X. ELECTRICAL RESISTIVITY of SOME METALLIC ELEMENTS and COMMERCIAL ALLOYS

CONTENTS

PREFACE to the ELECTRICAL RESISTIVITY of METALLIC ELEMENTS

The electrical resistivities of pure, or nearly pure, metallic elements are presented here as a function of temperature for the range from 1 to 300°K. These metallic elements include only those that exhibit an increase in resistivity with increasing temperature. These values of resistivity are presented as ratios, ρ/ρ_{273}, that is, the resistivity divided by the value of the resistivity at 273.15°K. The resistivity may then be determined as a product of the ratio and the value of ρ_{273} listed on the graph sheet for each metal. Each graph is for a separate metal and generally includes the values reported by several investigators. The several sources of data are listed on the data sheet and the individual curves on the graph are referenced by the author's name.

The several data sources used in this compilation reported the values of electrical resistivity in several forms, such as specific resistivity ρ, or values of resistivity ratio, ρ/ρ_T, where the datum temperature T, is not consistent from one reference to another. Often the value of resistivity for the datum temperature used in the resistivity ratio is not available. In this compilation, where the original data are values of resistivity, a common value of ρ_{273} is used in the calculation of the ratio. Where the original data are values of resistivity ratios, the value of ρ_{273} indicated on the graph sheet for calculation of resistivity is either the value of ρ_{273} from the original data in those instances where it was given, or the most probable value of ρ_{273} from another source when it is not available from the original experimenters. Where the original data are resistivity ratios, ρ/ρ_T, and T is not 273°K, a suitable correction has been used to convert the ratio to ρ/ρ_{273}.

Comments on sample purity, accuracy of the tabulated data and other pertinent information reported in the source of data are included in the comments for each data sheet. Some of the references list interpolated values between experimental data points. Where these interpolated values have been used in the construction of the graphs, the interpolated values are also listed in the tables of values and so indicated in a footnote.

The graphs of the electrical resistivity ratios are presented on linear, semi-log or logarithmic coordinates as necessary for satisfactory representation of the data. The use of logarithmic coordinates serves to emphasize the differences in the values reported by the several experimenters at low temperatures. This variation may be attributed primarily to differences in the purity of the sample measured or in some cases to the use of a sample with residual mechanical strains that were not relieved by annealing.

The graphs also serve to illustrate Matthiessen's rule that the increase of resistance in pure metals due to imperfections in the crystal lattice structure is independent of temperature. The resistivity of these nearly pure metals may thus be separated into two independent parts,

$$\rho = \rho_i + \rho_o$$

where ρ_i is the intrinsic resistivity (the electron-lattice interaction) and

is a function of temperature, and ρ_o is the imperfection resistivity (the electron-imperfection interaction) and is dependent on the type and concentration of the imperfections and is almost independent of temperature. The imperfections are either chemical impurities, isotopes, or mechanical imperfections such as vacancies, dislocations, etc., in the lattice structure. The effect of impurities is then to shift the curve uniformly upward. At very low temperatures ρ_o is much greater than ρ_i so that temperature change has little effect on the resistivity, while at high temperatures ρ_i is much greater than ρ_o, so that the differences in resistivity for various samples becomes relatively insignificant. The graphs on linear coordinates illustrates the above for those metals where alternate data sources are represented in a temperature range where ρ_o is much less than ρ_i and is evidenced by a constant vertical displacement of the data. Several theoretical and empirical equations have been proposed for the ideal resistivity as a function of temperature, but no general law, valid for all conductors, has come forward. The intrinsic electrical resistivity of most simple metals at intermediate temperatures however, may be adequately represented by an empirical equation of the form $\rho_i = aT^b$, where b varies from 4 to 5. This is further indicated on these data sheets, where a straight line may be used on the logarithmic coordinates to represent the data for large intervals of temperature.

When considering the resistivity of the metallic elements at low temperatures, the phenomenon of superconductivity should also be noted. Superconductivity is attributed to the complete absence of resistance to an electric current. Twenty-three metallic elements are presently known to exhibit superconductivity at various temperatures below 12°K.

This graphical presentation of the electrical resistivity of the superconducting elements does not include data in the superconducting temperature range. An exception is the data sheet for lead, where electrical resistivity data extending into the superconducting region appeared in the reference and were included in this compilation. These data below the transition temperature were based on actual observations of electrical resistance in lead in a super critical magnetic field at temperatures which would normally make lead a superconductor.

As in the case of lead, elements in the superconducting state when subjected to an external magnetic field of a given strength, will regain normal resistance to an electric current. The strength of this critical magnetic field depends on the element concerned and temperature. This relationship may be approximated by:

$$H_c = H_o \left[1 - (T/T_c)^2 \right]$$

where H_o is the value of the critical magnetic field (in oersteds) at 0°K, T_c is the transition temperature (in °K) and H_c is the value of the critical field at a temperature T. Values for T_c and H_o are given in Table 2.

