Physics. — *Measurements on the electrical resistance of some metals below the boiling point of oxygen.* By W. TUYN. (Communication N⁰. 196*b* of the Physical Laboratory at Leiden). (Communicated by Prof. W. H. KEESOM).

(Communicated at the meeting of February 23, 1929).

§ 1. When collaborating with professor KAMERLINGH ONNES in measuring the electrical resistance of some metals in liquid helium, I had the opportunity to measure their resistances in liquid oxygen and hydrogen also. The results may follow here, as accurate measurements of this kind are few in number; for the sake of completeness some data obtained at liquid helium temperatures are added [1]).

Cryostat, stirring apparatus and temperature regulator are of the usual Leiden type. The measuring method used is that of compensating the potential at the ends of the unknown and a known resistance, connected in series, with the aid of a DIESSELHORST compensation apparatus, free of thermo-forces, and supplied by O. WOLFF. The temperatures of the baths were measured and regulated with a platinum thermometer, allmost allways *Pt-23-1915* [2]), after the method of overlapping shunts according to KOHLRAUSCH; the platinum thermometer was calibrated with the helium gasthermometer. Zero-point determinations were made in the way, described allready before. [3])

As this paper must be regarded as a continuation on others, we may refer to the latter [4]) for details about the resistances, such as the purity of the material used and the manner in which they are constructed.

§ 2. *Cadmium.* The resistances are *Cd*-1919-*I* and *Cd*-1920-*I* and *II.* The material was obtained from KAHLBAUM, but the sample for

[1]) Some of the data given in this paper have been used for composing Comm. Leiden Suppl. N⁰. 58, by W. TUYN and H. KAMERLINGH ONNES.

[2]) This thermometer, made in 1915, has been described by J. PALACIOS MARTINEZ and H. KAMERLINGH ONNES in Comm. Leiden N⁰. 156*b*; an interpolation table below —80° C. was given in Comm. Leiden Suppl. N⁰. 58.

[3]) H. KAMERLINGH ONNES and W. TUYN. Comm. Leiden N⁰. 160*a*.

[4]) H. KAMERLINGH ONNES and W. TUYN. Comm. Leiden N^os 160*a* and *b*; W. TUYN and H. KAMERLINGH ONNES. Comm. Leiden N^os 167*a* and 181.

the first resistance was the eldest. The two first resistances have been described and their different behaviour in liquid helium treated in an earlier paper. [1]) Data are given in table I.

TABLE I. *Cd* — 1919 — *I*.
Cd — 1920 — *I*.
Cd — 1920 — *II*.

$\frac{T.}{^{\circ}K.}$	$(R/R_0)_{Cd-1919-I}$	$(R/R_0)_{Cd-1920-I}$	$(R/R_0)_{Cd-1920-II}$
90.41	0.28913	0.28820	
90.40			0.28907
81.02	0.25219		0.25218
81.01		0.25125	
73.06		0.21967	
73.05	0.22060		0.22061
65.99	0.19251	0.19158	0.19256
56.77	0.15572	0.15475	0.15581
20.51	0.02362	0.02267	0.02386
18.06	0.01759	0.01666	0.01786
16.53	0.01424	0.01331	0.01450
14.22	0.00997	0.00907	0.01022
4.22	0.00290	0.00143	
3.42	0.00237	0.00141	
2.81	0.00063		
2.62	supra-conductive		
1.46		0.00140	

Copper. Natural copper crystals were obtained from professor W. WIEN at Würzburg. In an other paper [1]) particularities were given of the resistances, made from these crystals. The results of the measurements are given in table II.

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[1]) W. TUYN and H. KAMERLINGH ONNES. Comm. Leiden N⁰. 181.

TABLE II. *Cu* — crystals — *I* — WIEN.
Cu — crystals — *III* — WIEN.
Cu — crystals — *IV* — WIEN.

