cating the strength of the current when its coil is included in an electrical circuit. The horizontal metallic plate, mounted on the columns, is concaved in the middle and supports a spring steel diaphragm that is held in place by the iron cap secured to the plate by several screws, so as to clamp the diaphragm tightly.

The cap is chambered out to receive mercury, and has a stuffing box for holding a glass tube of small caliber. A vulcanite screw in the cap serves to bring the mercury in the tube to zero before taking a reading, thus avoiding variations by the expansion of the mercury. The graduations on the scale at the side of the tube, which are empirical, represent the amperes of the current passing through the coil. A short rod is attached to the middle of the diaphragm, and projects downward through a hole in the base plate to receive a soft iron cylindrical armature or core which extends into the coil.

The diameter of the diaphragm is 2 inches; the caliber of the glass tube, 0·02 inch; a very slight motion of the diaphragm is indicated by a considerable movement of the mercury in the tube.

This instrument, placed anywhere in the main circuit, will indicate the strength of the current. An increase in the strength of the current results in the drawing of the iron core into the coil, and a consequent deflection of the diaphragm and downward movement of the mercury column. The engraving is five-eighths of the actual size of the instrument. The glass tubes and scale are shown only in part.

RECORDING VOLTMETER.

In making electrical tests it is often desirable to consider the element of time, but, as every electrician knows, to do this with the ordinary appliances is tiresome, and the result is liable to be inaccurate.

The extreme delicacy of the action of the galvanometer renders it difficult to apply to it any device capable of recording the movements of the needle without interfering more or less with its action. In the instrument shown in the en-

graving a disruptive spark from an induction coil is utilized for making the record. The indicating parts are made and

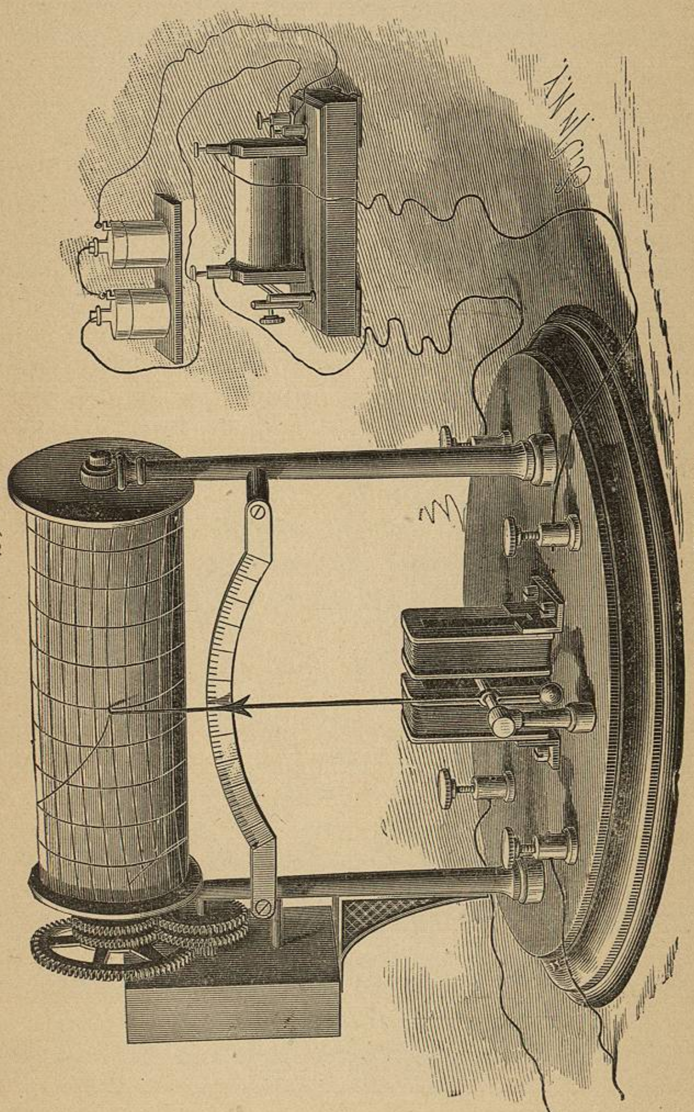


Fig. 439.

