Physics. — *On the change of the dielectric constant of liquid helium with the temperature. Provisional measurements.* By M. WOLFKE and W. H. KEESOM. (Comm. N⁰. 190*a* from the Physical Laboratory at Leiden.)

(Communicated at the meeting of December 17, 1927).

§ 1. *Introduction.* The dielectric constant of liquid helium has been measured at the temperature of the boiling-point under normal pressure by M. WOLFKE and H. KAMERLINGH ONNES [1]). Now it was of the greatest importance to get to know the course of the dielectric constant of liquid helium with the temperature, particularly in connection with the peculiar density-maximum, found by KAMERLINGH ONNES [2]) and more closely studied by KAMERLINGH ONNES and BOKS [3]) and which until now has not yet found an explanation.

For these measurements by which very small differences in the dielectric constant had to be accurately determined, the method, applied to former ones, was no more sufficient. For that reason a new method for measuring was developed for this purpose by one of us at the Physical Laboratory of the Technical Institute at Warsaw. This method and the corresponding arrangement are described in the following report.

§ 2. *Measuring-method. Apparatus.* The measuring-method is literally a compensation-method by which the changes of the dielectric constant in the measuring-condenser are compensated by measurable changes of the capacity of a cylinder-condenser which can be very accurately adjusted by a micrometer-screw. This cylinder-condenser we shall call in future „micro-condenser". This microcondenser is connected parallel to the measuring-condenser which contains liquid helium. The capacity of both these condensers together has been compared with a constant capacity by means of a method depending on the beats of two high-frequent electromagnetic oscillation circuits.

The diagram of connections is represented in Fig. 1. It consists of two mutually independent oscillation circuits according to MEISSNER : 1 and 2. The oscillation circuits are fed by a joint anode-battery of 160 V in the constant-current connection [4]). In order to avoid a mutual influence of

1) These Proc., **27**, 621, 1924. Comm. Leiden, N⁰. 171*b*.

2) These Proc., March 1911, p. 1093. Comm. Leiden N⁰. 119.

3) Reports and Communications presented by H. KAMERLINGH ONNES to the 4th International Congress of Refrigeration, London 1924. Comm. Leiden N⁰. 170*a*.

4) Comp. J. ZENNECK und H. RUKOP, Lehrbuch der drahtlosen Telegraphie, 1925, p. 607, fig. 547.

both the circuits, the high-frequency currents are arrested by both the choking-coils D_1 and D_2.

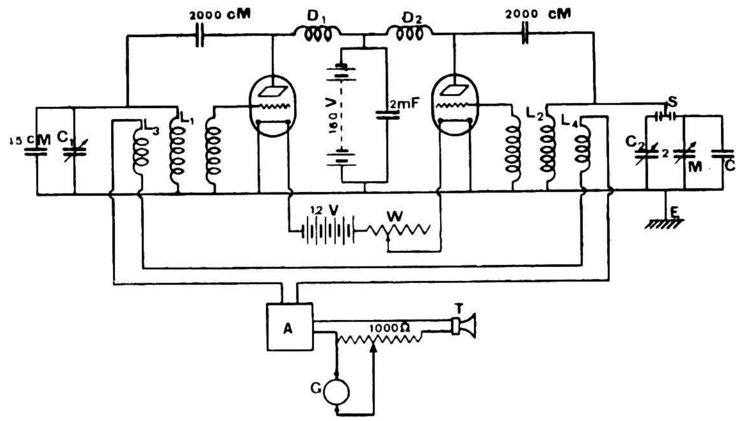

Fig. 1.

The oscillation circuit 1 consists of the self-inductions L_1 and the variable precision-condenser C_1 with a capacity of about 250 cm. Parallel to this a constant capacity of 45 cm has still been connected. In the oscillation circuit 2 is found, beside the self-induction L_2 identical to L_1, a system of condensers : the measuring condenser C which is found in the cryostat (see further), the microcondenser M connected parallel to it (fig. 2) and the normal variable condenser C_2. By changing the plugs in S either both the condensers C and M or the variable condenser C_2 can be switched in the oscillation circuit 2. Both the oscillation circuits have a joint earth-point E. For generating the oscillations the Philips-lamps type E proved to be the most suitable. The heating-current was produced by the same battery of accumulators of 12 V with in series the resistance W.