$\frac{T.}{^{\circ}K.}$	$(R/R_0)_{Cu-I}$	$(R/R_0)_{Cu-III}$	$(R/R_0)_{Cu-IV}$
88.56	0.1918	0.1749	0.1730
81.05	0.1578	0.1440	0.1407
73.11	0.1252	0.1103	0.1088
66.15	0.0966	0.0840	0.0821
55.00	0.0551	0.0469	0.0463
20.52	0.0042	0.0015	0.0018
18.03	0.0041	0.0013	0.0013
16.46	0.0035	0.0011	0.0012
14.32	0.0037	0.0010	0.0008

Gold. The wire *Au-*12-*1915*, described by CATH, KAMERLINGH ONNES and BURGERS [1]) as a drawn wire of 0.05 mm diameter, of pure minting gold, and also calibrated by them, was measured again in liquid oxygen and hydrogen. The calibration in liquid oxygen is the result of two series of measurements, a time of one year lying between both ; the agreement is good. Data are given in table III.

TABLE III. *Au* — 12 — 1915.

$\frac{T.}{^{\circ}K.}$	$(R/R_0)_{Au-12-1915}$	$\frac{T.}{^{\circ}K.}$	$(R/R_0)_{Au-12-1915}$
90.41	0.27342	56.77	0.13031
88.57	0.26565	56.76	0.13037
81.05	0.23407		
81.02	0.23400	20.51	0.00912
73.06	0.20008	18.06	0.00656
73.06	0.20015	16.53	0.00539
65.99	0.16992	14.22	0.00415
65.98	0.16983		

[1]) Comm. Leiden N^{0}. 152*c*.

Indium. From chemically pure indium, supplied by E. DE HAËN, G. m. b. H., the resistances *In*-1922-*I*,-*II*,-*III* and -*A* were made in the way, described allready before.[1]) The values of the resistances follow in table IV.

TABLE IV. *In*—1922—*I*. *In*—1922—*III*.
In—1922—*II*. *In*—1922—*A*.

$\frac{T.}{^{\circ}K.}$	$(R/R_0)_{In-1922-I}$	$(R/R_0)_{In-1922-II}$	$(R/R_0)_{In-1922-III}$	$(R/R_0)_{In-1922-A}$
90.30	0.3708	0.28759	0.28763	0.28905
79.03	0.3361	0.24922	0.24923	0.25054
71.02	0.3115	0.22202	0.22202	0.22319
63.12	0.2873	0.19527	0.19525	0.19635
54.79	0.2618	0.16717	0.16717	0.16815
20.45	0.1602	0.05739	0.05737	0.05781
18.14	0.1548	0.05173	0.05174	0.05213
16.48		0.04796	0.04796	
16.47	0.1511			0.04834
14.20	0.1463	0.04317	0.04315	0.04352
4.22	0.1373		0.03390	0.03420
3.60	0.1372	0.03392		0.03418
3.42	0.1371	0.03387	0.03381	0.03392
3.40	0.1364	supra-conductive	supra-conductive	supra-conductive
3.38	supra-conductive			

Lead. The resistances *Pb*-1919-*I* (made of *Pb* "KAHLBAUM") and *Isotope Pb*-1919-*I* (*RaG*), described allready before[2]), were measured again May 1922, when placed in different baths. The temperature-resistance curve, for liquid hydrogen, does not wholly coincide with that found two years before[3]), the additive resistance having changed. Measurements are given in table V.

[1]) W. TUYN and H. KAMERLINGH ONNES. Comm. Leiden N⁰. 167*a*.
[2]) H. KAMERLINGH ONNES and W. TUYN. Comm. Leiden N⁰. 160*b*.
[3]) W. TUYN and H. KAMERLINGH ONNES. Comm. Leiden N⁰. 181.

TABLE V. *Pb*—1919—*I*.
Isotope Pb—1919—*I*.

