made of thin brass tube (preferably nickel-plated) about 4 in. or 4½ in. long and ¾ in or more in diameter. They are joined to the secondary terminals by means of flexible silk-covered copper wires the ends of which are soldered to brass connectors.

The contact breaker is shown at Fig. 15. C is an ordinary bell contact screw pillar, the screw itself being tipped with platinum W. The brass spring H is of suitable height to carry the iron armature A exactly opposite the core end. The lower end of the spring is soldered to a stout bar of brass B, to which also is soldered the small terminal R. A stout piece of platinum foil, P, is soldered on the spring just where W meets it. The connections of the coil are those shown in the last chapter at Fig. 7, the primary terminals W and X in that illustration being here connected one to one terminal of the primary winding (*a* Fig. 11) the other to C Fig. 15; terminal *b* Fig. 11 being also joined to R in Fig. 15. For appearance sake connections should be effected as far as possible by wires carried in grooves underneath the baseboard.

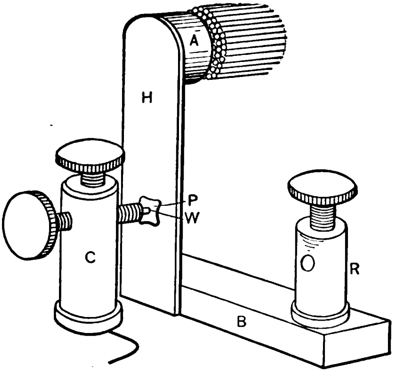


Fig. 15.

Regulation in this coil is effected first by sliding the secondary coil on or off the primary coil and secondly by withdrawing the brass tube from the core. To do this easily its end should be fitted with a tight plug of wood turned to the form of a little handle as in Fig 9.

The full effect of this coil is obtainable when two small bichromate cells are employed, and it should then prove very powerful indeed. One cell will ordinarily serve, and even two dry cells will give good results if not worked for too long a time.

CHAPTER IV.

How to Make a ½-in. Sparking Coil.

The amateur who has successfully built a shocking coil, and has thus gained an insight into the difficulties and principles of coil construction, will find a ½-in. sparking coil an excellent test of the skill he has acquired. To those more advanced in such work a coil of this size may be commended as one of practical utility, a special application being the ignition of the charge in a gas or oil engine, or for motor car purposes.

Materials required. The principal dimensions can be taken from Chapter VII., from which it will be seen that the core is to consist of a bundle of iron wires—the softer and finer the better—6 in. long, 5 x 8 in. diameter. This should be made very compact and tight, and should be wrapped from end to end with a layer of tape, being secured at the finishing end by stitching. On this is to be wound—very tightly and closely—two layers of primary wire No. 16 D.C.C., leaving ½ in. of the core at each end uncovered. The simplest way of securing the ends of the primary wire is to bend each along in the direction of the core, but on opposite sides of it, securing by means of strong cotton tied across, as in Fig. 16.

Insulation. The importance of sound insulation between primary and secondary winding cannot be overrated, but it can be easily ensured. To do this, cut a strip of calico or linen about 5 in. wide and 30 in. long This is to be wound evenly and rather tightly over the primary wire, and the last edge stitched. The whole core and primary winding should then be soaked in hot paraffin wax until the absence of bubbles shows that it has penetrated all parts.

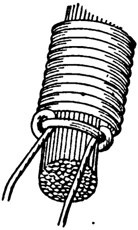


FIG. 16.

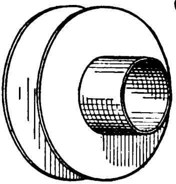


FIG. 17.

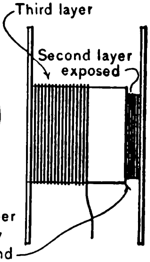


FIG. 18.

Winding. Two ways of winding the secondary wire are allowable. The best is undoubtedly that shown and described in the next chapter for a much more powerful coil, but this is perhaps unnecessarily troublesome for coils up to 1 in. spark length. The other consists in winding in four sections only, which implies a somewhat different treatment. The method of winding 'in layers' from end to end, as described in the previous chapter, is much to be deprecated, as it is too liable to lead to breakdowns—particularly annoying if the coil is used for ignition of the charge in a motor car engine.

It may here be remarked that a smaller coil—for ¼ in. spark—might be built in two sections only; but up to 1 in., four sections should be employed.

For the four sections of the present coil, make four spools each barely 1 in. long and 2¾ in. diameter. These are made by winding three or four layers of paper on top of the finished primary, securing with glue or shellac and glueing on circular cardboard ends; the bobbin (shown in Fig. 17) should be removed from the primary to dry, and is then to be well soaked in paraffin wax.

A wooden mandrel should be turned on which the spools will just fit, and this should either be mounted in the lathe or in a simple winding machine. On the whole, it will be found advisable not to soak the spool of wire in wax before winding, as when that is done it cannot then be wound so closely. About ¾ lb. of No. 36 D.C.C. wire will be needed; silk-covered wire would, of course, give better results, but its cost hardly warrants its use.

A tiny hole should be made in one of the ends of each spool close to the central paper cylinder; another similar hole is to be made in the other ends near the outer edge. These holes are best made with a red-hot needle, and the burr (if any) should be removed inside and out. The winding should be as close and even as possible, and if the first layer is well done the second may be continued back over it. It will then almost certainly be necessary to cover the wire with a layer of thinnish paper (one turn is all that is needed), as otherwise any gap between adjacent turns will allow a turn of wire to sink down into contact with those in the first layer, the difference of potential being then sufficient to break down the insulation to that part. The paper may be secured by a little shellac, and the third layer of wire wound over it.

Quite possibly it will be found that the winding will ' pull ' the paper by causing it to sink between the turns of the previous layer. This will result in leaving the end of that layer bare (see Fig. 18). It is important to cover this with a narrow strip of paper or thin tape before winding over it. Paper should cover every layer that is not quite perfect, before proceeding to wind the next layer.

Spools. All four spools are to be wound in exactly the same direction, but they may advantageously contain different quantities of wire. The outer spools might each contain about two-thirds the amounts on the others as indicated by dotted lines in Fig. 19. When all are finished the spools must be well soaked in hot paraffin wax; if carefully done the wax will penetrate every part of the winding and form a solid mass of the whole. The four spools are now to be assembled on the finished primary. Their arrangement will be shown in Fig. 19 the two lighter spools on the ends of the coil. They must be put on in a definite order as shown, the end spools having their *finishing* ends outside and the finishing ends of the middle coils to be in the middle space. Just a sufficient length of wire should be led outside the spools, cleaned, scraped, twisted together and soldered. These joints are to be pushed down between the spools, which can then all be closed up on middle of the core.

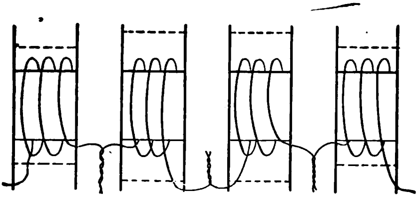


Fig. 19.