The oscillations of both the circuits 1 and 2 are superposed by means of the self-inductions L_3 and L_4. The beats caused in this way are amplified by the amplificator A. The latter consists of a detector-lamp, two low-frequency amplificator-lamps in the usual transformator-circuit and of an output-transformator. The thus amplified beats can be observed either in the radio-telephone T or in the string-galvanometer G. The string-galvanometer G has been joined to the telephone circuit in potentiometer connection. With some practice the beats can be made so slow that the swinging to and fro of the wire in the string-galvanometer can be followed.

The place of the observer is at about 4 m from the apparatus. The two variable condensers C_1 and C_2 are adjusted by the observer by means of thin cords and pulleys, the microcondenser by means of a 4 m long stick of bamboo. In this way the oscillation state during measuring is not disturbed by the movements of the observer. Further all precautions have been taken, as the earthing of the metal covers of the condensers etc. In order to avoid over-oscillations the self-inductions L_1 and L_3 on the one side and L_2 and L_4 on the other side have been coupled very loosely to the concerning regenerative-coils.

The normal variable condenser C_2, capacity about 300 cm, from the firm SPINDLER and HOYER at Göttingen has been calibrated by the P.T.R. in Berlin. This condenser has a scale divided in degrees, with nonius; the change of capacity is 1.35 cm for each degree. In order to improve the exactness of reading, a dish of 14 cm diameter with a division in degrees and nonius, was attached to the fine-regulating axis; the turning of this dish over 1 degree answers to a change of capacity to the amount of 0.17 cm.

The *microcondenser* M was made in the workshop of the Physical Laboratory I of the Technical Institute in Warsaw. Figure 2 shows this condenser in section. Within an iron cylinder A is a brass cylinder B which is isolated by an amber stop C and a fitting of ebonite C'. Exactly in the axis of this brass cylinder B is an iron cylinder D which can be exactly adjusted by means of the micrometer-screw E.

The micrometer-screw has been made very accurately and has a pitch of 0.5 mm; it possesses a head G of which the circumference is divided in 100 parts. A scale F put at one side serves for the reading of the number of complete rotations. The entire change of capacity of the micro-condenser by screwing in the cylinder D was accurately measured in the arrangement itself by means of the normal variable condenser described above; the mean of 10 different measurings was 5.2 cm. This agrees up to 1 % with the value which was calculated from the measurements of the condenser. At the zero-point in the beginning the movable cylinder D is already 10 mm in the isolated cylinder B, so that the boundary disturbances of the electric field do not come into account. In the final state the cylinder D is only 40 mm in the cylinder B, so that it is still 20 mm removed from the bottom. Through this the proportionality between the change of capacity and the number of rotations of the micrometer-screw E is amply secured. To the change of capacity of 5.2 cm correspond 60 rotations of the micrometer-screw each of 100 divisions at a rotation, so 6000 divisions in all, hence to each division of the head G of the micrometer-screw a change of capacity corresponds of $8.7 \cdot 10^{-4}$.

The cryostat with the measuring-condenser agrees substantially with that one, which has been used with the first measurings of the dielectric constant of liquid helium [1]), and has been represented in Fig. 3. The condenser now consists of 6 concentric brass cylinders with a capacity of about 175 cm. The movable contact, which was formerly found at K, has been replaced by a junction directly soldered on.

Further above the glass vessel g, silvered over inside, in which is the

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[1]) These Proc. **27**, p. 622; Comm. Leiden N⁰. 171*b*. p. 11, fig. 3.

measuring condenser C, a reservoir A was placed which was also filled with helium in order to keep the surface of helium, notwithstanding the volume-contraction at the cooling, continually above the upper part of the condenser-vessel g. The condenser C itself hangs by the leads.

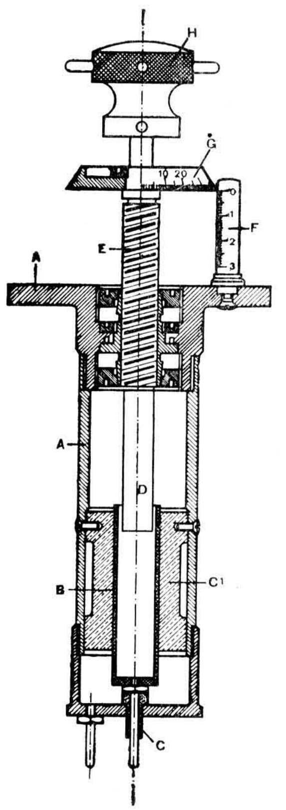

Fig. 2.

