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manner as those of the rods in the vacuum glass. Now we have taken only a double glass filled with wool, enveloped in a card-board funnel and tube for letting out the cold vapours.

The measurements are given in table III.

The λ's found in the experiment are of the same order of magnitude as those found with the long rods. The calculation with the coefficients a and b found in § 2 yields:

$L_{N_2O} = 227{,}547$ while we have found $L_{N_2O} = 227{,}544$

$L_{O_2} = 227.487$ „ „ „ „ $L_{O_2} = 227{,}488$.

In conclusion we wish to express hearty thanks to Miss T. C. JOLLES and Miss A. SILLEVIS for their assistance in this investigation.

Physics. — "*On the measurement of very low temperatures.* XI. *A comparison of the platinum resistance thermometer with the hydrogen thermometer.*" By Prof. H. KAMERLINGH ONNES and J. CLAY. Communication N°. 95^c from the Physical Laboratory at Leiden.

(Communicated in the meeting of June 30, 1906).

§ 1. *Introduction.* The following investigation has been started in Comms. N°. 77 and N°. 93 VII of B. MEILINK as a part of the more extensive investigation on the thermometry at low temperatures spoken of in Comm. N°. 95^a. In those communications the part of the investigation bearing on the electrical measurements was chiefly considered.

The hydrogen thermometer was then (comp. Comm. N°. 93 § 10) and has also this time been arranged in the same way as in Comm. N°. 60. Afterwards it appeared, however, that at the time the thermometer did not contain pure hydrogen, but that it was contaminated by air. The modifications which are consequently required in tables V and VI of Comm. N°. 93 and which particularly relate to the very lowest temperatures, will be dealt with in a separate communication.

Here we shall discuss a new comparison for which also the filling with hydrogen has been performed with better observance of all the precautions mentioned in Comm. N°. 60.

We have particularly tried to prove the existence of the *point of inflection* which may be expected in the curve (comp. § 6) representing the resistance as a function of the temperature, especially with regard to the supposition that the resistance reaches a *minimum* at very low temperatures, increases again at still lower temperatures and even becomes infinite at the absolute temperature 0 (comp.

Suppl. N°. 9, Febr. '04). And this has been done especially because temperature measurements with the resistance thermometer are so accurate and so simple.

From the point of view of thermometry it is important to know what formula represents with a given accuracy the resistance of a platinum wire for a certain range, and how many points must be chosen for the calibration in this range.

In Comm. N°. 93 § 10 the conclusion has been drawn that between 0° and — 180° a quadratic formula cannot represent the observations more accurately than to 0°.15, and that if for that range a higher degree of accuracy is required, we want a comparison with the hydrogen thermometer at more than two points, and that for temperatures below — 197° a separate investigation is required. In the investigation considered here the temperatures below — 180° are particularly studied; the investigation also embraces the temperatures which can be reached with liquid hydrogen.

It is of great importance to know whether the thermometer when it has been used during a longer time at low temperatures would retain the same resistance. We hope to be able later to return to this question. Here we may remark that with a view to this question the wire was annealed before the calibration. Also the differences between the platinum wires, which were furnished at different times by HERAEUS, will be considered in a following paper.

§ 2. *Investigations by others.* Since the appearance of Comm. N°. 93 there has still been published on this subject the investigation of TRAVERS and GWYER [1]). They have determined two points. They had not at their disposal sufficient cryostats such as we had for keeping the temperatures constant. About the question just mentioned: how to obtain a resistance thermometer which to a certain degree of accuracy indicates all temperatures in a given range, their paper contains no data.