Testing the spools. Tests have been presumably been made of the whole secondary spool of wire and of the separate coils before assembling them. They may now be again tested by joining the electrodes of a battery to the primary winding, the secondary ends being held about $\frac{1}{8}$ in. apart.

On breaking the primary circuit, a spark should jump the air gap at the secondary electrodes, but will not much exceed the length named until the condenser has been fitted.

The condenser consists of about 40 sheets of tin-foil 7 in. × 3 in., interleaved with waxed papers 8½ in. × 4½ in., constructed and connected as elsewhere described. With a suitable battery (two good-sized bichromate cells or two accumulators such as are used for motor cycle work) a ½ in. spark should be easily obtained, but with four dry cells of the usual motor cycle type the length would not be so great unless the battery is quite new.

To finish the coil, fit wooden ends over the core close against the primary winding. These ends may be 3 in. diameter or square, and ⅜ in. or ½ in. thick. If the coil is for experimental use, it may be fixed to a baseboard by screwing through to the wooden ends. The two primary ends are brought out and taken down through the baseboard, and the secondary wires can be carried to terminals, as in the case of the medical coil previously described. A contact breaker of the usual type should be fitted, and the condenser placed in a shallow box below the baseboard. The coil can be finished off by a turn of paper-ebonite cemented in place.

For motor car work the coil may be fitted with ends about 3¼ in. diameter. The secondarv should be covered with paraffin wax until it presents a smooth, cylindrical surface 2⅜ in. in diameter. Round this and between the ends, the condenser may very well be fixed, first warming it through to make it pliable, and this will constitute a neat and compact coil for the work. Several sheets of paraffined paper may surround the whole, and a final immersion in hot wax will make the coil quite impervious to water.

CHAPTER V.

THE CONSTRUCTION OF A 4-IN. SPARKING COIL.

The materials and tools required are simple and few in number. The ordinary light wood and metal working tools possessed by the average amateur should suffice to turn out a well finished and efficient coil. The aid of a lathe will greatly facilitate the construction, but it is by no means indispensable.

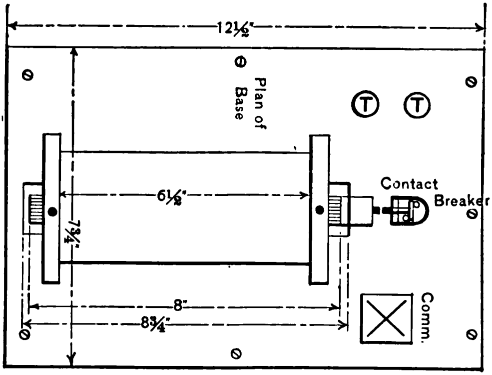


FIG. 20.

Materials required. The first thing to do will be to obtain all the materials. The most expensive item will be the secondary wire. Obtain 4¾ lbs. No. 36 D.C.C. wire; this is about $2.25 per lb. (silk insulation is unnecessary). For the primary 1½ lb No. 12 D.C.C. wire at about 23 cents per lb., 1½ lb. of thin tin-foil at about 30 cents per lb., one piece of hard rubber tube 8¾ in. by 1 3/16 in. outside diameter and ⅛ in. thick, $1.50. Two pieces of sheet hard rubber ½ in. thick 4¼ in. × 4⅝ in. at about $2.10. 1 lb. No. 22 soft iron wire 15 cents. 1½ quire white filter paper (obtain at chemical warehouse) 30 cents; a piece of No. 14 platinum wire ⅜ in. long at $1.30; two large binding posts; two small ditto at about 10 cents each; a few square inches of 3/16 in. sheet brass 25 cents; 4 in. of ½ in. width clock spring; one contact screw about one in. long, 3/16 thick with lock nut; one piece of soft iron rod, ⅝ in. in diameter and 1 in. long; four 3/16 in. machine screws, 1¼ in. long; two ⅛ in. machine screws, ½ in. long; two 3/16 in. screws (brass), ¾ in. long; two dozen assorted wood screws, ⅜ in. to ¾ in. long, about 50 cents the lot; a few square feet of ⅜ in. basswood or good pine for the base, 25 cents; 2 lbs. of paraffin wax, about 15 cents per lb.; solder, resin, and shellac varnish. These quantities are a liberal allowance for a coil this size, and are intended only as a guide for the amateur.

Fig. 20 shows a plan of base for this coil.

The baseboard of the apparatus (19, Fig. 21) is in the form of a shallow box, 12½ in. by 7¾ in. by

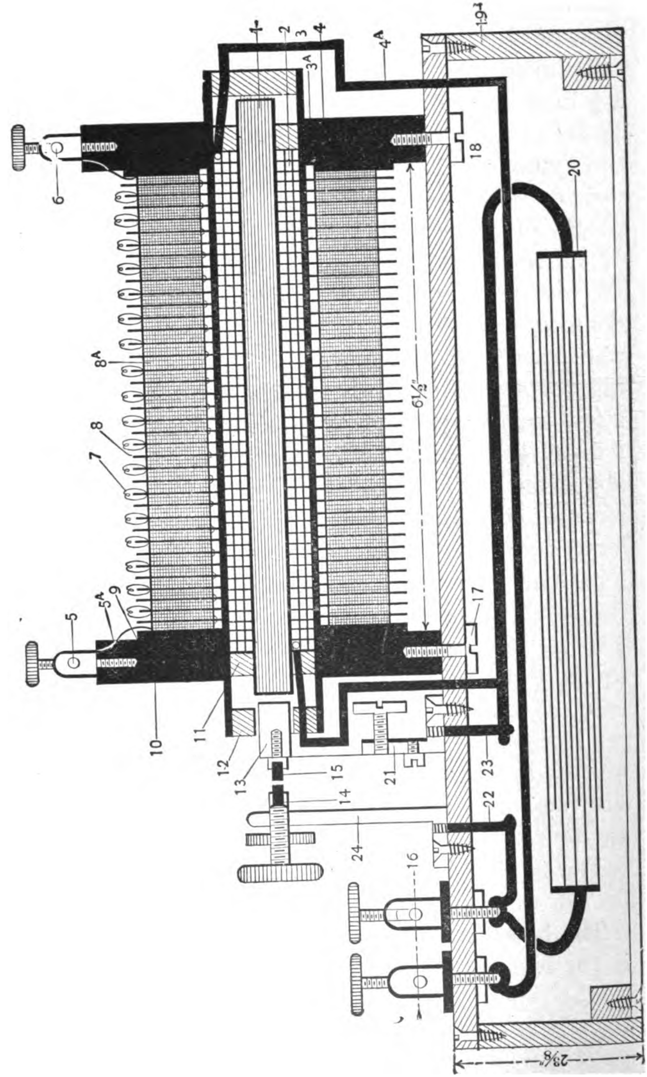

1
2
3
4
3A
4A
19
6
5
5A
9
7
8
8A
6½"
10
11
12
13
14
15
16
17
18
20
21
22
23
24
2⅜"

Fig. 21.

