armatures in these machines are contructed on Siemens's principle, and consist of long bars of iron magnetized transversely, and having the wire wound longitudinally. During the rotation of the armature, so much heat is developed that special means are taken to prevent its accumulation. In another form of Wilde's machine, a vertical disk carrying a number of coils, each with its own core, is caused to rotate between two rings of magnets. A powerful machine, with multiple armatures of this kind, is used by Messrs Elkington at Birmingham, and is capable of depositing 4½ cwt. of copper every 24 hours.

Another recent modification of the magneto-electric machine used by electro-metallurgists is that invented by M. Gramme. A ring of soft iron carrying a large number of coils of insulated copper wire is caused to rotate between the poles of a fixed horse-shoe magnet, and the currents induced in the coils are collected by two metallic disks, whence they may be drawn off for use in electro-deposition. As the core is circular, the magnetization proceeds continuously, and hence the current is uniform; but as both poles of the magnet are used, two opposite continuous currents are simultaneously produced.

Thermo-electricity is another source of electromotive power of which the practical worker has availed himself. In 1843 a patent was taken out by Moses Poole for the use of a thermo-electric pile in place of a voltaic battery, but it is only within the last few years that such a source of electricity has been introduced into the workshop. The best-known form of thermopile is that devised by M. Clamond of Paris. One element is formed of tinned sheet-iron, and the other of an alloy composed of two parts of zinc to one of antimony. A large number of these pairs, insulated from each other, are arranged in circular piles around a central cavity, in which their junctions are heated by means of a Bunsen burner. The ease with which such an apparatus can be manipulated recommends this source of electricity to the electro-metallurgist.

Having procured a supply of electricity from one or other of these sources, the electro-metallurgist applies it either to the deposition of a metal upon a matrix or to the coating of one metal by another. Hence the art of electro-metallurgy divides itself into two branches, one being called *electrotypy*, and the other being generally known as *electro-plating*. In an electrotype the reduced metal is separated from the mould on which it is deposited, and forms a distinct work of art; whilst in electro-plating the deposited metal forms an inseparable part of the plated object.

It has already been explained how electrotypes are generally taken. One of the most important branches of this art is that of producing copper duplicates of engravings on wood. A cast of the block is first taken in wax or in gutta-percha, and when cold the surface of this mould is brushed over with black-lead; by means of a wire, the black-leaded mould is suspended in a bath of sulphate of copper connected with a battery, and in the course of a few hours a sufficiently thick plate of copper is deposited. The copy, on removal from the mould, is strengthened by being backed with type-metal; it is then planed smooth at the back, and mounted for use on a wooden block. This process is now carried out on a large scale, since it is found that a greater number of sharp impressions can be obtained from the electro than from the wood. For rotary printing machines the electrotypes are curved. Set-up type is also sometimes copied thus instead of being stereotyped, the electro-deposited copper being harder than the stereo metal.

Copper is sometimes thrown down as a thin coating upon plaster busts and statuettes, thus giving them the appearance of solid metal. In Paris, too, it is now common to give a thin coat of electro-deposited copper to exposed iron-work, such as gas-lamps, railings, and fountains. The iron is first painted, then black-leaded, afterwards electro-coppered and finally bronzed. Cast-iron cylinders used in calico printing are also coated with copper by a single-cell arrangement; and it has been suggested to coat iron ships in a similar manner. Usually, however, the electro-plater has to cover the baser metals with either silver or gold.

