Leaflet No. 44.

THE CAMBRIDGE SCIENTIFIC INSTRUMENT COMPANY, LTD., CAMBRIDGE, ENGLAND.

GOLD LEAF ELECTROMETERS,

As designed and used by Mr. C. T. R. WILSON, F.R.S.

UNIVERSAL PORTABLE ELECTROMETER.

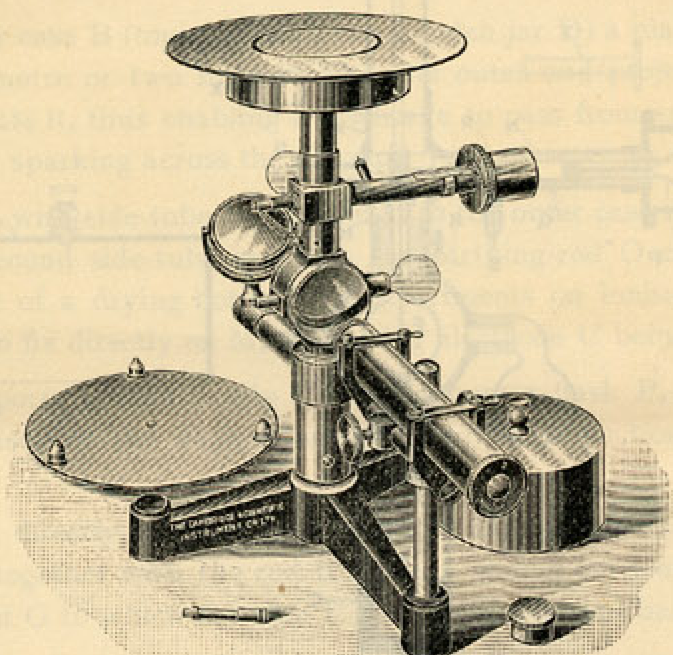

Fig. 1.—UNIVERSAL PORTABLE ELECTROMETER, ½-Full Size.

The instrument has an outer earth-connected case and an inner insulated case supported on the neck of a small quartz Leyden jar, with the inner coat of which it is connected, the outer coat being connected to the outer case of the instrument. For ordinary use the inner case is charged to a positive potential of about 50 volts. The insulating power of the Leyden jar is very high, so that in spite of its comparatively small capacity (less than 100 centimetres) the potential does not fall more than a small fraction of a volt in 24 hours.

When the gold leaf is earthed, its potential differs from that of the inner case by 50 volts, and it is, therefore, in a deflected position. If we raise its potential, the deflection will diminish (the charge of the inner case being positive), if we give it a negative potential, the deflection will increase. If we adjust the observing microscope so that the gold leaf is near the centre of its micrometer scale when its potential is zero, the instrument is in condition to measure potentials in the neighbourhood of zero up to about 5 volts positive or negative. For greater potentials the leaf will be outside the field of view of the microscope; over the range available the scale is nearly uniform. If the gold leaf is raised to a gradually increasing positive potential it will continually fall and will pass beyond the scale of the microscope when a potential of a few volts has been attained. When the potential has risen to 50 volts, that of the surrounding case, the deflection is a minimum, and beyond this point it will again increase. The gold leaf will come into sight again in the microscope when the potential rises to within a few volts of 100, and at 100 volts will be the same as for zero potential, the difference of potential between leaf and case being now the same as at first, the sign being, however, reversed. The instrument is then available over a second range of potentials, say from + 95 to + 105 volts. The displacement of the leaf for an increase of potential of one volt will be the same as for potentials in the neighbourhood of zero, the direction of the movement, however, being opposite.