2⅜ in. deep. It will be a fairly simple piece of work; the joints being either screwed or dovetailed together, according to the skill of the worker. The main thing is to make it strong and square. Smooth up the sides and top well, so that it can be varnished. It will be seen from the sketch that the under side is covered in by a thin, well-fitting board. This is fixed by screws to fillets glued into the corners of the box.

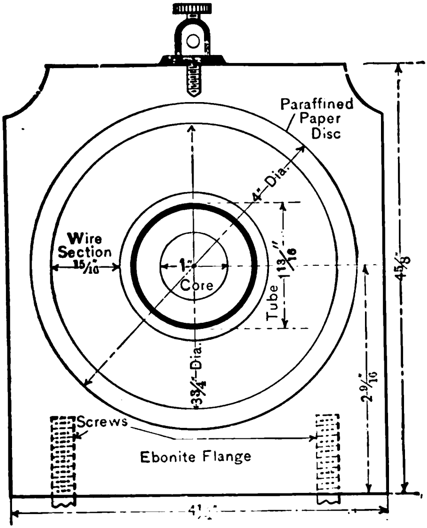


FIG. 22.

The coil ends are indicated by Nos. 4 and 10 in Fig. 21. The best possible material for these is ebonite, although paraffined oak would make a good substitute. These must be nicely filed up to size, and the edges and surfaces finished off with fine emery cloth and oil. Then bore a 13/16 in. hole (a good fit for ebonite tube) a little above the centre as sketched. This can be done in the lathe or by means of a fret-saw, finishing off true with a half round file. Two holes must now be drilled in the lower edges and tapped for a $\frac{3}{16}$ in. screw; also one hole in the top edge for the terminals of secondary wire.

Insulating tube. The important insulating tube between primary and secondary (3, Fig. 21) must be obtained cut to size, straight and circular; be very careful that no minute holes perforate the walls. This would cause a speedy breakdown of the coil. If an ebonite tube cannot be obtained make one by wrapping thin 'paper' ebonite around a mandrel, cementing each layer with shellac varnish.

Core wire. For the soft iron wire core cut the No. 22 iron wire into 8 lengths; straighten and make into a neat round bundle 1 in. in diameter. Next pour some shellac varnish down between the wire, and dry in the oven. The core is shown by 1, Fig. 21. Two wood flanges must now be made (No. 11) so as to fit the core tight at the ends and slip easily into the ebonite tubes. Fix on tight so as to leave a space of 7 in. between them.

A layer of paper should now be cemented around the core and three layers of No. 12 D.C.C. wire wound in the space. Two small holes will require to be drilled one at each end, 12 in. of the wire being passed through the hole close to the core from the inside; the end of the third layer is brought out through the hole drilled in the edge of the opposite flange. Keep the winding as close and tight as possible, and finally give it a coat of shellac varnish.

Fig. 22 shows a cross-section of a 4-in. spark coil.

A section winder will be required for making the secondary sections, No. 8A in the figure. This will be understood by looking at the sketch, Fig. 23. It consists of two discs of hard wood, $3\frac{3}{4}$ in. diameter, separated not more than $\frac{1}{8}$ in. by a disc of metal $1\frac{13}{16}$ in. diameter. The three are fixed upon a screw spindle and clamped together by nuts. This has now to be mounted in uprights secured to a wood base. A small handle is bent or attached to the end of the spindle. This being made, the spools of No. 36 wire must be well saturated with hot paraffin. This will best be done by obtaining a metal vessel deep enough to hold the spools. Melt the paraffin carefully in it and then immerse the spools in it till no more air-bubbles are driven out; the spools may then be hung up to drain. Now fix the winder securely to the table, and fix a stout wire horizontally and about 2 ft. above the table. On this the spool is placed, and a Bunsen burner fixed underneath; the hot air rising from it will render the paraffin on the wire soft. Secure a turn of wire around the centre disc of the winder, and proceed to carefully wind until the space is full. Then cut the wire and remove the inner disc of the winder; the wire section will readily come away from the disc, this being tapered for the purpose. The wax will reset on the turns of wire and hold them quite firm. Forty sections must be made, and it would be advisable to test each one for continuity with battery and galvanometer or a magneto before mounting.

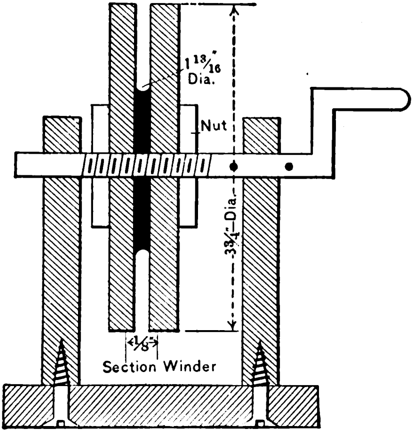


FIG. 23.

The discs insulating one secondary section from the next (No. 8 in Fig. 21) are to be made from filter paper, and soaked in paraffin wax. For melting the wax, obtain a shallow baking tin, which should not be less than 11 in. × 7 in. As the condenser sheets will also require paraffining make a true cardboard gauge, 4 in. diam. by $1\frac{13}{16}$ in. hole in centre; place this over a number of the sheets together, and cut through with a sharp penknife. About ninety discs will be re-

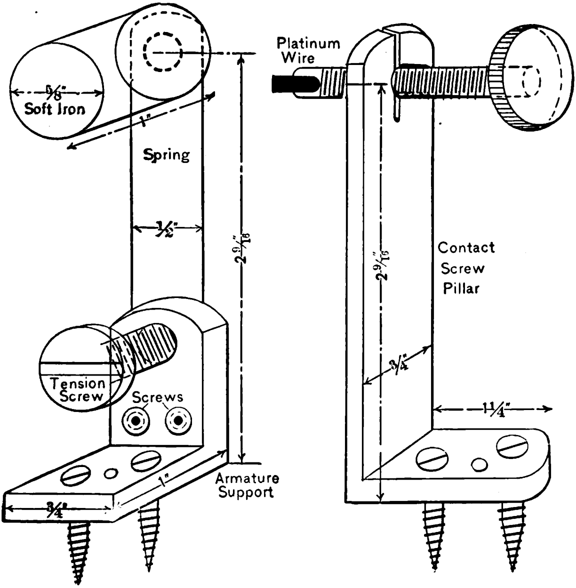
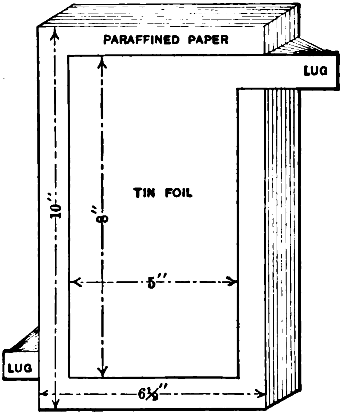


FIG. 24.

quired. Next, have the paraffin nicely melted, and soak the discs in it; take them out one at a time, allow to set for an instant, and then place them on a clean sheet of paper to cool. It is important that no dust or metallic particles adhere to the surfaces.