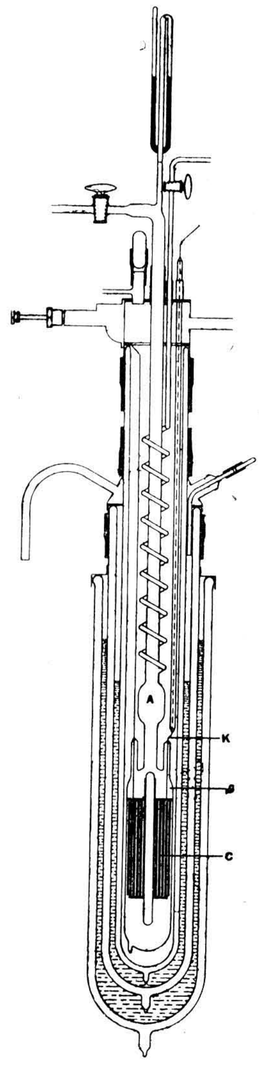

Fig. 3.

The *measurements* were made in the following way. As has already been said, they depend on the comparison of the unknown capacity with that of a normal-condenser, the small changes of the unknown capacity being compensated by means of the micro-condenser. The course of a measuring is as follows : In the oscillation circuit 2 (Fig. 1) the measuring-condensor C with the microcondensor M is switched in ; then by turning the condensor C_1 in the oscillation circuit 1 the beats are made slower till the wire in the string-galvanometer G remains quiet ; this point is accurately adjusted. Then without changing the condenser C_1 in the oscillation circuit 1 the normal-condenser C_2 is connected with the oscillation circuit 2 by means of the plug S and regulated so long until the wire of the string-galvanometer remains quiet again. With this, attention should be paid that the adjusting is always brought about through a last turning in the same direction as well by the condenser C_1 as also by C_2. The capacity of the two condensers C and M is then equal to that of the normal-condenser C_2. However with this the capacities of the leads have not been reckoned with, so that this method only allows to measure capacity-differences, not the absolute values of the capacities. Small changes of the capacity of the measuring-condenser C are measured by compensating with constant adjusting of the normal-condenser C_2 at a definite initial-capacity of the measuring-condenser, each capacity-change of the latter by means of the microcondenser M and then to read scale and head from this.

The *accuracy of adjusting the normal-condenser* was determined in this way that at a constant capacity of the measuring-condenser and a constant position of the microcondenser the normal-condenser was adjusted several times and the position of the dish was read. From that followed as mean error of adjusting of the normal-condenser a value which corresponds to a capacity of $\pm$ 0.03 cm.

In suchlike way the *adjusting accuracy of the microcondenser M* was also determined. The mean deviation was $\pm$ 6 divisions of the head which corresponds to a capacity of about $\pm 5.10^{-3}$ cm. With a capacity of about 175 cm of the measuring condenser this adjusting-accuracy allows a capacity-change of about 3.10^{-3} % still to be measured, so that the accuracy of the fourth decimal in the relative value of the dielectric constant is completely secured.

At all measurements the wave-length was 600 m. Before the beginning of a measurement some time was waited after the putting into work of the apparatus, until the oscillation circuits were stable. This was the case after about an hour.

§ 3. *Capacity of the measuring-condenser.* As has already been said the here described measuring-method was worked out specially for the accurate measurement of very small capacity-changes and it is not well fit for the accurate determining of the absolute values of capacities. For that reason an indirect method was applied for measuring the absolute value of the capacity of the measuring-condenser. With this method the capacity was determined from the difference of the capacities in the vacuum and in liquid helium boiling under atmospheric pressure and from the formerly (Comm. Leiden N⁰. 171*b*) measured value of the dielectric constant of liquid helium at the boiling-point.

