
(Communicated at the meeting of October 31, 1925).

§ 1. Method and apparatus. In order to determine the surface tension of liquid helium in contact with its saturated vapour we used, as did Kamerlingh Onnes and Kuypers 1) in the case of hydrogen, the method of the capillary elevation in a narrow tube. To diminish irregular pressure differences at the open ends of the capillaries these were made comparatively short (Fig. 1, c.f. Fig. 1, Comm. N°. 142d). Also it appeared desirable to have an immediate control as to whether or not the measured rise was the true rise corresponding to the temperature used. It often happened that gas bubbles rose in the narrow tube, causing the meniscus to oscillate for a considerable time and then to remain stationary for some minutes at an entirely wrong height. By placing two capillaries of about the same diameter alongside one another in the same wide tube and by comparing the elevations in both, this uncertainty was eliminated. It is hardly to be expected that precisely the same disturbance to the elevation would appear in both tubes at the same time.

A platinum wire bearing two loops, in which the capillaries were fixed with a little Kothinsky cement, was fused into the wall of the wide tube.

§ 2. Calibrations. Two capillaries about 10 cms. long were chosen, one twice as wide as the other. Each capillary was calibrated several times by two different methods, namely, by filling with mercury threads of various lengths which were measured, the mercury used being weighed, and by placing the tube filled with mercury in a liquid (an approximately 10:1 mixture of chloralhydrate and glycerine) of the same refractive index, for Na-light, as glass and then measuring the diameter of the mercury thread with the micrometer eyepiece of a microscope.

The two calibrations of both tubes (of radius about 0.009 and 0.02 cms.) could not be made to agree to more than $1/2^0/0$. A calibration

curve was drawn for each capillary from which the radius at the position of the meniscus could be read off. From each tube two pieces about 3 cms. long were taken to be placed alongside one another.

§ 3. Observations. The positions of the menisci in the capillary tubes (the top and the edge could not be distinguished) and the positions of the liquid in the wide tube, in the neighbourhood of the capillaries and somewhat further off, were measured. Besides these the tops of the tubes were also read to determine the positions of the menisci in relation to the tubes.

The corrected rise \( 'H' \) was calculated from the rise \( 'h' \) measured in a capillary tube placed inside a wider tube by introducing the following two corrections:

\[
H = h + \frac{r}{3} + h'
\]

where \( r \) is the inner radius of the capillary and

\[
h' = \left( h + \frac{r}{3} \right) \frac{2d}{(R-r_1)^2} \frac{1}{r} \frac{(R-r_1)^2}{2d} \]

1) See J. E. VERSCHAPPELT, Leyden Comm. No. 18. These Proc. 1895. This correction is not properly applied in Communication No. 142d. For the there communicated measurements of Hydrogen we now can borrow the above corrections from the elevation in two concentric tubes as these have been more accurately calculated by a graphical method by VERSCHAPPELT, Bull. Acad. Roy. de Belg. Cl. d. Sc. 1921, p. 574. The following values for \( H \), which are to be substituted for the values given in Table I of Communication No. 142d were obtained.

The corresponding values of \( \psi_f \) are also given (c.f. Table II, Comm. No. 142d)

<table>
<thead>
<tr>
<th>( T )</th>
<th>( H )</th>
<th>( \psi_f )</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.40</td>
<td>1.694</td>
<td>1.910</td>
</tr>
<tr>
<td>18.70</td>
<td>1.883</td>
<td>2.1945</td>
</tr>
<tr>
<td>17.99</td>
<td>1.962</td>
<td>2.3195</td>
</tr>
<tr>
<td>16.16</td>
<td>2.169</td>
<td>2.631</td>
</tr>
<tr>
<td>14.68</td>
<td>2.324</td>
<td>2.860</td>
</tr>
</tbody>
</table>

(c.f. also J. E. VERSCHAPPELT, Comm. Phys. Lab. Ghent, No. 2, Wis- en Natuurkundig Tijdschrift 2, 231, 1925). In the formula of VAN DER WAALS \( \psi_f = A (1-\frac{1}{B}) \) the values of \( A \) and \( B \) become \( A = 5.554, B = 1.119 \), and the constant of EOTVOS \( k_{E0} = 1.363 \), and EINSTEIN's constant, \( 6.64 \times 10^{-9} \).