CONDENSER

Fig. 25.

The condenser (Fig. 25) consists of sixty sheets of tin-foil interleaved with paraffined paper. Cut the paper 10 in. × 6½ in., and paraffin them as before. The foil sheets must be cut to size (8 in. × 5 in.) with a connecting lug as sketched. This may be done by first cutting the sheet ½ in. longer and slitting it across to within 1 in. of the edge, then simply bend back the lug thus formed.

Proceed to build up the condenser by first cutting two pieces of cardboard, 10 in. × 6½ in. Lay one flat on a level table; on the top place a sheet of paraffined paper; next place a foil sheet symmetrical with it, with its lug projecting over the edge; over this a paper sheet, next a foil sheet, with its lug at the opposite lower corner, and so on alternately, till the full number are built up. Fasten the lugs on each side firmly together. The other cardboard sheet is now to be placed on top. Heavily weight it for some hours, and afterwards tie firmly together with tape.

Contact breaker. The construction of the contact breaker or interruptor (21 and 24) will be readily understood from the sketch, Fig. 24. The soft iron armature is made from a piece of ⅝ in. round iron 1 in. long. This is drilled and tapped and secured to the spring, this being rigidly attached to a brass angle plate. A screw passes through so as to press against the spring and increase the tension if necessary. The head of the armature screw must be filed down, and a small hole drilled in its centre to allow a small piece of No. 14 platinum wire being driven in tight. The contact screw end must be tipped in the same manner. This screw is supported by a long angle-piece, into which it screws nicely. A lock nut should be added to the screw, or else a slot cut through into the hole, so that the sides can be closed up on to the screw to keep it firm.

Holes for small wood screws are drilled, as shown, into the bases of the plates; also a third hole, to allow of a connecting pin being screwed or soldered in.

The commutator or reverser is not absolutely necessary, but is a useful addition to the coil. The form illustrated in Fig. 26 is as good as any. It consists of a short cylinder of ebonite or hard wood E, through the centre of which passes a brass pin F. This is really in two parts, so as to be insulated from each other. Two contact plates are screwed to opposite sides of the cylinders, and one put into contact with each of the pins by a screw passing through it The cylinder is supported by two angle-pieces A and B, and two brass springs C and D, arranged to press against the contact plates. An ebonite or brass handle is attached to the spindle. Plates A and B form the terminals, and the springs C and D are attached—one to the free end of the primary coil and the other to the contact screw. It will readily be seen that the springs C and D can be put into contact with either poles of the battery at will by simply turning the cylinder round.

Building up secondary. The most important detail in fitting the parts together is to build up the secondary. For this a small vessel of melted paraffin, soldering iron, solder, resin, and a warm laundry iron will be required. Have all the discs and sections at hand, and fix the ebonite tube into one of its flanges, so as to pass through $\frac{3}{4}$ in., and stand it up vertical. Slip three or four paper discs over the tube and flat against the flange; then fix a section in position, withdraw inner end

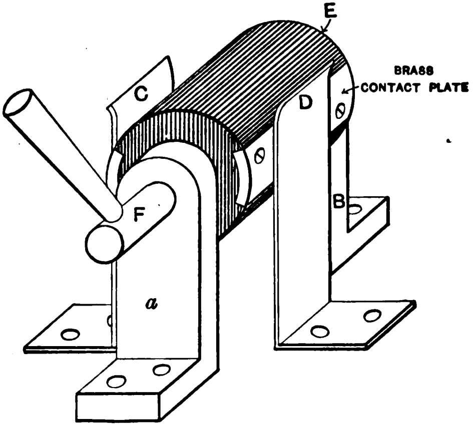
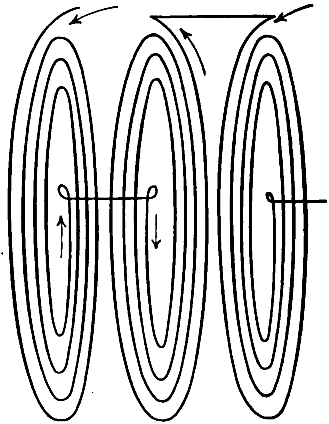


FIG. 26.

of the wire and arrange it concentric with the tube. The space (3A, Fig. 21) must be filled up solid with melted paraffin. When set, place two insulating discs on top (the wire being brought up through them); then smooth them down with the warm iron. The sections must be connected—two insides together, then two outsides, and then insides, and so on. Be most careful to get the proper face down, otherwise some of the sections will be opposing each other. The proper way is shown on diagram, Fig. 27. The joints will require to be soldered, the inner joint being neatly tucked in the space between section and tube. The outer joint (No. 7) is brought over the top of discs, and then slipped in between them. When all the sections are in place, bring the inner end of the last one up between three or four insulating discs, and fit on the other coil flange. Any space between it and the last sections, when the tube is projecting through equally on each side, should be filled up with more paraffined discs. Two small holes are now to be drilled slantwise up



How to Connect the Sections

FIG. 27.

through the flange to the terminals 5 and 6, and the secondary wires passed through and joined to them.

Assembling. The position of the fastening down holes on the base is now to be found, and the holes drilled to allow the screws to pass through into the holes into the flanges (17 and 18). The primary is now slipped into the tube, and two tight-fitting end pieces of wood (12) made to fit the tube. One must have a $\frac{3}{4}$ in. hole drilled through its centre (12), and both will require small holes drilling to pass the primary wires through. These are then taken through holes in the baseboard. The contact breaker should now be fixed in position as shown on the diagram, and the end of the wire nearest soldered to the brass pin in the armature support. The contact screw is taken direct to one of the large terminals (16), the other terminal making contact to the free end of the primary (4A). The lugs of the condenser are put in contact, one to each contact pillar and spring. Make a good connection to foil lugs by wrapping some No. 24 tinned copper wire tightly around them and making a soldered connection to each of the pins (22 and 23). The condenser can be wedged in place with a few strips of wood and the wood base cover screwed on when all is secure inside.

The covering for the secondary consists best of 'paper' ebonite, cut to a good fit between the flanges and made to overlap about 1 in. The lap is cemented with strong shellac varnish, a few turns of string keeping it in place till set. An excellent substitute for ebonite is paraffined cartridge paper fixed in the same way, afterwards varnished black. The coil can now be tested. Arrange the armature to be about $\frac{3}{16}$ in. from the core, and adjust the contact screw, so that when the armature touches the core the circuit is broken $\frac{1}{32}$ in. Next fix a short piece of wire in each secondary terminal, so that they stand 4 in. apart. On connecting three large bichromate cells in series on to the primary terminals, the interruptor should vibrate and produce a torrent of sparks between secondary terminals. If the full length of spark is not obtained right off, try putting more or less tension on the armature spring till successful. No difficulty should occur in obtaining a full $4\frac{1}{4}$ in. spark if the directions are closely followed. If storage batteries are used to work the coil, place a small resistance in series, otherwise the platinum contacts will burn away quickly, due to the heavy current on short circuiting at the contacts; also be careful not to overwork the coil with too many cells.

