AN ELECTROMETER METHOD FOR MEASURING DIELECTRIC CONSTANTS OF LIQUIDS

By A. P. Carman

Abstract

Differential idiostatic electrometer for the measurement of dielectric constants of liquids.—The suspended system includes two cylindrical quadrants C_1 and C_2 suspended so as partly to overlap two fixed cylindrical plates A and B coaxical with C_1 and C_2 and so placed and connected that the torque due to the condenser AC_1 is opposite to that due to the condenser BC_2. To determine the dielectric constant of a liquid, one of the condensers is immersed in it and the other immersed in a liquid or gas of known constant, and the differences of potentials V_A-V_1 and V_2-V_B for zero deflection are read by the potentiometer method. The dielectric constants are then proportional to $(V_A-V_1)^2/(V_2-V_B)^2=R_1^2/R_2^2$. This method gave for the *dielectric constant for distilled water* at 25°C with 60 cycle e.m.f. the value 78.07.

THE instrument used is a form of idiostatic electrometer, or electrostatic voltmeter, part or all of which is immersed in a liquid or liquids. The immersed electrometer for measurement of dielectric constants was first used by Silow[1] in 1875, and similar methods have been used by several investigators[2] since then. Two investigators, Perot[3] and Heerwagen[4] employed differential instruments, each using a double quadrant electrometer with the needles on a common stem, of which the lower set of quadrants and needle can be immersed in the liquid. The theory of these two methods is similar to that presented below, but the construction, adjustments and manipulation of the instrument are very different from those of the instrument described in this paper.

The electrometer used is shown in Fig. 1. The plates C_1 and C_2 of the needle system are cylindrical and are suspended to rotate about the vertical axis. The fixed plates A and B are parts of a coaxial external cylinder, placed as shown in the figure to produce a torque on the needle when differences of electrical potential between the needle and the plates are maintained. The shape of the wire frame carrying the needle plates is shown in the figures and, as indicated, either plate C_1 and its opposite fixed plate A or C_2 and B can be immersed in a given liquid by raising

---

[1] Silow, Ann. der Phys. **156**, 389 (1875)

[2] Cohn and Arons, Ann. der Phys. **33**, 13 (1888); Tereschin, Ann. der Phys. **36**, 792 (1889); Tomaszewsky, Ann. der Phys. **33**, 33 (1888); Rosa, Phil. Mag. **31**, 188 (1891)

[3] Perot, Jour. de Phys. **10**, 149 (1891)

[4] Heerwagen, Wied. Ann. **48**, 35 (1895)

around the plates a beaker containing the liquid. The suspension is by a long phosphor-bronze ribbon which also serves for charging the needle to the desired potential. The needle is damped by means of an attached vane, which dips into a beaker of oil. The deflections of the needle system are read by the standard method of mirror, lamp and scale.

In the actual instrument which was made and used, the plates A, B, C_1 and C_2, were each 2.5 cm square and the needle plates were 6.5 cm apart. The distance between the needle and fixed plate and also their relative positions can be varied. Other sizes can of course be used and a design is possible in which the pairs of plates are not the same in size on the two sides. Gold plates have been used for liquids which corrode other metals. For some dense liquids, the boyancy is compensated by small lead weights on the horizontal bar of the needle.

