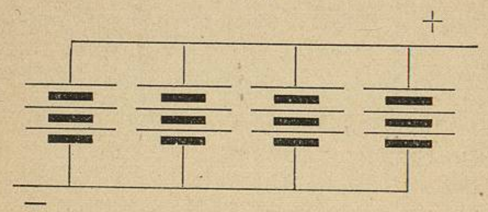
be 5 ohms per cell, the resistance of one series would be 15 ohms, and that of four series connected parallel would be $\frac{15}{4} = 3{\cdot}75$. Now, making the external resistance of the circuit equal to the resistance of the battery, the

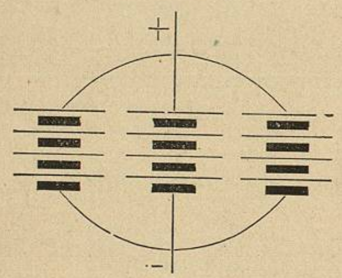
FIG. 423.



total resistance of the circuit would be internal resistance 3·75 + external resistance 3·75 = 7·5 ohms; and by the formula $C = \frac{E}{R}$ we will have $\frac{3}{7{\cdot}5} = 0{\cdot}4$ ampere.

In Fig. 424 the cells are arranged in three parallel series

FIG. 424.

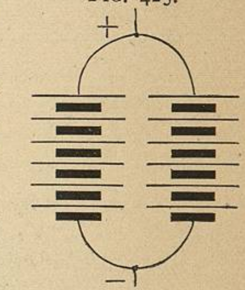


of four each. The electro-motive force is 4 volts, the resistance of each series is 20 ohms; this divided by the number of series = 6·66 ohms. Adding the resistance of the external circuit, which should be the same, the total resistance of the circuit would be 13·32 ohms. The electro-motive force, which is 4 volts, divided by this resistance = 0·3 ampere.

Take another example, in which 12 cells are arranged in two series of 6 each. The electro-motive force will be 6 volts, the resistance 15 ohms, and if a similar resistance be added in the external circuit, the total resistance will be 30 ohms, and the current strength will be 0·2 ampere.

If, however, a resistance of 60 ohms be placed in the external circuit, with cells arranged as in Fig. 425, the total resistance of the circuit then being 75 ohms, the current strength would be $\frac{6}{75} = 0{\cdot}08$ ampere, which is much less than that obtained by the first arrangement, in which all the cells are in series. Or take the first example, in which all of the cells are in series, and make the external resistance 15 ohms, instead of 60. The current strength would be 0·16 ampere, but the extra strength would be attended with an undue loss in the battery.

FIG. 425.



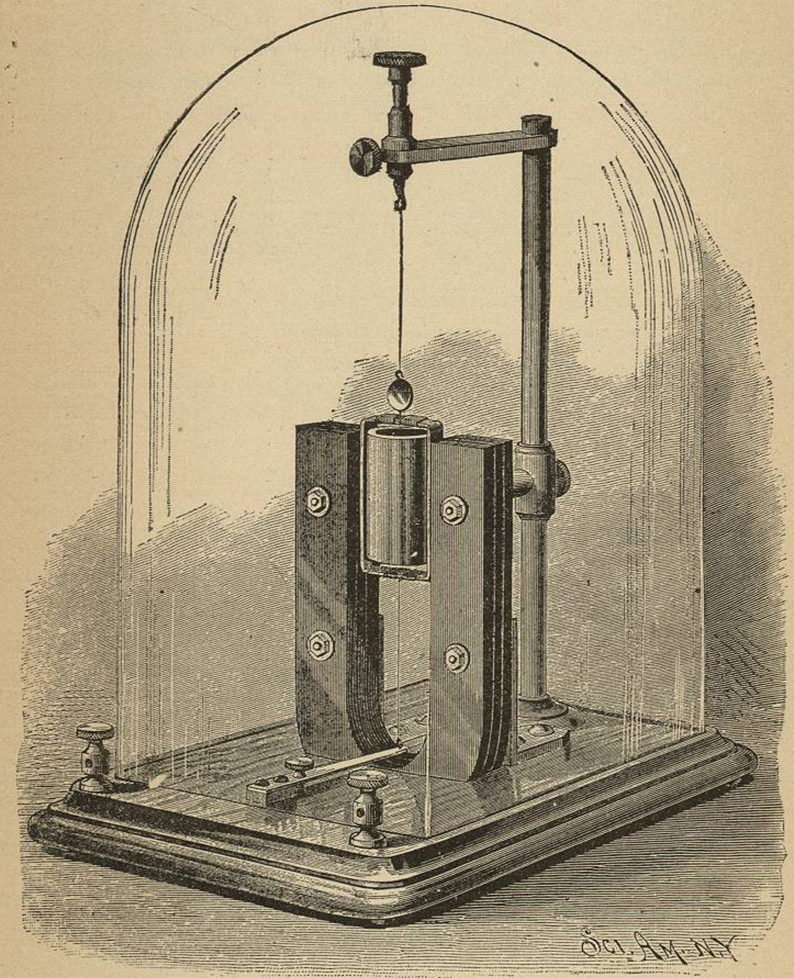
It will thus be seen that by connecting cells in series the highest electro-motive force is secured, while cells must be connected parallel for the greatest strength of current.