The appearance of the coil will be greatly improved by finishing off the brass work, such as the contact breaker, commutator and terminals, to as high a polish as possible; then lacquer the parts with a good white or gold metal lacquer. The commutator, if used, is best placed in the position shown in the baseboard plan.

A word of warning should also be given against using the coil on high voltage circuits with the electrolytic interruptor. The insulation is almost certain to be broken down if the current is kept on more than a few seconds. This is due to the intense pressure induced in the secondary, and as the current is also fairly heavy for the wire to carry, it is liable to warm it up and soften the paraffin, and thereby allow a spark to perforate it.

This coil will stand the use of an electrolytic interruptor very well if the following changes in the construction of the apparatus are made. Instead of D.C.C. wire on the secondary, use D.S.C. wire. In place of the paraffined paper insulation between each section of the secondary, mica-disks $\frac{1}{32}$ in. thick, or "micanite" $\frac{1}{16}$ in. thick, should be used. These changes will bring the cost of the induction coil about $12 to $13 higher.

CHAPTER VI.

HOW TO INCREASE THE EFFICIENCY OF SPARKING COILS.

The principal fault to be found in coils of good design and construction is in regard to the contact breaker. The ordinary form so commonly fitted because of its great simplicity is to be seen in the drawing of the various coils described in this book. The trouble with this type of break is that its armature is usually attracted by the soft iron core of the coil before this latter has really had time to become thoroughly magnetized, and as on this degree of saturation the effect of induction largely depends, it follows that the full power of the coil is not called into play. Various means have been adopted for the purpose of prolonging the contact to enable the core to feel the full effect of the current in the primary winding; and sometimes the substitution of a strong for a weak spring will effect a very considerable improvement in the sparking length of a given coil.

Sparking troubles. Another trouble with large coils especially is the destructive sparking when the ordinary break is employed. This results in a comparatively uncertain contact between the platinum surfaces, which becomes very marked after the coil has been used for some time, the platinum becoming volatilized, and depositing on the negative side of the contact, making the surfaces very uneven, and having a burnt appearance. Consequently, unless they are trimmed up with a smooth file occasionally, the full current necessary to magnetize the coil cannot pass the contacts.

Mercury interruptor. These defects are absent in the type of break called a mercury interruptor, which can be readily adapted to any coil without interfering with the construction in the least. The principal of the mercury break is that devised by Foucault many years ago, and which has recently been revived in several modified and unnecessarily complicated forms. In the type here described and illustrated in Fig. 28, the lines of the original break are followed, but the vibrating wire or contact rod is actuated by an independent electro-magnet, instead of utilizing the core. The parts and materials for constructing this break are of a very simple character, and they are easily fitted together in the following manner:

Obtain an ordinary bell magnet with armature and contact complete, but substitute good massive platinum contacts if these are too light. The magnet should be wound with plenty of fairly thin wire. Make a suitable baseboard, say 7 in. × 4 in. × $\frac{1}{2}$ in., and get also about 6 in. of $\frac{3}{8}$ in. brass rod, four terminals, two 4-oz. wide-mouthed glass bottles, two feet of No. 10 bare copper wire, a few inches of glass rod, and some mercury. The diagram, Fig. 28, will indicate the method of fitting up. The magnet is to be mounted by means of a tapped hole in the yoke on top of the brass rod, the end of which is suitably screwed. The other end of this brass rod, R, is screwed firmly into the baseboard. The two phials are fixed close together in recesses cut in the base, and a portion of the No. 10 copper wire is bent to

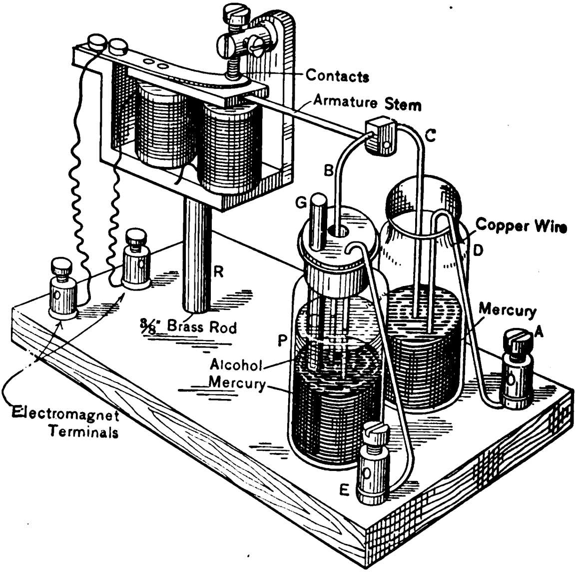


FIG. 28.

a U-shape, so that one leg dips into each bottle, the top of this U being securely soldered to the hammer shaft of the magnet. The leg, C, dips nearly to the bottom of its jar; B is pointed and goes to within half an inch of the bottom. A cork being fitted in the jar, P, has in it three holes, one large enough to admit B freely without any chance of binding; and in the second is fitted the glass rod G, which can slide up and down. A permanent connection of No. 10 or 12 copper wire must reach to the bottom of the jar D, and be connected to the terminal A; a similar arrangement being made also in regard to the second jar P, ½ in. of clean mercury is then placed in each phial, and also 1 in. deep of alcohol (methylated spirits) in P. The purpose which the alcohol serves is to extinguish the electric arc or spark which is formed while breaking the current.

The magnet terminals are joined up to a couple of Leclanché cells, and E, A connected, one each, to the existing contact and spring pillars. The platinums must be separated by a small bit of cardboard, and the screw turned till there can be no movement of the armature. The usual battery is then joined up to the coil terminals, and a few trial adjustments of the speed of interruption by the armature contact and the wire dipping into the mercury made, when excellent results should be obtained. The object of the glass rod G is to enable a greater or less height of mercury to be obtained by pushing the rod down or up as required.

Dimensions. The exact dimensions of the various parts are not of great importance, and the method of fitting up should easily be understood

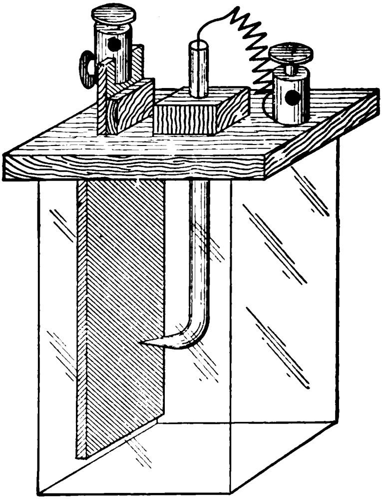


Fig. 29.

from the diagram. This is approximately one-third size, and is suitable for coils between 2-in. and 12-in. spark.

Wehnelt interruptor. Better than any mechanical circuit breaker for very large coils is the very modern apparatus known as the Wehnelt interruptor. A practical form of this is illustrated in Figs. 29 to 33, and may be made as follows:

Construction. To construct the interruptor as shown in Fig. 30, procure a square glass (or earthenware (accumulator cell measuring about 5 in. × 3 in. × 3 in., and from mahogany, ⅜ in. in thickness, cut a piece to form for it a lid or cover 4 in. square to allow ½ in. overhang all round.