$\frac{T.}{°K.}$	$(R/R_0)_{Pb-1919-I}$	$(R/R_0)_{Isotope\ Pb-1919-I}$	$\triangle (R/R_0)_{Pb-Isot.\ Pb}$
88.56	0.28947	0.28962	— 0.00015
81.05	0.26171	0.26178	7
73.11	0.23208	0.23218	10
66.15_5	0.20600	0.20617	17
55.00	0.16384	0.16397	13
20.52	0.03014	0.03042	28
18.02_5	0.02188	0.02215	27
16.46	0.01715	0.01742	27
14.32	0.01135	0.01164	29
7.2	supra-conductive	supra-conductive	

Platinum. As the platinum wire is the usual auxiliary thermometer,

TABLE VI. *Pt* — 1914 — *C*.
Pt — 1914 — *D*.

$\frac{T.}{°K.}$	$(R/R_0)_{Pt-1914-C}$	$(R/R_0)_{Pt-1914-D}$	$\triangle (R/R_0)_{C-D}$
88.57	0.25054	0.24894	0.00160
81.05		0.21680	
73.06		0.18275	
65.98	0.15490	0.15310	180
56.76	0.11771	0.11582	189
20.47	0.02082	0.01886	196
18.04	0.01893	0.01700	193
16.47	0.01798	0.01606	192
14.16	0.01696	0.01503	193
4.23	0.01559	0.01372	187
2.62	0.01556	0.01369	187
1.36		0.01370	

Data on this metal may be found in the publications of several laboratories. It therefore seems unnecessary at this moment to publish the calibrations of the platinum resistance thermometers, kept in the archives of the Leiden laboratory. We must however make an exception for the wires *Pt*-1914-*C* and -*D*, probably sent to Leiden by H. SCHULTZE of the P. T. R. at Charlottenburg, before the war. After a private communication of professor KAMERLINGH ONNES this was done to test them on supra-conductivity, for in that time it was thought possible that each metal could become supra-conductive when absolutely pure, and both wires were supposed to be of high purity. Both resistances have been described allready before. [1]) Data are given in table VI. (See p. 119).

Thallium. The resistances measured, made of thallium from KAHLBAUM, are *Tl*-1916-*VIII* and *Tl*-1916-*IX*, described in an earlier paper. [2]) Data are given in table VII.

TABLE VII. *Tl* — 1916 — *VIII*.
Tl — 1916 — *IX*.

$\frac{T.}{{}^{\circ}K.}$	$(R/R_0)_{Tl-1916-VIII}$	$(R/R_0)_{Tl-1916-IX}$	$\triangle (R/R_0)_{VIII-IX}$
88.57	0.27286	0.27205	+ 0.00081
81.05	0.24611	0.24529	82
73.06	0.21775	0.21692	83
65.98	0.19272	0.19187	85
56.76	0.16009	0.15929	80
20.47	0.03116	0.03023	93
18.04	0.02379	0.02286	93
16.47	0.01935	0.01841	94
14.16	0.01350	0.01259	91
4.23	0.00168	0.00084	84
3.26	0.00155	0.00072	83
2.62	0.00151	0.00069	82
2.48	0.00149	0.00066	83
2.47	supra-conductive	supra-conductive	

Tin. Four of the resistances *Sn*-1922-*I*, -*II*, -*III*, -*IV*, -*V* and -*VI*, all made of tin "KAHLBAUM", have been described before [1]); the remaining two are of the same type. Data are given in tables VIII and IX.

[1]) W. TUYN and H. KAMERLINGH ONNES. Comm. Leiden N⁰. 181.
[2]) H. KAMERLINGH ONNES and W. TUYN. Comm. Leiden N⁰. 160*a*.

TABLE VIII. *Sn* — 1922 — *I*.
Sn — 1922 — *II*.
Sn — 1922 — *III*.

