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V.H. Veley F.R.S.

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IV. *A Modified Form of Apparatus for the Determination of the Dielectric Constants of Non-Conducting Liquids.* By V. H. VELEY, F.R.S.*

WITHIN recent years the determination of the dielectric constants of liquids has attracted considerable attention, partly on account of the simplification of the methods, and partly with a view of ascertaining the validity of the Maxwell equation

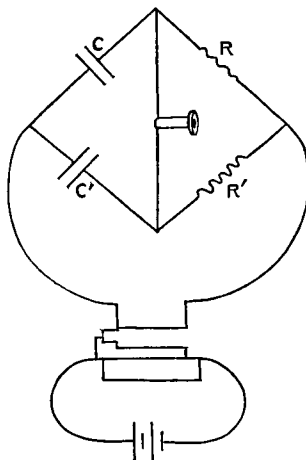
$$(\mu^2 - 1)M/(\mu^2 + 2)d = (K - 1)M/(K + 2)d, \quad . \quad . \quad (1)$$

or that of Clausius and Mosotti

$$K = 1 + 2d/1 - d. \quad . \quad . \quad . \quad . \quad . \quad (2)$$

As regards the latter point the determinations have led to no satisfactory conclusion; but as regards the former, the application of the bridge method, the substitution of the telephone for the galvanometer or electrometer, of liquid resistances (Nernst†) for many yards of wire (Paluz‡) or

Fig. 1.



high-resistance coils, have all served to simplify and render more accurate determinations based upon the conditions of balance according to the principle represented by the diagram (fig. 1).

* Communicated by the Author.

† *Zeits. f. phys. Chem.* xiv. p. 622 (1894).

‡ *Journ. de Phys.* [2] v. p. 270 (1885).

Herein, if C and C' are two condensers, R and R' two capacity free resistances, then a balance is attained when

$$R : R' = C' : C. \quad . \quad . \quad . \quad . \quad . \quad (3)$$

The general method of working has been to keep one resistance and one capacity constant, and to vary the other resistance concomitantly with the other capacity so as to restore the balance.

The method to be described differs only from the above in keeping both resistances constant, and varying one capacity concomitantly with the other, as also to measure the capacities in terms of a length according to the principle that *cæteris paribus* the capacity of a condenser varies inversely with the distance between the metallic plates, provided that such distance is small relatively to the area of the plates.

Before passing on to a description of the apparatus, it seems desirable to discuss the method worked out by Nernst (*cf. supra*) and certain of his pupils in Germany, and in this country by Sir James Dewar and Prof. Fleming*. The disadvantage of this method appears to consist in the fact that the dielectric constant is determined indirectly, since an air-condenser is not balanced simultaneously against a condenser containing the liquid under investigation; on the other hand, its advantages are (1) the substitution of a small induction-coil instead of a rapidly alternating commutator, and (2) the substitution of liquid resistances instead of bobbins.

As regards the latter improvement, I might mention that for some of my earlier experiments Herr Wolff of Berlin wound for me two 10,000 (international) ohm coils of manganin according to Chaperon's method; these coils were placed in the same box and provided with connecting screws so that either one coil could be placed in each of the two arms of the bridge, or both coils could be put into the same arm. But these coils were discarded as self-induction was not avoided, and consequently it was impossible to determine the point of minimum sound of the telephone owing to the consequent and irritating after-tone.

However, by using liquid resistances the above difficulty was overcome. My apparatus, as stated above, consisted of two condensers, two liquid resistances, telephone, and induction-coil with actuating battery; the only point of novelty consists of the first named, while of the remainder various forms were tried with a view of obtaining more satisfactory results.

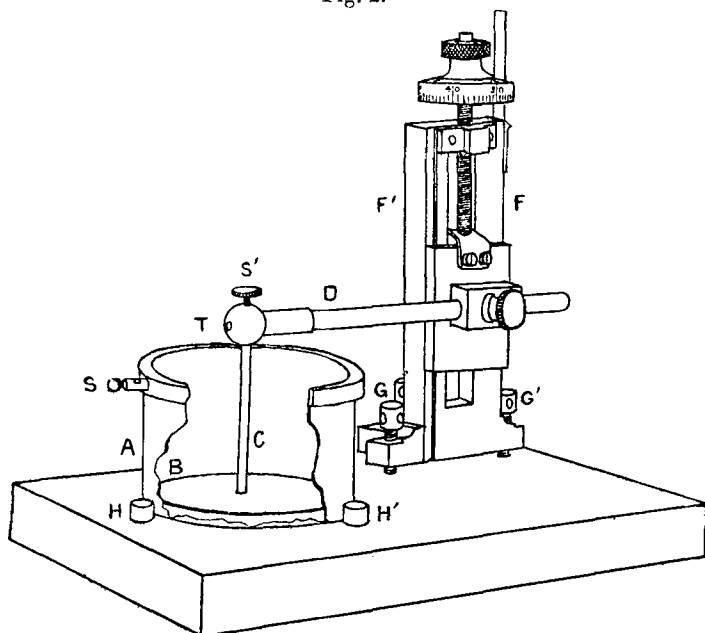
* Proc. Roy. Soc. lxii. p. 250 (1898).