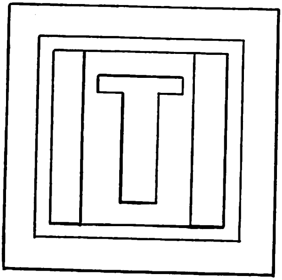


FIG. 30.

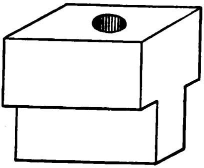


FIG. 31.

On a centre line drawn across its grain, cut an aperture 1½ in. long × ½ in. wide, and at one end, and right angles thereto, cut another 1¼ in. × ¼ in., thus making the complete aperture T-shaped.

The cover. On that side of the cover which ultimately will be innermost, screw on two narrow fillets, one at each side of the larger part of the opening, in such a manner that their ends and one side will just butt against the upper edges of the vessel, so as to serve the twofold service of forming a step for the cover and a prevention of warping. Fig. 30 shows this, the dotted line indicating the top of the vessel. The under side of the cover should be rendered impervious to steam and water by enamelling it two or three coats, and the edges and upper side finished by polishing or varnishing.

Next, cut a piece of close-grained cork to the shape shown in Fig. 31. Virtually it is a 1-in. cube rabbetted ½ in. deep on either side to fit and slide rather stiffly in the larger slot in the cover.

The tube. Take a piece of uranium glass tubing of ¼ in. diameter by 8 in. or 9 in. long, and with the aid of a spirit-lamp or gas Bunsen flame heat it near one end until soft. Before it has time to cool, stop the end with the finger-tip, and blowing gently with the lips at the other, bend it to as near a right angle as possible. The object of blowing, it may be mentioned, is to prevent the walls of the tube in their plastic condition from collapsing; on the other hand, if blown too violently, an unsightly bulb probably will appear.

The tube, at this stage, should be as at A, Fig. 32. At a distance of about ¾ in. from the bend, re-heat the tube and carefully draw in it a narrow contraction by pulling, ensuring, in so doing, to keep the part perfectly straight (see B, Fig. 32). When cool, take the tube in both hands.

and with thumb nails together at the point marked by a dotted line in the figure, break it cleanly in two. Insert in the small orifice, which the tube will then have, a piece of No. 20 B. & S. platinum wire about $\frac{5}{8}$ in. long, projecting $\frac{1}{4}$ in. or $\frac{3}{8}$ in., and secure it by playing on the tip of the glass with a very fine blowpipe flame. Let the glass accumulate only sufficiently to hold the wire in place, as, should it become much thickened, it will be liable to fracture when in use. The instant the final operation is completed, thickly cover the tube from point to bend with the deposit of a smoky gas flame. Beneath this carbonaceous envelope cooling will progress comparatively slowly, so that, for all practical purposes, the glass will be thoroughly annealed—a most desirable quality, it is to be noted.

Bore a hole in the piece of cork previously fitted to the vessel's lid, and thrust the upper end or straight part through it from its under side, adjusting the tube in the hole, which, by the way, it should fit tightly, so that the platinum point may reach about midway down the depth of the bath. A piece of sheet-lead must now be cut to the form and dimensions given in Fig. 33, a suitable gauge for this being No. 14 B. & S., or about $\frac{1}{16}$ in. thick, though it is scarcely necessary to be particular within one or two numbers of that guage.

Cut a small wedge-shaped piece of any wood $1\frac{1}{4}$ in. wide 1 in. long, and tapering from $\frac{1}{4}$ in. to

⅛ in. Place the lug of the lead plate through the smaller slot of the lid from underneath, fasten it firmly into position *from above* with the wedge, and finish that electrode by clamping to its upstanding portion an appropriate brass binding-screw.

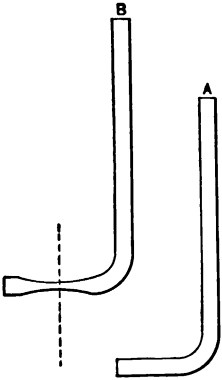


FIG. 32.

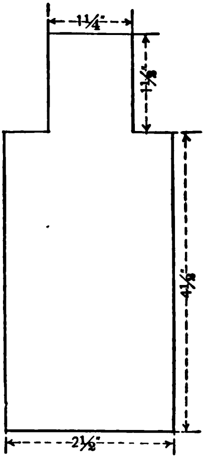


FIG. 33.

A terminal for the anode may be screwed into the cover on the side opposite to the cathode. Twist a piece of fairly heavy-gauge silk-covered copper wire into spiral form, bare both ends, bending one to the shape of a ring that it may be clamped securely under the base of the binding-screw, and straightening the other to dip an inch or so into the top of the glass tube. To complete the interruptor for use, fill the vessel to within ¾ in. of the top with water and sulphuric acid in the proportions of 8 to 1, and pour sufficient pure mercury into the tube to enable connection to be made between the platinum point and the dipping wire.

Electrodes. Generally it will be found convenient to make several platinum electrodes, each with its distinctive feature, such as length and thickness of the point, its degree of sharpness, and the reverse. If one only is made, it is well to decide upon the e.m.f. of the current usually to be applied, and then to shorten or, it may be, lengthen the piece of platinum until the best effect on that particular circuit is attained. Needless to say, the former course is the better of the two.

When first trying the break, the bath being cold, switch on a current of from 2 to 3 amperes at a potential difference of about 45 volts. Fig. 34 shows another very efficient form of electrolytic interruptor, which is easily made, and should not cost more than 75 cents complete. The interruptor is so simple that it needs very little explanation. A is a glass or porcelain jar 5 or 6 in. high, about 4 in. in diameter; B a porcelain cup or beaker 4 in. × 2 in. or 2½. A glass rod C ⅜ in. thick with a point on one end. Into each jar a lead electrode D and E are placed which have the shape as shown in F. Two covers are fitted to the jars G H. G has a hole to receive a cork I which holds the glass rod in place. Openings must be made at L and M into these covers to pass the lead terminals through. The cup B has a hole in the bottom not larger than $\frac{3}{64}$ in. This

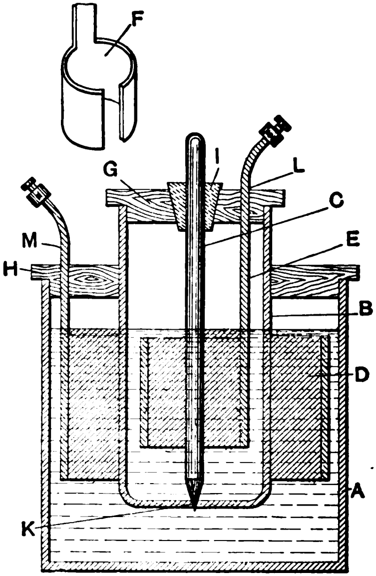


Fig. 34.

hole K receives the point of the glass rod C which acts as a valve. After the apparatus is assembled it is filled about $\frac{2}{3}$ full with diluted sulphuric acid 8 to 1. It is ready now for connecting up and can be tried. To start push the glass rod as far down into the hole K as possible. The effect and operation of this interruptor is the same as Fig. 29.