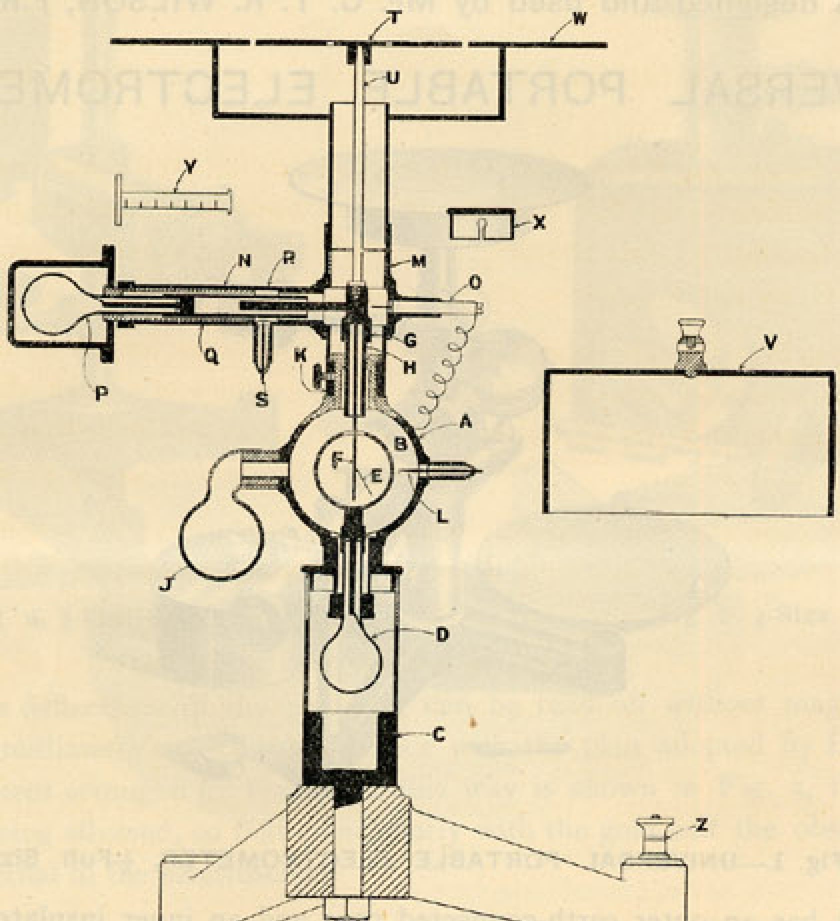

Fig. 2, $\frac{1}{3}$-Full Size.

The actual form of the instrument is shown in Fig. 2, which is drawn approximately to scale.

The outer case A is a short horizontal brass cylinder whose ends are closed by vertical glass plates, the inner case B being concentric with A and similarly closed by glass plates. Both pairs of glass plates are silvered internally, a strip of silvering being removed from each plate to enable the gold leaf to be seen. The inner case B screws on to the top of a brass rod passing through the neck of a quartz Leyden jar D and connected with its inner coat. The outer coat of the jar D is in metallic connection with the earthed outer case A and pedestal C, the support of the jar providing for a vertical adjustment, so that B may be made concentric with A.

The quartz bulb is silvered inside and outside, while the outer coating is to earth, the capacity of the condenser thus formed being from 50 to 100 centimetres, and the insulation almost perfect, so that the fall of potential due to leakage is not more than a small fraction of a volt in the course of 24 hours.

The gold leaf E is of very small dimensions, 1·1 centimetres long and from 0·1 to 0·2 millimetre wide.

The wire F to which the leaf E is attached is carried from a socket G supported by a concentric quartz tube H, which in turn is fitted at K in to the outer case of the instrument.

The fitting carrying the wire and gold leaf can be readily removed from the instrument when desired.

As will be seen, the wire F carrying the leaf E passes clear through a hole at the top of the inner case B.

For charging the inner case B (together with the Leyden jar D) a platinum wire L is provided, whose inner end is a millimetre or two from B, while its outer end projects just beyond the glass tube which serves to insulate it, thus enabling a discharge to pass from an electrophorus or rubbed rod to the inner case B, by sparking across the air-gap.

The tubular fitting M, with side-tube N, is secured to the outer case A by means of screws, and is removable. It has a second side-tube in which the earthing-rod O can slide, and a third (not shown) for the attachment of a drying bottle. In experiments on ionisation or radio-activity, the testing vessel is arranged to fix directly on M, the testing electrode U being screwed into G.