Table 1

Conversion Factors for Electrical Resistivity

ρ	ohm-cm	ohm-in	ohm-cir mil/ft
1 ohm-cm =	1.000	0.3937	6.015×10^{6}
1 ohm-in =	2.540	1.000	1.528×10^{7}
1 ohm-cir mil/ft =	1.662×10^{-7}	6.545×10^{-8}	1.000

Table 2

Transition Temperatures for Superconducting Elements *

Element	Transition Temp., °K	Critical Magnetic Field Ho, Oersteds
Aluminum	1.175	106
Cadmium	0.56 - 0.65	27 - 28.8
Gallium	1.103	47 - 50.3
Hafnium	0.37	
Mercury	4.160	400 - 419
Indium	3.374 - 3.432	269 - 275
Lanthanum	4.8, 5.8	
Niobium	8.7 - 8.9	1960
Osmium	0.71	65
Lead	7.22	800
Rhenium	1.70	188
Rhodium	0.9	
Ruthenium	0.47	46
Tin	3.74	304 - 310
Tantalum	4.38	860
Technetium	11.2	
Thorium	1.388 - 1.40	131
Titanium	0.39	100
Thallium	2.392	171
Uranium	1.1	
Vanadium	4.89	1340
Zinc	0.93	42 - 52.5
Zirconium	0.55	46.6

* American Institute of Physics Handbook, McGraw-Hill Book Co. Inc., New York (1957) Sec. 4, P. 49

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ELECTRICAL RESISTIVITY of ALUMINUM, Al

(Atomic Number 13)

Sources of Data:

Landolt-Börnstein Zahlenwerte und Funktionen aus Physik, Chemie, Astronomie, Geophysik und Technik, sechste Auflage, II Band, 6 Teil, Springer-Verlag, Berlin (1959) pp. 1-46

International Critical Tables of Numerical Data, Physics, Chemistry, and Technology, VI, 1st Edition, Published for the National Research Council by the McGraw-Hill Book Co. Inc. (1929) pp. 124-135

Other References:

Albert, P., Bull. inst. intern. froid, Annexe 1956-2, 41-49 (1956)

Alley, P. and Serin, B.; Phys. Rev. 116, No. 2, 334-338 (1959)

Boorse, H. A. and Niewodniczanski, H., Proc. Roy. Soc. (Loncon) A153, 463-475 (1936)

Caron, M., Bull. inst. intern froid, Annexe 1956-2, 51-62 (1956)

Caron, M., Compt. rend. 236, 1169 (1953)

Caron, M., Albert, P. and Chaudron, G., Compt. rend. 236, 686-688 (1954)

Chaudron, G., Nature 174, 923 (1954)

Grüneisen, E. and Goens, E.; Z. Physik. 44, 615 (1927)

Holborn, L.; Z. Instrumentenk. 22, 114 (1902)

Holborn, L.; Ann. Physik. 59, 145 (1919)

Justi, F. and Scheffers, H.; Physik. Z. 39, 105 (1938)

Meissner, W. and Voigt, B.; Ann. Physik. (5) 7, 761, 892 (1930)

Thomas, J. G. and Mendoza, E.; Phil. Mag. (7) 43, 900 (1952)

Comments:

Reference should be made to the preface at the beginning of the Electrical Resistivity section for an explanation of the graph. The value of electrical resistivity at 273°K (ρ_{273}) for aluminum to be used in calculating values of electrical resistivity (ρ_T) is listed below the authors' names labeling each individual curve on the graph. These curves should not be extrapolated to lower temperatures since aluminum becomes superconducting at 1.175°K.

The data for this graph were taken from the references cited above under "Sources of Data". The values listed in the Landolt-Börnstein tables are those reported by Grüneisen and Goens; Holborn (1919); Justi and Scheffers; Meissner and Voigt; and Thomas and Mendoza, while those values listed by the International Critical Tables are from Holborn (1902 and 1919). These primary sources are listed above under "Other References". The original authors are used in labeling the several curves on the graph.

Comments: (cont.)

The data reported in the Landolt-Börnstein tables, the International Critical Tables and tabulated here are listed as ratios of electrical resistivity with respect to the resistivity at a datum temperature of 273°K. The value of ρ_{273} to be used with the Holborn data in calculating values of electrical resistivity is $\rho_{273} = 2.53 \times 10^{-6}$ ohm-cm. The actual values of ρ_{273} are not available for the samples used by the other investigators so a datum value reported by Grüneisen and Goens ($\rho_{273} = 2.50 \times 10^{-6}$ ohm-cm) is suggested for calculating values of electrical resistivity from the remaining ratios.

The samples used by Holborn are reported in Landolt-Börnstein as polycrystalline with 0.4% impurities of unknown composition. The Holborn sample was annealed at 250°C. Grüneisen and Goens are reported to have used a polycrystalline sample with a small amount of impurities present. The sample used by Meissner and Voigt is reported as an annealed polycrystalline sample with undetermined impurities.

A single crystal with a small amount of impurities present is reported as the sample used by Justi and Scheffers. The sample used by Thomas and Mendoza was an annealed polycrystalline sample with 0.005% impurities of unknown composition. No other pertinent information was presented about any of the samples from any of the sources of data.

