

RECENT IMPROVEMENTS IN D'ARSONVAL
GALVANOMETERS.

BY NELSON H. GENUNG.

[Read at the stated meeting of the Electrical Section, November 22, 1892.]

To see an elaborate electrical instrument highly lacquered and polished standing in the show-case of some college laboratory is one thing; to see the same or a similar instrument in the working drawings or in a thousand and one pieces on the workman's bench ready for assembling is quite another thing. It is in the latter case only, when one sees here and there a part insignificant in itself but on which may depend the success of the instrument as a whole, that one is brought to realize the necessity of looking after the smallest details in instrument construction. It is certainly difficult for a person unacquainted with the manufacture of fine instruments to fully appreciate the range of electrical and mechanical knowledge which one must possess in order that he may plan the working drawings for a high-grade instrument which shall work satisfactorily when completed, which shall conform strictly to mathematical principles, which shall include in neat and attractive mechanical form all the latest improvements applicable to that particular type of instrument, and which shall, in so far as is possible, conform to standard sizes of material so as to reduce the cost of manufacture to a minimum. It is only by continuous study and practice that one acquires satisfactorily the knowledge necessary for such an undertaking.

A thorough and systematic study of the Deprez-d'Arsonval type of galvanometer has recently been made by the writer with the ultimate intention of throwing this class of instruments into a variety of forms for both the college and commercial trades. The paper presented to you this evening will include, among other things, an historical sketch of the Deprez-d'Arsonval galvanometer, a little mathematical reasoning concerning aperiodic galvanometers of this type.

a brief review of the most noteworthy improvements recently made in this class of instruments, and a detailed description of a d'Arsonval galvanometer, which, in the course of its design, has been thoroughly criticised from both a theoretical and mechanical standpoint, and which, although not yet fully completed, has yielded extremely satisfactory results.

A galvanometer is an electrical measuring instrument in which use is made of the electro-magnetic properties of currents. A coil of wire traversed by an electric current sets up a magnetic field of its own, the strength of which at any point depends on the strength of the current flowing. Suppose this coil to be mounted vertically, and with its plane parallel to the magnetic meridian, a magnetic needle suspended in its axis will, when no current is flowing, assume a direction parallel to the horizontal component of the earth's field, but on introducing a current the needle will be deflected from this its zero position, through some definite angle depending on the relative strengths of the two magnetic fields involved. Thus we see that by this method the measurement of current is reduced to a measurement of the strength of field produced by it.

Numerous modifications may be introduced so that for a given strength of current the angular deflection of the needle may be materially increased. This increase in the sensibility, as it is called, has been brought about in several ways, such as decreasing the torsional control of the suspension fibre, reducing the moment of inertia of the movable parts, increasing the length of wire acting on the needle, reducing the mean distance of the coil from the needle and decreasing the strength of the earth's field in the vicinity of the needle by means of a control magnet. A discussion of these points being beyond the range of this paper will be omitted. Brief reference, however, will be made to the last one mentioned as it furnishes a stepping-stone to what is to follow concerning d'Arsonval galvanometers.

The extreme annoyance experienced in attempting to use a galvanometer of the above-described type, made sensitive by neutralizing the earth's effect on the needle by means of a control magnet is well-known. The original or earth's field

and the temporary field set up by the control magnet being nearly equal and opposite in direction destroy, almost completely, each other's effect on the needle. A slight variation in strength or direction of either of these fields or the introduction of a third field, however weak it may be, is often sufficient to cause the needle to turn completely around. This subject received full and thorough treatment in a paper read by Mr. Elmer G. Willyoung,* at our last meeting.

It was mainly with the idea of obviating this difficulty that Marcel Deprez,† about the year 1880, introduced into galvanometer construction what has since proved an important and desirable modification. He placed the galvanometer needle between the poles of a powerful horse-

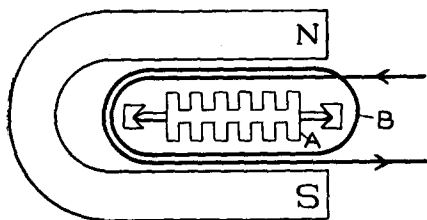


FIG. 1.

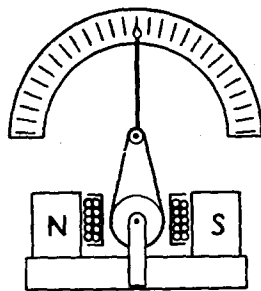


FIG. 2.

shoe magnet, thus freeing it from all local magnetic disturbances and giving it a short period of oscillation, but at the same time causing it to lose almost entirely its sensibility. He afterwards substituted a soft iron laminated needle which when placed in position became strongly polarized by induction. *Fig. 1* shows the general arrangement adopted by him, and known under the name "*galvanomètre à arête de poisson*," galvanometer of herring-bone work. The soft iron needle *A* is mounted within the galvanometer coil *B*, and both are surrounded by the horseshoe magnet *N S*.

* "A New Standard Ballistic Galvanometer with Variable Sensibility and without 'Drift,'" by Mr. Elmer G. Willyoung, New York *Electrical Engineer*, November 16, 1892.

