

Citation:

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where \mathfrak{B}_t is the value of the function \mathfrak{B} of the reduced temperature belonging to $t = \frac{293.04}{T_k}$.

For \mathfrak{B} we have used a function of a form differing slightly from the form VI.1, given in Suppl. N°. 8, which did not only agree with hydrogen, oxygen and nitrogen but also with ether, viz. a form VI. 2, which instead of agreeing with ether in the same way as VI. 1, agrees with the average of ether and isopentane :

$$10^8 \cdot \mathfrak{B} = + 179,883 t - 374,487 - 181,324 \frac{1}{t} - 110,267 \frac{1}{t^3}$$

The agreement appears from the following table, where we find in the first column the values calculated according to the last formula, and in the second column those of the quadratic formula of § 3;

	according to corresponding states	according to quadratic formula	difference
1	— 0.021920	— 0.020772	— 0.001148
$\frac{1}{2}$	— 0.016502	— 0.015866	— 0.000636
$\frac{3}{4}$	— 0.012179	— 0.011855	— 0.000324
0	— 0.006485	— 0.006515	+ 0.000030

The deviations on the side of the methyl chloride are larger than those of the errors of observation and those of the quadratic formula. Methyl chloride, therefore, does not agree so well with ether and isopentane as carbon dioxide. This same result is also arrived at in another way. It appears, however, that the mixtures do not deviate more than the methyl chloride itself.

(To be continued).

Physics. — “*On the measurement of very low temperatures. VII. Comparison of the platinum thermometer with the hydrogen thermometer*”. (Continuation of Comm. N°. 77. Febr. 1902). By B. MEILINK. Communication N°. 93 from the Physical Laboratory at Leiden by Prof. H. KAMERLINGH ONNES.

(Communicated in the meeting of June 25, 1904).

§ 5. *The measurements at low temperatures.* The thermometers were mounted as described by KAMERLINGH ONNES in Comm. N°. 83 Febr. 1903 § 5. During the first preliminary measurements, the hydrogen thermometer and the resistance thermometer (cf. Comm. N°. 77 § 2) were placed in the cryostat (described in Comm. N°. 51, Sept. 1899),

which was modified as described in § 2 Comm. N°. 83. In this cryostat a vacuum vessel was placed inside of B_1 (Pl. I, Comm. N°. 51), which vacuum vessel by means of cork was pressed against the walls of B_1 (cf. end of § 2 and also Pls. I and II of Comm. N°. 83). The inner wall took the place of ξ_0 in Pl. II, Comm. N°. 83 (the same parts of Comms. N°. 83 and N°. 77 are marked with the same letters).

These preliminary experiments had shown, that, after repeated measurements at the lowest temperatures, the original value was again found for the resistance at 0° C., hence that the platinum wire, though its expansion differed from that of glass, was not lengthened and that it also remained properly in the notches. Further it had become clear that an accurate comparison of the two thermometers was only possible when the temperature of the bath was kept constant with the utmost care, and there we met with the difficulties treated in § 2 of Comm. N°. 83. It was attained by arranging the cryostat as described in § 5 of Comm. N°. 83. It may moreover be remarked that the liquid gas was always kept higher than ξ_2' (Comm. N°. 83, Pl. II); else, notwithstanding the level in and outside the protecting cylinder would go up and down through the motion of the stirrer, no circulation would be produced.

The course of a measurement was as follows. As soon as the circumstances under which we desired to make a measurement were established, the resistances of the leads were determined, then the resistance of the platinum wire was adjusted and, by giving signs to the assistant charged with the regulation of the pressure, care was taken that this resistance, and hence the same temperature, were maintained. After about ten minutes we began, while constantly reading the galvanometer, the measurements with the hydrogen thermometer and continued them until the liquid was evaporated or until we deemed that sufficient data were obtained. At the end the measurement of the resistance of the leads was repeated.

The observer at the galvanometer had, therefore, only to look after the continual closing and breaking of the currents and the noting down of the values of the galvanometer readings and of the time belonging to them. Afterwards the deflections were derived from this (see Pl. III Comm. N°. 83) and the mean deflection during the time of observation was found by means of a planimeter.

§ 6. *Zero after the measurements.* By a too rapid decantation of liquid oxygen, numerous bursts had unfortunately come in the cylinder of the resistance. To repeat with it the above described operations for the determination of the zero seemed rather dangerous, especially

as the refastening in the cryostat would have involved many difficult operations.