§ 3. *Modification in the arrangement of the resistances.* The variation of the zero of the gold wire, mentioned in Comm. N°. 93 VIII, made us doubt whether the plates of mica between the metallic parts secured a complete insulation, and also the movability of one of the glass cylinders made us decide upon a modification in the construction of the resistances, which proved highly satisfactory and of which we

[1]) TRAVERS and GWYER. Z. f. Phys. Chem. LII, 4, 1905. The wire of which the calibration is given by OLSZEWSKI, 1905, Drude's Ann. Bd. 17, p. 990, is apparently according to himself no platinum wire. (Comp. also § 6, note 1).

have availed ourselves already in the regulation of the temperatures in the investigation mentioned in Comm. N°. 94^d.

A difficulty adheres to this arrangement which we cannot pass by unnoticed. Owing to the manner in which this thermometer has been mounted it cannot be immersed in acid. Therefore an apparatus consisting entirely of platinum and glass remains desirable. A similar installation has indeed been realized. A description of it will later be given. The figures given here exclusively refer to the thermometer described in Comm. N°. 94^d (p. 210).

Care has been taken that the two pairs of conducting wires were identical. Thus the measurement of the resistance is performed in a much shorter time so that both for the regulation of the temperature in the cryostat and, under favourable circumstances, for the measurement the very same resistance thermometer can be used.

§ 4. *The temperatures.*

The temperatures were obtained in the cryostat, described in Comm. N°. 94^d, by means of liquid methyl chloride —39°, —59°, —88°, of liquid ethylene —103°, —140°, —159°, of liquid oxygen —182°, —195°, —205°, —212°, —217°, by means of liquid hydrogen —252° and —259°. The measurements were made with the hydrogen thermometer as mentioned in § 1.

§ 5. *Results for the platinum wire.* These results are laid down in table I (p. 210).

The observations marked with [ ] are uncertain on account of the cause mentioned in Comm. N°. 95^a § 10 and are not used in the derivation and the adjustment of the formulae. For the meaning of $W—R_{A_I}$ in the column "remarks" I refer to § 6.

§ 6. *Representation by a formula.*

a. We have said in § 1 that the quadratic formula [1]) was insufficient even for the range from 0° to —180°.

If a quadratic formula is laid through —103° and —182°, we find:

[1]) The correction of CALLENDAR, used at low temperatures by TRAVERS and GWYER, Z. f. Phys. Chem. LII, 4, 1905 comes also to a quadratic formula. DICKSON's quadratic formula, Phil. Mag. June 1898, is of a different nature but did not prove satisfactory either; comp. DEWAR Proc. R. Soc. 64, p. 227, 1898.

The calibration of a platinum thermometer through two fixed points is still often applied when no hydrogen thermometer is available (for instance BESTELMEYER Drude's Ann. 13, p. 968, '04).

TABLE I.

COMPARISON BETWEEN THE PLATINUM RESISTANCE THERMOMETER AND THE HYDROGEN THERMOMETER.

Date		Temperature hydrogentherm.	Resistance measured	Remarks
0°		0°	137 884 Ω	mean of 5 measurements.
27 Oct. '05	5 h. 0	— 29.80	121.587	
	2 h. 50	— 58 75	105.640	
30 Oct. '05	3 h. 50	— 88 14	89.277	
8 July '05	10 h. 12	— 103 83	80.448	
26 Oct. '05	5 h. 20	— 139 87	59 914	
7 July '05	4 h. 25	— 139.85	59 920	
26 Oct. '05	3 h. 16	— 158.83	48.929	
27 June '05	1 h. 40	[— 182 69]	34 861	$W - R_{A_I} = -0\ 061$
30 June '06	11 h. 0	— 182.75	34 858	
27 June '05	3 h. 50	[— 195.30]	27.598	$W - R_{A_I} = +0\ 082$
2 March '06	3 h. 35	— 195.18	27 595	
29 June '05	11 h. 6	[— 204.53]	22 016	$W - R_{A_I} = -0.110$
2 March '06	1 h. 30	— 204 69	22 018	
30 June '05	3 h. 0	[— 212.83]	17.255	$W - R_{A_I} = -0.082$
5 July '05	5 h. 53	— 212 87	17 290	
5 July '05	3 h. 20	— 217.41	14.763	
3 March '05	10 h. 0	— 217 41	14 770	
5 May '06	3 h. 0	— 252 93	1 963	
5 May '06	5 h. 7	— 259 24	1.444	

$$W_t = W_0 \left\{ 1 + 0{,}39097 \left(\frac{t}{100}\right) - 0{,}009862 \left(\frac{t}{100}\right)^2 \right\}.$$