† "On Electrical Measuring Instruments: Ammeters and Voltmeters," by Marcel Deprez, *La Lumière Électrique*, April 30, and November 5, 1881.

The range of movement of the needle is, however, very small and the deflections far from being proportional to the currents measured.

A multiplying device, similar to that shown in *Fig. 2*, was added a little later, which obviated these difficulties to a considerable extent. The scale was at that time usually divided into degrees, thus necessitating the use of a table of values or a calibration curve.

The next step was to retain this powerful control magnet and astaticise the movable system. M. d'Arsonval* concluded that so long as the moving parts contained any magnetic material this would be utterly impossible, the directing force being always very great as compared with the deflecting force. In order to accomplish this he aimed at making the directing forces very weak and the deflecting force very

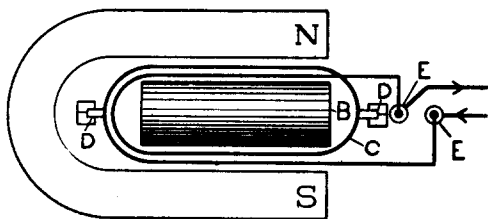


FIG. 3.

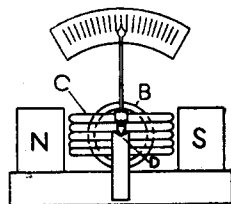


FIG. 4.

powerful, and succeeded by fixing the soft iron needle and making movable the current coil of the Deprez instrument. The general arrangement remaining the same, the number of parts was not materially increased. The control being non-magnetic could be made as weak as might be desired, the deflecting force remaining practically the same. *Figs. 3 and 4* show d'Arsonval's arrangement in which *NS* represents the permanent horseshoe magnet, the poles of which are thirty millimetres apart; *B*, the fixed soft iron tube or needle, about twenty-five millimetres outside diameter, which extends nearly the whole length of the magnet; *C*, the coil mounted on knife-edges *DD* and provided with mercury contacts *EE*, coinciding with the axis of rotation.

* "A new Deprez-d'Arsonval Astatic Galvanometer," by M. Deprez, *La Lumière Électrique*, September 7, 1881.

Almost any desired sensibility may be attained by properly adjusting the centre of gravity of the movable system.

A few years later this galvanometer was constructed as shown in *Fig. 5*, by M. Carpentier, in which form it has practically remained to the present day.

Lord Kelvin probably first made use of the above principle in the construction of his siphon recorder used as a receiving instrument in submarine telegraphy. M. d'Arsonval* says regarding his own application of this principle: "This apparatus rests upon the same principle as does the siphon recorder of Wm. Thomson. It is seen that I have

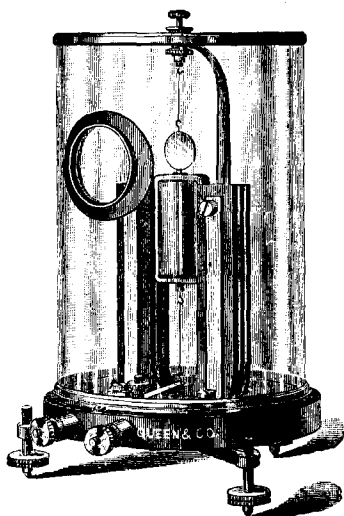


FIG. 5.

arrived at the same combination, starting from another point of view and that I have also transformed into a *galvanometer*, an apparatus which up to then had been used only as a telegraph receiver." In the same article he continues, "I have given to this apparatus the name of *Deprez-d'Arsonval galvanometer* in order to recall its origin."

A successful attempt was made in 1884 by Deprez† to

* "Aperiodic Galvanometers of Great Sensibility," by M. d'Arsonval, extract de la *Revue Internationale de l'Électricité et de ses Applications*, April, 1886.

† "On a Galvanometer in which the Indications are Proportional to the Current Strength," by M. Deprez, *La Lumière Électrique*, December 13, 1884.

construct a d'Arsonval galvanometer giving proportional indications. In an article published by him at about that time he says, "The deflections of the needle are exactly proportional to the intensities of the current even when deflected 120° ." Two soft iron pole pieces circularly cut out were employed. These pole pieces *B B*, see *Fig. 6*, and the soft iron cylindrical core *C* were rigidly attached to the magnet. Within the annular space occupied by the coil *A*, the magnetic field is strong and uniform and the lines of force are normal to the polar and core surfaces. The coil thus always moves through a uniform magnetic field, cutting the lines of force everywhere normally.

Another arrangement of pole pieces,* see *Fig. 7*, has been proposed which is capable of giving to the coil a much

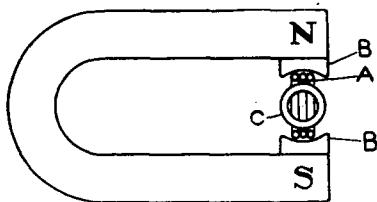


FIG. 6.

