

Physics. — *New measurements about the way in which the dielectric constant of liquid helium depends on the temperature.* By M. WOLFKE and W. H. KEESOM. (Communication N^o. 192a from the Physical Laboratory at Leiden).

(Communicated at the meeting of June 30, 1928)

§ 1. *Introduction.* The first measurements about the way, in which the dielectric constant of liquid helium depends on the temperature, were made by us in the preceding year ¹⁾. These measurements were, it is true, only preliminary, but yet sufficient in order to fix the general course of that quantity. We thereby found, that the dielectric constant of liquid helium shows a jump at about 2.3° K. This observation became for us the starting-point for a further research into other properties of the liquid helium, especially at the temperature mentioned and led us to the discovery of the existence of two different modifications of the liquid helium ²⁾.

In the course of this year we undertook further measurements in this direction, in order to fix with greater exactness the values of the dielectric constant of the liquid helium at different temperatures.

§ 2. *The apparatus.* This one was nearly the same, as at the former measurements ³⁾.

The first series of measurements took place on March 15th last. In order to be more sure of the temperature of the liquid in the measuring-condenser, the glassvessel *g* (see Fig. 3 Comm. N^o. 190a) had therefore been taken away, so that the condenser *C* was at once in the cryostat-bath.

Meanwhile during these measurements it was stated, that the temperature of the liquid helium in the cryostat was not sufficiently constant, so that consequently the regularity of the results was disturbed. While in general at exact measurements the helium in the cryostat is being continually stirred by means of special automatic stirrers, we had not put in a stirrer at this first series of measurements because of the difficulties attending the construction of it: in the first place room was wanted in the Dewarvessel, in which the measuring-condenser is placed and further we feared an influence of the moving parts of the stirrer on the capacity of the measuring-condenser. However, these difficulties have been solved by a construction of the stirrer, which has been worked out by Mr. G. J. FLIM. The principal

¹⁾ These Proc. 31, 81, 1928. Comm. Leiden N^o. 190a.

²⁾ These Proc. 31, 90, 1928. Comm. Leiden N^o. 190b.

³⁾ Compare Comm. Leiden N^o. 190a, Fig. 1.

thing of this construction is, that the moving part of the stirrer R (Fig. 1) is enclosed sideways in a metal cover, which is joined to the earthed part of the measuring-condenser C . A careful examination of this apparatus showed, that a difference in the place of the movable part has no influence on the capacity.

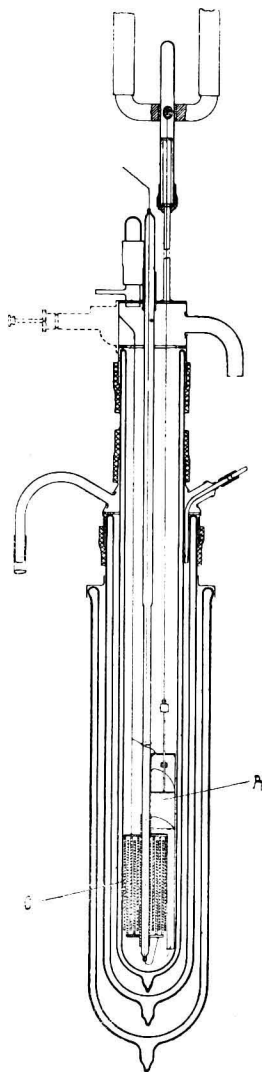


Fig. 1.

A new series of measurements was then made on March 23rd. From these it appeared however, that the results were not yet sufficiently exact; moreover, the readings from the micro-condenser showed a distinct course. On closer research it appeared, that the cause of this inexactitude had to be found in disturbances of the oscillation-condition of the oscillation-circuit 2¹⁾, which were caused by the continual changing over of the two condensers C and C_2 . In order to eliminate this source of errors, we then have connected the measuring-condenser C permanently to the oscillation-circuit. At the same time we have replaced the variable condenser C_1 in the oscillation-circuit 1 by the more accurate normal-condenser C_2 , which got off now. After these improvements it appeared, that the sensibility had remained the same, but that the stability of the oscillations had greatly improved, so that during several hours the readings from the micro-condenser belonging to a same measuring-capacity, did not show any important irregularities, nor a distinct course.

