For comparison we refer to the value of c_p found by SCHEEL and HEUSE [1]) being 7.162 at the temperature 92° K. and a pressure of about one atmosphere.

We gladly record our thanks to Mr. W. BEVELANDER, phil. nat. cand., for his assistance in this investigation.

Summary.

The velocity of sound in nitrogen gas has been measured in the temperature range extending from 0° C. down to liquid nitrogen temperatures, in dependence on the pressure. Four resonators are used to get an idea of the validity of the formula of KIRCHHOFF-HELMHOLTZ. This formula proves to give good results. A curve $B = f(1/T)$ (B being the second virial coefficient) has been calculated holding from 150 down to 80° K. Also the ratio c_p/c_v and the specific heats c_p and c_v were calculated.

[1]) K. SCHEEL and W. HEUSE, Ann. d. Phys. (4) **40**, 473, 1913.

Physics. — *On the Anomaly in the Specific Heat of Liquid Helium.* By W. H. KEESOM and Miss A. P. KEESOM. Communication N⁰. 221*d* from the KAMERLINGH ONNES Laboratory at Leiden.

(Communicated at the meeting of June 25, 1932).

§ 1. *Introduction.* The investigation on the specific heat of liquid helium made by one of us with Dr. CLUSIUS [1]) gave rise to some questions which made a nearer investigation of the anomaly of the specific heat of that substance, revealed by the investigation mentioned, desirable.

So it seemed important to see whether the curve of the specific heats obtained should undergo some change if a better heat conduction in the liquid was provided for. In this connection the course of the curve of the specific heats above 2.19° K attracted special attention. Although we have not yet been able to make experiments in which the conditions of heat supply and heat conduction were the most ideal ones, we could make some measurements with improved heat conduction in the liquid in such a way that we can draw at least a preliminary conclusion concerning this question.

[1]) W. H. KEESOM and K. CLUSIUS. These Proceedings, **35**, 306. 1932; Comm. Leiden No. 219*e*.

Furthermore an examination of the course of the specific heat in the vicinity of the top of the specific heat curve by measurements with a very small temperature rise was interesting.

This paper contains the results of some series of experiments on these lines.

§ 2. *Method.* We followed the method and used the same apparatus as described by one of us and Dr. CLUSIUS in Comm. N⁰. 219*e*, with the following alterations:

a. A better heat conduction in the liquid helium was ensured by means of a copper cross about 1 mm thick soldered to the cover of the copper container of the liquid helium. This cross reached as far as quite near to the bottom and to the side wall of the container.

b. The temperature rise in the specific heat measurements was chosen of the order of magnitude of 0.01 degree in the vicinity of 2.19° K [1]).

c. The change of temperature during the experiment was observed by reading the galvanometer deflection [2]). Moreover by properly switching in a shunt in the galvanometer circuit, the temperature of the core during the heating period was followed.

The temperatures were always measured with the phosphorbronze thermometer. On April 28th we used a measuring current of 1.34 mA, with which CLUSIUS calibrated the wire. On April 21st we used a measuring current of 0.406 mA and derived our calibration curve from measurements made with this measuring current by one of us and VAN DEN ENDE on another part of the same phosphorbronze wire. For this purpose we took two cooling curves, on which the point 2.19° K very clearly distinguished itself. We estimate the accuracy reached to be 0.01° K. The accuracy of our measurements of temperature differences is much higher.

In order to derive the temperature increase $\triangle T$ from the increase of the resistance of the phosphorbronze wire $\triangle W$, we made a curve of dT/dW as a function of T.

§ 3. *Results.* Tables I and II contain the results obtained.

In Fig. 1 the galvanometer readings during the measurements I*f*—I*i* of April 28 are represented. The readings during the heating periods (scale 42—46) were made while the galvanometer was shunted.

From the regularity of the readings it is seen that measurements of the specific heat with a temperature increase of about 0.01 degree are quite

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1) KEESOM and CLUSIUS (These Proceedings **35**, 317, 1932, note 1) had already made a successive series of such small heatings in this temperature region, and so reached the important conclusion concerning the absence of any transformation heat, without however making exact measurements in that experiment.