Electro-plating was introduced very soon after the discovery of the art of electro-metallurgy, the earliest investigators being Messrs G. R. and H. Elkington, Mr Alexander Parkes, and Mr John Wright in this country, and M. de Ruolz in France. It was Mr Wright who first employed a solution of cyanide of silver in cyanide of potassium, and this is the solution still in common use. It should be borne in mind that the cyanide of potassium is a very dangerous poison. The objects to be silver-plated are usually made of German silver, which is an alloy of copper, zinc, and nickel. Before being placed in the depositing vat, the articles must be thoroughly cleansed. Grease is removed by a hot solution of caustic potash, and mechanical cleaning is commonly effected by means of a bundle of fine brass wires, known as a "scratch-brush;" the brush is mounted on a lathe, so as to revolve rapidly, and is kept moist with stale beer. Articles of copper, brass, and German silver are usually prepared by being dipped in different kinds of "pickle," or baths of nitric and other acids. To insure perfect adhesion of the coating of silver, it is usual to deposit a thin film of quicksilver on the surface, an operation which is called "quicking." The quicking liquid may be a solution of either nitrate or cyanide of mercury. After being quicked, the articles are rinsed with water, and then transferred to the silver-bath, where they remain until the deposit is sufficiently thick. The quantity of silver must depend upon the quality of the article: one ounce of silver per square foot forms an excellent coating, but some electro-plated household goods are turned out so cheap that they must carry but the merest film of silver. The vats in which the electro-plating goes on were formerly made of wood, but are now usually of wrought iron. Plates of silver are suspended from a rectangular frame connected with the positive pole, whilst the articles to be plated are suspended by wires from a similar smaller frame communicating with the negative pole. Large articles are suspended from wires, looped at the end, and protected in tubes of glass or india-rubber, whilst small articles may be placed in wire cages or in perforated stoneware bowls. On removal from the depositing vat, the plated objects are usually dipped in hot water, then scratch-brushed with beer, again washed with hot water, and finally dried in hot sawdust. A bright silver surface, requiring no further treatment when removed, may be obtained by adding to the silver bath a very small proportion of bisulphide of carbon.

Electro-gilding is effected in much the same way as electro-silvering. It is found, however, that magneto-electricity cannot be employed with advantage. Various gilding solutions are in use, but preference is usually given to the double cyanide of gold and potassium, originally introduced by Messrs Elkington. The solution is generally used hot, its temperature ranging from 130° Fahr. to the boiling-point. If the object to be gilt is not of copper, it is usual to coat it with an electro-deposit of copper before submitting it to the gilding solution. The coating of gold is generally very thin, and only a few minutes' exposure to the hot solution is necessary to effect its deposition. When the solution is fresh, a copper anode may be employed, its place being taken by a small gold electrode after the solution has been in work for some time. The presence of copper in the solution imparts a full reddish colour to the electro-deposit of gold; and the tone of the metal may also be modified by the presence of salts of various other metals, such as those of silver. Sometimes only part of an object is to be gilt, such as the inside of a silver-plated cream-jug; in this case the vessel would be filled with the gilding solution, in which the anode of the battery is immersed. Gold is sometimes deposited not as a coating upon other metals, but as an electrotype in gutta-percha or in plaster moulds; small objects of elaborate workmanship being thus produced in solid gold, without the workmanship of the chaser and engraver.

Although copper, silver, and gold are the metals to which the attention of the electro-metallurgist is usually restricted, it should be remembered that he is also able to obtain electro-deposits of a very large number of other metals. Many of these are not practically used, but one of them has of late years become of considerable importance. This is the metal *nickel*. In 1869 Dr Isaac Adams of Boston, United States, patented a process for depositing nickel from solutions of various double salts; but Dr Gore had many years previously employed similar salts in England, and had published the results of his experiments. The deposition of nickel, especially from the sulphate of nickel and ammonium, is now carried out on a large scale both in England and in the United States. The metal is deposited as a very thin but excessively hard coating, and has the advantage of not readily tarnishing or corroding even in a moist atmosphere. Hence it has become common to electro-nickel iron and steel objects for use on board ship, as well as gun-barrels, sword-scabbards, harness furniture, gas-burners, and various articles for household use.

Iron, like nickel, may be deposited from its double salts, and excellent results have been obtained by Klein, of St Petersburg, with the double sulphate of iron and ammonium. Engraved copper-plates are much harder when faced with electro-deposited iron than when unprotected, and they consequently yield a much larger number of impressions before losing their sharpness. Plates for printing bank-notes have been treated in this way.