The side-tube N supports concentrically a silvered quartz flask P, similar to D, the tube Q being carried upon the neck of the flask P and in metallic connection with the inner coating of silver.

An axial displacement directly readable in millimetres can be imparted to the flask P, carrying with it the tube Q, which together with the rod R forms a sliding condenser. As will be seen, R is directly joined to the socket G to which the wire F and leaf E are attached.

The tube N is kept at a negative potential by being connected to the jar P, which is charged by a rubbed ebonite rod through a platinum wire and spark-gap S similar to L.

The movement of the tube of the sliding condenser is limited by stops, so that when fully in or out its position is definite. For the purpose of charging the gold leaf system the condenser is used as a kind of electrophorus. The slider is pushed in, the gold leaf terminal earthed by the earthing rod, and the slider pulled out against its stops. The leaf is thus left with a positive charge. It is convenient to give the condenser such a charge that the operation of making the earth connection when it is fully in and then drawing it out to its limit leaves the gold leaf at a convenient part of the field of view of the microscope, its potential being the higher potential corresponding to this position, *e.g.*, 105 volts if the inner case of the Electrometer is at 50 volts. When this has once been done the operation of charging the gold leaf to this definite potential of, say, 105 volts may be repeated indefinitely by simply pushing the condenser in up to its stops, earthing the gold leaf and pulling the condenser out to the extremity of its range again. Thus, in measuring the leak from an electrode initially at 105 volts, the above operation would be repeated between the successive observations. To charge to a low potential, say 5 volts, the slider would be moved across in the negative direction over the proper number of scale divisions, the earth connection would then be made and the slider pulled fully out again. It is convenient to make the actual measurements always with the slider completely out, as in this position the condenser tube is too far removed from the rod to have any influence upon its potential. The gold leaf reading is then entirely uninfluenced by any possible failure of the condenser insulation.

The sliding condenser is also useful as a compensator for measuring charges gained or lost by the gold-leaf system. To do this we keep the potential of the gold-leaf system constant by sliding the condenser in or out. A reading of the scale attached to the slider will then give us the charge, when the instrument has once been standardised, if the potential of the condenser tube be kept always the same. The charge acquired by the gold-leaf system has in fact been compensated by that which has been abstracted into the rod of the condenser on account of increased capacity, the difference of potential remaining constant. The change of capacity per millimetre is found to be sensibly constant over about 2 centimetres of the scale, while if the condenser be moved further out it falls off very rapidly.

The Electrometer stands on a substantial iron base. On one of the three feet of this base is fixed an upright iron rod, to which is clamped a cradle which carries the microscope.

The displacement of the gold leaf for a change of potential of one volt depends, of course, on the particular gold leaf used; it amounts to about $\frac{1}{10}$ of a millimetre per volt.

The readings of the instrument are very steady; owing, no doubt, to the double case, there is apparently a complete absence of disturbances due to convection currents. The gold leaf takes up its position of equilibrium within a small fraction of a second, so that very rapid potential changes can be followed.

The zero remained steady when the instrument, mounted on a camera tripod, was tested in the open air in a fairly high wind.

APPLICATION OF THE INSTRUMENT TO MEASUREMENTS IN ATMOSPHERIC ELECTRICITY.

The horizontal conducting "test" plate T, a few square centimetres in area, is fixed, by means of a vertical rod U, to the terminal G of the Electrometer. It is surrounded by a considerably larger plate W, lying in the same plane and forming a guard ring for it. On this guard-plate is placed a conducting cover V, of which the roof is some centimetres above the flat plate. The Electrometer is momentarily earthed by means of the earthing rod O, the cover is then removed. If this operation has been performed in an open field, the Electrometer will, under normal fine weather conditions, have its potential raised, and the gold leaf will thus be displaced. The potential can be at once brought back to zero, as indicated by the gold leaf, by sliding in the tube of the condenser. The testing plate being now at zero potential, the charge on its exposed surface is the same as if it were earth connected. This charge is given at once by the reading of the sliding condenser if it has been previously standardised. The charge per unit area of the plate will be proportional to the strength of the earth's field.