Description of Condensers.

These were constructed for me by Mr. Pye of Cambridge, according to the specifications of the Rev. F. Jervis-Smith, F.R.S., who kindly assisted me in working out the principle of measuring capacities and hence dielectric constants in terms of lengths.

Each condenser consisted essentially of a gilt nickel dish 46 mms. deep (A in sketch) and 70 mms. internal diameter, provided with a binding-screw S; within each there was a moveable gilt disk B about 58 mms. diameter (actually 59·62 mms. for one, and 57·87 mms. for the other) and 5 mms. thick, provided with a vertical metal spindle 56 mms. long, C, at the end of which was a binding-screw S' and a metallic T-piece, in the hollow of the horizontal arm of which a glass

Fig. 2.



rod D was cemented in. This form of condenser is so far similar to that described by Cohn and Arons*, except that the position of the disk is variable, and the capacity of the condenser thereby alterable.

The following device was adopted for moving the disk vertically up and down, as also for ensuring that its lower surface remained strictly parallel with the upper surface of

* Wied. Ann. xxviii. p. 461 (1886).

the bottom of the dish. The above mentioned glass rod passed through a metal collar in which it could be rigidly fixed by a screw; the collar was connected with a sliding piece working upon two upright struts, F, F', one smooth and the other provided with V-groove; at the upper end of the sliding piece was fixed a micrometer-screw, the head of which, divided into 50, revolved once for each .5 millimetre on a vertical scale, so that .01 mm. could be read directly and less than half that amount by estimation; the vertical play of the screw amounted to 31 mms.

The glass rod could be fixed rigidly in any desired position by a clamping screw. The vertical struts were fixed upon a white marble slab by three levelling-screws (two G, G' shown) arranged in a triangle; at the other end of the slab was placed the gilt nickel dish kept in position by three ebonite knobs (two H, H' shown) let into the slab.

The corrections for the zero point and the graduation errors of the vertical scale were determined by taking away the dish, placing the apparatus in a horizontal position, and measuring the displacement of the edge of the rim of the disk by a Hilger travelling microscope. A table of corrections for each condenser was drawn out once for all.

One of these condensers was throughout kept as an air-condenser, while the other was used to contain the liquid dielectric; during working, each condenser was closed with an ebonite plate cut into half and with a small semicircular piece cut out of each half for the spindle to pass through; these plates served to exclude dust.

The two dishes were regarded as the outer, and the two disks with their spindles as the inner plates of a pair of diagrammatic condensers.

The major portion of the capacity* of such a condenser (or leyden) is made up of three terms: (a) that due to the area of the lower surface of the disk and the corresponding area of the dish, (b) that due to the area of rim of the disk and likewise, (c) that due to the area of spindle and likewise. Of these, (a) varies with the distance and nature of dielectric, (b) is constant according to the method of working adopted, (c) varies according to the length of spindle immersed within the dish. In actual working, the alteration of capacity due to (c) varied about 1 per cent. on an average; as the maximum

* The total capacity of such a condenser is a very complex matter, and could only be solved by the method of conjugate functions as discussed by Clerk Maxwell, 'Electricity and Magnetism,' Articles 195 *et seq.*, and J. J. Thomson, 'Recent Researches in Electricity and Magnetism,' pp. 208-250 (Clarendon Press, 1893).

variations in readings amounted to 1 per cent., the correction to be applied would be of the second order.

Liquid Resistances.

In earlier experiments these consisted of electrolytic cells of the H-bottle shape (Kohlrausch type) filled with redistilled water; the electrodes were platinized in the usual way. One cell was put into each of the two arms of the bridge, the two cells being immersed side by side in a beaker of cold water to eliminate effects of temperature. The resistance introduced into each arm was approximately 9000 ohms, which was found sufficient for air or liquids of low dielectric constant. In later experiments, liquid resistance-tubes of the Nernst type were used, filled with Manganini's (manniteboracic acid) solution; these were found to be more suitable for liquids of relatively higher dielectric constant.