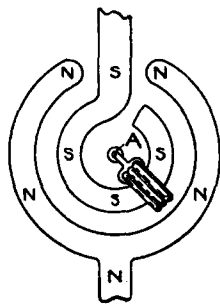


FIG. 7.

wider range of movement in a perfectly uniform field. This arrangement has, however, one or two disadvantages worth mentioning. The coil being pivoted at the centre *A*, has a comparatively large moment of inertia, which prevents it from coming to rest so quickly as it otherwise would. The amount of "dead" wire is also very great. By "dead" wire is meant all that portion of the coil not so disposed with reference to the field as to assist properly in the deflection, the "active" wire being that portion which moves properly in the magnetic field. This point is very satisfactorily illustrated in *Fig. 8*. The portions *LN* and *MR* in all three of the coils are so disposed, with reference to the axis of rotation and to the lines of force, as to assist in the deflection.

* See *La Lumière Électrique*, March 24, 1888.

The wire making up these portions is called the "active" wire of the coils. The wire making up the portions *L M* and *N R* takes no active part in the deflection, and is, in consequence, called the "dead" wire.

In an instrument to be used merely as a current detector, the deflections being usually very small, it is desirable to concentrate the field as much as possible by employing convex or conical pole pieces, so as to give to the coil a maximum deflecting force. Square or concave pole pieces give a weaker field for the coil at the start, but as the deflections increase the active portions of the coil pass into a gradually increasing strength of field, which makes up for

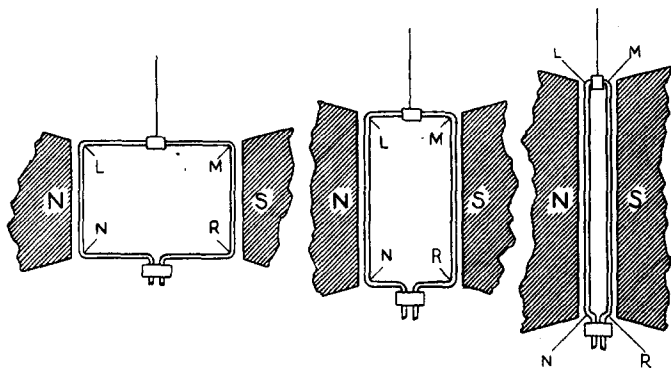


FIG. 8.

the loss in deflecting moment due to the shortening of the arm of the couple.

The leakage of the lines of force around the space occupied by the coil is likely to be much greater in horseshoe than in circular magnets, see *Figs. 9 and 10*. By adopting an arrangement similar to that shown in *Fig. 3*, nearly all the lines are utilized, but the great length necessarily given to the coil in order to capture the comparatively small number of lines near the bend in the magnet, is not a desirable feature in instrument construction. The iron core, however, doubtless tends to distribute the lines somewhat uniformly throughout its entire length. The increase in sensibility by this means is more than counter-balanced by the additional moment of inertia necessarily given to the

coil, which shows that the lines might better be concentrated at or near the poles proper, circular magnets being employed to avoid any appreciable loss due to leakage.

A novel arrangement of coil and magnets has recently been adopted by M. Gaiffe,* of Paris, in milliampèremeter construction. He has done away with the soft iron core and makes the deflections proportional to the intensities by employing two magnets of cylindrical form, as shown in *Fig. 11*. The coil in this arrangement contains a large amount of "dead" wire, being necessarily quite broad, and has a considerable moment of inertia as well. The range of movement, also, is not materially increased.

Turning our attention now to the movable system we find that when the coil is deflected from its position of

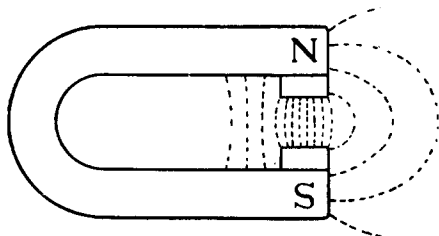


FIG. 9.

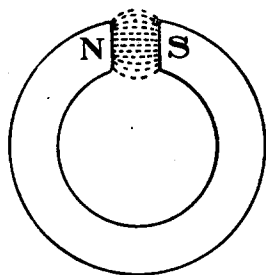


FIG. 10.

equilibrium there is a torsional couple due to the suspension which tends to bring it back. This is the only directive force brought to bear on the system. The moment of this couple is a function of the angle of deflection, and may be made almost anything desired by varying the length and cross-section of the suspension wire. Aside from this directive force, there are various retardative forces at work when the coil is in motion, due to the reaction of induced currents, friction with the air, and the like, which tend to bring the system to rest. These forces are functions of the angular velocity of the system.

In the movement of the coil of a galvanometer of this type we have an example of the rotation of a solid about an

* *La Lumière Électrique*, September 3, 1892.

axis in which case the product of the angular acceleration by the moment of inertia of the movable system is equal to the sums of the moments due to the directive and retardative forces. The differential equation for the movement of the coil thus becomes

$$\Sigma m r^2 \frac{d^2 \theta}{dt^2} + A \frac{d\theta}{dt} + B \theta = 0$$

in which θ represents the angular deflection in time t , $\Sigma m r^2$ the moment of inertia of the coil, A a constant for the retardative forces and B a constant for the torsional couple.