Therefore in order to bring the resistance thermometer to a constant temperature near 0° C., the case U of the cryostat (Pl. I, Comm. N^o. 83) was screwed off from the cover N_2 (Pl. I, Comm. N^o. 51), while the other parts of the cryostat remained fastened to the cover, and it was replaced by a zinc cylindrical vessel, which could be managed more easily. This vessel was provided with a rim fitting on to N_1 and was placed in another larger zinc vessel, so that a jacketing space of 5 c.m. remained which was entirely filled with ice. Then isopentane was distilled into B_{02} (Pl. II, Comm. N^o. 83) and the apparatus was left to itself during one night. The next day the temperature (near 0°) had become constant and we determined it (while stirring) by means of a thermoelement (Θ Pl. II, Comm. N^o. 83).

§ 7. *Corrections.* A survey of the mounting of the WHEATSTONE's bridge (cf. § 3 Comm. N^o. 77) is given in fig. 5. R indicates the

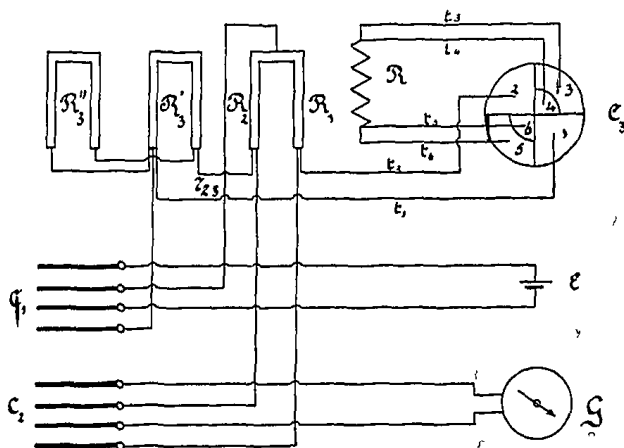


Fig. 5.

resistance to be measured, R_1 and R_2 the two coils of manganin wire, R_3' and R_3'' the resistance boxes of HARTMANN and BRAUN and of SIEMENS and HALSKE giving together the resistance $R_3 = R_3' - \frac{R_3''}{R_3' + R_3''}$ which with r_3 forms the fourth arm of the bridge; C_1 and C_2 are the commutators with mercury contact (Comm. N^o. 27, May and June 1896), C_3 is the copper commutator treated in § 3 Comm. N^o. 77 and represented there in fig. 2.

Putting for the factor for the inequality of the branches of the bridge $\frac{R_1}{R_2} = 1 - a$, we found $a = 0.00216$ (as mean value of twenty

values ranging from 0.00219 to 0.00214). As according to § 3 Comm. N°. 77 the resistance of the platinum wire R is equal to the difference between two measured resistances, one t (the resistance of the leads), another $R + t$, and as the branches of the bridge are so nearly equal, r_{23} is eliminated, and hence we need not know the value of r_{23} .

To the resistances read on the box R_s' , the corrections found by calibration must be applied. We may easily convince ourselves that the arrangement of box R_s'' parallel to box R_s' has no perceptible influence on the value of the corrections at R_s' . The corrections of the errors in the nominal box values could be neglected for all coils below 1 Ohm.

For the measurements at low temperature a correction had to be applied, because during the regulation of the temperature the mean deflection was not zero.

In order to express that deflection in terms of the resistance, the platinum thermometer in the bridge, after the measurements were made, was replaced by an equally large box resistance and for a known modification of this resistance the deflection was observed. The regulation of the temperature was in most cases so successful that it was hardly necessary to take the correction into consideration.

The resistance, measured near 0° , was reduced to 0° C. with the approximate formula $W = 110.041 (1 + 0.0038644 t - 0.000001031 t^2)$, derived from preliminary observations.

§ 8. *Survey of a measurement.* The course of a measurement is described in § 5.

The quantities which are derived directly from observation are given in table I (p. 294). Under the head "Connection" I have recorded between which blocks of the commutator C_s a conducting connection existed.

Therefore commutator C_s was not used while the measurement lasted. This had become possible because the platinum wire was wound free from induction, so that no induced current was observed when the principal current was closed.

From these data we now derive for each connection the value of R_s , i. e. the resistance of the branch of the bridge in which the resistance boxes are placed (apart from r_{23}).

If the value of R_s which is found when we measure the platinum wire with the leads, is diminished by the value of R_l which is found with the leads alone, we obtain the resistance of the platinum wire, in the supposition 1°. that the arms of the bridge are equal, 2°. that during the measurement the mean deflection was zero and 3°. that the resistance box requires no correction. For each of these suppositions

TABLE I. Calibration Platinum Thermometer in Oxygen
Boiling under Reduced Pressure (May 22, 1902).
Resistance Measurements.