Not only can the electro-metallurgist deposit simple metals, such as those noticed above, but he is able likewise to deposit certain *alloys*, such as brass, bronze, and German silver. The processes by which this can be effected are not, however, very generally used.

Among the minor applications of electro-metallurgy we may mention the process of electrotyping flowers, insects, and other delicate natural objects. These are first dipped for a moment in a warm solution of nitrate of silver in alcohol, and then exposed to a reducing liquid, such as a solution of phosphorus in bisulphide of carbon; an electro-deposit may then be thrown down upon this metallized surface. Daguerreotypes are sometimes improved by coating them with a very delicate film of electro-deposited gold. Again, in some of the modern photographic processes for printing, copper electrotypes are taken directly or indirectly from the bichromatized gelatine. Of late years, too, a method of refining crude copper by means of electro-metallurgy has been introduced, and is now successfully carried out on a large scale. Slabs of blister-copper are plunged into a solution of sulphate of copper, and form the anodes of a battery; the copper then dissolves, and is deposited in a condition of great purity at the opposite pole, most of the impurities sinking to the bottom of the depositing vat. The process should be restricted to copper which is free from any metals likely to be deposited along with the metal under purification.

It has been considered desirable not to include within the limits of this article any of the numerous formulæ for preparing the solutions used by electro-metallurgists. For these, and for other details, see the treatises of G. Gore (1877), J. Napier (5th ed., 1876), A. Watt (5th ed., 1874), A. Smee (3rd ed., 1851), and G. Shaw (1844); C. V. Walker's *Electrotype Manipulation* (1850); and H. Dirck's *History of Electro-metallurgy* (1863). (F. W. R.*)

ELECTROMETER. An electrometer, according to Sir Wm. Thomson, who is the greatest living authority on this subject, and has done more than any one else to perfect this kind of physical apparatus, is "an instrument for measuring differences of electric potential between two conductors through the effects of *electrostatic* force." A galvanometer, on the other hand, which might also be defined as an instrument for measuring differences of electric potential, utilizes the *electromagnetic* forces due to the currents produced by differences of electric potential. An instrument designed merely to *indicate*, without measuring, differences of electric potential is called an *electroscope*. It is obvious that every electrometer may be used as an electroscope, and it is also true that all electroscopes are electrometers more or less; but the name electrometer is reserved for such instruments as have a scale enabling us, either directly or by appropriate reduction, to refer differences of potential to some unit.

The modern electrician is far more concerned with measurements of electric potential than with measurements of electric quantity; and consequently all modern electrometric instruments are suited for direct measurements of the former kind. It is only indirectly that such instruments measure electric quantity. With the older electricians it was otherwise; and some of the earliest electrometers were designed for the direct measurement of quantity.

Such was the measuring jar of Lane,[1] represented in fig. 1 (after Riess). D is a Leyden jar, fastened to a stand in such a way that its outer armature can be insulated or connected to earth at will. The inner armature is in good metallic connection with the knob C. A horizontal metal piece A is mounted on a glass pillar, and carries another knob, which can be set at any required distance from C by means of a screw and graduation. The piece A is connected with the outer armature of the jar by a thin wire B contained in a glass tube. This last piece was added by Riess,[2] whose arrangement of the apparatus we have been describing. One way of using the instrument is as follows. The balls are set at a convenient distance apart, the stand is carefully insulated, and the outer armature of the jar connected with the battery of jars or other system to be charged, and the inner armature with the source of electricity, say the prime conductor of an electric machine. The electricity accumulates on the inner armature till a certain difference of potential between C and A is reached, and then a certain quantity q of electricity passes from C to A in the form of a spark, after which a quantity q remains distributed between the outer armature and the accumulator which is being charged. This process is continued, and as each spark passes, a quantity q is added to the charge on the outer armature and accumulator. Hence if the capacity of the outer armature be negligible compared with that of the accumulator, the charge of the latter will be proportional to the number of sparks between the balls. The measuring jar may also be used to measure the overflow of electricity from one armature of an accumulator when the other is connected with an electric machine. In this case the outer coating of the jar is connected with the earth, and C is connected with the armature of the accumulator. There is no occasion to discuss minutely here the corrections necessary in the latter method of using the apparatus; on these and kindred points