It must be remembered that in using an electrolytic interruptor *no condenser is necessary.*

The action of the apparatus is peculiar; the interruptions of the current being caused apparently by an incredibly rapid formation and disruption around the anode of a gaseous sheath. The circuit into which it is inserted should possess a certain degree of self-induction, as otherwise it will fail to operate. It is also upon this induction, the electro-motive force of the current and the surface area of the anode, that the frequency of the interruptions or oscillations depend, it being possible, by the relative alteration of these three factors, to effect wide variations.

Examination with a rotating mirror, such as is usually employed for determinations of this kind, has shown that the interruptions may reach if not actually exceed, the extraordinary number of 1500 per second. This admirably fits the break for radiographic work, the fluorescent screen particularly, since at such a rapidity there can be no flickering of the light sensible to the eye.

It has been found, in experimenting with the Wehnelt contact breaker, that the potential difference of the circuit must be greater than that which customarily suffices, though the voltage may need but slight augmentation if the electrode bath be heated to about 150° F.— a quality self-acquired to some extent, after a short period of use; that the secondary spark or, as it more resembles, flame discharge of the coil is of extreme heat, whilst, also, its thickness far surpasses that which could be obtained by using a hammer, or indeed, any mechanical break.

Owing to the heat of the discharge, the current must be regulated with the greatest nicety, and for this purpose it is advisable to insert in the circuit either a choking coil or a rheostat and suitable measuring instruments.

From two to three or, at most, four amperes of current will, in the majority of cases, be found sufficient for radiography, a heavy current being most destructive to the vacuum tubes.

Whilst a good coil can be much increased in usefulness by the adoption of special apparatus as here described, it should always be remembered that the secret of *building* a good coil with the minimum amount of secondary wire is to have it most thoroughly insulated, and, at the same time well arranged with regard to its primary winding. In other words, the closer the secondary can be got to the primary winding, always supposing the insulation to be perfect, the better will be the results obtainable.

CHAPTER VII.

PARTICULARS OF COILS FOR VARIOUS LENGTHS OF SPARK.

The following tables are designed to assist readers in forming an estimate of the dimensions they should choose when about to build an induction coil to give a certain length of spark. It should be observed that these particulars are necessarily of an approximate character only—the ability of different workers being extremely wide in range, and this being the determining factor in induction coil construction. Consequently, it may be remarked that the dimensions and quantities here quoted are the minimum that should be employed ordinarily, and they will only give the stated results under conditions of excellent workmanship.

The most suitable primary batteries for working induction coils are those of the ordinary single-fluid bichromate type, unless a very long 'run' is anticipated, when the double fluid or 'constant-current' bichromate battery is better. In nearly all cases an accumulator is the most satisfactory source of current, but is not always available, and the only primary battery, other than the bichromate types already mentioned, that can be regarded as quite satisfactory is the Edison-Lalande cell: this is, however, expensive in the large sizes necessary for coil work.

TABLE I.

APPROXIMATE SPECIFICATIONS FOR SPARK COILS.

Spark.	Core.		Primary.			Insulating tubes between primary and secondary	Secondary.					Condenser.		Current.		Spark.
	Length.	Diameter.	Diameter over winding.	Size of wire.	Weight of wire.		Length.	Diameter.	Size of wire.	Number of sections.	Weight of wire.	Size of tinfoil.	Number of sheets.	Volts.	Amperes.	
in.	in.	in.	in.	No.	oz.	in.	in.	in.	No.	No.	lbs.	in.	No.			in.
1/4	5	9/16	15/16	16	5	1/16	3 1/2	2 3/8	36	2	1/4	3 x 1 1/4	30	4	2	1/4
1/2	6	5/8	1	16	6	1/16	4	2 1/2	36	4	3/4	4 x 3	40	4	4	1/2
3/4	6 1/4	3/4	1 1/8	16	7	1/16	4 1/2	2 9/16	36	4	1 1/8	5 x 2 3/4	40	6	4	3/4
1	6 1/2	1 3/16	1 1/4	14	8	3/32	4 3/4	2 5/8	36	4	1 1/2	6 x 3	40	8	4	1
1 1/2	7	7/8	1 5/16	14	10	3/32	5	2 11/16	36	10	2	7 x 4	40	10	4	1 1/2
2	7 1/2	15/16	1 3/8	14	12	3/32	5 1/2	2 13/16	36	40	2 1/2	7 x 5	60	12	4	2
3	8	1	1 1/2	12	14	1/8	5 3/4	3	36	44	3 1/2	8 x 4 1/2	60	12	4	3
4	8 1/2	1 1/16	1 9/16	12	16	1/8	6	3 1/4	36	48	4 1/2	8 x 5	60	12	6	4
6	12	1 1/8	1 5/8	12	24	3/16	8	4	36	100	6 1/4	9 x 5	60	18	6	6
9	16	1 3/8	1 15/16	10	32	5/16	12	5 1/4	36	140	9	10 x 6	60	22	8	9
12	20	1 1/2	2 1/16	10	40	3/8	16	6 1/2	36	200	12	12 x 8	60	24	10	12

TABLE II.

WIRE GAUGES COMPARED IN DECIMAL PARTS OF AN INCH.

Number.	American or Brown & Sharpe Gauge.	Roebling's and Washburn & Moen's Gauge.	Birmingham or Stub's Wire Gauge.	British Imperial Standard. English Standard Gauge.	Old English or London Wire Gauge
0	.32486	.307	.34	.324	.34
2	.25763	.263	.284	.276	.284
4	.20431	.225	.238	.232	.238
6	.16202	.192	.203	.192	.203
8	.12849	.162	.165	.16	.165
10	.10189	.135	.134	.128	.134
12	.08081	.105	.109	.104	.109
14	.06408	.08	.083	.08	.083
13	.05082	.063	.065	.064	.065
18	.0403	.047	.049	.048	.049
20	.03196	.035	.035	.036	.035
22	.02535	.028	.028	.028	.0315
24	.0201	.023	.022	.022	.025
26	.01594	.018	.018	.018	.0205
28	.01264	.016	.014	.0148	.0165
30	.01002	.014	.012	.0124	.01375
32	.00795	.013	.009	.0108	.01125
34	.0063	.01	.007	.0092	.0095
36	.005	.009	.005	.0076	.0075

CHAPTER VIII.

EXPERIMENTS WITH THE INDUCTION COIL.

A book dealing with the subject of induction coils would hardly be complete without some reference to the experiments which may be performed with any sparking coil. Those in which a shocking coil is employed are of too obvious a nature to require description, but it is worth while reminding readers that many people cannot safely bear the most moderate electrical shocks, so that great care should be exercised when experimenting with an ordinary medical coil. It need hardly be said that experiments with sparking coils should be conducted with the greatest possible care. There should be no hurry; wires should all be connected up before the current is switched on, and no one but the operators should be allowed to touch any part of the apparatus.