If we call C_0 the capacity of the measuring-condenser in a vacuum at the normal boiling-point of helium, 4.21° K., C the capacity in liquid helium at the same temperature, K_0 the dielectric constant of liquid helium at that temperature, $\triangle C$ the difference of the two capacities, measured and read on the normal condenser, then we see that :

$$\triangle C = C - C_0, \text{ and } C = KC_0, \text{ with } K_0 = 1.048,$$

from which follows :

$$C_0 = \frac{\triangle C}{K_0 - 1} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

First the measurement was made in a vacuum. The glass vessel g in the cryostat (Fig. 3) which contains the measuring-condenser, was evacuated and filled with helium-gas under a pressure of some mm of mercury. The cryostat was filled with liquid helium, so that the vessel g was quite immersed. The gasfilling in g has no measurable influence on the value of the capacity ; its purpose was to secure the exchange of temperature between the liquid helium in the cryostat and the measuring-condenser. The temperature in the cryostat was deduced from the vapour-pressure of the helium by means of the formula given by KAMERLINGH ONNES and WEBER [1]).

We found $\triangle C = 8.36$ cm from which by means of (1) follows for the capacity of the measuring-condenser empty at the boiling-point of helium :

$$C_0 = 174 \text{ cm.}$$

The formerly measured value of the dielectric constant of liquid helium at the boiling-point (see Comm. Leiden N⁰. 171*b*) is exact up to 0.1 %. Accordingly K_0—1 is exact up to about 2 %. Since the readings on the normal-condenser are much more exact we can consider the value of C_0 exact as up to 2 %. The accuracy of this measurement is of secondary importance to the proper purpose of the research, treated in this Communication, since the relative values are only required in investigating the variation of the dielectric constant of the liquid helium with the temperature.

§ 4. *Change of the dielectric constant of liquid helium with the temperature.* For these measurements the glassvessel with the measuring-condenser in the cryostat was filled with liquid helium, while it was immersed itself in liquid helium.

The *temperature* in the cryostat was adjusted in the usual way by reducing the vapour-pressure of the helium in the cryostat till the point desired was reached; its value was deduced from the vapour-pressure (see § 3). As initial temperature served the normal boiling-point of helium.

The changes of the dielectric constant at different temperatures were measured as follows. The normal-condenser was accurately adjusted at the initial-temperature of the liquid helium and then changed no more during the entire measurement. At each further temperature the adjusting was only

[1]) These Proc., Sept. 1915, p. 493. Comm. Leiden N⁰. 147*b*.

performed with the aid of the microcondenser. The changes of capacity were then read on the latter.

From the position of the microcondenser the value of the dielectric constant at a definite temperature can be calculated in the following way: If we call C the capacity of the measuring-condenser filled with liquid helium at the initial temperature and if $\triangle C$ be the increase of this capacity by the passing on to the new temperature, then the dielectric constant K at this new temperature follows from :

$$K=\frac{C+\Delta C}{C_0}=K_0\left(1+\frac{\Delta C}{C}\right), \quad \ldots \ldots \quad (2)$$

where $C = K_0 C_0 = 182.4$.

With that the capacity C_0 of the empty condenser has been accepted as constant for all temperatures in liquid helium. This may be done without objection as the relative capacity-changes in consequence of the thermal expansion in this temperature-region should make themselves perceivable only in the 6^{th} decimal of the dielectric constant.

The first measurements were made on the 11^{th} of June 1927. The results obtained are given in table I. The 4^{th} column contains the change in the position of the microcondenser counted from that one at the initial temperature, the 5^{th} the relative value of the dielectric constant calculated according to (2), the 6^{th} that one of the dielectric constant itself, calculated from the value formerly measured at the normal boiling-point of helium.

TABLE I.

N⁰.	p mm Hg	T °K.	Micro-condenser.	$\frac{K}{K_0}$.	K
1	766.5	4.21	0	1	1.0480
2	82.9	2.64	1735	1.00824	1.0566
3	69.6	2.55	1920	1.00912	1.0576
4	60.1	2.48	1988	1.00944	1.0579
5	49.8	2.39	2054	1.00976	1.0582
6	38.1	2.28	2211	1.01050	1.0590
7	25.8	2.12	1948	1.00925	1.0577
8	13.8	1.90	2013	1.00956	1.0580

With the values of K from table I and the densities of the liquid helium according to KAMERLINGH ONNES and BOKS [1]) the molecular electric

[1]) H. KAMERLINGH ONNES and J. D. A. BOKS, l. c., p. 1 note 3.

polarization can be calculated by means of the formula of CLAUSIUS—MOSOTTI. These values are united in table II.