Imagine now the retardative forces to become negligible, the coil, when set in motion, acquires the same velocity every time it passes its position of equilibrium and makes a series of perfectly identical oscillations. It is thus said to

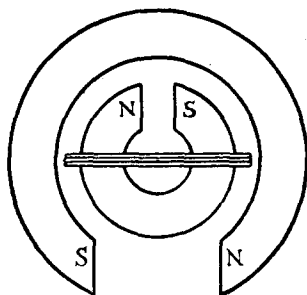


FIG. II.

have a *periodic* movement. The time of oscillation of the coil may be greatly increased, either by increasing its moment of inertia or by decreasing the directive moment due to the suspensions, the oscillations still remaining isochronous.

If, now, B is left constant and A made to increase gradually, the period becomes greater and greater as the logarithmic decrement increases. Finally, A having attained a considerable value, due to self-induction in this case, the coil on being drawn to one side and released, returns to its position of equilibrium, moving rapidly at first then more and more slowly, finally coming to rest. Infinite time is required theoretically for accomplishing this; practically, however, the zero point is reached in the course of a few seconds.

Suppose the only damping effect on the needle to be that due to induction; A is then equal to

$$\frac{F^2 S^2 n^2}{R}$$

where F represents the strength of the field; S , the area of the coil; n , the number of turns composing it, and R , the total resistance in circuit. Since the value of A depends on the total resistance R as the only variable, the field remaining constant, it should become zero when R reaches infinity; that is, when the coil is on open circuit. As a matter of fact, however, A does not become zero quite since the damping, due to friction with air, is not wholly negligible. By decreasing R the value of A increases and the coil finally assumes an *aperiodic* movement. A solid rotating about an axis is said to have an "aperiodic" movement when it takes up its new position immediately and without oscillation. By setting a d'Arsonval galvanometer coil of low resistance to oscillating on open circuit between the poles of a powerful horseshoe magnet, the transition from the periodic to the aperiodic movement is easily followed, as the circuit is closed through a high external resistance which is gradually reduced until the coil is short-circuited.

Time will not be taken to go more deeply into the theory of this instrument, as there are many points of more interest and greater importance which should be taken up. The theory of aperiodic galvanometers of the Deprez-d'Arsonval type has been thoroughly reviewed and experimentally verified by M. Ledebøer,* to whose paper the reader is referred in case he desires to go more deeply into the theoretical reasoning.

As early as 1881, Deprez† speaks of short-circuiting the coil for the purpose of damping the oscillations. The only resistance in circuit then being that due to the coil, the

* "Theory of Aperiodic Galvanometers," by M. Ledebøer, *Journal de Physique*, second series, vol. vi, p. 53, 1886. Also *La Lumière Électrique*, June 26, 1886.

† "New Deprez-d'Arsonval Astatic Galvanometer," by M. Deprez, *La Lumière Électrique*, September 7, 1881.

currents induced are sufficient to bring the needle slowly to rest. Closing the article, Deprez says: "This characteristic makes the instrument applicable to the measurement of resistances."

In the well-known Weston instrument, constructed on the Deprez-d'Arsonval plan, the coil is wound on a copper frame which serves the purpose of damping very effectively. This frame acts the same as would a single turn of heavy wire dead short-circuited on itself, and moving as it does in a powerful magnetic field the inductive effect is sufficient to make the instrument practically "dead beat."

Weston has also proposed the electrolytic deposition of a layer of copper over the entire surface of the coil, which shall serve the same purpose. Ayrton and Mather* have encased the coil of their recently constructed d'Arsonval in a silver tube, which serves both as a damper and as a protection to the coil. The coil is rigidly attached to this tube, which forms a part of the movable system.

Numerous other modifications of this method for damping have been proposed, such as short-circuiting any number of turns on the coil, adding a separate coil which shall be short-circuited, providing a copper disc which shall rotate properly between the poles of a powerful magnet, and the like, all of which are amply sufficient for the purpose.

Apparently no particular attention was paid to the best form of coil to be used in d'Arsonval galvanometers at the time when the best shape of pole pieces was being so thoroughly studied. In a paper on galvanometers, by Messrs. Ayrton, Mather and Sumpner,† the conclusion is drawn that the most sensitive galvanometer attainable is one of the d'Arsonval type suitably modified. For accomplishing this they say that the pole pieces should be very close together, the coil very small and no stationary iron core employed. The sensitiveness could be further increased by employing electro-magnets instead of permanent ones.

* "The Ayrton-Mather-d'Arsonval Galvanometer," *London Electrician*, July 29, 1892.

† "On Galvanometers," a paper read before the Physical Society, *London Electrician*, February 7, 1890.

The coil should also be long and narrow and the controlling force reduced to a minimum whenever great sensibility is desired.

Mr. Mather,* a little later, presented a paper before the Physical Society, in which he exhibited the results of a thorough study on the best section of coil perpendicular to the axis of rotation. Quoting from this article: "Since for a constant period the controlling moment at unit angle must be proportional to the moment of inertia, the problem is to determine the shape of the section so that the ratio of the deflecting moment to the moment of inertia may be a maximum." The six sections shown in *Fig. 12* are taken from the above-quoted article. In *A* the deflecting moment per unit moment of inertia is 1.02, in *B* it is .80, in *C* .97, in

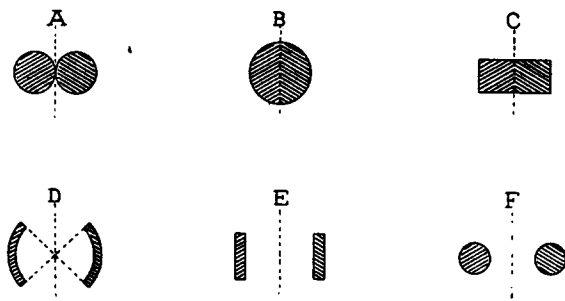


FIG. 12.

