Physics. — *Two different liquid states of helium.* By W. H. KEESOM and M. WOLFKE. (Communication N°. 190*b* from the Physical Laboratory at Leiden.)

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

§ 1. When measuring the dielectric constant of liquid helium between the boiling-point and 1.9° K. on June 11th last, we observed [1]) that at a temperature almost corresponding with that one at which KAMERLINGH ONNES had found a maximum in the density curve, the dielectric constant shows a sudden jump or at least a jump made in a very small temperature-region. The thought suggested itself that at that temperature the liquid helium transforms into an other phase, liquid as well. If we call the liquid, stable at the higher temperatures "liquid helium I", the liquid, stable at the lower temperatures "liquid helium II", then the dielectric constant of liquid helium I should be greater than that of liquid helium II. Seeing that this result was only founded on one series of measurements we wished to repeat the measurements in order to get more security. Two attempts for that purpose failed (on June 17th and July 12th). At a repetition on July 19th the circumstances were less favourable, so that in our opinion the results, though they *did* point in the same direction as those of June 11th, did not yet give a sufficient affirmation. So we decided to wait for new measurements.

§ 2. Meanwhile our attention had been drawn by the following facts:

a. The results of the density-measurements of KAMERLINGH ONNES and BOKS [2]) may be associated as well, if not better (see Fig. 1, which we must compare with Fig. 5 of Comm. No. 170*b*) with the admission of a jump in the density at 38 mm helium-pressure (to the amount of about $1^0/_{00}$, the density of liquid helium II smaller than that of liquid helium I) than with that of a smooth maximum at that place.

b. In the paper of DANA and KAMERLINGH ONNES [3]) on the specific heat of liquid helium results are only mentioned at temperatures higher than the one expressed above. However, they have also experimented round that temperature, but then they found values, which did not agree with those measured at higher temperatures. For a part of the experiments this will be due to condensation of the helium-vapour, as DANA and KAMERLINGH ONNES point out. With some experiments leading

1) These Proc., p. 81. Comm. Leiden N°. 190*a*.

2) Comm. Leiden N°. 170*b*.

3) These Proc. **29**, 1061, 1926. Comm, Leiden N°. 179*d*.

to deviating results a suchlike condensation would not have been expected according to the data, which are kept in the archives of the laboratory.

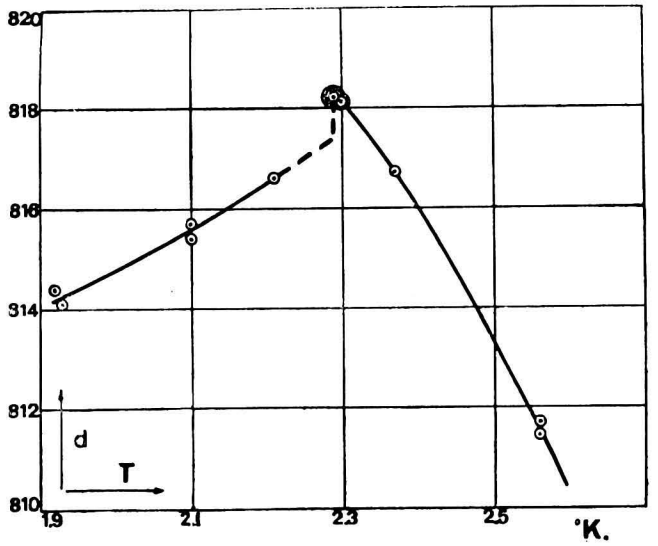

Fig. 1.

In fact from three of those experiments we could deduce nearly corresponding values for the transformation heat with a mean value :

liquid helium I = liquid helium II + 0.13 cal./gram.

c. The results of the measurements of DANA and KAMERLINGH ONNES [1]) concerning the heat of vaporization of liquid helium clearly point to a jump in the heat of vaporization (see Fig. 3 there). They already say that it may be possible that those results should indicate "that near the maximum density something happens to the helium, which within a small temperature range takes place perhaps even discontinuously" [2]). According to those results at the transformation point the heat of vaporization of liquid helium II would be greater than that of liquid helium I and that to an amount which corresponds in order of magnitude with the value of the transformation heat given under *b*.

d. Measurements of VAN URK, KEESOM and KAMERLINGH ONNES [3]) concerning the surface tension of helium seem to indicate clearly a jump in the value of the surface tension between 33 and 39 mm mercury-pressure to the amount of about 3 % (see Fig. 2 there) and in such a way that the surface tension of liquid helium II is smaller than that of liquid helium I.

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[1]) These Proc. **29**, 1051, 1926. Comm. Leiden N°. 179c.

[2]) These Proc. **29**, 1057 note 2, 1926. Comm. Leiden N°. 179c, p. 31 note 1. The authors continue: "The change of density of the liquid also indicates something of the same kind".

[3]) These Proc. **28**, 958, 1925. Comm. Leiden N°. 179a.

§ 3. While the repetition, under improved circumstances, of the measurements of the dielectric constant mentioned in § 1, had to be put off on account of the absence of one of us from Leiden [1]), the provisional value of the transformation-heat mentioned in § 2 *b* raised the surmise that the transformation of the liquid helium should show itself in the cooling- or heating-curve, when a quantity of liquid helium was being cooled regularly (by gradual lowering of the pressure) resp. heated itself in consequence of the supply of heat by conduction and radiation.