GALVANOMETERS.

No one can go very deeply into the study of electricity without reaching the subject of electrical measurements; certainly very little can be done in this direction without a galvanometer of some kind. The simple instrument already described answers very well for detecting currents and showing their direction, but it is not sufficiently delicate to be of value in electrical measurements.

Among all the galvanometers yet invented, there is perhaps none possessing so many good qualities as the one shown in Fig. 426. It is very simple. The materials are inexpensive. No great mechanical skill is required in its construction, and its sensitiveness and accuracy are sufficient for most requirements. Besides all this, it is perfectly "dead beat," so that no time need be wasted in waiting for the instrument to come to rest. This galvanometer is the joint invention of MM. Deprez and D'Arsonval, of Paris.

FIG. 426.



Deprez-D'Arsonval Galvanometer.

It consists essentially of a rectangular coil of fine wire suspended on strained torsional wires in a strong magnetic field. To the base is secured, by means of angle plates, a com-

pound U-magnet, 7 inches high, formed of three steel magnets, one-quarter inch thick, secured together and to the angle plates by bolts. The distance between the inner faces of the poles of the magnet is $1\frac{7}{16}$ inches. Two and three-quarter inches behind the center of the magnet a brass column rises from the base, and is provided near its center with an adjustable brass arm, supporting at its outer end, and exactly in the center of the space between the poles of the magnet, a hollow soft iron cylinder, $2\frac{1}{4}$ inches long, $1\frac{1}{32}$ inches in external diameter, $\frac{13}{16}$ inch in internal diameter. The top of this cylinder is even with the upper ends of the magnet. To the top of the brass column is secured, at right angles, an arm that extends over the hollow iron cylinder, and is provided with a vertical sleeve, in which is clamped a rod having on its lower end a small silver hook, arranged axially in line with the iron cylinder.

To a block attached to the base, opposite the center of the magnet, is secured a tapering spring, $\frac{1}{16}$ inch thick and $3\frac{3}{4}$ inches long, carrying at its free end a small silver hook, which is arranged in line with the axis of the iron cylinder.

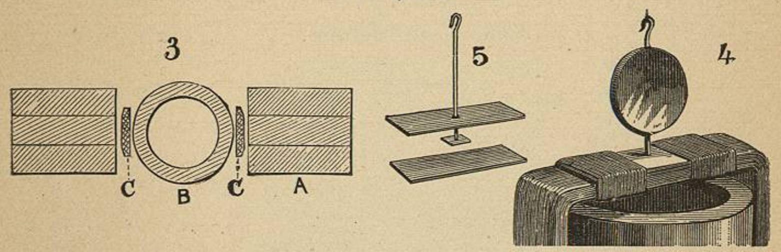
A rectangular coil of No. 40 silk-covered copper wire, large enough to swing freely over the iron cylinder, is suspended by a hard-drawn No. 32 (0·008 inch in diameter) silver wire from the hook above, and is connected by a similar wire with the hook on the spring below. The upper wire is $2\frac{1}{4}$ inches long between its connections, the lower one $2\frac{3}{4}$ inches.