D .44, in *E* .47 and in *F* .40. Coil *A* is, as may be seen, more efficient than any of the others. These calculations are based on coils in which the length is great in proportion to the cross section.

As to the kind of wire to be used in these coils nothing in particular need be said. Copper is usually employed the same as in most galvanometers of the various other types. If, however, the accuracy of the instrument depends to any considerable extent on the permanency of its resistance, it is better to employ a wire, having a much lower temperature coefficient although its resistance may be considerably increased.

As has already been pointed out, the coil of the d'Arsonval

* London *Electrician*, April 11, 1890.

galvanometer in its earliest form rested on knife-edge supports, and was provided with mercury cup connections and gravity control. In the Carpentier arrangement the coil was mounted on a vertical axis. The suspensions in this latter case being of wire served the threefold purpose of suspension, conductor and control. A little later, long spiral springs were employed as conductors and control the coil being supported by means of a cocoon fibre.*

Suspension wires in a variety of sizes, shapes and materials have been employed at various times. Silver, platinum, silver-platinum, platinoid, German silver and phosphor-bronze are all materials for this purpose, the phosphor-bronze being on the whole the best, as it is little likely to corrode and is the least likely to take a permanent "set," thereby causing a slight change in the "zero point." The variation in sensibility due to the "time change," is also very small in the case of phosphor-bronze suspensions.

Flat strips possess a much smaller control than do round specimens of the same material having the same area of cross section. A suspension having a rectangular cross section the breadth of which is five to ten times the thickness has been recommended as the best form to adopt whenever a minimum control is desired. All other conditions remaining the same, Prof. Ayrton concludes that a flat strip suspension will give a deflection five times as great as will a round suspension of the same cross section. The liability to error due to a shifting of the "zero point," the result of a slight permanent "set," is much reduced by employing the strip. The radiation surface is at the same time considerably increased, this being often a matter of great importance in cases where very fine suspensions are necessary.

For commercial work the coil is usually supported in jewel bearings, springs serving for both control and conductors. In the well-known Weston instrument and in the milli-ampèremeters recently placed on the market by Mr. Gaiffe, flat spiral springs made from phosphor-bronze strip have been adopted.

* *Lumière Électrique*, 1887, p. 530.

In Prof. Ayrton's article, to which reference has previously been made, is described a form of d'Arsonval galvanometer having a coil of platinoid wire, the cross section of which is the same as that shown in *A*, *Fig. 12*, the iron core being necessarily absent. In this form the coil, mountings and frame work supporting the same are bodily removable from the instrument. A d'Arsonval galvanometer, designed by Messrs. Ayrton and Mather, was exhibited for the first time at a recent meeting of the Physical Society. This instrument, as you can readily see from the one before you, employs the narrow coil mounted in a silver tube, which forms a part of the movable system, and is suspended by a flattened phosphor-bronze wire. A button presses against the side of the silver tube by means of a spring which preserves the system from injury, when transportation is desired. The magnet is of one piece of metal, and has square pole faces. The movable system is mounted in a brass tube which may be removed, and another tube containing another coil slipped in place. The mirror cage and clamping device are both attached to this tube. The total height of the instrument is 6 inches, length of suspension tube $5\frac{3}{4}$ inches, outside diameter of magnet 4 inches, length of coil 2 inches, and diameter of silver tube $\frac{1}{4}$ inch. The coil has a period of about one and one-fourth seconds and is damped by the silver tube sufficiently to bring it to rest with about five complete oscillations.

We will now turn our attention to the new Queen-d'Arsonval galvanometer, this being its first appearance outside of their factory and electrical laboratory. *Fig. 13* shows the assembled instrument. All the parts are of rigid construction, and the instrument, as a whole, while it presents a pleasing appearance, presents a rugged workshop-like appearance as well.

The magnet has an outside diameter of four and one-half inches, and is built up of thirty-five discs one-tenth of an inch thick held together by means of three bolts. These discs are cut from the best sheet steel obtainable and are hardened glass hard. After having been thoroughly magnetized great care is exercised not to subject them

to any rough usage. The magnet rests on a sheet of hard rubber *A*, *Fig. 14*, which insulates it completely from the metal tripod base. The pole faces *BB* are concaved, thus tending towards uniform deflections. At the same time the corners are slightly rounded, thus avoiding too great a leakage around the coil. The suspension tube *C*,