2) KEESOM and CLUSIUS continually adjusted the compensation bank and made their readings on the bank.

TABLE I.

Specific heat of liquid helium.
Measurements of April 21st. 1932.

No.	Current mA	Time seconds	Tension Volts	Heat supplied cal.	Temperature °K	Temp. increase °K	Heat capacity cal/°K	Spec. heat cal/°K.g.
Ia	16.75	48	1.017	0.1836	1.315	0.117_8	1.559	0.138
b	22.48	28	1.366	0.1931	1.330	0.118_6	1.628	0.144
c	23.80	44	1.448	0.3406	1.593	0.069_3	4.915	0.434
d	28.24	68	1.725	0.7439	1.918	0.069_7	10.673	0.968
IIa	19.75	46	1.199	0.2447	2.126	0.011_8	20.734	1.828
b	16.74	42	1.021	0.1612	2.089	0.009_1	17.697	1.559
c	16.74	48	1.021	0.1842	2.113	0.009_9	18.610	1.642
d	16.74	36	1.021	0.1382	2.125	0.007_1	19.467	1.717
e	16.76	34	1.022	0.1308	2.134	0.006_4	20.408	1.800
f	16.74	62	1.020	0.2377	2.147	0.011_5	20.651	1.821
g	16.74	72	1.020	0.2761	2.160	0.011_8	23.943	2.065
h	16.72	68	1.019	0.2602	2.172	0.010_2	25.508	2.251
i	16.72	78	1.019	0.2984	2.184	0.009_4	31.749	2.802
j	24.11	66	1.470	0.5253	2.205	0.030_2	17.394	1.535
k	16.41	64	1.003	0.2366	2.230	0.025_1	9.425	0.832
l	16.41	64	1.003	0.2366	2.257	0.030_1	7.859	0.694
m	16.41	44	1.003	0.1626	2.282	0.024_4	6.666	0.588
n	16.43	50	1.003	0.1850	2.305	0.027_4	6.753	0.596
o	16.43	52	1.003	0.1924	2.330	0.029_5	6.523	0.576
p	16.43	44	1.003	0.1628	2.356	0.026_4	6.168	0.544
q	29.6_3	80	1.801	0.9587	2.451	0.153_4	6.250	0.551
r	30.6_3	78	1.873	1.0049	2.613	0.164_5	6.109	0.539
s	30.6_3	78	1.875	1.0060	2.784	0.160_7	6.260	0.552
t	30.6_3	80	1.873	1.0307	2.949	0.149_9	6.876	0.607

The resistance in the Voltmeter circuit was 1000 Ohm. The calorimeter was for series I filled at 2.734 °K and contained 11.314 g. helium. For series II it was filled at 2.706 °K and contained 11.332 g helium. Measuring current 0.406 mA.

TABLE II.

Specific heat of liquid helium.
Measurements of April 28th, 1932.

No.	Current mA	Time seconds	Tension Volts	Heat supplied cal.	Temperature °K	Temp. increase °K	Heat capacity cal/°K	Specific heat cal/°Kg.
Ia	15.98	60	0.967	0.2083	2.120	0.0105_8	19.688	1.740
b	16.00	62	0.969	0.2164	2.137	0.0103_2	20.969	1.854
c	16.00	60	0.969	0.2089	2.150	0.0094_3	22.153	1.958
d	16.00	60	0.969	0.2089	2.160	0.0088_9	23.498	2.077
e	15.96	60	0.967	0.2080	2.170	0.0082_0	25.366	2.242
f	15.96	60	0.967	0.2080	2.179	0.0075_3	27.623	2.442
g	15.92	60	0.967	0.2075	2.186	0.0066_9	31.016	2.742
h	15.94	60	0.967	0.2077	2.196	0.0118_5	17.527	1.549
i	15.92	60	0.967	0.2075	2.210	0.0182_8	11.351	1.003
j	15.92	58	0.967	0.2008	2.231	0.0196_9	10.198	0.901
k	15.90	60	0.965	0.2068	2.253	0.0241_9	8.549	0.756
l	15.90	60	0.965	0.2068	2.279	0.0263_6	7.845	0.693

The resistance in the voltmeter circuit was 1000 Ohm. The calorimeter was filled at 2.730 °K and contained 11.313 g helium. Measuring current 1.34 mA.