Time.	Connection.	R'_3	R''_3	Position commutator C_1	Position of equilibrium of galvanometer.	Deflection galvanometer.
	1-5 2-6 Leads.	0.4	1.5	Left.	58.5	74.5
				Right.		41.7
			1.6	Left.		43.4
	1-3 2-4	0.4	1.6	Left.	58.2	43.8
					58.0	
3h.49'	1-5 2-4 platinum wire.	20 ± 2 ± 0.3	3200	Left.	45.2	44.0
						45.0
						46.0
						46.7
						47.0
50'						45.0
						44.2
to 4h.25'				Right.	45.1	
						and so on for all minutes to 4h.25'.
4h.27'	Leads.					
	1-3 2-4	0.4	1.5	Left.	46.0	55.7
	1-5 2-6	0.4	1.5	Left.		53.8
					46.0	

we must apply the correction mentioned in § 7 in order to find the true resistance. The mean deflection during the measurement is found, according to Comm. N°. 83 § 5, by means of a planimeter.

(See for the graphical representation Pl. III, Comm. N°. 83, which does not, however, bear upon our case).

In the following table the corrections are combined.

TABLE II. Calibration Platinum Thermometer in Oxygen Boiling under Reduced Pressure (May 22, 1902).		
Resistance measurement, Corrections.		
Ratio arms.	+ 0.00216	
Correction to R for box values 20 and 2	+ 0.0005	
Mean deflection	+ 0.1 cM.	

After what has been said above about the method of calculation the further calculation will be sufficiently clear from the following table.

TABLE III. Calibration Platinum Thermometer in Oxygen Boiling under Reduced Pressure.						
Resistance at $-197^{\circ}.08$ C.						
Time	Connection	R'_3	R''_3	R''_3 mean	R_3	Resistance Pt wire
3h.49— 4h.25	1—5 2—6	0.4	1.54	1.55	0.3182	21.8281
	1—3 2—4	0.4	1.57			
	1—5 2—4	20 + 2	3200			
		+0.3		1.53	0.3171	
	1—3 2—4	0.4	1.53			
	1—5 2—6	0.4	1.53			
	Correction arms of the bridge					+0.0485
	Correction resistance box					+0.0005
	Correction to mean deflection 0					+0.0002
	Resistance					21.8773

Determinations made at other temperatures did not yield anything particular. Only for the zero determination the corrections are somewhat different, as that for the reduction to the mean deflection 0 is no longer necessary. A new one, however, is added because the determination has not been made exactly at 0° C. but at a little higher temperature. After what has been remarked about this in § 7, it seems superfluous to illustrate this small variation by an instance.

§ 9. *Determinations of the resistance at 0° C.* They are made in three series. For the first we still used leads of 0.5 m.m. (Comm. No. 77 § 2 and fig. 3), the insulating liquid was petroleum ether or amylene; for the second the leads were 5 m.m. thick (l.c. fig. 4), the insulating liquid was isopentane; and the third (insulating liquid isopentane) was that treated in § 6.

TABLE IV. Calibration of Platinum Thermometer. Zero.				
	Number of determina- tions.	Resistance. Smallest Largest		Mean value.
Series 1. June '01	4	110.031	110.048	110.040
2. Nov. Dec. '01	7	033	57	43
3. Nov '02.	3	043	51	48
Mean resistance at 0° C.				110.045

§ 10. *Determinations at low temperatures.* The measurements were made at fairly gradually decreasing temperatures, at the lowest temperatures the intervals are smaller.

The measurements with the hydrogen thermometer (see Comm. N°. 77 § 2) are made by Dr. W. HAUSS: to whom my best thanks are due for the trouble he has taken.

The determinations are made up of two series.

The first series was made between May 13 and July 10, the second series between Dec. 10 and Dec. 22, 1902.

It seems desirable to consider the two series separately.

The first series has yielded results that may be derived from the following table.

In order to judge how the values given here agree inter se, I have first calculated the formula of the form

$$w = w_0 (1 + at + bt^2),$$

TABLE V. Calibration of Platinum Thermometer.

First Series.

Date	Temperature determined with the hydrogen thermometer	Resistances measured.	Bath in which the measurements were made
	0° C.	110.045	comp. § 9.
May 24, '02	— 51°.43 C	87 760	methyl chloride boiling under reduced pressure.
May 13, '02	— 104° 66	64 256	ethylene.
"	— 104° 38	64 371	id.
"	— 127° 71	53.910	ethylene boiling under reduced pressure.
"	— 128° 88	53 372	
May 16, '02	— 161° 15	38.676	methane.
"	— 161°.15	38.672	id.
"	— 161° 47	38.515	id.
May 22, '02	— 182°.63	28 692	oxygen
July 10, '02	(— 195° 75) ¹⁾	(22 600)	nitrogen.
May 22, '02	— 197° 08	21.877	oxygen boiling under reduced pressure.
"	— 197° 58	21.673	
July 10, '02	— 209°.93	16.025	nitrogen boiling under reduced pressure.

which agrees with the observations at 0°, at —104°.66 C. and at —182°.63 C., the temperatures which best correspond with those which as a rule are also used by other observers.