The capacity of the measuring-condenser, filled with liquid helium under normal pressure, in the cryostat, was determined in the following way: Instead of the measuring-condenser, a normal-condenser of a definite capacity was put on. After that the capacity of this normal-condenser together with the leads and the micro-condenser was accurately measured. After subtracting the known capacity of the normal-condensor, we obtained the capacity of the leads and the micro-condenser. Then the measuring-condenser filled with helium was put on and the capacity of the latter together with the same leads and the micro-condenser were again accurately measured. From that we then got the capacity of the measuring-condenser filled with helium. It appeared from this that, by putting in the stirrer, the capacity of the measuring-condenser had somewhat increased. For the capacity of the measuring-condenser in liquid

¹⁾ Compare Comm. Leiden N^o. 190a, Fig. 1.

helium at the temperature of the normal boiling-point, we found the value : 186.8 cm.

§ 3. *The measurements.* The final measurements took place on March 29th last. They lasted about 5 hours ; during this time the apparatus remained sufficiently constant, so that the readings on the micro-condenser, which took place at the same temperature, but at different times, didn't show any real differences. In order to eliminate a possible course in the readings, which would be the consequence of a systematic change in the oscillation-condition of the apparatus, the succession of the temperatures, at which we measured the dielectric constant, was chosen in such a way, that always every new point came between two measurements at similar temperature (see table I). The temperature of the helium was deduced in the usual way from the pressure of the helium-bath in virtue of the formula given by KAMERLINGH ONNES and WEBER¹⁾. These temperatures will possibly suffer a small change, when the results will be fixed of the new measurements²⁾ already announced, concerning the saturated vapour-pressure of helium. The adjustments and readings of the micro-condenser took place for each temperature in two series of three times in each case. During the adjustment at the temperature desired and also between both series of three readings, we stirred.

§ 4. *The results.* These are summarized in Table I.

The first column gives the numbers of the points in the order in which they have been measured. In departure from the remaining points (see § 3) for the numbers 10a and b and 14a and b the averages of a series of three readings at every time, are given. The meaning of the following columns appears from the readings.

During the evaporation of the helium in the cryostat, the surface of the liquid helium gradually lowered ; at the two last measurements it was already so low, that no sufficient stirring took place any more. Consequently we see, that these last readings on the micro-condenser strongly deviate from those, which were done before, compare for instance N^o. 18. We therefore shall leave out the last measurements N^{os} 20 and 21. In connection with this, we already consider N^o. 19 as doubtful.

From the readings on the micro-condenser, the values of the dielectric constant of the liquid helium can be calculated in the way as given in our former communication³⁾, observing the new value of C, being the capacity of the measuring-condenser in the liquid helium at the temperature of its normal boiling-point (§ 2).

1) These Proc. 18, 493. Comm.Leiden N^o. 147b. The readings of the pressure and the calculation of the temperatures have been made by Mr. H. VAN DIJK, phil. cand., whom we heartily thank for this.

2) Compare Comm. N^o. 190b, § 3.

3) Compare Comm. N^o. 190a, formula (2).

The course of the dielectric constant of the liquid helium with the temperature has been represented in Fig. 2 in virtue of these values.