Let us maintain the potential at zero for some minutes, compensating for any change in the earth's field by the proper movement of the slider. Then let us replace the cover and draw out the condenser tube till the potential, as indicated by the gold leaf, is again brought to zero; the compensator reading then gives the charge gained by the plate in a known number of minutes when kept at zero potential—that is, under the same conditions as when earth connected.

We have thus obtained by these observations a measurement of the charge on our horizontal plate when earth connected and of the current through its surface. The ideal condition would, of course, be to have the plate on a level with the surface of the ground. We should then have both the charge per unit area of the earth's surface $= \sigma$ (and therefore also the magnitude of the electric field $= 4\pi\sigma$) and also the vertical current per square centimetre of the earth's surface at the place of observation.

DIRECTIONS FOR STANDARDISING THE COMPENSATOR.

To standardise the compensator so that its readings may give a measure of the charge in absolute units, a condenser plate supported on three insulating feet is placed on the guard plate W, so as to form, with the test plate T, a condenser of which the capacity can readily be calculated.

The condenser plate (which may be seen lying to the left of the instrument in Fig. 1) is initially earthed, the gold leaf system F, E being also earthed, and the compensator being drawn out to its full extent. The earth connection of the gold leaf system is then broken, the condenser plate raised to a known potential by connecting it to the positive pole of a battery, of which the other pole is connected to the terminal attached to the base of the electrometer, and the potential of the gold leaf system brought back to zero by sliding in the condenser P. We have then the test plate T and guard ring W at zero potential, and the condenser plate above them at a known potential. Thus the negative charge on the upper surface of the test plate T is known, and an equal and opposite charge must have entered the rod R of the compensator as a consequence of the displacement of the compensator tube; for the conditions throughout the rest of the system are the same as initially and the total charge on the system T, U, R, F, E has remained unaltered.

We have thus found the compensator reading corresponding to a known charge. We may now, leaving the compensator in its new position, earth both the condenser plate T and the gold leaf system F, E, then break the earth connections, again connect the condenser plate T to the positive pole of the battery, and move the compensator P, Q to bring the gold leaf back to the reading corresponding to zero potential. The charge on the compensator rod R corresponding to this second reading is twice that corresponding to the first reading; and by a repetition of this process we may with a single cell construct a complete calibration curve giving the charge corresponding to any reading of the compensator. The curve is a straight line except for the initial portion.

The reading of the compensator for any given value of the charge depends on the potential to which the inner coat of the Leyden jar P of the compensator has been charged; this would be adjusted according to the magnitude of the charges to be measured. For most purposes it would be given such a value that with the ordinary cover V on, a displacement of the compensator over its whole range would move the gold leaf over something like the whole length of its scale. To measure large charges, such as would without the compensator be beyond the range of the instrument, the charge of the compensator would have to be increased. To measure very small charges, such as would if uncompensated cause a movement of the gold leaf through perhaps one division or less, the charge of the compensator Leyden jar would be reduced to such an extent that the displacement of the compensator over its whole range would cause a displacement of the gold leaf through one or two divisions.

When once a calibration curve has been constructed for one value of the charge on the compensator Leyden jar, it is unnecessary, if the charge be altered, to construct a new curve; for all the ordinates of the curve would be found to be altered in the same ratio (the charge on the compensator rod when in any position at zero potential being proportional to the potential of the compensator tube), so that a single observation is all that is required to give the necessary reduction factor.

It is generally easy to arrange, by having its Leyden jar P at a suitable potential, that the compensator readings are on the straight portion of the curve; so that the charge to be measured is given by C $(r - r_1)$, where r is the compensator reading and r_1 is a constant which remains the same whatever be the charge on the Leyden jar P; a single observation will give the other constant C.

The charge corresponding to a given reading of the compensator when used to bring the potential of the gold leaf system to zero is independent of the capacity of that system; we may remove the test plate and guard ring, and substitute whatever arrangement may happen to be convenient. It is easy also, if we wish, to determine the capacity of the whole system by charging it (with the compensator out to its zero position) to a known potential, as indicated by the gold leaf, and then pushing in the compensator to bring the potential back to zero. The compensator reading then gives us the charge which was required to raise the system to the known potential; thus the capacity is at once obtained.