The sides of the rectangular coil are flat, being about $\frac{1}{8}$ inch thick and $\frac{5}{16}$ inch wide. The resistance of the coil is 150 ohms. The silver hooks are connected with opposite ends of the coil, in the manner shown at 4 and 5, Fig. 426*a*. Each hook is provided with a flat head, which is secured between two thick plates of mica, the shank of the hook projecting through a hole in the outer mica plate. Each pair of mica plates is secured in place on the coil by a winding of silk, which is coated with shellac varnish to prevent the plates from slipping. The hooks are arranged exactly in the middle of the ends of the coil, so that when the coil is supported in the position of use by the silver wires, it will oscillate freely between the poles of the magnet and the iron cylinder. The terminals of the coil are soldered to the silver hooks. The upper hook is made a little more than a half inch long, to receive a small concave mirror, as shown at 4, which is secured in place by cement or wax. The mirror has a focus of 1 meter.

The relation of the magnet, A, the coil, C, and the iron cylinder, B, are clearly shown at 3, which is a horizontal section taken through those parts.

A glass shade protects the delicate parts of the instrument. The two binding posts, which are outside of the glass shade, are connected under the base with the brass column and the spring, so that the current passes from one

Fig. 426*a*.



3, Horizontal Section of Magnet, Coil, and Core. 4 and 5, Details of Deprez's Galvanometer.

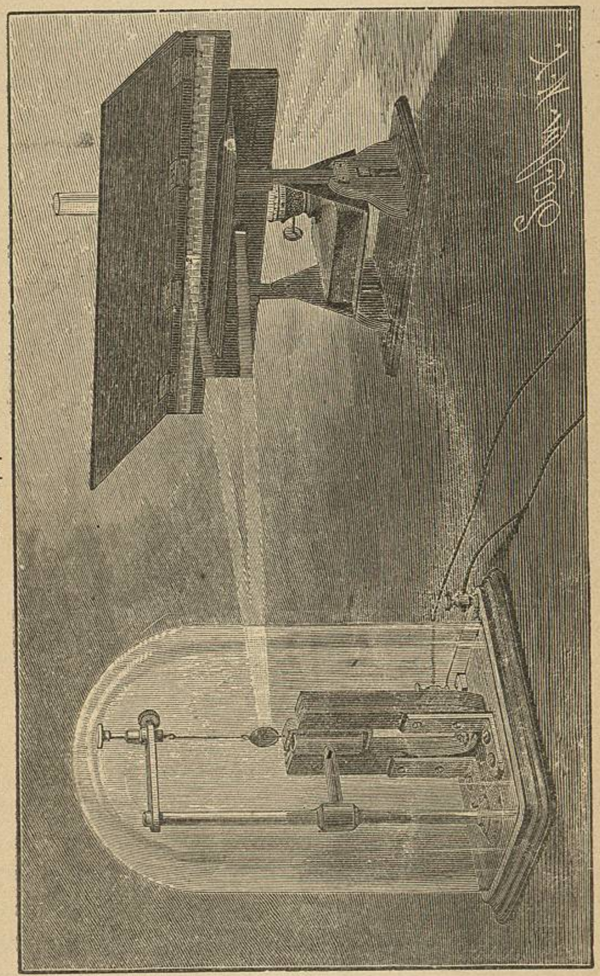
binding post to the column, thence down the upper silver wire, then through the coil, the lower silver wire, and the spring to the other binding post.

The silver wires are placed under considerable tension, and the coil is adjusted to a central position by turning the hooked rod at the top of the instrument.