Inductoria.

Two forms of inductorium were used, namely, that of Ostwald-Luther and the wire form (Saiten-unterbrecher). My experience was to the effect that the latter gave the sharper note, and consequently a more distinct minimum in the telephone, but was more liable to break down in the course of work, but this might be due to some slight mechanical defect in the particular instrument.

My observations were in complete accordance with those of Nernst*, that a more decided minimum is produced in the telephone when the inductorium gives a buzzing, rather than a humming or singing sound. The inductoria were actuated by a small chromic-acid battery or accumulator.

Telephone.

The form of telephone used was that of Mix and Genest (resistance about 130 ohms) with an insulating handle; it was found preferable to hang up the telephone on a glass rod; when the wire inductorium was used, the note of the telephone, except at or about the minimum point, could be heard some feet away, so that the initial adjustments of the micrometer-screws could be made with comfort and convenience. The whole apparatus (namely, liquid resistances, condensers, connecting wires) was disposed symmetrically as far as possible, and each of the two former pairs was placed together.

* Nernst (*loc. cit. supra*) writes: "Ich habe oft beobachtet dass das Minimum leidet, wenn die Saite summt oder singt, anstatt rasselt; ich vermag dies nicht sicher zu erklären."

Method of Working.

Firstly, an observation was made with both condensers with air as dielectric, the disk of one (on the right hand, called R) being clamped in a fixed position, and the distance of the disk of the other (on the left hand, called L) from the upper surface of the dish being varied by the micrometer-screw, until the minimum sound in the telephone was attained.

Secondly, the liquid to be experimented with was then introduced into the R condenser by means of a pipette (the dish being slightly tilted to avoid the inclusion of air-bubbles) to the point at which the surface of liquid was level with the bottom of the rim of the disk, when the dish was replaced in a vertical position. Superfluous liquid accidentally introduced was removed by the pipette or blotting-paper. The distance of the disk from the dish in the L condenser was varied by the micrometer-screw until the minimum sound was again attained. The ratio of the distance of the disk in the second observation to that in the first is the ratio of the dielectric constant of the liquid to that of air (=1). Hence, therefore, as explained above, the dielectric constants can be determined in terms of a length, measured by one micrometer-screw.

Two sets of observations of the first operation are quoted to show the degree of accuracy:—

First Set.

L (Air) condenser.	R (Air) condenser fixed at
Scale Readings.	7.615 mm. on scale.
8.650	
8.645	
8.645	
8.710	
8.681	

The mean value of the readings of the L condenser is $8.666 \pm .0086$.

Second Set.

L (Air) condenser.	R (Air) condenser fixed at
Scale Readings.	12.595 mms.
14.05	
14.12	
14.13	
14.11	
14.12	
14.15	
14.12	
Mean 14.12	

It will be seen from the above that the results are approximately within an error of 1 per cent.

The dielectric constants of certain organic liquids were determined to test the accuracy of the method.

Benzene.

The sample (thiophene free) was purchased of Kahlbaum, and subsequently purified by freezing and distilling over sodium; the following results were obtained:—

Temperature 17°.	
L (Air).	R (Air) condenser fixed at
7·680 mms.	7·615 mms.
L (readings).	Benzene introduced.
3·3	
3·4	
3·4	
3·42	
3·4	
Mean	3·384

$$\text{Dielectric constant } K = \frac{7\cdot68}{3\cdot384} = 2\cdot27.$$

Nernst* gives 2·258 for carefully dried benzene, Thwing† 2·310 as a mean of nine observers; the value given above is approximately the mean of these two values.

Another set of observations, probably less accurate, was made in the reverse manner, namely, by varying the benzene condenser and keeping the air-condenser constant; the mean value of nine concordant observations gave $K = 2\cdot267$, which differs from the above approximately in the ratio 1/600.

Carbon Tetrachloride.

Purchased of Kahlbaum, purified by fractional distillation, the portion coming over between 76°·59 and 76°·99 being collected. Mean boiling-point 76°·79 at Bar. 750·4 (corr.). Density $4/4 = 1\cdot62611$ (corr. to vacuum). Thorpe‡ gives the values for B.P. = 76°·76 at 755·4, and D. $0/4 = 1\cdot63195$. Young§ for B.P. = 76°·75 at 750·1. These several values are concordant.