DIRECTIONS FOR CHARGING THE LEYDEN JARS.

In adjusting the charge of the inner case of the electrometer with its Leyden jar D, the gold leaf system F, E should be connected to earth by means of the earthing rod O. The inner case is then charged positively by sparking through the platinum wire L, till the gold leaf is deflected to an angle of about 30°. If the inner case is initially uncharged, this is most conveniently done with a small electrophorus; if too large a charge is put in, it is easily diminished by means of a rod of sealing wax or ebonite electrified by friction. The instrument may initially have the inner case charged to a sufficiently high potential to keep the gold leaf stretched out at right angles to its support. This is for greater safety in carriage, as the instrument may then be inverted or turned on its side without risk of damage to the gold leaf. The rubbed sealing wax or ebonite rod would in this case be used to reduce the potential of the inner case till the gold leaf came to the desired position.

When once charged to a suitable potential, the inner case should not require recharging for many weeks.

The Leyden jar of the compensator is most conveniently charged negatively. The compensator should be pushed in to its full extent while its Leyden jar P is being charged; the charging may be effected by means of a rubbed sealing wax or ebonite rod. The charge is adjusted till the deflection of the gold leaf across the scale of the microscope for a given displacement of the compensator is suitable for the intended measurement.

SIMPLE MICRO-ELECTROSCOPE.

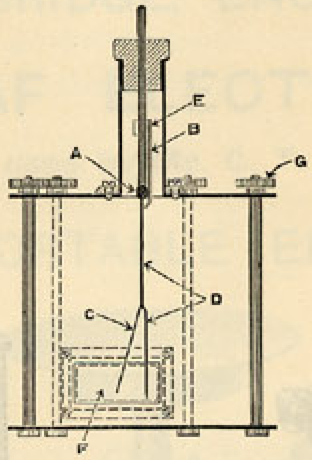

Fig. 3.—SIMPLE MICRO-ELECTROSCOPE, ½-Full Size.

This is essentially a gold leaf electroscope in which only a single movable leaf is employed, repulsion taking place between this and a prolongation of the wire which supports it. In Fig. 3, C is the gold leaf, which is cut in the form of a very narrow strip, and D is the wire supporting it. This wire is insulated by a bead of sulphur A from another wire which is seen passing up through an ebonite plug at the top of the instrument, and may be called the "upper wire." By means of this the gold leaf C and wire D can be put in connection with bodies outside the instrument. Normally there is no electrical connection between this upper wire and the wire D, contact being established when desired through a small key B, which can be actuated from outside the case by means of a magnet. When the instrument has been charged, the magnet is withdrawn so as to break the connection between the gold leaf and the outer knob of the instrument. The latter may then be maintained at the original potential of the gold leaf, as in some of Mr. Wilson's experiments,* so that the observed loss of charge of the gold leaf is wholly due to leakage through the space within the case of the instrument, any defect from perfect insulation tending to give too low a value for the leakage.

When so ordered the instrument is surmounted by a terminal, which can be turned into three positions. In one of these it is insulated, in another it is connected to the "upper wire," while in the third position it is connected both to the "upper wire" and to the case of the instrument. The case is also fitted with an independent terminal.

The whole instrument is enclosed in a metal case, in which are two small plane windows for purposes of observation.

For enabling the ionizing agent to exert its influence upon the air within the electrometer, two other openings are provided, one in the side and one at the bottom of the case. Both of these are ordinarily covered by thin paper, which is a sufficiently good conductor to form part of the conducting case, while it offers no appreciable obstacle to the passage of most types of ionizing rays. The side opening when not in use can be further protected by a brass shutter, while the bottom opening is so arranged that the paper diaphragm can be readily replaced by a diaphragm of any desired substance.

* "On the Ionization of Atmospheric Air," *Proc. R. S.* LXVIII. p. 151; "On Radio-Active Rain," *Proc. Camb. Phil. Soc.* Vol. XI. Pt. VI. p. 428.