We see, that the jump in the dielectric constant stated by us in the former measurements, is also seen here. The amount of the jump is, however, considerably smaller than was expected at the first series of measurements

TABLE I.					
Nº.	Time	Pressure mm. Hg.	Temp. °K.	Micro- condensator	Dielectric constant
1	13 ^h 54 ^m	751.1	4.19	0	1.048 ¹⁾
2	14 ^h 15 ^m	377.2	3.57	777	1.05179
3	50	387.2	3.59	808	194
4	15 ^h 3 ^m	189.6	3.09	1183	377
5	28	385.8	3.58	747	165
6	41	83.6	2.64	1506	535
7	58	188.9	3.09	1218	394
8	16 ^h 26 ^m	40.1	2.311	1596	579
9	41	82.3	2.630	1485	525
10a	55	38.8	2.296	1628	594
b	58	38.0	2.288	1604	583
11	17 ^h 4 ^m	40.4	2.311	1611	586
12	13	42.5	2.335	1584	573
13	25	37.5	2.282	1599	580
14a	33	38.65	2.295	1626	593
b	36	38.66	2.295	1611	586
15	43	37.2	2.279	1608	585
16	52	37.9	2.286	1601	581
17	18 ^h 8 ^m	20.7	2.055	1535	549
18	23	37.0	2.276	1607	584
19	48	20.0	2.04	1588	575?
[20	19 ^h 2 ^m	30.5	2.20	1699]
[21	14	36.9	2.28	1702]

¹⁾ This value has been derived from the measurements of M. WOLFFKE and H. KAMERLINGH ONNES, Comm. Leiden N°. 171b.

(Comm. N^o. 190a). The course of the dielectric constant near this jump has been given on a scale ten times larger, in the right corner of Fig. 2.

Now we can, in virtue of these new measurements, much more accurately fix the temperature, at which the jump appears ¹⁾. From the measurements

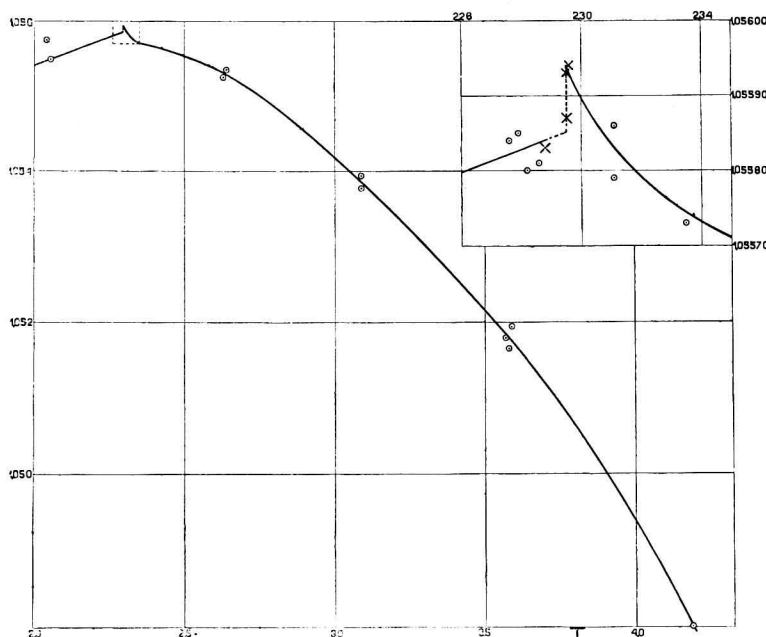


Fig. 2.

N^o. 10 and 14, we conclude, that the jump appears at a vapour-pressure of 38.65 mm, to which answers a temperature of 2.295° K. ²⁾ on the accepted temperature scale. So these are (comp. Comm. N^o. 190b) at the same time the pressure, resp. the temperature of the triple-point liquid helium I — liquid helium II — vapour.

§ 5. By deriving values for the density of liquid helium from the measurements of KAMERLINGH ONNES and BOKS ³⁾ the electric polarization can be calculated according to the formula of CLAUSIUS-MOSOTTI. The results of this calculation are summarized in Table II. In Table IIa the measurements considered are summarized for that to averages. For the immediate surroundings of the transformation-point, the values for the dielectric constant in Table IIb have been derived from Fig. 2, the values

¹⁾ In the measurements of Comm. N^o. 190a there was a small uncertainty in the temperature, brought about by a small difference in temperature of the liquid helium in the condenser and that of the cryostat bath.