When an electric current is sent through the coil, it tends to assume a position at right angles with a line joining the two poles of the magnet, the amount of displacement of the coil from its normal position depending on the strength of the current. As the deflection for a very light current is small, a beam of light reflected from the concave mirror is employed as an index. The scale is arranged as shown in Fig. 427, the light being projected from a lamp,

supported at the proper height behind the scale, through a slit below the scale and on to the concave mirror. The mirror reflects the beam on to the scale. The mark at the center of the scale is 0, and arbitrary numbers, running upward

Fig. 427.



Arrangement of Galvanometer, Lamp, and Scale.

regularly, are arranged on the marks on opposite sides of 0. The common paper scale used by draughtsmen answers for this purpose.

When the coil is at rest, the light spot remains at the center of the scale, but when a current passes through the coil, the beam moves steadily forward and stops without oscillation, the distance through which it moves depending, of course, on the strength of the current. The coil is returned to its normal position by the spring of the silver wires.

By employing shunts, heavy currents may be measured with the aid of this instrument. The sensitiveness of this galvanometer is so great as to indicate a current when the ends of two No. 18 copper wires connected with it are placed on opposite sides of the tongue.

The coil is carefully wound over a form covered with paper, each layer of wire being varnished with shellac varnish as the work of winding progresses. When the coil is complete, the coil, together with the form, is heated in a warm oven until the varnish becomes hard throughout the coil.

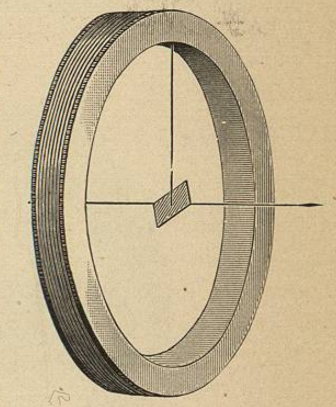
The concave mirror may be purchased from the optician, or a very fair mirror may be made by cutting a small disk from a double convex spectacle lens of 20 or 30 inch focus, and silvering it. A simple and quick way of silvering a small surface consists in scraping from the back of a piece of ordinary looking glass all the silvering, except a patch of the size of the mirror to be silvered. A small drop of mercury placed on the patch soon loosens it, so that it may be slid from the glass and transferred to the disk, which must be perfectly clean. After the patch is in position, a piece of tin foil is placed on the back of the disk, pressed down firmly, and allowed to remain long enough to absorb all of the surplus mercury. It is then removed, and the transferred silver will be found adhering strongly to the disk.

The various dimensions above given are taken from an almost exact copy of a Deprez-D'Arsonval galvanometer made by Carpentier, of Paris. The copy operates admirably. It is probable, however, that a considerable deviation from these dimensions might be made without seriously affecting the value of the instrument.

The tangent galvanometer is of great importance in

electrical measurements, especially in the class relating to currents. The principle of the instrument is illustrated by Fig. 428. In a narrow coil of wire is suspended a short magnetized needle, whose length does not exceed one-twelfth the diameter of the coil. Two light pointers are connected with the needle at right angles thereto. When a current is sent through this coil, the needle is deflected to the right or left, according to the direction of the current, and the amount of deflection is dependent upon, but not proportional to, the strength of the current. It is, however, proportional to the tangent of the angle of deflection.

Fig. 428.



Principle of Tangent Galvanometer.