The deflections of the gold leaf strip are observed through a microscope with micrometer eye-piece, as indicated in Fig. 4, and so long as the instrument remains undisturbed, the readings obtained agree well and will indicate small fractions of a volt.

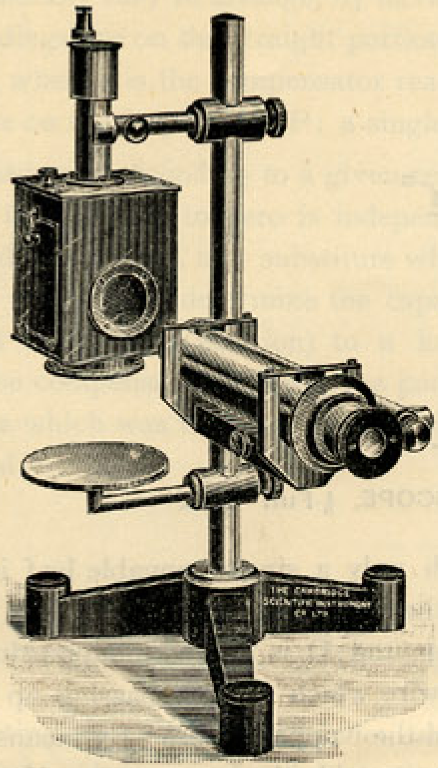

Fig. 4, $\frac{1}{3}$-Full Size.

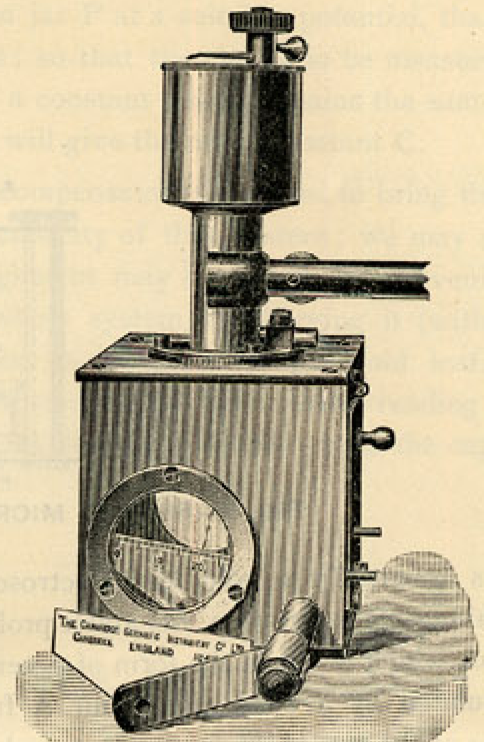

Fig. 5, $\frac{1}{2}$-Size.

Alternatively the deflections of the gold leaf can be read off without magnification against the reflected image of a millimetre scale, in accordance with the plan adopted by Professors Elster and Geitel. The instrument arranged for reading in this way is shown in Fig. 5, the lower part of the inspection window being silvered, so that coincidently with the gold leaf the observer sees the virtual image of a scale external to the electroscope.

PRICES.

	£ s. d.	$	Code Word.
Universal Portable Electrometer, Fig. 1, in wooden case, complete	~~15 0 0~~ 20 0 0	~~73.00~~ 97.40 *c.*	*Linden*
Simple Micro-Electroscope, Fig. 4, without microscope	2 10 0	12.20 *c.*	*Aumone*
Three-way Switch Terminal, extra	0 10 0	2.45 *c.*	*Auriscalp*
Stand, without accessories	0 7 0	1.70 *c.*	*Aureolus*
Clip for holding electroscope, and Table for supporting the object under examination	0 12 0	3.00 *c.*	*Auricle*
Microscope and Cradle	4 13 0	22.60 *c.*	*Aurigal*
External Millimetre Scale and Clip for use as in Fig. 5 ...	1 0 0	4.90 *c.*	*Limpid*

No. 14.—2,000. 9/06.

Hudson & Kearns, London, S.E.