For the best experiments a coil capable of producing at least ½-in. sparks is desirable. With this, deflagration, vacuum tube, and wireless telegraphy experiments can be carried out. For X-ray work or radiography, a 4-in. spark is practically essential; and if the work is to be on a professional or semi-professional scale, a 6-in. spark is the least the coil should give.

Begin by observing the character of the secondary spark. If two points, one connected to each terminal of the secondary, are made to approach from beyond sparking distance, nothing will be observed in daylight until such a position is reached that the longest spark can bridge the space. It will be seen that this spark is of a very beautiful violet color, tending to red at one end. The character of the spark depends upon the distance it is made to traverse; at its greatest length it is thin, blue, and snapping, and takes a crooked course; when shortened, it assumes a flaming appearance, especially at one pole, goes in a straight line, and has a more rushing sound. The short thick spark is the 'calorific spark' and it has the power of deflagrating explosive mixtures.

Experiments should be made on the character of the discharge when different metals are used for the electrodes, as for instance, fine iron wire. In this case, when the spark begins to assume the calorific character, one of the wires will be found to grow hot and ultimately to melt off at the end. This is the negative pole of the secondary, and the effect appears to be due to a kind of bombardment which takes place from the positive pole.

For ordinary sparking experiments the negative electrode should terminate in a fairly large brass disc, the positive being a needle point adjustable as to distance, but moving opposite the centre of the disc. By this means the longest sparks can be obtained. It will be noticed that the sparks constantly strike fresh places, and they almost invariably traverse very crooked paths through the air. In this respect they are like lightning flashes —'small editions' of which they really are, as a matter of fact. These crooked paths represent 'lines of least resistance,' the electric current, no doubt, finding irregularly distributed particles of conducting matter floating in the atmosphere.

If the space between the electrodes be increased beyond sparking distance, sparks can be made to pass by holding a lighted spirit-lamp so that the heated gases from it rise up between the poles. Similarly, the electrodes being adjusted so as to bear on a glass plate even twice the usual maximum distance apart, a spark can be made to pass by breathing on the glass.

Keeping the electrodes in the position last indicated, scatter some fine metal filings on the glass. Sparks at once scintillate in a beautiful way over the intervening space, leaping from one particle to another, and diverging very considerably from a straight path. Repeat this experiment, but using finely scraped 'blacklead' from an ordinary pencil. This gives slightly different effects, and a further experiment is to approach the electrodes closely amongst the carbon particles, which then begin to glow vividly like a tiny arc-lamp. Next put a considerable quantity of this powdered carbon on the plate and approach the poles to the little heap; it will be seen that a clear space is made round the positive pole, the particles being apparently blown from the electrode.

All phenomena of sparking are very much more beautiful when the experiments are conducted in the dark. It will then be obvious that a great deal has been lost in the previous experiments, and glowing brush-like but silent discharges will be found on the electrodes when these are separated quite beyond sparking distance. All this time the characteristic odor of ozone will be noticeable even when a small coil is being worked. This becomes marked when a large coil is operated, and too, much of this very energetic form of oxygen should not be inhaled.

A darkened room is the proper place to exhibit the beautiful experiments which can be performed with vacuum or Geissler tubes. These are too varied in number and character to be dealt with here at any length, and the earnest experimenter should study the subject carefully, especially if an insight into the marvels of X-ray and other radiographic work have attractions for him. With the smallest sparking coil even, very beautiful experiments can be made with small vacuum tubes, though the simplest of these is an ordinary electric incandescence. It does not matter if this is a 'burnt-out' specimen, so long as the vacuum is perfect. Hold the lamp by the top of the glass bulb and present the capped end to either electrode of the coil, when the space inside the lamp will glow with an indescribable bluish light, which appears even when the lamp is held several inches away from any part of the coil. Various rotating devices are obtainable, by means of which a group of vacuum tubes can be spun round while glowing, and most delightful combinations can be made in that way.

Wireless telegraphy and radiography (or X-rays) are two of the most modern instances involving the use of induction coils. Since, however, in these matters the coil and its sparking properties are but means to other ends, and as very long explanations would be absolutely necessary, they cannot be dealt with here. Suffice it to say that coils as described in this book are quite the proper apparatus for experiments in these directions.

Reference may be made in conclusion to the discontinuous nature of the secondary spark. Many people suppose that the bright flash is uninterrupted, but that this is not the case can be shown by a very simple yet striking piece of apparatus. A large disc of white card— say not less than 18 in. diameter—is marked out and blackened as in Fig. 35. The various rows of squares, circles, etc., contain each a different number of these spaces. This disc is mounted by being nailed to a wooden boss fixed on a spindle. The spindle is carried by a simple wooden frame, and has on its further end a small grooved wheel. Below is another spindle on which is fixed a much larger pulley wheel, in which again is fastened a crank handle to turn it. A leather bootlace forms a driving belt. When this apparatus is worked in a darkened room and the coil is set in operation, the curious effect will be observed that some of the rows of circles, etc., appear to travel in one, and others in the other, direction. This is due to the intermittent and instantaneous lighting up of the secondary spark. As the disc is driven faster or slower, some of the moving circles run slower,

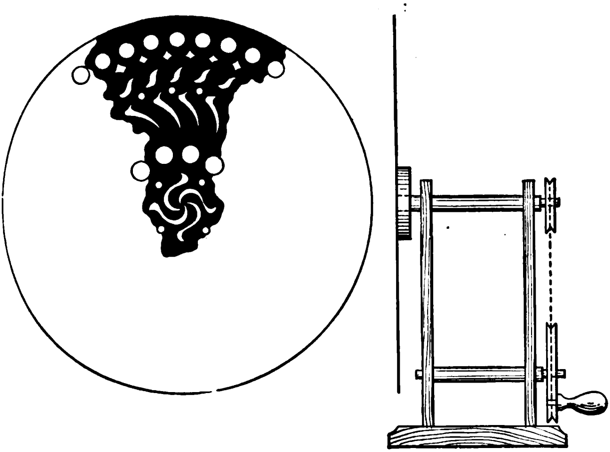


Fig. 35.

stop, and reverse their apparent direction. This experiment is an extremely interesting one, and usually takes well even amongst the variety of other striking effects obtainable from a good induction coil.

NOTE.—For a more complete description of the construction of induction coils, see Norrie.

Also, Norrie on "Experimenting with Induction Coils."

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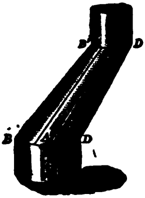

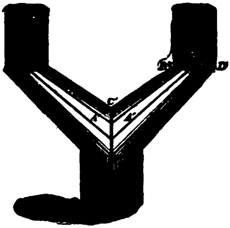

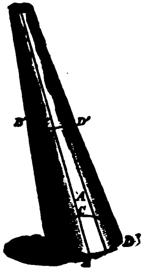

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