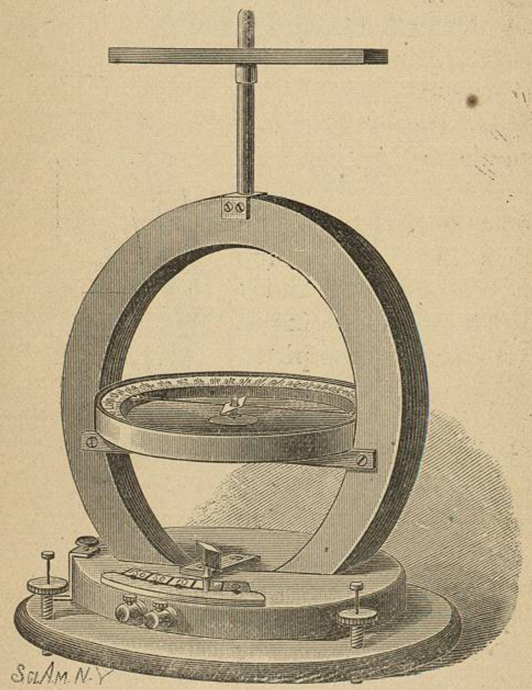
A practical tangent galvanometer is shown in Fig. 429. In this instrument the conductor is wound upon a grooved wooden ring 9 inches in diameter, the groove being $\frac{3}{4}$ inch wide and 1 inch deep. The wooden ring is mounted in a circular base piece, which is pivoted to the lower base to admit of adjustment. The lower base is provided with three leveling screws, which are bored longitudinally to receive pointed wires, which are driven into the table to prevent the instrument from sliding. The lower base is provided with an angled arm, which extends over the upper base piece, and is provided with a screw for clamping the latter when adjusted.

The winding of the ring is divided into five sections having different resistances, so that by means of a plug inserted in the switch on the base the resistance may be made 0, 1, 10, 50, or 150 ohms.

Fig. 430 is a diagram showing the coils and the switch connections stretched out. The first coil, *a*, is a band of copper $\frac{3}{4}$ inch wide and $\frac{1}{16}$ inch thick, with practically no resistance. The other coils are of wire. The coils, *b* and *a*, together, have a resistance of one ohm. The coils, *c*, *b*, *a*, have a combined resistance of 10 ohms. The coil, *d*, together with the preceding, offers a resistance of 50 ohms, and the combined resistance of all of the coils, *e*, *d*, *c*, *b*, *a*, is 150 ohms.

The conductors are connected with the binding posts, *f g*, and the current flows through the coils in succession,

FIG. 429.



Tangent Galvanometer.

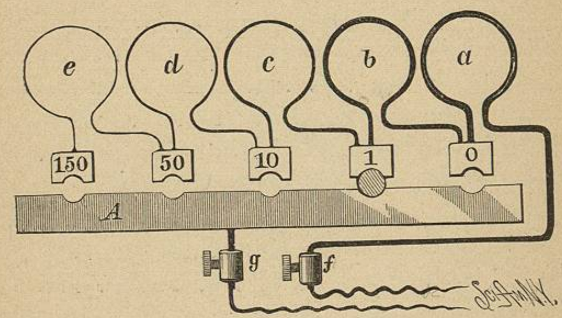
until it reaches one of the smaller switch plates, which is connected with the plate, A, by the plug. In the present case the plug is inserted between the plate marked 1 and the plate, A, causing the current to flow from the binding post, *f*, through the coils, *a*, *b*, and plate, A, to the binding post, *g*. The resistance of the galvanometer is obviously one ohm.

The magnetic needle, which is $\frac{3}{4}$ inch long, is located

exactly at the center of the ring, and delicately poised on a fine hard steel point. The needle should be jeweled to reduce the friction and wear to a minimum. To the sides of the needle are attached indexes of aluminum having flat ends, each of which is provided with a fine mark representing the center line of the index. The box containing the scale and the needle is supported by a cross-bar attached to the wooden ring. To the top of the wooden ring is attached a brass standard, which is axially in line with the compass needle.

Upon the standard is mounted a bar magnet, which may be adjusted at any angle or raised or lowered. This

FIG. 430.



Arrangement of Switch Connections.

magnet serves as an artificial meridian when the galvanometer is used for ordinary work. When it is used as a tangent galvanometer, the magnet is removed.