Recording Voltmeter.

arranged as in an astatic galvanometer. The helixes are wound with rather coarse wire (No. 22). The needle is astatic, the inner member swinging in the central opening in the helixes in the usual way, the outer member being located behind the helixes. The arbor supporting the needle has very delicate pivots, and carries a long and very light aluminum index, which is counterpoised so that it assumes a vertical position when no current passes through the helixes. The needle is unaffected by terrestrial magnetism.

The upper end of the index swings in front of a graduated scale, and is prolonged so as to reach to the middle of the cylinder, carrying a sheet of paper upon which the movements of the needle are to be recorded. This cylinder is of brass, and its journals are supported by metal columns projecting from the base upon which the other parts of the instrument are mounted. The scale is supported by vulcanite studs projecting from the columns, and to one of the columns is attached a clock movement provided with three sets of spur wheels, by either of which it may be connected with the arbor of the cylinder. One pair of wheels connect the minute hand arbor of the clock with the cylinder, revolving the cylinder once an hour; another pair of wheels connect the hour hand mechanism with the cylinder, so that the latter is revolved once in twelve hours; while a third pair of wheels give the cylinder one revolution in seven days.

This instrument is designed especially for making prolonged tests. It is provided with four binding posts, two of which connect the wires of the batteries under test with the helixes. The other binding posts are connected respectively with the posts supporting the needle and with the journals of the recording cylinder. These posts receive wires from an induction coil capable of yielding a spark from one-eighth to one-quarter inch long.

The induction coil is kept continuously in action by two Bunsen elements, and a stream of sparks constantly pass between the elongated end of the index and the brass cylinder, perforating the intervening paper and making a permanent record of the movement of the needle. To render the line of perforations as thin as possible, the end of the index is made sharp and bent inward toward the cylinder.

The spur wheels are placed loosely on the arbor of the cylinder, and the boss of each is provided with a set screw by means of which it may be fixed to the arbor. This arrangement admits of giving to the cylinder either of the speeds, as may be required.

The paper upon which the record is to be made is divided in one direction to represent volts, and in the other into hours and minutes. The hour and minute lines are curved to coincide with the path of the end of the index.

These records may be duplicated by using the sheet as a stencil and employing the method of printing used in connection with perforating pens. When the tests are of long duration, the action of the induction coil is rendered intermittent by an automatic switch connected with the clock.

ELECTRO-MAGNETS.

A body of iron with an insulated conductor wrapped one or more times around it constitutes an electro-magnet. The power of an electro-magnet depends upon the form, size and quality of its iron core, upon the number of turns the conductor makes around the core, and upon the current passing through the conductor. The number of amperes flowing through the wire of a magnet, multiplied by the number of turns the wire makes around the core of the magnet, gives the number of ampere turns; one ampere flowing ten times around is equal to ten amperes flowing once around. Two amperes flowing five times around is the equivalent of either of the foregoing.

The magnetizing power of the circulating current is proportional to the number of ampere turns. The magnetism produced in the iron core is not always proportional to the ampere turns, as the current produces comparatively little effect when the magnet core approaches saturation.

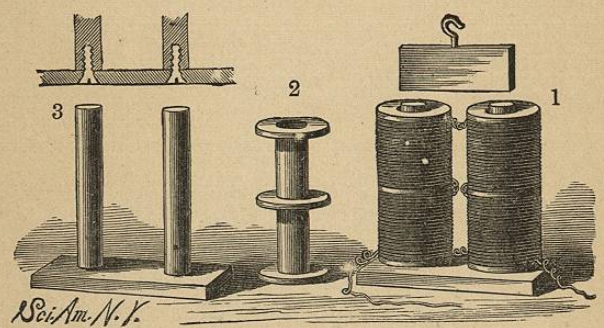
The battery must be proportioned to the resistance of the magnet to secure the best results; or, if the magnet is arranged with its winding in sections, so that they may be connected up parallel or in series, as will presently be described, the magnet may be adapted to the current.

A large magnet made on this plan is shown in Fig. 440.

It is well adapted for experimental work. With a current from six medium sized bichromate battery cells it is capable of sustaining about one thousand pounds. It is provided with a switch, so that it may readily be adapted to a light or a heavy current by combining the several coils in series or in parallel. It is made separable, to permit of using the coils detached from the core.

For the construction of the magnet 18 pounds of No. 14 double-covered magnet wire are required, also two well annealed cylindrical bars of soft iron, 8 in. long and $1\frac{1}{2}$ in. in diameter for the core, a flat, soft iron bar $2\frac{1}{2}$ in. wide, 8 in. long, and $\frac{3}{8}$ in. thick for the yoke, a bar of the same kind

Fig. 440.