For instance at — 139° it gives $W—R$: + 0,084. A straight line may be drawn through — 182°, — 195°, — 204° and — 212° and then — 217° deviates from it by 0°,25 towards the side opposite to — 158°. Hence the existence of *a point of inflection* is certain (comp. sub *d*). Therefore it is evident that a quadratic formula will not be sufficient for lower temperatures.

b. But also a cubic formula, even when we leave out of account the hydrogen temperatures, appears to be of no use.

For the cubic formula through the points —88°,14, —158°,83, —204°,69, we obtain:

$$W_t = W_0 \left\{ 1 + 0{,}393008 \frac{t}{100} - 0{,}0_2 73677 \left(\frac{t}{100}\right)^2 + 0{,}0_3 58386 \left(\frac{t}{100}\right)^3 \right\}.$$

It gives for instance at — 182° a deviation of — 0,110, at — 217° a deviation of + 0,322 [1]).

c. In consequence of difficulties experienced with formulae in ascending powers of *t*, we have used formulae with reciprocal powers of the absolute temperatures (comp. the supposition mentioned in § 1 that the resistance becomes infinite at the absolute zero).

Three of these have been investigated:

$$\frac{W_t}{W_0} = 1 + a \frac{t}{100} + b \left(\frac{t}{100}\right)^2 + c \left(\frac{t}{100}\right)^3 + d \left(\frac{10^2}{T} - \frac{10^2}{273{,}09}\right) \quad . \quad . \quad (A)$$

$$\frac{W_t}{W_0} = 1 + a \frac{t}{100} + b \left(\frac{t}{100}\right)^2 + c \left(\frac{t}{100}\right)^3 + d \left(\frac{10^2}{T} - \frac{10^2}{273{,}09}\right) + e \left[\frac{10^4}{T^2} - \frac{10^4}{(273{,}09)^2}\right] \quad . \quad (B)$$

$$\frac{W_t}{W_0} = 1 + a \frac{t}{100} + b \left(\frac{t}{100}\right)^2 + c \left(\frac{t}{100}\right)^3 + d \left(\frac{10^2}{T} - \frac{10^2}{273{,}09}\right) + e \left(\frac{10^6}{T^3} - \frac{10^6}{(273{,}09)^3}\right) \quad . \quad (C)$$

We shall also try a formula with a term $\frac{e}{T^4}$ instead of $\frac{e}{T^3}$.

For the first we have sought a preliminary set of constants which was subsequently corrected after the approximate method indicated by Dr. E. F. van de Sande Bakhuyzen (comp. Comm. N°. 95*a*) in two different ways. First we have obtained a set of constants A_I with which a satisfactory accurate agreement was reached down to — 217°, a rather large deviation at — 252° and a moderate deviation at — 259°. Column $W—R_{AI}$ of table II contains the deviations. Secondly we have obtained a set of constants which yielded a fairly

[1]) These values deviate slightly from those communicated in the original.

accurate agreement including — 252°, but a large deviation at — 259°. These are given in table II under the heading $W—R_{AII}$.

Lastly we have obtained a preliminary solution B which fairly represents all temperatures including — 252° and — 259° and from which the deviations are given in table II under $W—R_B$, and a solution of the form C which agrees only to — 252° and to which $W—R_C$ relates.