After attempts of a repetition of this measurements had failed on the 17th of June and on the 12th of July, both times through the breaking of the helium-glass in the cryostat, a second series of measurements was made on the 19th of July. The obtained results are given in table III.

TABLE II.

T °K.	ρ	$\frac{K-1}{K+2} \cdot \frac{1}{\rho}$
4.21	0.1251	0.1259
2.64	0.1443	0.1283
2.55	0.1451	0.1299
2.48	0.1454	0.1304
2.39	0.1459	0.1305
2.28	0.1462	0.1320
2.12	0.1458	0.1295
1.90	0.1455	0.1305

TABLE III.

N°.	Time		p mm Hg	T °K.	Micro-condenser.	$\frac{K}{K_0}$	K
1	14 u	26 m	753.0	4.19	0	1.00000	1.0480
2	15	25	48.8	2.39	1933	1.00922	1.0577
3		39	40.1	2.30	2024	1.00966	1.0581
4		59	34.1	2.24	2014	1.00961	1.0581
5	16	09	30.2	2.19	1975	1.00942	1.0579
6		22	24.9	2.11	1937	1.00924	1.0577
7		34	19.9	2.03	1974	1.00942	1.0579
8		46	10.1	1.80	1921	1.00917	1.0576
9		58	8.8	1.75	1898	1.00906	1.0575
10	17	11	31.1	2.20	2027	1.00967	1.0581
11		19	36.2	2.26	2041	1.00974	1.0582 [1]

[1]) During this measurement the helium in the cryostat had sunk so low, that the temperature of the condenser began to become uncertain.

During these measurements the circumstances were less favourable than with the preceeding series. Besides that we apparently did not wait long enough until the temperature should have completely regulated itself, a possible source of errors had also arisen because the leads outside the cryostat were possibly in connection with the earth through a precipitated moisture, through which an undefined most probably also variable resistance was switched parallel to the measuring-condenser.

As it appears from the graph (Fig. 4) the two measuring-series point to a discontinuity, a jump, in the course of the dielectric constant with the temperature.

Since this result however principally depends only on one series of

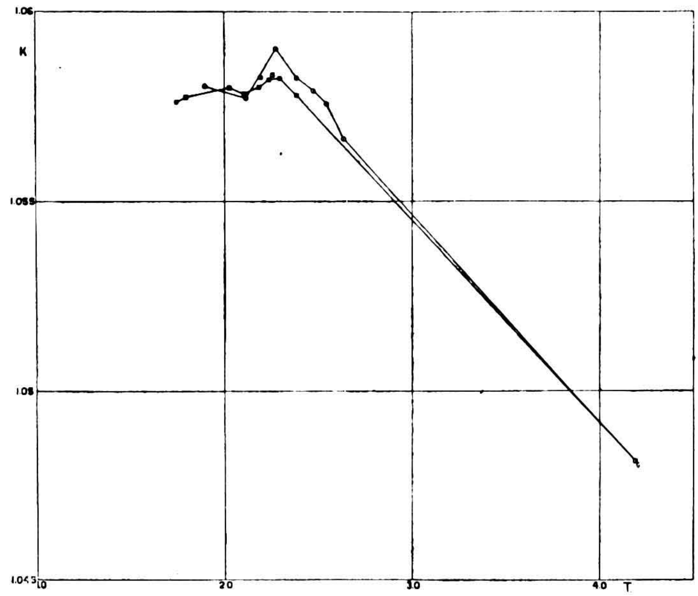

Fig. 4.

⊙ Measurements of June 11, 1927.

⊡ Measurements of July 19, 1927.

measurements (the first) we decided to wait for a new series of measurements under improved circumstances before passing on to publication. However, now that in the mean time in different ways (compare the following communication) the appearance of an abrupt change in the liquid helium has been asserted we were of opinion not to put off the publication any longer. Meanwhile we consider the results given here as being only provisional, also because there is some possible doubt about the accurate equalness of temperature of the helium in the condenser with that of the helium in the cryostat.