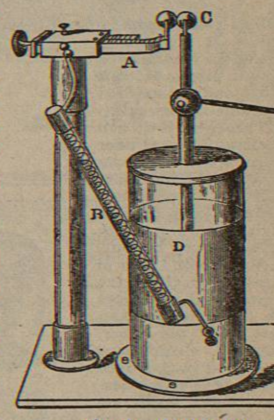

FIG. 1.—Lane's Jar.

[1] *Phil. Trans.*, 1769.

[2] The object of the fine wire is to absorb the energy of the discharges, and prevent the disintegration of the metal of the balls which renders the action of the apparatus irregular (see Riess, *Reibungselectricität*, § 386).

consult the account given by Mascart, *Traité d'Electricité Statique*, tom. i. §§ 313–316, and Riess, *l.c.*

The torsion balance of Coulomb is another instrument suited for the direct measurement of electrical quantity. For its construction and use see the article ELECTRICITY, p. 18.

The discharging electroscope of Gaugain belongs to the present class of instruments. It consists (fig. 2) of an ordinary (old-fashioned) gold-leaf electroscope, with the addition of a small knob B, connected with the metal sole of the instrument, and standing a little to one side of one of the leaves. The charge on any conductor is measured by connecting it with the knob A through a sufficient length of wet cotton to retard the discharge properly. When a certain amount of electricity has reached the gold leaf, it is attracted to the knob B and is discharged; it then falls back, is recharged, then discharged by contact with B a second time, and so on. It is found that the same quantity of electricity is discharged at each contact if the process be properly regulated; so that the whole charge on the conductor is measured by the number of oscillations of the gold leaf required to discharge it completely.[1]

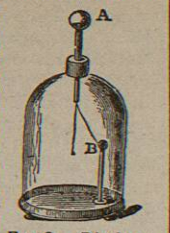

FIG. 2.—Discharging Electroscope.

The rest of the instruments (save one) to be described may be classified under the three heads given by Sir Wm. Thomson in his valuable report on electrometers,[2] viz., (1) repulsion electrometers, (2) attracted disc electrometers, and (3) symmetrical electrometers.

I. *Repulsion Electrometers.*—The electroscopic needle of Gilbert is the oldest specimen of a repulsion electroscope. The linen threads of Franklin, and the double pendulum used by Canton, Du Fay, and others, which was an improvement thereon, are typical of another species of electroscope coming under the same genus.

Cavallo's electroscope. Cavallo's electroscope[3] (fig. 3) embodies the double pendulum principle. It consists of two fine silver wires loaded with small pieces of cork or pith, and suspended inside a small glass cylinder. Through the cap which closes the cylinder passes the stout wire from which the pendulums are suspended. This wire ends in a thimble-shaped dome A, which comes down very nearly to the cap; the outside of the cap and part of the wire are covered with sealing wax, and the object of the dome is to keep moisture from the stem, so that the electroscope could be used in the open air even in rainy weather. To add to the sensitiveness of the instrument two strips of tinfoil are pasted on the glass at B and C opposite the pith balls. An electroscope similar to this was used by Saussure.[4] Volta used a pair of straws instead of the pith ball pendulums.

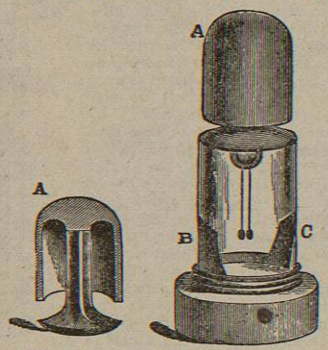

FIG. 3.—Cavallo's Electroscope.