The formula becomes

$$w = 110.045 (1 + 0.0038788 t - 0.000\,000\,9257 t^2).$$

The deviations of the observed resistances from the formula are given in the column Obs.—Comp._I of table VI, and are quite appreciable. In the case of methyl chloride the deviation amounts to 65 on 87760 or a difference in temperature of 0°.15 C. For methane these deviations are 63 on 38674 or a difference in temperature of also 0°.15 C. In oxygen, boiling under reduced pressure, the deviation is 90 on 21637 or about 0°.2 C.

¹⁾ This observation is less reliable because an uncertain correction to the hydrogen thermometer attained a rather high value.

To find out whether these deviations are perhaps due to irregular errors in the measurement, it will be useful to investigate whether, by addition of another term, the differences between these observations and the calculation might be reduced to within the limits of the errors of observation. It succeeded indeed fairly well as may be seen in column Obs.—Comp._{II} of table VI. The calculated values are derived by means of the formula

$$w = 110.045 (1 + 0.0039167 t - 0.000\,000\,3432 t^2 + 0.000\,000\,002069 t^3).$$

TABLE VI. Test of a Parabolical and of a Third Degree Formula.			
First series.			
Temperatures determined with the hydrogen thermometer.	Measured resistances	Obs.—Comp. _I	Obs.—Comp. _{II}
0°	110.045	0	0
— 51° 43	87.760	— 0 065	+ 0.012
— 104° 38	64.371	— 0.011	— 0 017
— 104° 66	64.256	0	— 0.005
— 127° 71	53.910	+ 0.039	0 —
— 128° 88	53.372	+ 0.030	— 0.011
— 161° 15	38.674	+ 0.063	+ 0 019
— 161° 47	38.515	+ 0 051	+ 0 008
— 182° 63	28.692	0	+ 0.008
(— 195° 75)	(22.600)	(+ 0 014)	(+ 0.078)
— 197° 08	21.877	— 0.083	— 0.014
— 197° 58	21.637	— 0 090	— 0.017
— 209° 93	16.025	+ 0 077	+ 0.229

The deviations from formula II, with the exception of the last, although they are not entirely within the limits of the errors of observation which were expected, are only little in excess.

In the case of methane, where the deviation is 19 on 38674, an error in the temperature of 0°.04 C. is sufficient to explain this amount.

In the case of nitrogen boiling under reduced pressure, however, the deviation has become very large, so large even that it cannot be explained by errors of observation. Hence the circumstance that the formula is not fit to represent the resistance so near to the absolute zero must account for this deviation. All the same it is remarkable that this turn appears so suddenly. At -197°C . the formula still holds, at -210°C . there is a deviation of 229 on 16025, i. e. a deviation of $0^{\circ}.49$ in temperature. But if we take into consideration that, according to the formula, the resistance at -243°C . would become zero and that we are only about thirty degrees from this point, we need not wonder at this result.

In order to gain certainty that there was indeed a fairly rapidly increasing variation in the shape of the curve that represents the resistance as a function of the temperature, I resolved to repeat especially these measurements at very low temperature in nitrogen. These constitute what I have called at the beginning the 2nd series. Unfortunately the result was unsatisfactory.

Though the observations indeed point in the same sense, yet one error or another seems to have crept into them and it could no more be detected at the time when the calculations revealed it. We shall omit them here.

Therefore the results as to the amount of the deviations remain more or less uncertain; yet it is very probable that even in nitrogen boiling under reduced pressure, a beginning may be observed of the variation in the course of the temperature function which, as follows from DEWAR's experiments, appears so strongly at the temperature of liquid hydrogen.

The conclusions to which the measurements lead may be summarized as follows.

A representation of the resistance by a quadratic formula, according to the temperature, even if we do not go below -180°C ., is only permitted when no higher degree of accuracy than $0^{\circ}.2\text{C}$. is aimed at. When a greater precision is desired we require for the calibration of a platinum thermometer a greater number of points of comparison. For a comparison to within $\frac{1}{20}^{\circ}\text{C}$. a number of at least 6 temperatures of comparison is considered very desirable.

Below -197°C . the deviations of the platinum thermometer become so large that before using it for this range an investigation must be made of the course of the resistance as a function of the temperature.