$\frac{T.}{°K.}$	$(R/R_0)_{Sn-1922-I}$	$(R/R_0)_{Sn-1922-II}$	$(R/R_0)_{Sn-1922-III}$
90.01	0.26230	0.26039	0.25777
78.73	0.21723	0.21550	0.21311
71.02	0.18654	0.18485	0.18257
63.16	0.15499	0.15343	0.15146
57.49	0.13226	0.13087	0.12909
20.51	0.01283	0.01262	0.01236
17.96	0.00883	0.00868	0.00846
16.40	0.00680	0.00668	0.00653
13.98	0.00428	0.00420	0.00408
3.77	0.00079		
3.72	supra-conductive	supra-conductive	supra-conductive

TABLE IX. *Sn* — 1922 — *IV*.
Sn — 1922 — *V*.
Sn — 1922 — *VI*.

$\frac{T.}{°K.}$	$(R/R_0)_{Sn-1922-IV}$	$(R/R_0)_{Sn-1922-V}$	$(R/R_0)_{Sn-1922-VI}$
90.01	0.26064	0.25975	0.25966
78.73	0.21593	0.21503	0.21496
71.02	0.18550	0.18460	0.18448
63.16	0.15414	0.15327	0.15318
57.49	0.13157	0.13074	0.13066
20.51	0.01277	0.01270	0.01267
17.96	0.00878	0.00877	0.00875
16.40	0.00674	0.00675	0.00673
13.98	0.00423	0.00426	0.00425
3.77	0.00075	0.00082	0.00080
3.72	supra-conductive	supra-conductive	supra-conductive

TABLE X. *Sn* — single — crystal — 1922 — *VII*.
Sn — 1922 — *A*.

$\frac{T.}{^{\circ}K.}$	$(R/R_0)_{Sn-single\ crystal-1922-VII}$	$(R/R_0)_{Sn-1922-A}$	$\Delta\ (R/R_0)_{VII-A}$
90.30	0.2774	0.25449	0.0229
79.02	0.2292	0.20983	0.0194
71.02	0.1942	0.17792	0.0163
63.12	0.1559	0.14676	0.0091
54.79	0.1216	0.11450	0.0071
20.45	0.0133	0.01162	0.0017
18.14	0.0100	0.00836	0.0016
16.48	0.0082	0.00637	0.0018
14.20	0.0058	0.00409	0.0017
4.23		0.00100	
3.76		0.00099	
3.72		supra-conductive	

TABLE XI. *Zn*—1921— *I*.
Zn—1921—*II*.

$\frac{T.}{^{\circ}K.}$	$(R/R_0)_{Zn-1921-I}$	$(R/R_0)_{Zn-1921-II}$	$\Delta\ (R/R_0)_{I-II}$
88.72	0.25367	0.25300	0.00067
81.04	0.22136	0.22078	58
72.71	0.18643	0.18581	62
66.10	0.15901	0.15838	63
57.86		0.12505	
57.83	0.12552		
20.48_5	0.01383	0.01278	0.00105
17.99	0.01119	0.01006	113
16.45	0.00984	0.00875	109
14.24	0.00838	0.00738	100
4.22	0.00378		
1.40	0.00378		

In order to obtain an idea about the behaviour of a single-crystal, regarding its electrical conductivity at low temperatures, a comparison was made between the single-crystal *Sn-single-crystal-*1922-*VII*, procured by the PHILIPS LAMPWORKS, and the extruded wire *Sn*-1922-*A*, made of tin "KAHLBAUM". Unfortunately the single-crystal was damaged, before measurements in liquid helium were made. The difference between the resistances in liquid oxygen diminishes here; that of two *wires* remains nearly constant on the other side. Data are given in table X.

Zinc. The resistance *Zn*-1921-*I*, made of *Zn* "KAHLBAUM", has been described allready before [1]; the resistance *Zn*-1921-*II* was made in the same way. Data are given in table XI.

I express my hearty thanks to Miss H. VAN DER HORST for her help in measuring and regulating the temperatures with the platinum thermometer.

[1]) W. TUYN and H. KAMERLINCH ONNES. Comm. Leiden N0. 181.