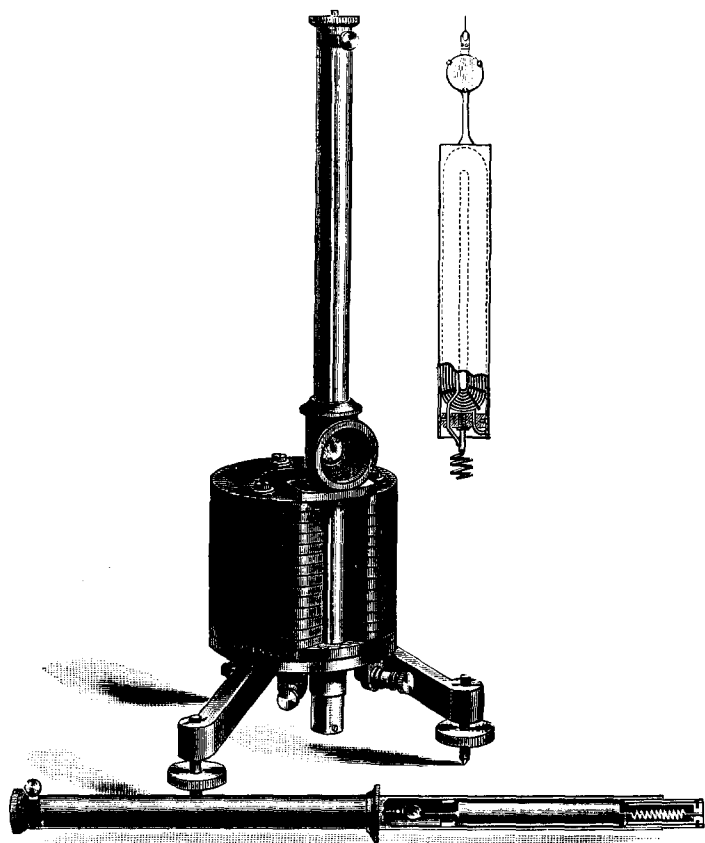


FIG. 13.

sixteen inches long over all, slides freely between the poles, which, together with the mirror cage *D* attached to them, hold it rigidly in position. This tube containing the entire system may be slipped out without the necessity of loosening a single screw and another tube put in place. Connections are made automatically by means of sliding contacts

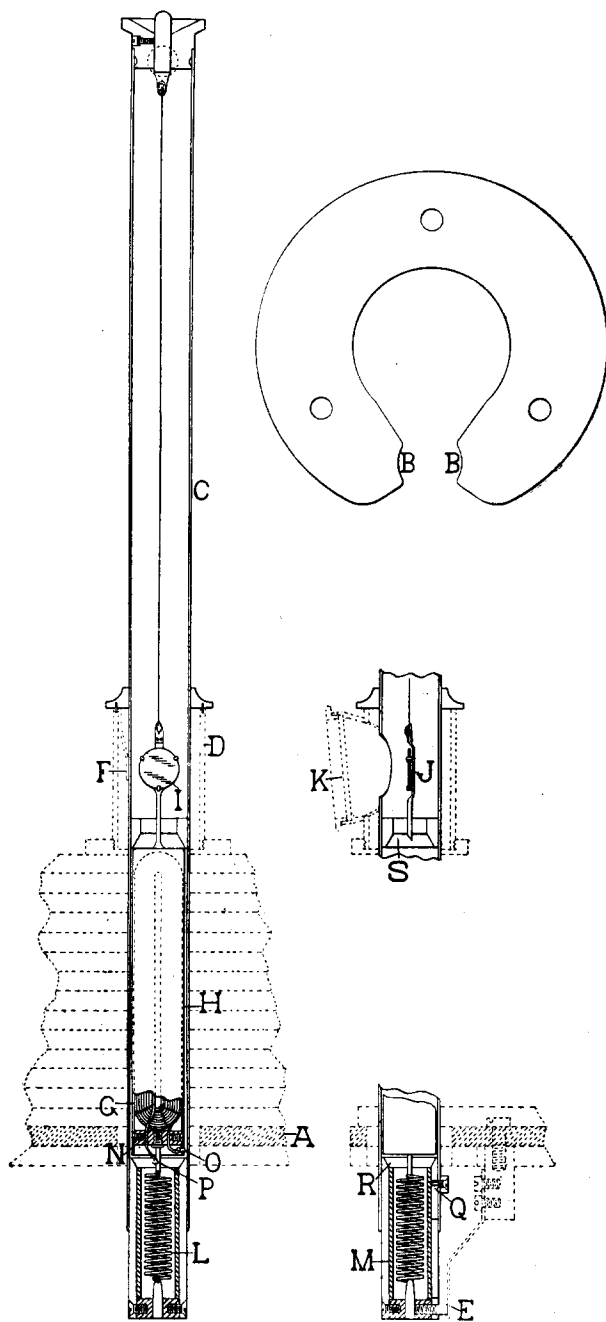


FIG. 14.