The Deprez galvanometer is independent of the earth's magnetism, but the tangent galvanometer must be arranged with the coil and the needle in the magnetic meridian, and its adjustment must be such that a current which produces a certain deflection of the needle in one direction will, when reversed, produce a like deflection in the opposite direction. The angle of maximum sensitiveness in the tangent galvanometer is 45°; therefore, when it is possible to do so, the current should be arranged to produce a deflection approximating 45°.

ELECTRICAL MEASUREMENTS.

The resistance of a battery may be ascertained by means of the tangent galvanometer as follows: The battery is connected with the galvanometer, and the deflection of the needle is noted; then a variable resistance is introduced and adjusted until there is a deflection, the tangent of the angle of which is equal to one-half the tangent of the angle of the first deflection. The resistance thus introduced is equal to that of the battery and galvanometer. Take from this quantity the resistance of the galvanometer, and the remainder will be the resistance of the battery.*

For example, when a battery placed in circuit with a tangent galvanometer produces a deflection of 48°, the tangent of that angle being 1·111, half of this quantity would be 0·555, which is very nearly the tangent of the angle of 29°; therefore, resistance is introduced until the needle falls back to 29°. Assuming this resistance to be 15 ohms, and the resistance of the galvanometer to be 10 ohms, the galvanometer resistance deducted from the resistance introduced leaves 5 ohms, which is the resistance of the battery.

To measure the electro-motive force of a battery, a standard cell is necessary. A Daniell or gravity cell, having an E. M. F. of 1·079 volts, is commonly used. This is connected with the tangent galvanometer, and the deflection and total resistance in the circuit, which should be high, is noted. The standard battery is then removed and the one to be measured is inserted in its place, and the resistance of the circuit is adjusted until the deflection of the galvanometer needle is the same as in the first case. It now becomes a matter of simple proportion, which is as follows:

E. M. F. of standard battery.	:	E. M. F. of battery being measured.	: :	Total resistance in first case.	:	Total resistance in second case.

Assuming the resistance in the first case to have been 2,500 ohms, and that in the second case 2,000 ohms, the proportion would stand thus:

1·079	:	Unknown E. M. F.	: :	2,500	:	2,000

* A table of natural tangents is given at the close of this chapter.

or as 5 to 4. The E. M. F. of the battery measured is therefore 0·8632 volt.

A convenient arrangement of the tangent galvanometer scale is to have one side of the scale divided into degrees, the other side being arranged according to the tangent principle, so that the reading will be direct and reference to the table of tangents will be avoided.

The simplest method of measuring resistance is that known as the substitution method, in which the unknown resistance and a galvanometer are placed in the circuit of the battery. The deflection of the galvanometer needle is noted. A variable known resistance is then substituted for the unknown resistance, and adjusted until the deflection is the same as in the first case. The variable known resistance will then equal the unknown resistance. If the current is so great as to cause a deflection of the needle much exceeding 45°, it should be reduced either by removing some of the battery or by the introduction of extra resistance into the circuit. The same conditions must obtain throughout the measurement.

FIG. 431.

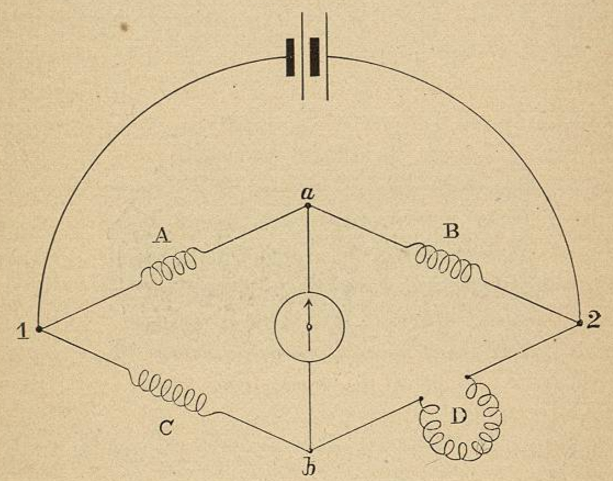


Diagram of Wheatstone's Bridge.