This experiment was carried out on November 18th last. The course of the pressure on a mercury-manometer was thereby followed with the eye. With the cooling as well as with the heating a short halt of the manometer was stated each time at 39 mm pressure.

Besides a stirrer, with which was continually stirred during the experiment, the helium-bath contained a constantin resistance. The intention was to register photographically by means of this the course of the temperature with the time. This, however, did not succeed on that day partly because the heating just like the cooling passed off sooner than we had expected, partly because the influence of a change in temperature of the leading wires to the constantin-resistance (Diesselhorst-galvanometer, Thomsonbridge connection) did not appear to be sufficiently eliminated.

A repetition took place on Nov. 29th. Seven experiments were made: 4 coolings and 3 heatings.

The course of the mercury-manometer showed again the same phenomenon as on Nov. 18th. Especially the course by heating was very characteristic. The manometer beginning from about 5 mm at first rose comparatively slowly, then stood still for a moment (always at the same point) and after that suddenly began to rise quickly. At one of these experiments, at which the manometer stood still (it was estimated during 4 sec.) the pressure was read 38 mm.

During each of those experiments the deflection of the galvanometer in the Thomsonbridge connection could be registrated [2]). On each of the thus obtained resistance-time-registrations, which can be almost considered as temperature-time-curves, the transformation-point can be clearly recognized. Visually nothing was to be seen of the forming of a second phase in the liquid helium. This need not astonish us as the refraction-indices of the two phases will differ very little [3]).

From the fact that at lower temperatures the liquid is evidently being moved as easily by the stirrer as at higher it also appears that the viscosity of the helium II must be small. On December 7th measurements were

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[1]) We hope that this repetition will soon take place.

[2]) We heartily thank Mr. J. N. VAN DEN ENDE, phil. cand., for his assistance in these experiments.

[3]) Herewith should be compared what has been observed at the experiments concerning the solidification of helium: these Proc. 29, 1136, 1926, Comm. Leiden N°. 184*b*.

made concerning the resistance of the constantin wire mentioned above, particularly near the transformation-point, the pressure of the helium being kept constant during each measurement. We shall possibly revert to these experiments later. After that we had the opportunity to register still 3 cooling- resp. heating-curves in the way mentioned above. During these registrations the temperature changed considerably slowlier than at the preceeding experiments. Though the then obtained curves show peculiarities, which we cannot yet quite interpret, still each of them shows very clearly that at a pressure of about 38 mm something very peculiar takes place.

On December 16th measurements were made by Dr. SOPHUS WEBER, Mr. NØRGAARD and one of us on the vapour-pressure of helium particularly also near the point in question here. This time the temperature was measured with a heliumthermometer of which the pressure was read by means of a hot-wire manometer. Later on the results of these measurements will be communicated. Fig. 2 gives the successive readings of the galvanometer in the hot-wire manometer connection, when after a series of these measurements the heliumbath heated itself. The transformation-point is very clearly indicated in this heating-curve.

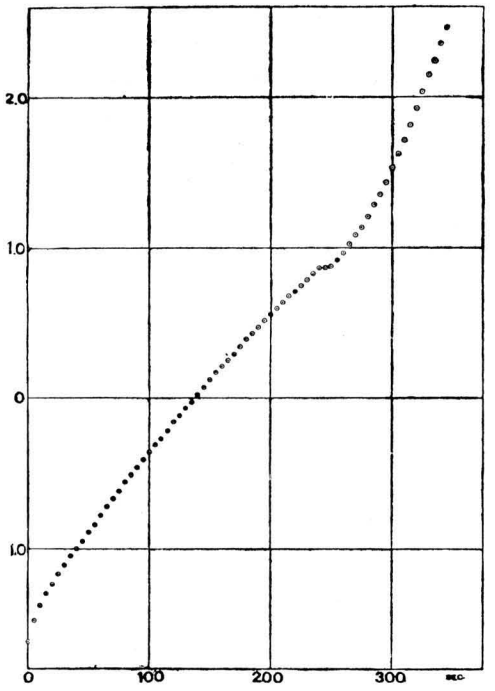

Fig. 2.

§ 4. Through the preceeding experiments we think the fact to be established that at a presure of about 38 mm a very peculiar change appears in the liquid helium, which in any case takes place within a very small temperature-region (0.08 of a degree). Though we have not been able

to observe visually the two phases side by side, we yet think it most probable that we have to do here with two different states of liquid helium, which transform into each other at the temperature corresponding to the pressure mentioned. Of those two phases the liquid helium II (stable at the lower temperatures) compared with liquid helium I has :

a smaller density,
a greater heat of vaporization,
a smaller surface-tension,

while the transformation liquid helium II → liquid helium I takes place with an absorption of heat, of which the amount can be valued for the present at 0.13 cal./gram.

We put the temperature, at which the transformation takes place, for the present at 2.3° K. [1]).

It is remarkable that this transition takes place at a temperature, which, roughly speaking, may be considered to correspond with those at which other substances have their melting-point.

So helium has a triplepoint liquid I-liquid II-vapour, which until now has only been found with a number of complicately composed substances, which have a mesomorphic (liquid crystalline) phase. Whether the latter is also the case with helium, will have to appear from further experiments.

Likewise whether and, if so, in which point the transformation curve liquid I-liquid II meets the melting-curve.

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[1]) It is evident that the deduction of the temperature from the value of the vapour-pressure especially near this point, shall want a reconsideration.