By far the most perfect form of electroscope on the double pendulum principle is the gold-leaf electroscope of Bennet.[5] Fig. 4 represents a modern form of this instrument. The gold leaves are gummed on the two sides of a flat piece of metal carried by a stout stem, which passes through the top of a glass shade and ends in a flat disc. By means of this disc we may convert the instrument into Volta's condensing electroscope (already described, see ELECTRICITY, p. 34). Inside the glass shade, and rising well over the leaves, stands a cylinder of wire gauze, which ought to be in metallic connection with the earth, or with some conductor whose potential is taken as the standard of reference. The introduction of the wire cylinder is due to Faraday, and is an essential improvement; it is absolutely necessary, in fact, to convert the instrument into a trustworthy indicator of differences of potential. It serves the double purpose of protecting the leaves from external disturbing influences, and of ensuring that the instrument always indicates the difference between the potential of the body connected with the leaves and another *definite* potential. Thus, if we insulate the sole of the electroscope, and connect A with the leaves, and B with the gauze, the divergence of the leaves corresponds to the difference between the potentials of A and B, and will always be same for the same potential difference.[6] Hence, if the divergence of the leaves were read off by means of a properly constructed scale, the instrument might be used as a rough electrometer. The value of the graduation would of course have to be determined by experiment. Peclet did, as a matter of fact, use the gold-leaf electroscope in this way.

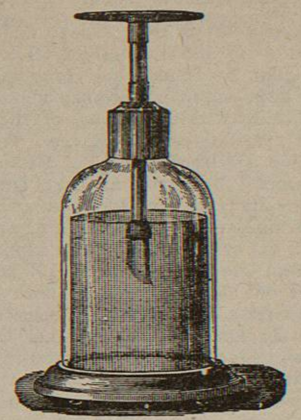
FIG. 4.—Bennet's Electroscope.

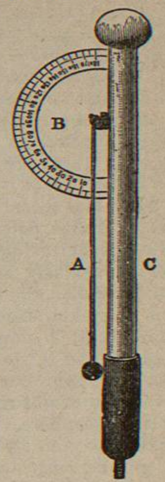

FIG. 5.—Henley's Electrometer.

Henley's electrometer. The electrometer of Henley,[7] sometimes called Henley's quadrant electrometer (fig. 5), may be taken as the type of single pendulum electroscopes. It consists essentially of a pendulum A hinged to a vertical support C, which carries a vertical graduated semicircle B, by means of which the deviation of A from the vertical can be read off. This form of electroscope is, or was, much used for indicating the state of electrification of the prime conductors of electric machines. The stem is screwed into the conductor, and the divergence of the pendulum indicates roughly the charge.

Pendulum sine electrometer. The sine electrometer of August, represented in fig. 6, is a modification of the single pendulum electroscope, analogous in principle to Pouillet's sine compass. A is a pendulum suspended by two threads to secure motion in one plane; B is a ball fixed to the case, and connected with a suitable electrode. Any charge is given to A; B is charged with q units of electricity; the case is turned through an angle ϕ in a vertical plane until the distance between A and B is the same as it was when both were neutral; then, if the charge on A be always the same,

$$q \propto \sin \phi .$$

This instrument is interesting on account of the principle employed in its construction; but we are not aware that it has ever been used in practice.

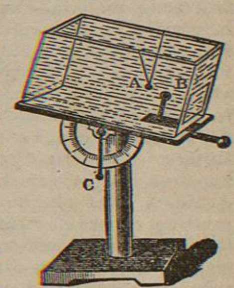

FIG. 6.—Sine Electrometer.

Another class of instruments, in which the movable part is a horizontal arm turning about a vertical axis, may be looked upon as the descendants of Gilbert's electroscopic needle. The electrometer of Peltier and its modification into a sine electrometer (by Riess) are instruments of this class. Descriptions of both will be found in Mascart, §§ 291 and 292.

