

Citation:

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Physics. — “On the measurement of very low temperatures. XIX. Derivation of the pressure coefficient of helium for the international heliumthermometer and the reduction of the readings on the heliumthermometer to the absolute scale”. Communication N°. 102^b from the Physical Laboratory at Leiden. By Prof. H. KAMERLINGH ONNES.

§ 1. *Pressure coefficients of helium.* As the absolute zero is known with sufficient accuracy — from the Leiden observations on hydrogen may be derived $T_{0^{\circ}\text{C.}} = 273^{\circ}.10 \text{ K.}$ ¹⁾ a value which, because it agrees with other determinations, is probably not far from the true one — we may by means of the virial coefficients B_A for helium at 0° C. and 100° C. , determined in the preceding communication (102^a), derive the pressure coefficients of helium at different densities for this range of temperature. For the pressure coefficient of the *international helium thermometer*²⁾ i. e. the mean relative pressure coefficient from 0° C. to 100° C. for helium with the density belonging to the zero pressure of 1000 m.m. $\left[\begin{smallmatrix} 0^{\circ} & (-100^{\circ} \text{ C.}) \\ \alpha_r & \end{smallmatrix} \right]$, or for shortness ${}_r\alpha_c$, the formula

$$100 \cdot {}_r\alpha_c = \frac{A_{A_0} \times 0.36617 + (B_{A,100^{\circ}\text{C}} - B_{A,0^{\circ}\text{C}}) \frac{100}{76}}{A_{A_0} + B_{A,0^{\circ}\text{C}} \cdot \frac{100}{76}} \dots (1)$$

yields

$${}_{\text{He}}\alpha_c = 0.0036613.$$

If one considers that according to table II of Comm. N°. 102^a the isotherm of 0° gives rather large values for Obs.—Comp., then it seems that the isotherm of 20° C. , where the Obs.—Comp. are only small, are more reliable for the derivation given above.

¹⁾ In Comm. N°. 101^b the value $273^{\circ}.08$ is found, but as will be explained in Comm. N°. 102^b, an erratum to Comm. N°. 97^b XV, the pressure coefficient 0.0036627 for hydrogen at 1090 m.m. must be restored instead of 0.0036629 which was derived in the above mentioned communication and used for a certain time. It is to be noted that the difference introduced by this recalculation is not greater than the other observational errors. The small differences between some numbers of this communication with the Dutch text are the consequence of this correction.

²⁾ The scale of the hydrogen thermometer of constant volume at 1000 m.m. zero pressure is generally called the scale of the normal hydrogen thermometer (this was also done in Comm. N°. 97^b). As 0° C. and 760 m.m. are accepted as the normal state for gases, it seems to me preferable to call the scale just mentioned the scale of the *international hydrogen thermometer*. In the same way we must speak of the *international helium thermometer*.

Therefore I have calculated $\left[\begin{smallmatrix} 0^{\circ}\text{C.} \\ \alpha_p \end{smallmatrix} \right]_{1000 \text{ mm.}}^{-100^{\circ}\text{C.}}$ by means of the data for 20°C. and $100^{\circ}.35\text{C.}$ With neglect of the deviations from the absolute scale for the hydrogen thermometer at 20°C. , $B_{A,0^{\circ}\text{C.}}$ was determined by means of rectilinear extrapolation. This gave

$$B_{A,0^{\circ}\text{C.}} = 0.0,499,$$

whence

$$A_{A_0} = 0.99950.$$

With these new data we derive from formula (1) of this section

$${}^{\text{He}}\alpha_p = 0.0036616.$$

From the data for B_A of table II of the preceding Comm. and $T_{0^{\circ}\text{C.}} = 273^{\circ}.10\text{ K}$ we may determine in the way mentioned in § 2 of Comm. N^o. 97^b the corrections of the readings of the helium thermometer of constant volume with a given zero pressure to the absolute scale. They have been calculated for a zero pressure of 1000 m.m. and are combined in table I where the remaining columns have the same signification as the corresponding ones of table XVI of Comm. N^o. 97^b.

θ	$10^3 \cdot B_T$	$(\Delta t)_a$	$(\Delta t)_b$
100 ^o .00	+ 0.492		
0 ^o (a)	+ 0.513		
0 ^o (b)	+ 0.500		
- 103 ^o .57	+ 0.544	+ 0 ^o .0034	- 0 ^o .006
- 182 .75	+ 0.532	+ 0.0158	+ 0 .002
- 216 .56	+ 0.463	+ 0.0252	+ 0 010

The corrections indicated with (a) are derived by means of the values of $B_{A,0^{\circ}\text{C.}}$ from the direct determination, for (b) we have used the value which is recalculated with $B_{A,20^{\circ}}$ (comp. the preceding Comm.). It is probable that on account of what has been said in the preceding section those of column (b) are the most reliable.

§ 3. Determinations of other observers.