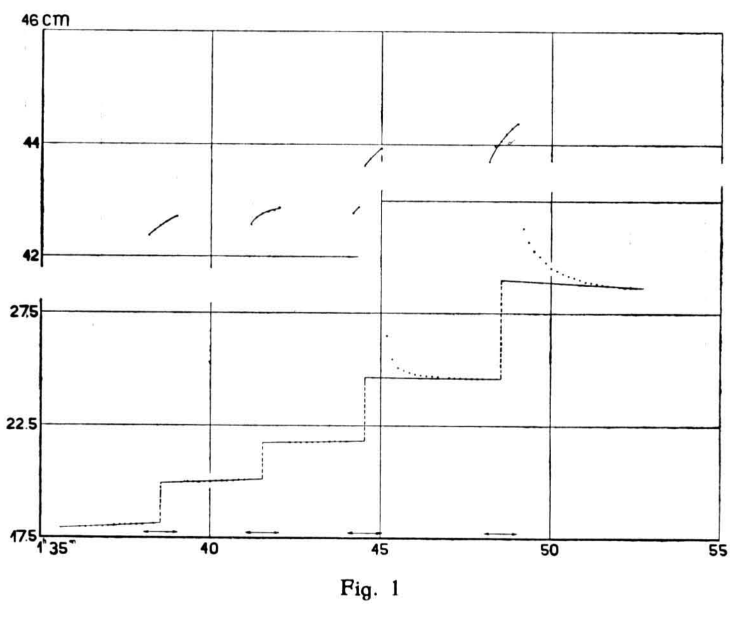

Fig. 1

feasible also in this region of temperatures. There are represented two heatings below (experiments I *f* and *g*) and one heating (I *i*) above the point 2.19° K, while from the jump in the heating period of experiment I *h* we derive that in this experiment that point was passed.

As the quantity of heat applied in these experiments was practically the same, the much larger temperature increase of I *i* compared with I *f* and I *g* immediately indicates the fall of the specific heat.

The attention is further drawn to the fact that the afterperiods above 2.19° K have quite another character than those below that point. It is evident that the distribution of the applied heat in the liquid is much faster below 2.19° K than above. One should be inclined to consider the facts that the heat supply is from above and that helium at 2.19° K has a maximum density, so that below that temperature convection currents are liable to occur, whereas this will not be the case at temperatures above 2.19° K, as an explanation of this difference. From certain thermodynamical reasoning it is however doubtful whether the density maximum really coincides with the jump in the specific heat, and it is therefore perhaps reasonable to look for another explanation. As such a change in the heat conductivity or in the viscosity of liquid helium present themselves. In this connection it is interesting that from other phenomena also the probability of a change in viscosity of liquid helium was deduced. It must be left to further experimental research to decide these questions.

The jump in the heating-period of experiment I *h* points to the same phenomenon: decrease of the heat transport through the liquid, possibly

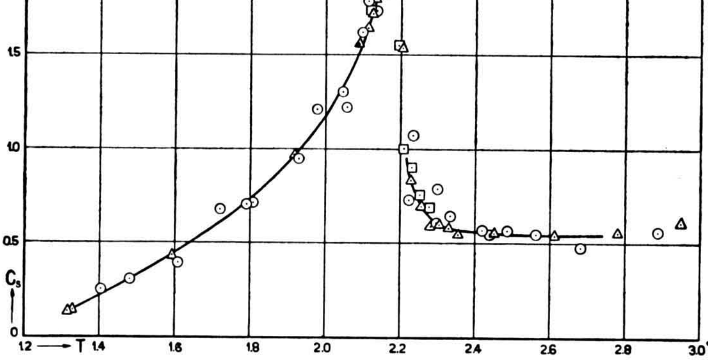

Fig. 2

△ April 21st. ⊡ April 28th. ⊙ KEESOM and CLUSIUS.

in consequence of a decrease in intensity of the convection currents by an increase of viscosity.