Dellmann's electrometer (fig. 7) is constructed on a principle similar to that applied in the two instruments last named. D is a needle, formed of light silver wire, suspended by a fine glass fibre from a torsion head A. Below the needle is a piece of sheet metal NE, divided half through by a notch in the middle, and then bent in opposite directions on both sides of the notch, so that, when looked at end on, it appears like a Y. Underneath NE is a

[1] There is a correction for residue, see Mascart, t. i. § 317, &c.

[2] *Brit. Assoc. Rep.* 1867, or *Reprint of Papers on Electrostatics and Magnetism*, § 343.

[3] 1777?

[4] Riess, §§ 49 and 50.

[5] *Phil. Trans.*, 1787.

[6] It was by no means safe to take this for certain in the old instruments, owing to the electrification of the glass.

[7] *Phil. Trans.*, 1772.

graduated disc PL, through the centre of which passes a glass tube F supporting NE, so that it can be raised or depressed by a lever G. Inside F is a spring by means of which the lever H, which serves as electrode, can be connected or disconnected at will with the metal piece NE. The whole contained in a metal case B, the lid of which is of glass, so that the position of the needle D on the graduation PL can be read off by means of the lens M. To use the instrument, the case is connected with the earth, the needle is brought nearly at right angles to NE, and NE is raised by means of G till the needle is in contact with it; then the electrode K is brought into communication with NE, and the body whose charge or potential is to be measured is connected with K. The connection with K is then suppressed, and NE lowered; and the needle, now free, is repelled by NE. If, by means of the torsion head, we bring the needle along to a fixed position relative to NE, the electrical couple will be proportional to the square of the charge communicated to NE and D, *i.e.*, to the square of the potential of the body connected with K, provided the capacity of the electrometer be negligible compared with that of the body. Hence the potential is measured by the square root of the torsion on the fibre when the needle is in a given position.

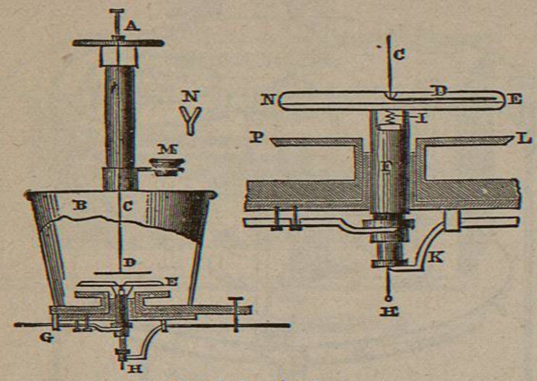

FIG. 7.—Dellman's Electrometer.

The form of Dellmann's electrometer we have just described was that used by Kohlrausch.[1] It has been simplified by its inventor, and applied in his important investigations on atmospheric electricity.

Coulomb's balance might be used as an electrometer on the repulsion principle. Special care would, however, be necessary to avoid or to allow for disturbances arising from the case of the instrument, which ought under any circumstances to be coated wholly or partially with tinfoil on the inside, according to Faraday's plan. Sir Wm. Thomson did, in fact, design an electrometer of this description, and has given tables (*Reprint of Papers*, § 142) for reducing its indications. This type of electrometer has not come into general use.

II. *Attracted Disc Electrometers.*—The first idea of this kind of instrument is due to Sir Wm. Snow Harris. One of the instruments in which he carried out the principle and the mode of using it will be understood from fig. 8. C is an insulated disc, over which is suspended another disc, hung from the arm of a balance, and connected with the earth. A weight w is put in a scale attached to the other arm of the balance. The insulated disc is connected with the internal armature B of a Leyden jar, whose outer armature is in connection with the suspended disc. Electricity is conveyed to B, and the quantity q measured by a small Lane's jar A, until the electric attraction at C is just sufficient to turn the balance. Snow Harris found that $w \propto q^2$. This and other laws established by him agree with the mathematical theory as developed in the article ELECTRICITY.[2]