* *Loc. cit. supra*, p. 658.

† *Zeits. f. physikal. Chem.* xiv. p. 300 (1894).

‡ *Phil. Trans.* 1894 (A), p. 494, and *Journ. Chem. Soc.* 1880, Trans. p. 59.

§ *Journ. Chem. Soc.* 1891, Trans. p. 912.

The following values for K were obtained in three sets of observations (temp. = $12^{\circ}5$) :—

Set (1) of 5 observations	Mean = 2.071
Set (2) of 4 " 	" = 2.027
Set (3) of 5 " 	" = 2.049
<hr/>	
Total Mean = 2.049	
<hr/>	

Drude* gives the value $K = 2.18$ at 17° ; Turner†, $K = 2.20$ at 14° ; but neither of these observers purified their samples or give physical data as criteria of purity.

Ethylene Chloride.

Purchased of Kahlbaum, portion on distillation at boiling-point $83^{\circ}71 \pm .15$ at Bar. 757.1 (corr.) collected; D. $4/4 = 1.27536$ (corr.).

Thorpe‡ gives the values B.P. = $83^{\circ}5$ at Bar. 753.9 and D. $4/4 = 1.27432$ (corr.) One set of five observations gave the value of $K = 11.29$ at 17° .

Turner† gives $K = 10.98$, but no details of purification or physical data.

Monochlorobenzene.

Purchased of Kahlbaum, portion on distillation at boiling-point $131^{\circ}55 \pm .2$ at Bar. 736.97 collected; D. $4/4 = 1.12355$.

Ramsay and Young§ give the value B.P. = 132° at Bar. 758.8, Young || D. $0/0 = 1.12786$.

One set of seven observations gave the value of $K = 10.95$ at $10^{\circ}8$; a previous observation for this substance does not appear to have been recorded.

The necessity for purifying halogen organic compounds before determining their dielectric constants appears to have been overlooked; most of such compounds decompose slowly, though slightly, in the presence of sunlight with liberation of traces of the halogen acid, which would impart a conductivity to the liquid, and thereby render useless determinations of the dielectric constant, except possibly by the method of Nernst. Thus, to select an example, the constant for chloroform has been determined by three observers, none of whom

* *Zeits. f. physikal. Chem.* xxiii. p. 309 (1897).

† *Ibid.* xxxv. p. 428 (1900).

‡ *Journ. Chem. Soc.* 1880, Trans. p. 182.

§ *Ibid.* 1885, Trans. p. 654.

|| *Ibid.* 1880, Trans. p. 488.

purified the sample used, and one definitely states that he used a "commercial preparation"; this would, without doubt, contain both moisture and hydrochloric acid, namely, a concentrated solution of the latter, the amount of which would increase with time and other conditions.

Personally I experienced such difficulty in purifying a sample of ethylene dibromide (though of correct melting- and boiling-point) so as to be fit for a determination of the dielectric constant, that the attempt was for a time abandoned. Turner* gives a value 4.865 for this substance, but makes no allusion to such difficulty.

It is hoped to proceed with further determinations with this form of apparatus and method of working; meanwhile it is thought that they possess sufficient novelty and give sufficiently accurate results to merit description.

V. The Theory of Phasemeters.

By W. E. SUMPNER, D.Sc.†

PHASEMETERS are instruments of the dynamometer type for indicating the phase relations of the currents and potentials in alternating-current circuits. With few exceptions they are made for use on multiphase circuits. Single phase instruments have been constructed, but they are not very satisfactory, as their calibration alters with both frequency and wave-form.

Such instruments consist essentially of two sets of coils, of which one set is fixed and the other forms a single moving system which is not provided with any form of control. The currents in one set of coils are determined by the voltages of the main circuits; while those in the other set are produced by the circuit currents. The total number of coils used in the two systems must be at least three, and as a rule actual instruments only contain this minimum number of coils: the fixed system usually consists of a single coil conveying one of the line currents, while the moving system consists of two independent but relatively fixed coils, traversed by currents produced, through suitable non-inductive resistances, by two of the voltages of the multiphase circuit. There is one instrument made commercially for three-phase circuits which is of a more elaborate construction, and contains three fixed coils for the currents, and a moving system—also of three coils—for the voltages. Such an

* *Loc. cit. supra.*

† Communicated by the Physical Society: read October 27, 1905.