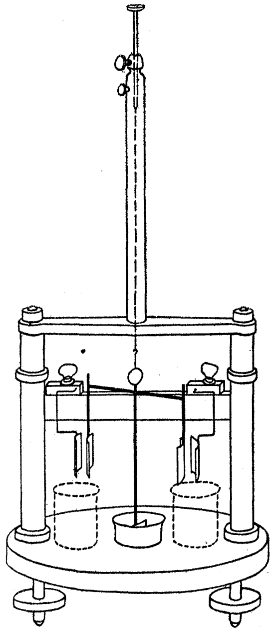

Fig. 1A

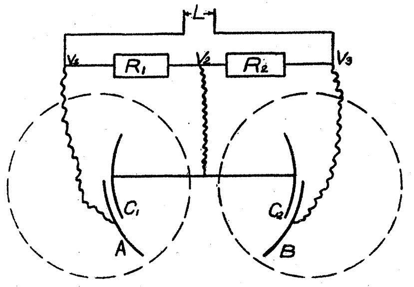

FIG. 1B

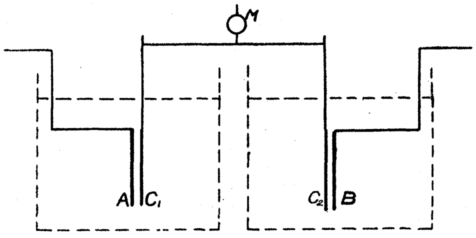

Fig. 1C

Fig. 1A. The electrometer. Fig. 1B. Electrical connections.
Fig. 1C. Section through the plates.

The electrical connections are shown in Fig. 1B. The plate A is brought to the potential V_1, the needle plates C_1 and C_2 to V_2, and the plate B to V_3, the potential V_1 being higher than V_2, and V_2 being higher than V_3. This is conveniently done by the usual potentiometer device of tapping off connections from a uniform wire which is stretched zig-zag on a board of convenient length. In many of our experiments, the potential difference $V_1 - V_3$ was 110 volts, and for conducting liquids this was alternating.

The plates are placed so that the charges on the pairs of plates tend to rotate the needle in opposite directions. Now for equal arm lengths the moments of force are respectively proportional to the squares of the difference of potential $(V_1 - V_2)^2$ and $(V_2 - V_3)^2$, and these in turn are proportional to R_1^2 and R_2^2, where R_1 and R_2 are the resistances of the two parts of the potentiometer wire. But the forces are also proportional to the dielectric constants K_1 and K_2 of the media between the pairs of plates A, C_1 and B, C_2. Hence for the null position of the needle, we have

$$\frac{K_1}{K_2} = C\frac{R_1^2}{R_2^2}.$$

To determine the calibration constant C, the resistances R_{10} and R_{20} for the zero balance when air is the medium between the plates on both sides are found; then if the resistances are R'_1 and R'_2 when the first pair of plates has the medium air and the second pair of plates has the given liquid X as the medium, assuming the dielectric constant of air to be unity, we get

$$C = (R_{20}/R_{10})^2 ; \qquad K_X = (R_2'/R_1')^2 \times (R_{10}/R_{20})^2 .$$

By immersing the first pair of plates in a medium Y, and the second pair of plates in a medium X, we can calculate the ratio K_X/K_Y of the dielectric constants of the two media from the ratios of the resistances in the calibrating and the comparison balances. This use of a chosen liquid instead of air for reference, has at times decided advantages. Thus in measurements with a substance such as water having a high dielectric constant, we can avoid a large and inconvenient ratio of R_2 and R_1 by using a reference substance with a fairly high dielectric constant, such as acetone or alcohol. The use of a liquid of high dielectric strength for reference instead of air also allows the convenient use of higher potential differences when the consequent increase of sensitivity is desired.

The above instrument is simple in construction, with few parts; its manipulation and adjustments are easily made, and the plates are readily accessible for cleaning, a very important feature in working with most liquids. As the plates on either side can be varied in position independently, the sensitivity and range are easily controlled. As the needle is brought back to zero each time, the actual readings used are readings of resistances which can be made with great accuracy. The immersion method has the advantage of allowing the use of alternating electromotive forces of a wide range of frequencies. For alternating currents the resistance readings must of course be corrected for reactance. The dielectric constants of semi-conducting liquids can also be satisfactorily measured by this method, particularly if leakage currents are measured and corrections are made for the potential differences caused by leakage.

The above method has been used for determining the dielectric constant of water. The water was doubly distilled in pyrex glass vessels, and the first third and the last third of the distillate were discarded, so that the water used was probably fairly pure. The value of the dielectric constant obtained for this water was 78.07 at 25°C for an alternating e.m.f. of 60 cycles, a value in satisfactory agreement with accepted values. Most of the work which we have been doing with this method has been on the dielectric constants of mixtures of liquids and of emulsions and is not yet ready for publication.

In developing the above method and instrument, the author acknowledges the great help received from Mr. F. E. Null, graduate scholar, who has carried out the experimental work.

LABORATORY OF PHYSICS,
UNIVERSITY OF ILLINOIS
June 20, 1924.