²⁾ This last number, after the calculation of the new vapour-pressure measurements (comp. § 3) may consequently still undergo a little change.

³⁾ Comm. Leiden N^o. 170b.

of the density from Fig. 1 of Comm. N^o. 190*b*. Especially for 2.295° K., the value of the density of the liquid helium II is still to be considered as preliminary.

From Table II it appears, that the electric polarization, at least in the

TABLE IIa.						
N ^o .	Pressure mm. Hg.	Temp. °K.	D. C.	ρ	Polarization	
1	751.1	4.19	1.048	0.12566 ¹⁾	0.1253	liq. He. I
2, 3, 5	383.4	3.58	1.05179	0.13606	0.1247	" " "
4, 7	189.3	3.09	1.05386	0.14152	0.1246	" " "
6, 9	82.9	2.63	1.05530	0.14535	0.1245	" " "
17	20.7	2.05 ⁵	1.05549	0.14638	0.1241	" " II
TABLE IIb.						
		2.35	1.05571	0.14679	0.1242	liq. He. I
		2.295	1.05594	0.14693	0.1246	" " "
			1.05585	0.14682	0.1245	" " II
		2.26	1.05580	0.14676	0.1242	" " "

first approximation, is constant and has the same value for the two modifications of the liquid helium. This makes it probable, that the helium-molecule as such does not undergo any change in internal structure in the transformation-point.

§ 6. *Comparison with optical data.* As it has appeared from our measurements, that the electric polarization per mass-unity in liquid helium is constant, at least by approximation, it lies at hand to accept, that the same value also holds good for gaseous helium, that is to say, that also at the change of gaseous helium into liquid, the helium-molecule is not altered. In this case we could calculate the dielectric constant of heliumgas from the value obtained by us for the polarization and from the density of the heliumgas. The polarization has been determined by $K-1$; this quantity, however, at the measurements of WOLFKE and KAMERLINGH ONNES ²⁾ has been measured accurately only to 2 %. The absolute values of the polarization consequently, can only lay a claim to this exactness. From this

¹⁾ Corrected according to Comm. N^o. 172*b*.

²⁾ Comm. Leiden N^o. 171*b*.

it follows, that the reversed way is better. So we shall calculate from optical data the refractive index for infinitely large wave-length, then we shall determine the polarization with the aid of this value, and after that, we shall calculate the dielectric constant of liquid helium at the temperature of the normal boiling-point.

As well from the measurements of BURTON¹⁾ as from those of J. KOCH²⁾ the value 1.0000346 follows for the refractive index for infinitely large waves. For the density of gaseous helium we take the value measured by BAXTER and STARKWEATHER³⁾ $1.7846 \cdot 10^{-4}$. From this, for the polarization per gramme, according to the formula of LORENZ-LORENTZ follows: 0.1292.

This value is about 4 % larger than the average value from Table IIa: 0.1246. If, in virtue to this value of the polarization deduced from optical data, we calculate the dielectric constant of liquid helium at the normal boiling-point, then we get 1.0495, instead of the value 1.048 measured by WOLFKE and KAMERLINGH ONNES. The difference comes only to 0.14 %, which means a favourable agreement.

From these considerations we conclude, that the helium-molecule remains the same as well in the gaseous condition, as also in liquid helium I and liquid helium II.

¹⁾ W. BURTON, Proc. Roy. Soc. (A) **80**, 390, 1908.

²⁾ J. KOCH, Ark. f. Math. Astr. och Fysik **9**, 11, 1913.

³⁾ G. P. BAXTER and H. W. STARKWEATHER, Proc. Amer. Acad. **11**, 231, 1925 and **12**, 20, 1926.