

Citation:

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heat of the "saturated electron vapour". As according to our theory the density of the saturated electron vapour becomes constant at low temperature, σ there reduces to the specific heat at constant volume. Paying attention to the units used we therefore obtain for σ , expressed in Joules, at those low temperatures

$$\sigma = 10^{-7} \cdot \frac{1}{N_e} \cdot C_v, \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

or

$$\sigma = 10^{-7} \cdot \frac{1}{N_e} \cdot 6b \cdot T^3 V^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

Again it is easily verified that the KELVIN's relation is satisfied.

Hence the THOMSON-effect also approaches to 0 at $T=0$, and this according to T^3 .

Physics. — *"Isothermals of di-atomic substances and their binary mixtures XIII. Liquid-densities of hydrogen between the boiling point and the triple point; contraction of hydrogen on freezing."*
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Comm. N^o. 137a from the Physical Laboratory at Leiden.

(Communicated in the meeting of June 28, 1913).

Densities of liquid hydrogen have so far only been determined by DEWAR¹⁾. As a more accurate knowledge of this quantity is of importance for the equation of state the following measurements were undertaken. They were made with the same apparatus as served for argon.²⁾

The temperature was determined by measuring the vapour pressure of the hydrogen in the cryostat. The sensibility of this method is very great, as 1 mm. difference in vapour pressure corresponds to 0°.004 at the boiling point and to 0°.02 at the triple point. The measurement does not therefore require great care being taken. As shown by measurements by KAMERLINGH ONNES and KEESOM, the vapour pressure may be determined by reading the pressure in the cryostat itself, instead of in a special vapour pressure tube filled with pure hydrogen and placed in the cryostat, if an accuracy of 0°.02 or 0°.03 is considered sufficient.

¹⁾ J. DEWAR, Proc. R. S. (A) 73 (1904) p. 251.

²⁾ E. MATHIAS, H. KAMERLINGH ONNES and C. A. CROMMELIN, Proc. Oct. and Dec. 1912 and Jan 1913 Comm. N^o. 131a.

The temperature on the KELVIN-scale¹⁾ corresponding to these vapour pressures are taken from measurements by KAMERLINGH ONNES and KEESOM, not yet published. Their results have not been definitely calculated, but the small corrections which may be as yet required are of no importance for the object of this paper.

For the method of calculating the volumes we may refer to the paper on the diameter of argon quoted above.

The results are contained in the table. It also gives the densities calculated by the quadratic formula

$$\rho_{\text{liq}} = a + bT + cT^2$$

with the following values of the constants:

$$a = + 0.084404$$

$$b = - 0.0002230$$

$$c = - 0.00002183$$

made to fit the readings at $-258^{\circ}.27$, $-255^{\circ}.99$ and the boiling point.

The deviations from this formula will be seen to be very small; they are within the limits of accuracy of the observations, except possibly at the highest temperature. It may be added, that the density at the boiling point was not directly observed, but was calculated from the neighbouring observations.

The first column contains the number of the observation, the second the temperature below 0°C. , on the KELVIN-scale, the third the density observed referred to the density of water at 4°C. , the

| $N^{\circ}.$ | θ | $\rho_{\text{liq}}^{\text{obs.}}$ | $\rho_{\text{liq}}^{\text{calc.}}$ | $\text{obs.} - \text{calc.}$ |
|--------------|-------------------------|-----------------------------------|------------------------------------|------------------------------|
| VIII | -252.68 | 0.07081 | 0.07076 | $+ 0.00005$ |
| — | -252.77 boiling point | 7086 | 7086 | — |
| XIV | -253.24 | 7137 | 7138 | — 1 |
| XIII | -253.76 | 7192 | 7194 | — 2 |
| XII | -255.19 | 7344 | 7342 | $+ 2$ |
| XI | -255.99 | 7421 | 7421 | — |
| X | -256.75 | 7494 | 7493 | $+ 1$ |
| III | -257.23 | 7538 | 7538 | 0 |
| IX | -258.27 | 7631 | 7631 | — |

¹⁾ The corrections for the reduction of the hydrogen-scale to the KELVIN-scale are given by H. KAMERLINGH ONNES and W. J. DE HAAS, Proc. Sept. 1912. Comm. N^o. 127c.

fourth the density according to the formula and the fifth the difference of the latter two.

In addition to the liquid-densities the density of solid hydrogen was also determined. It was first of all ascertained that *solid hydrogen is heavier than liquid hydrogen* and, therefore, that *on freezing contraction takes place*. For this purpose the hydrogen in the cryostat was frozen; a solid crust is then formed on the liquid. If the pressure is now made to rise slowly, this crust divides into fragments which sink down in the liquid and collect at the bottom of the vacuum-glass. It was not till this observation was made, that we ventured to freeze the hydrogen in the dilatometer without fear of bursting the very carefully calibrated instrument.

In order to be sure, that the freezing would proceed from the bottom, the tube of the dilatometer was movable in a stuffing box, which was fitted in the lid of the cryostat. After the hydrogen in the cryostat had been frozen to an opaque solid mass, the dilatometer was pushed down slowly. The hydrogen in the dilatometer was then frozen to a homogeneous transparent mass. At the moment of reading the volume of the solid hydrogen, the pressure in the cryostat was 0.66 cm.

In order to obtain an estimate of the temperature, the vapour pressures of solid hydrogen being practically unknown, the vapour pressures according to KAMERLINGH ONNES and KEESOM were extrapolated by means of the $\log p, \frac{1}{T}$ diagram, in which the vapour pressure curves are known often to be very nearly straight lines, neglecting the break in the curve at the triple point. In that manner the temperature θ corresponding to a pressure of 0.66 cm. was found to be

$$-262^{\circ}.0.$$

The density of solid hydrogen at this temperature was found to be

$$\rho_{\text{sol}} = \underline{0.08077}.$$

Putting the triple point temperature, according to the same measurements at

$$\theta_{\text{coex. liq. vap. sol.}} = -259^{\circ}.2$$

extrapolation by means of the above formula gives for the liquid density at that point

$$\rho_{\text{coex. liq. vap. sol.}} = \underline{0.07709}.$$

Assuming that the density of solid hydrogen at the triple point does not differ appreciably from that at -262° , the contraction on freezing is found to be about 4.8 % of the liquid volume.