The constants of the formulae under consideration are:

	A_I	A_{II}	B	C
a	+ 0 399625	+ 0 400966	+ 0 412793	+0 40082
b	— 0.0002575	+ 0.001159	+ 0 013812	+0.001557
c	+ 0.0049412	+ 0.0062417	+ 0 012683	+0.00557
d	+ 0.019380	+ 0 026458	+ 0.056221	+0.01975
e			— 0.0033963	—0.16501

TABLE II.

COMPARISON BETWEEN THE PLATINUM RESISTANCE THERMOMETER AND THE HYDROGEN THERMOMETER.

Temperature observed with the hydrogen thermometer.	Number of observations with the hydrogen therm.	Resistance observed in Ω	$W—R_{AI}$	$W—R_{AII}$	$W—R_B$	$W—R_C$
0°		137.884	0	0	0	0
— 29.80	3	121.587	+ 0.025	+ 0 066	+ 0.210	+ 0.063
— 58.75	3	105 640	+ 0.011	— 0.011	+ 0.153	+ 0.048
— 88.14	4	89.277	— 0 012	— 0.050	— 0.001	+ 0.008
— 103.83	3	80.448	— 0 023	— 0.061	— 0.075	— 0.015
— 139.87	3*	59 911	+ 0.004	— 0.005	— 0.082	— 0.005
— 158.83	3	48 929	+ 0.023	+ 0.044	0	+ 0.008
— 182.75	2	34.858	— 0.029	+ 0.027	+ 0.083	— 0 035
— 195.18	2	27 595	+ 0 009	+ 0.061	+ 0.148	+ 0 007
— 204.69	1	22 018	— 0.014	+ 0 012	+ 0 100	— 0.014
— 212.87	3	17 290	— 0.024	— 0 065	— 0.001	— 0.031
— 217.41	4*	14.766	+ 0.028	— 0.048	+ 0.270	+ 0.007
— 252.93	2	1 963	+ 2 422	+ 0.057	— 0.001	0
— 259.24	1	1.444	+ 0.199	— 4.201	0	

In those cases where the $W—R$ have been derived from two determinations the values in the 2nd column are marked with an * [1]).

If we derive from the differences between the observed and the computed values as far as —217° the mean error of an observation by means of A_I, this mean error is expressed in resistance ± 0,025 Ω, in temperature ± 0°,044.

The mean error of an observation of the hydrogen thermometer, as to the accidental errors, amounts to 0°,02 corresponding in resistance to ± 0,010 Ω, while that of the determination of the resistance may be left out of consideration. We cannot decide as yet in how far the greater value of the differences between the observations and the formula is due to half systematic errors or to the formula.

For the point of inflection in the curve representing the resistance as a function of the temperature we find according to B — 180° [2]).

In conclusion we wish to express hearty thanks to Miss T. C. JOLLES and Mr. C. BRAAK for their assistance in this investigation.

Physics. — "*On the measurement of very low temperatures. XII. Comparison of the platinum resistance thermometer with the gold resistance thermometer.*" By Prof. H. KAMERLINGH ONNES and J. CLAY. Communication N°. 95^d from the Physical laboratory at Leiden.

(Communicated in the meeting of June 30, 1906).

§ 1. *Introduction.* From the investigation of Comm. N°. 93, Oct. '04, VIII it was derived that as a metal for resistance thermometers at low temperatures gold would be preferable to platinum on account of the shape of the curve which indicates the relation between the resistance and the temperature.

Pure gold seems also better suited because, owing to the signification of this metal as a minting material, the utmost care has been bestowed on it for reaching the highest degree of purity and the quantity of admixtures in not perfectly pure gold can be exactly determined. The continuation to low temperatures of the measurements described in Comm. N°. 93 VIII — which had to be repeated because, although MEILINK's investigation just mentioned had proved the usefulness of the method, a different value for the resistance

1) The deviations of the last two lines differ a little from the original Dutch paper.

2) Owing to e being negative (B) gives no minimum; a term like that with e does not contradict, however, the supposition $w = \infty$ at $T = 0$ (§ 1) as the formula holds only as far as —259°.