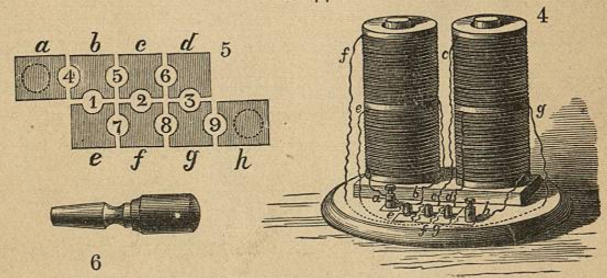
Magnet for Experimentation.

7 inches long for the armature, two double wooden spools 4 in. in diameter and $7\frac{3}{4}$ inches long, with flanges $1\frac{1}{16}$ in. wide and $\frac{7}{16}$ in. thick.

The walls of the spools are $\frac{1}{16}$ in. thick. Each space in each spool is filled with the No. 14 magnet wire. There are two ways of winding the wire. According to one method a hole is drilled obliquely downward in the flange, and one end of the wire is passed from within outward through the hole, and the spool is wound in the same manner as a spool of thread, the wires at the end of the coil being tied together with a stout thread to prevent unwinding. Each section of each spool is filled in the same manner.

Although this is the quickest way to wind the magnet, it is not the best way, as the inner end of the coil is liable to be broken off, when the entire coil must be rewound to secure a new connection with the inner end. The correct way to wind the wire is to take a sufficient length and wind it from opposite ends on two bobbins. Wind the wire once over the spool from one of the bobbins, then wind from the ends of the coil thus formed toward the middle, first with wire from one bobbin, then from the other bobbin, then wind from the middle back each way toward the ends in the same way, then again toward the center, and so on. By this method both terminals of the coil are made to come out on the outer layer.

Fig. 441.



Magnet and Switch.

At 1, Fig. 440, is shown the completed magnet and its armature. 2 is a detail view of the spool. 3 shows the cores and yoke, both in perspective and section, the sectional view exhibiting the method of fastening the cores to the yoke by means of screws. 4 (Fig. 441) shows the magnet mounted on a wooden base provided with a plug switch for connecting the coils in parallel or in series. 5 is an enlarged view of the switch, and 6 shows one of the plugs by which the connections are made.

The switch is formed of brass blocks, *a*, *b*, *c*, *d*, *e*, *f*, *g*, *h*, arranged in two series, as shown at 5 (Fig. 441). The blocks, *a*, *h*, are provided with binding posts for receiving the battery wires. The blocks are provided with semicircular notches forming the plug holes, 1, 2, 3, 4, 5, 6, 7, 8, 9.

The block, *a*, is connected with the lower terminal of the lower left hand coil, and the block, *e*, is connected with the upper terminal of the same coil. The block, *b*, is connected with the lower terminal of the upper left hand coil, and the block, *f*, is connected with the upper terminal of the same coil. The block, *h*, is connected with the lower terminal of the lower right hand coil, and the block, *d*, is connected with the upper terminal of the same coil. The block, *g*, is connected with the lower terminal of the upper right hand coil, and the block, *c*, is connected with the upper terminal of the same coil.

When the holes, 1, 2, and 3, are plugged, the current goes in series through all the coils. By plugging the holes, 4, 7, 2, 6, and 9, the current goes through the coils two in parallel and two in series, reducing the resistance to a quarter of the original amount, by halving the length and doubling the sectional area. By plugging the holes, 4, 5, 6, and 7, 8, 9, the current goes through all the coils in parallel, and the resistance is reduced to $\frac{1}{16}$ the original amount, by reducing the length to ¼ and increasing the sectional area four times.

The polar extremities of the magnet are drilled axially and tapped to receive screws by which are attached extension pieces for diamagnetic experiments.

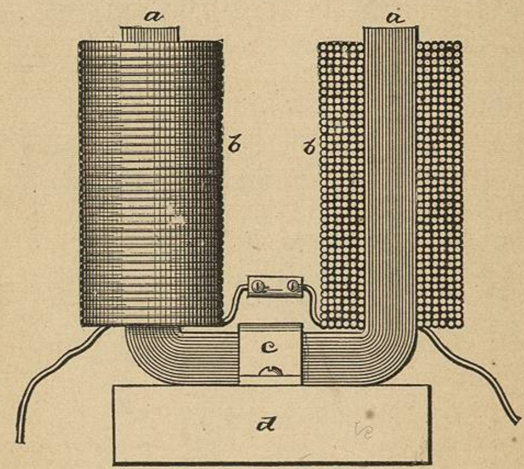
To retain the spools on the cores when the magnet is in an inverted position, a thin brass collar is screwed on the end of each core. The armature is provided with a hook for receiving a rope or chain, and the yoke has a threaded hole at the center for receiving the eye for suspending the magnet.