In Fig. 2 the results of the series of measurements of April 21st and 28th are compared with those obtained by KEESOM and CLUSIUS. It is clear that a good agreement exists. From this follows that the fact that heat is not immediately conducted through the liquid has not had an appreciable influence on the results of the measurements.

It is evident as well from Fig. 2 as from the data given in Table I and II that the points at temperatures 2.205 and 2.196 (experiments II *j* of April 21st and I *h* of April 28th) belong to measurements in which the jump in the specific heat is passed, so that the specific heat of these points is a certain average between the large and the small specific heats.

In Fig. 3 the results of the measurements of April 28th are represented separately.

§ 4. *Conclusions.* *a.* Each value of the specific heat measured is an average value over the temperature interval of the heating period. Considering this one can safely conclude from the experiments II *i* of April 21st and I *g* of April 28th that the true specific heat at the higher limit of the temperature intervals involved was at least 3.0. This value corresponds to the temperature 2.189° K.

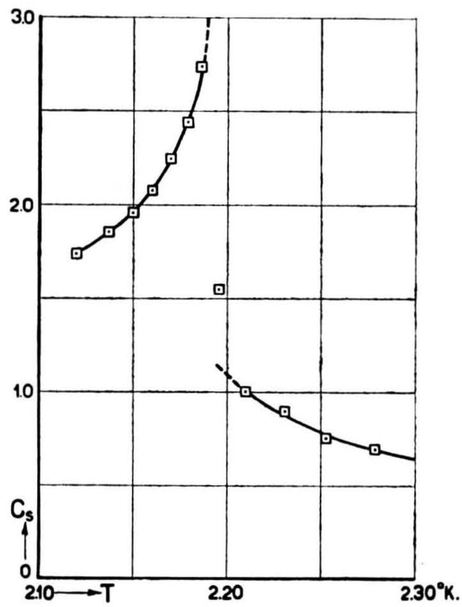

Fig. 3

The highest specific heat measured above the point 2.19° K is 1.003 at 2.210° K (I *i* April 28th). This is the average specific heat between 2.201 and 2.219° K. Considering also the results of the following experiments one may conclude that the true specific heat at 2.201° K probably surpasses 1.1 very little, if at all. The same conclusion is arrived at by an analysis of experiment I *h* of the same day. To explain the average specific heat found in this experiment one must moreover assume that the jump in the specific heat must have occurred very shortly after the reading of 44 m 20 sec (cf. Fig. 1), and must have been completed within some thousandths of a degree.

So our conclusion is that the specific heat of liquid helium at about 2.19° K falls from a value of 3.0 to a value of about 1.1 certainly within 0.02 degree, very probably even within a couple of thousandths of a degree.

b. Leaving open the question whether the fall of the specific heat really occurs discontinuously in the strict sense of the word, or in a very small temperature interval, it will be appropriate from an experimental point of view to consider the fall to occur abruptly. For convenience sake it is desirable to introduce a name for the point at which this jump occurs. According to a suggestion made by Prof. EHRENFEST we propose to call that point, considering the resemblance of the specific heat curve with the Greek letter λ, the *lambda-point*.

The curve that shows how the lambda-point depends on the pressure will be called the *lambda-curve* [1]).

As in several cases it is also convenient to distinguish between the two conditions of the liquid helium with such different values of the specific heat, we will continue to call liquid helium I the liquid helium above the lambda-temperature (for the pressure considered) and liquid helium II the liquid helium below that temperature.

We gladly express our thanks to J. A. KOK, phil. nat. cand., for his help with these measurements.

Summary.

The specific heat of liquid helium under its saturated vapour pressure was measured in the vicinity of 2.19° K with temperature increases of 0.01 to 0.02 degree. The specific heat has a maximum value of about 3.0 at 2.19° K and falls down to 1.1 certainly within 0.02° K, probably within a couple of thousandths of a degree.

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1) Cf. W. H. KEESOM and K. CLUSIUS. These Proceedings **34**, 605, 1931. Comm. Leiden. N⁰. 216*b*.