at *E* and *F*. The coil *G* fills the aluminum tube *H*, to which it is rigidly attached. The space within this tube allotted to the coil is $3\frac{1}{2}$ inches long by $\frac{9}{16}$ inch in diameter. The coil itself has a cross section represented by two tangential circles, as shown in *Fig. 8*, this being the most approved shape. It may be wound either of copper, or of platinoid wire as may be desired. To the top of the aluminum tube is attached the mirror *I*, held in place by a three-armed aluminum clip, thus avoiding the use of wax. The silvered surface of this mirror lies in the axis of rotation as shown at *J*, thus eliminating one source of error usually overlooked in galvanometer construction. The glass window *K* of the mirror cage is tilted, as shown, so as to avoid reflection of the scale from its surface into the telescope. The suspensions may be of any desired material. Flattened phosphor-bronze wire is, however, usually employed, a long spiral spring *L*, forming the lower connection. The portion of the tube surrounding the spiral has a hard rubber lining *M*, which avoids all possibility of short-circuiting. The terminals of the coil pass through the hard rubber base *N*, of the aluminum tube, one being soldered at *O*, to a copper plug riveted into the side of the aluminum tube, and the other at *P*, to the projection to which the spiral spring is attached. The lower end of this spiral is electrically connected, by means of the platinized spring contact *E*, to one binding post. The other binding post is reached through the aluminum tube, the upper suspension, the suspension tube, the platinized contact at *F*, the mirror cage *D*, and the magnets. The lower end of the suspension tube makes sliding contact with the tube proper, its range of movement being limited by the slot and pin at *Q*. As a means for clamping the system, the upper edge of this sliding portion is reamed out, as shown in the figure at *R*, and just above the aluminum tube is fastened a collar *S*, similarly shaped. When the lower end of the tube is shoved up, the coil is not only clamped but lifted slightly as well, thus entirely relieving the suspension wire of all strain. By this means the coil is held perfectly rigid during transporta-

tion without the least fear of injury to any part of the system.

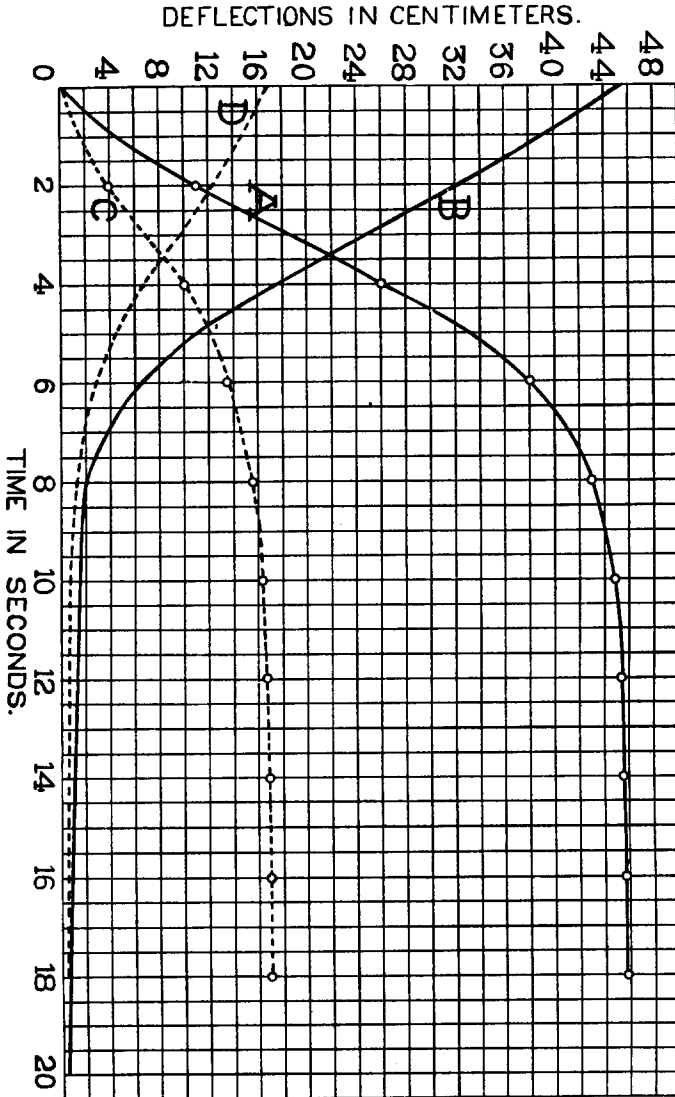


FIG. 15.

Starting the coil of this instrument from a position of rest, its position was noted every two seconds until it had again come completely to rest. The curves, *Fig. 15*, are

intended to represent this movement. Curve *A* was obtained by closing the circuit through a resistance sufficient to give about forty-six centimetres deflection. Curve *B* was obtained