Although this magnet is very complete and desirable, a large proportion of the experiments possible with it may be performed by means of the inexpensive magnet shown in Fig. 442.

The core of this magnet is made of twenty thicknesses of ordinary one inch hoop iron, about $\frac{1}{20}$ inch thick, thus making a rectangular U-shaped core one inch square. The parallel arms of the magnet are five inches long, and the distance between the arms four inches.

The pieces of hoop iron are readily bent and fitted one over the other in succession, the inner one being fitted to and supported by a rectangular wooden block. When the core has reached the required thickness, the layers of which it is formed are fastened together by means of iron rivets passing through holes traversing the entire series of iron strips near the ends of the core. If it is inconvenient to secure the layers in this way, they may be wrapped from the extremities down to the angles with very strong carpet

Fig. 442.



Electro-Magnet Partly in Section.

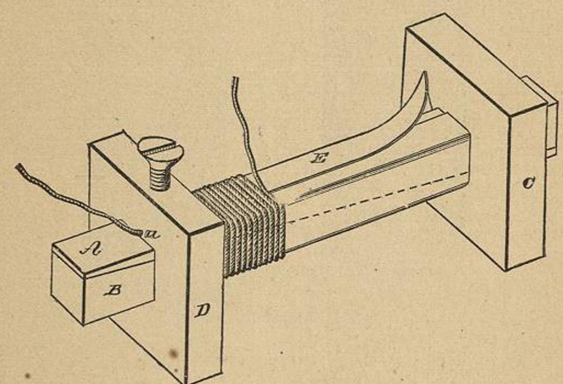
thread or shoe thread and afterward coated with shellac varnish, which holds on the thread and assists in cementing the whole together.

The extremities, *a a*, of the core are filed off squarely. The yoke is clamped to the base, *d*, by the clip, *c*, made of hoop iron or of wood.

To the arms, *a a*, are fitted the coils, *b b*, which are formed by the aid of the device shown in Fig. 443. This consists of two wedge-shaped wooden bars, A B, which together form a bar a little larger than the core of the magnet, and two mortised heads, C D, fitted to the bar with a space of $4\frac{3}{4}$ inches between them. The head, D, is provided with a screw for clamping the wedge bars, A B, and with an aperture, *a*, for the inner end of the wire. The heads are lined with thick paper, and the bar between the heads is covered with a single thickness, E, of heavy paper.

The winding is begun by passing the end of the wire (No. 16 copper cotton-covered magnet wire) through the aperture, *a*, allowing it to project about three inches, then winding the wire evenly over the bar from one end toward the other until the head, C, is reached. Before the second layer of wire is wound, the first one is brushed over with

FIG. 443.



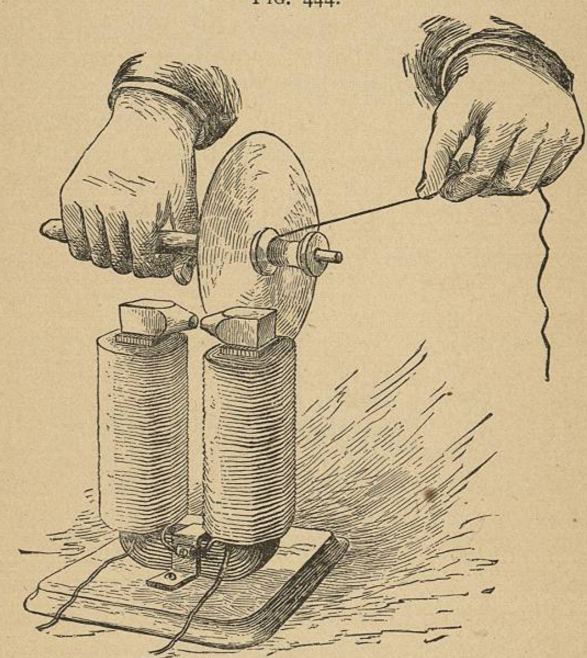
Form for Coils.

thin glue. The second layer is then wound, starting from the head, C, and winding in the same direction toward the head, D, and when the second layer is complete it is brushed over with the glue, after which the third layer is wound and glued, and so on, laying the wire on like thread on a spool until six or eight layers have been applied.