For a comparison with the results of the two preceding sections

we can only use the determinations of TRAVERS, SENTER and JACQUEROD.¹⁾ They have found:

1st. for the pressure coefficient of the helium thermometer at 700 m.m. zero pressure $\left[\alpha_p \right]_{700}^{0^{\circ}\text{C}-100^{\circ}\text{C}} = 0.00366255$ which agrees with 0.0036628 for $\left[\alpha_p \right]_1^{0^{\circ}\text{C}-100^{\circ}\text{C}}$ and

2nd. for the difference between the indications of the helium thermometer t_{He} and the hydrogen thermometer t_{H_2} (each of about 1000 m.m. zero pressure) at the boiling point of oxygen $(t_{\text{H}_2} - t_{\text{He}})_{-180^{\circ}\text{C}} = 0^{\circ}.10$, and at that of hydrogen $(t_{\text{H}_2} - t_{\text{He}})_{-252^{\circ}\text{C}} = 0^{\circ}.20$, which differences are so considerable that CALLENDAR²⁾ concludes thence that the corrections of the helium thermometer to the absolute scale are negative.

The two results which strongly deviate from mine may be readily explained if one adopts that the determination of the coefficient of pressure variation of helium by TRAVERS, SENTER and JACQUEROD has not yielded the true value. For if the differences in indication found by them between their helium- and their hydrogen thermometer are reduced by means of the corrections of each of these thermometers to the absolute scale which are given in Comm. 100^a and in Table I of this Comm., to the difference in readings on the absolute scale, which are found at the same temperature by means of the hydrogen thermometer which gives θ_{H_2} and by means of the helium thermometer which gives θ_{He} , there remains at -182° a difference

$$(\theta_{\text{H}_2} - \theta_{\text{He}})_{-182^{\circ}} = 0^{\circ}.10 - 0^{\circ}.049 - 0^{\circ}.002 = 0^{\circ}.05$$

while by extrapolation of the corrections found to -217° for -252° one would find

$$(\theta_{\text{H}_2} - \theta_{\text{He}})_{-252^{\circ}} = 0^{\circ}.20 - 0^{\circ}.12 - 0^{\circ}.02 = 0^{\circ}.06$$

When calculating the temperatures t_{H_2} and t_{He} the investigators mentioned have taken the pressure coefficient of the helium thermometer $\left(\alpha_p^{\text{He}} \right)_{\text{Travers}}$ to be equal to that of the hydrogen thermometer at the same zero pressure (for 1000 m.m. therefore 0.0036626 according to our value of Comm. N^o. 60). If the corrections applied by me are right that pressure coefficient must therefore, at -182° in order that $\theta_{\text{H}_2} - \theta_{\text{He}} = 0$ be diminished by 0.0000010 so that

$$\alpha_p^{\text{He}} = 0.0036616$$

1) Phil. Trans. Ser. A. Vol. 200 p. 105—180. KUENEN and RANDALL (Proc. Roy Soc. Vol. 59) have made a determination, which, being only intended to show whether the helium behaved normally, is not made to the high degree of accuracy which is required for a comparison with isothermal determinations.

2) Phil. Mag. [6] 5. 1903.

and in order $\theta_{H_2} - \theta_{He}$ at -252° by 0,0000013 to that

$$\alpha_{He} = 0,0036614.$$

The first value which has been derived without extrapolation and which is therefore the most reliable, appears to agree perfectly with the one derived by me from the isothermals in § 1.

With regard to the method of derivation followed here we may remark that it allows of a fairly large accuracy. Though the certainty of the determinations of temperature on which it is based may be doubted to the absolute value, yet the only difference which comes into account here is known with sufficient certainty. The calculation mentioned above therefore not only gives an explanation of the too large differences found by TRAVERS, SENTER and JACQUEROD, but is also a welcome control for the coefficient of pressure variation of helium found in section 1.

Physics. — “*The absorption spectra of the compounds of the rare earths at the temperatures obtainable with liquid hydrogen, and their change by the magnetic field*”, by JEAN BECQUEREL and H. KAMERLINGH ONNES. Communication N^o. 103 from the Physical Laboratory at Leiden.

§ 1. *Introduction.* The investigations of one of us (J. B.)¹⁾ proved that the absorption spectra of the compounds of the rare earths, cooled down to the temperature of liquid air, may serve to acquire new data for the nature, the number, and the motion of the electrons which play a part in the formation of these spectra. So it seemed to us of great importance to continue these investigations at the temperatures obtainable with liquid hydrogen, which are so many times lower and seem particularly adapted²⁾ to reveal the forces which the ponderable substance exerts on the electrons. For this purpose the apparatus used at Paris for the observation of the spectra were conveyed to the cryogenic laboratory at Leiden, so that we were enabled to obtain some three hundred of spectrograms which represent the observed phenomena. The study of these photographs will take a long time; we shall therefore confine ourselves on this occasion to the communication of some facts which immediately draw the attention.

¹⁾ JEAN BECQUEREL, Radium IV. 9, p. 328 and IV, 11, p. 385 (1907).

²⁾ H. KAMERLINGH ONNES, The importance of accurate measurements at very low temperatures. Comm. of the phys. lab. of Leiden Suppl. no. 9, p. 25 sqq. (1904).