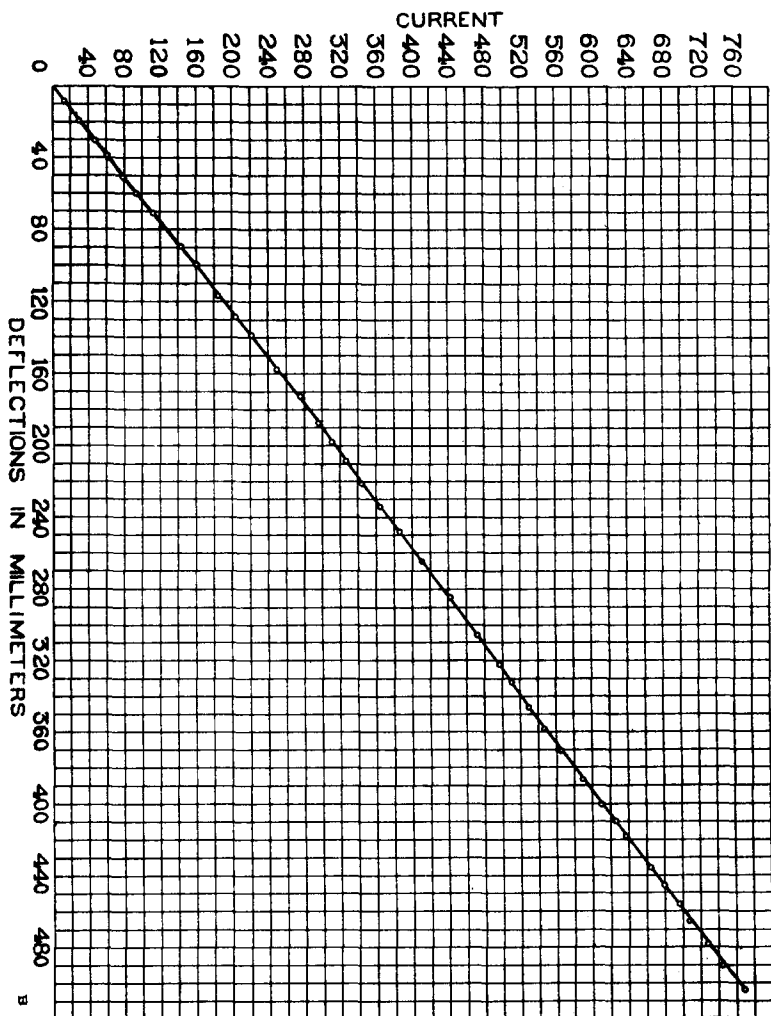


FIG. 16.

by breaking the circuit thus allowing the needle to return to zero. Curves *C* and *D* were obtained in a similar manner, the deflection being only about sixteen centimetres. From
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these curves it is easily seen that the movement of the coil is absolutely aperiodic; that is, it moves directly to its position of rest, approaching it more and more slowly, without showing the least sign of an oscillatory movement.

The curve, *Fig. 16*, is practically a calibration curve of the instrument. Abscissæ show the deflections in millimetres on a scale placed at a distance of one metre and the ordinates the corresponding currents. To obtain the values of the currents in fractions of an ampère multiply the ordinate readings by '0000001. This curve, practically the first one yet taken from the instrument, is very nearly a straight line curve which shows that the readings on a straight scale are very nearly proportional to the currents producing them.

The coil employed in obtaining the above data was wound with No. 36 copper wire, single silk insulation, having 694 turns and a resistance of 178 ohms. Its size and shape were as previously mentioned. The suspension was of platinum silver wire, 0'0014 inch round, and the spiral spring at the bottom was of the same material 0'0019 round. Phosphor-bronze strip has been delayed in reaching us in time for the paper. A small amount, however, has just been received and given the barest trial. The width of this strip is 0'006 inch and the thickness 0'0005 inch. The round platinum silver suspension and spring being replaced by this phosphor-bronze strip made the instrument much more sensitive, one volt pressure through 200 megohms now giving a deflection of one millimetre on a scale one metre distant. Under these conditions about fifty-five seconds are required for the coil to deflect and about forty for it to return to zero, which shows that a perfect aperiodic movement has been attained. The damping effect can easily be modified, so that this extremely slow movement will by no means appear as an objectionable feature to the instrument.

Extra tubes containing coils and suspensions of any desired material, resistance, etc., are supplied with the instrument. Tubes containing coils intended for ballistic purposes are also supplied. These latter are free from damping due to induction, a short-circuit key being amply sufficient to stop all movement of the system whenever desired

The work on d'Arsonval galvanometers is being continued with the intention of getting out an instrument of this type which shall have an extremely high sensibility, rivalling that of the Thomson square pattern galvanometer. The results thus far are very encouraging, and within a few months you may hope to see this instrument in tangible form.

ERRORS IN THE DETERMINATION OF AREAS FROM MEASURED DIAMETERS.

By O. T. LOUIS.

[Read at the meeting of the Electrical Section, held November 22, 1892.]

In scientific determinations made at the present day, the accuracy of the determination is the paramount question. The problem is not to measure a length to '01 millimetre or a resistance to '0001 of an ohm, but to determine a length or a resistance with an accuracy of '01 or '001 of one per cent. Little improvements often increase accuracy to a marked extent. To one of these little wrinkles, I would call attention to-night.

In some recent work in the measurement of conductivity at Queen's Laboratory at Ardmore, I had occasion to study the methods of determining the cross section of the specimens in question. The area could be determined in two ways: by calculation from the volume obtained by the determination of the mass and specific gravity and by calculation from a directly measured diameter. The latter method is of course the simpler and where a good chemical balance is absent the only one to be employed. To call attention to a few points to be observed in this latter method is the object of this paper.

Let δ equal the true diameter of any geometrical cross section, the area of which is to be determined.

Then $k\delta^2$ can be taken as the area of that cross section, k being a constant varying from

$$1 \text{ to } \frac{\pi}{4}$$

for all figures from the square to the circle.