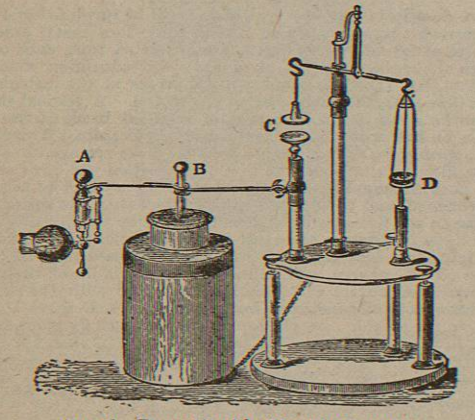

FIG. 8.—Snow Harris's Disc Electrometer

Great improvements have been effected in this kind of electrometer by Sir Wm. Thomson—(1) by his invention of the "guard ring" or "guard plate;" (2) by using the torsion of a platinum wire for the standard force; (3) by devising proper means for attaining a definite standard potential, and by protecting the vital parts of the electrometer from extraneous disturbance; and (4) by introducing sound kinematical principles into the construction of the movable parts.

In order to illustrate these points it will be well to describe the portable electrometer (fig. 9), one of his simpler instruments, in detail.

The principal electrical parts of this electrometer are sketched in fig 10. HH is a plane disc of metal (called the "guard plate") kept at a constant potential by being fixed to the inner coating of a small Leyden jar MM (fig. 9), which forms the case of the instrument. At F a square hole is cut out of HH, and into this fits, as nearly as it can without danger of touching, a square piece of aluminium foil as light as is consistent with proper stiffness. One side of this disc is bent down, and then runs out horizontally into a narrow stem ending in a stirrup L—the whole being not unlike a spade. The sole of the stirrup consists of a fine hair, which moves up and down before a vertical enamelled piece bestridden by the fork of the stirrup. On the enamel are two small dots very near each other. When the hair seen through a small convex lens appears straight, and bisects the distance between the dots, the stirrup is said to be in the sighted position. The aluminium spade is suspended on a horizontal platinum wire stretched by platinum springs at its two ends, and is carefully balanced with its centre of gravity in the line of suspension, so that the only force other than electric that can affect it is the torsion of the wire, which acts like the string in the toy called the "jumping frog," or like the hair rope in the catapulta of the ancients. The spade is so arranged that F is as nearly as possible in the same plane with the guard plate when the hair is in the sighted position. It is the torsional couple exerted by the wire in this position that forms the standard force. The remaining important electrical part is the plane horizontal disc G.

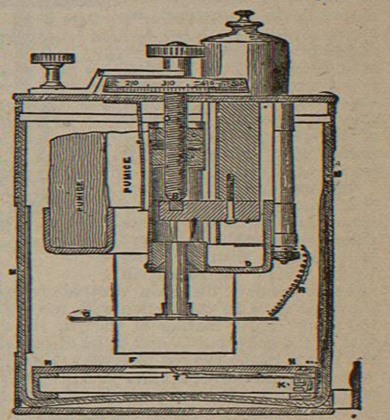

FIG. 9.—Section of Thomson's Portable Electrometer.

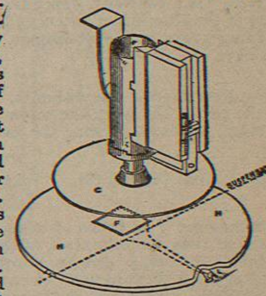
Fig 10.

It is essential to the action of the instrument that we should be able to move the disc G parallel to itself and to HH through measured distances. The mechanism by which this is accomplished is a remarkable instance of the application of geometrical principles to mechanism, and the reader will do well to read Thomson's "Lesson to the instrument makers" on this subject in the *Reprint* of his papers, § 369. The glass stem which carries G is fixed into the lower end of a hollow brass cylinder; in the upper end of the cylinder is fixed a nut AC, through which works a carefully cut screw ending in a rounded point B of polished steel. The point B rests on a horizontal agate plate let into a foot which projects from

[1] *Pogg. Ann.*, 1842 and 1852.

[2] See also *Reprint* of Sir Wm. Thomson's Papers, § 158.