In the case of helium we have been unable to use the new calculations of the rise between two concentric tubes by VERSCHAPPELT, as the capillary constant of helium is small and the table given by him does not go far enough. However the difference lies within the experimental errors.
The combination of both corrections gives

\[ H = \frac{h + \frac{r}{3}}{1 - \frac{2dr}{(R-r_1)^2}}. \]

We have applied this formula to the present case in which two tubes are placed in a wider tube; as the total correction \( h' \) amounts to 1\% for the wider capillary, and only \( \frac{1}{2} \)\% for the narrower, any error thus involved is negligible.

Corrections for the expansion of the glass have been neglected as they would certainly lie within the experimental error.

The temperature was calculated from the vapour pressure according to the formula given in Comm. No. 147b 1).

§ 4. Results. The differences between the two values found for \( Hr \) at the same temperature amount to a maximum of 5\%. It must be remembered that the largest rise was 5 mm and that this had to be read through two vacuum vessels and then through the walls of two glass tubes.

The surface tension \( \psi_r \) and the molecular surface tension \( \psi_M \) (in ergs) can be calculated from the product \( Hr \) by means of the following formulae 2)

\[ \psi_r = (\theta_l - \theta_0) \frac{g}{2} \cdot Hr \]
\[ \psi_M = \frac{\psi_r}{(\theta_l)}^{\frac{\eta_s}{\eta}}. \]

The results are shown in Figure 2. The points \( \Theta \) and \( \Delta \) refer to the measurements with the capillaries of radius 0.02 and 0.009 cms. respectively. The values of \( \psi_M \) given in table II have been interpolated by means of this graph. To them correspond the values given for \( a^2 = Hr \), \( a \) being the capillary constant.

<table>
<thead>
<tr>
<th>( T )</th>
<th>( \psi_M )</th>
<th>( a^2 )</th>
<th>( T )</th>
<th>( \psi_M )</th>
<th>( a^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.20</td>
<td>0.98</td>
<td>0.00181</td>
<td>2.50</td>
<td>2.69</td>
<td>0.00419</td>
</tr>
<tr>
<td>4.00</td>
<td>1.19</td>
<td>211</td>
<td>2.00</td>
<td>3.08</td>
<td>477</td>
</tr>
<tr>
<td>3.50</td>
<td>1.68</td>
<td>280</td>
<td>1.50</td>
<td>3.22</td>
<td>496</td>
</tr>
<tr>
<td>3.00</td>
<td>2.19</td>
<td>350</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1) These Proceedings 18, 493, 1915.
2) The densities \( \theta_l \) and \( \theta_0 \) for helium were obtained from E. Mathias, C. A. Crommelin, H. Kamerlingh Onnes and J. C. Swallow, these Proceedings 28, 526, 1925, Leyden Comm. No. 172b.
§ 5. Discussion.
From Fig. 2 it is seen that the line which represents the surface tension as a function of temperature has a curvature which first appears at 2.4° K. Above this temperature the line appears to be quite straight.

We have calculated the Eötvös' constant ¹) for the straight portion and this amounts to about 1.0. Thus helium obeys the rule, stated by Kamerlingh Onnes and Keesom ²), according to which normal substances in this respect form a series in which the Eötvös' constant increases with the critical temperature. According to this rule the constant for helium must be the smallest, which is actually the case.

The curvature just mentioned probably indicates, as does the maximum that is observed in the liquid density ³), a peculiarity in the molecular

---

¹) \( d\psi_M/dT \). See „die Zustandsgleichung“. Enz. d. math. Wiss. V. 10, Leyden Suppl. No. 23, § 37b.
²) „Die Zustandsgleichung“, note 381.
³) The observations of this phenomenon published up to now only indicate the existence of a maximum of the apparent density of liquid helium in a glass vessel. Here it can be further stated that measurements have been made in which a graduated silver scale was placed next to the glass scale of the reservoir in the helium bath and both scales compared with the aid of a cathetometer. No difference in the expansions of either scale could be recorded, from which it can be concluded that such a difference, if it exists, amounts to less than a thousandth part of the calculated density of the liquid helium. It is hardly
attraction. With regard to the former no such curvature is observed with the other so-called permanent gases. The surface tension of the latter, however, because of the appearance of the solid state, cannot be observed at such a low reduced temperature as is the case with helium.

We wish to acknowledge our very great indebtedness to Mr. G. P. Nijhoff, who made part of the observations and to Miss A. F. J. Jansen and Mr. J. Voogd for their help in the temperature measurements.

Possible that both substances undergo the same transformation at the same temperature; hence it follows that the maximum of the apparent density of the helium in a glass reservoir is due to the helium itself.