To prevent the destruction of the coil by the loosening of the ends of the wire, a loop of tape should be placed on the beginning of the first convolution and laid over the first layer of wire, so that it may be clamped by the second layer, and in a similar manner some stout threads should be placed between the outer layer and the adjacent layer, so that they

may be tied over the last convolution of the last layer. After the glue has become thoroughly dry and hard, the heads, C D, are removed from the bars, A B, and the tapering bars are knocked out of the coil in opposite directions, their wedge shape facilitating this removal. Two coils precisely alike are required. When they are placed on the core, the outer end of one coil is connected with the outer

FIG. 444.



Foucault's Experiment.

end of the other, and the remaining ends are connected with a battery.

To give the coils a finished appearance, they may be coated with shellac varnish colored with a pigment of suitable color, vermilion for example.

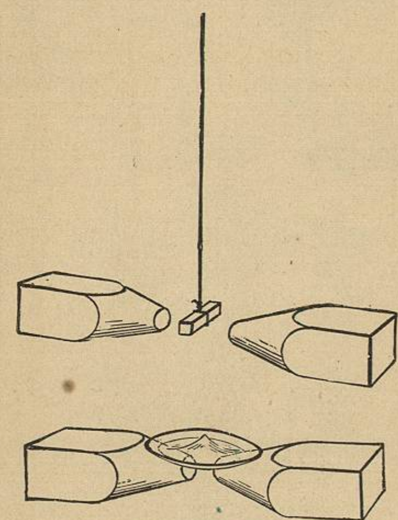
Almost any battery may be used in connection with this magnet. The simple plunge battery shown in Fig. 393 will answer admirably.

EXPERIMENTS WITH THE ELECTRO-MAGNET.

To the poles of the magnet should be fitted two short iron bars having conical ends. These bars will need no special fastening, as the attraction of the magnet will hold them in place.

In Fig. 444 is shown a simple way of reproducing Foucault's experiment. A centrally apertured copper disk, 6 inches in diameter, is attached by means of small nails to the end of a common spool, and the spool is mounted so as to turn on a screw inserted in a handle. The short iron

FIGS. 445 AND 446.



Diamagnetism.

bars are arranged on the poles of the magnet, as shown in the engraving, with the conical ends about one-fourth inch apart. A strong current is sent through the magnet, and the copper disk is whirled rapidly by quickly unwinding a string from the spool, after the manner of top spinning. The edge of the disk is then inserted between the conical poie pieces, but without touching them. The rotation of the disk is almost instantly stopped. A sheet of copper moved back and forth between the pole pieces offers a sensible resistance.

Most experiments in diamagnetism may be performed with this magnet. Short bars of various metals may be suspended, by means of a silk fiber, between the poles. Iron, nickel, cobalt, manganese, etc., will arrange themselves in line with the poles, while bismuth, antimony, and several other metals will arrange themselves across the line of the poles. The former are known as paramagnetic bodies, the latter as diamagnetic.

Liquids placed in a watch glass, as shown in Fig. 446, exhibit paramagnetic or diamagnetic properties: by piling up at the center of the glass, as shown in the engraving, if paramagnetic, or by piling up on opposite sides of the center, if diamagnetic.

The coils of this magnet, being removable, may be used in magnetizing steel bars, and for other purposes requiring the coils only.

There are about three pounds of wire in each coil of the magnet.

EXPERIMENTS ILLUSTRATING THE PRINCIPLE OF THE DYNAMO.

The great development of electricity in recent years, especially in the line of electric illumination, has served to add luster to the name of the immortal Faraday, and to show with what wonderful completeness he exhausted the subject of magneto-electric induction.

Since the close of his investigations no new principles have been discovered. Physicists and electrical inventors have merely amplified his discoveries and inventions, and applied them to practical uses.

The number of those who are familiar with the discoveries of Faraday and their bearing on modern electrical science is not only large, but rapidly increasing, but there are those who are still learners, to whom new things, or old things placed in a new light, are ever welcome. To such the simple experiments here given may be an aid to the understanding of induction as developed in dynamos and motors.

Any one at all acquainted with electrical phenomena