Tables of Values of Electrical Resistivity

ρ = Resistivity, (ohm-cm)

ρ_{273} = Resistivity at 273°K, (ohm-cm)

Holborn					
Temp. °C	$100\rho/\rho_{273}$	Temp. °C	$100\rho/\rho_{273}$	Temp. °C	$100\rho/\rho_{273}$
- 78.3*	64.80*	-140	37.7	-200	12.0
- 80	64.1	-160	28.9	-220	7.1
-100	55.2	-180	20.2	-240	4.9
-120	46.4	-191.9*	14.85*	-253*	4.27*
		-192.9*	14.49*		

* Observed values. All other values have been interpolated.

Justi and Scheffers		Meissner and Voigt		Thomas and Mendoza	
Temp. °K	ρ/ρ_{273}	Temp.* °K	ρ/ρ_{273}	Temp. °K	ρ/ρ_{273}
14	0.0014	1.35	0.0067	4	0.0026
20	0.0018	4.21	0.0065		
		20.44	0.0075		
		77.7	0.1008		

* The second decimal place of the temperature values is somewhat in doubt.

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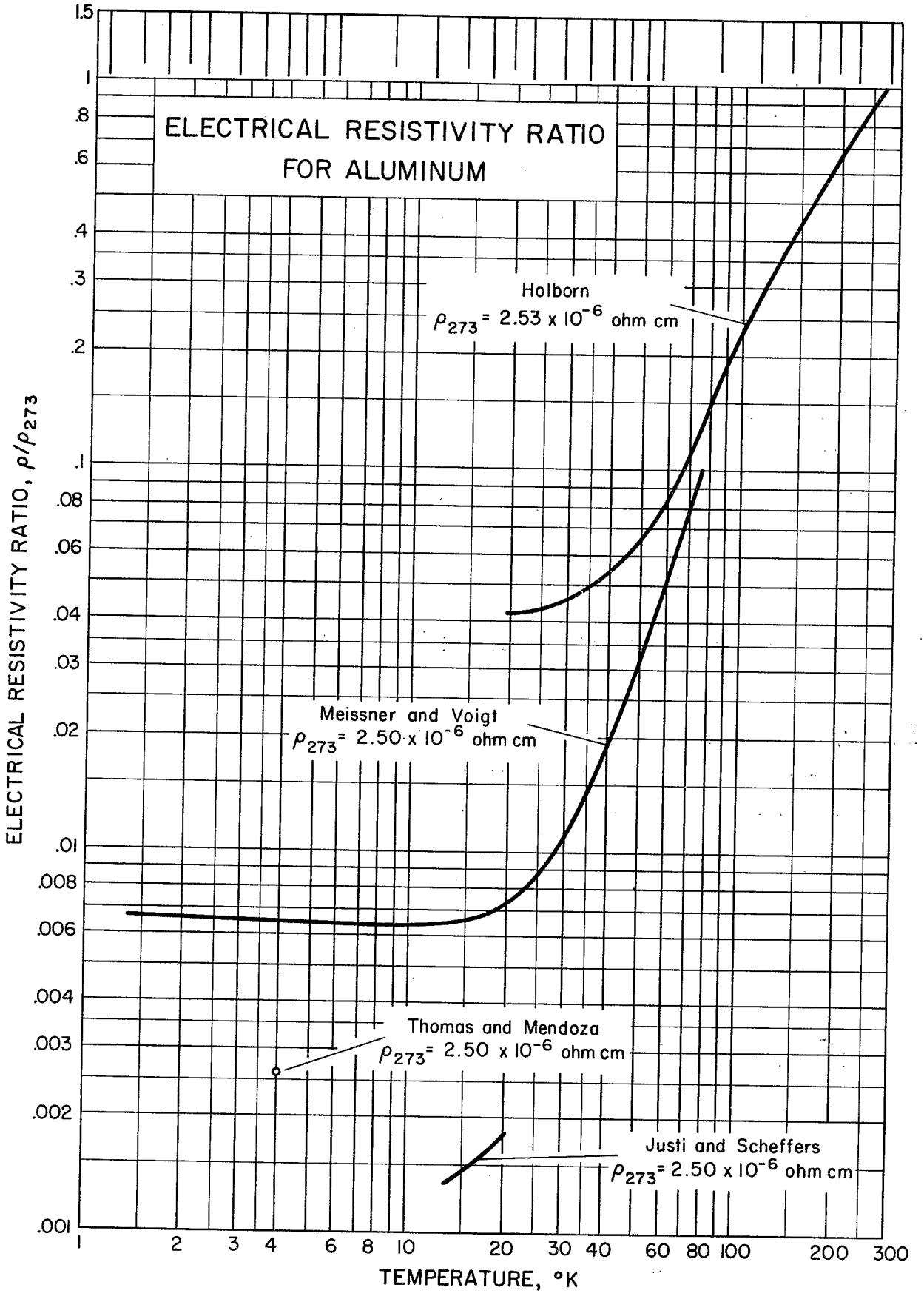
ELECTRICAL RESISTIVITY RATIO FOR ALUMINUM
Holborn
ρ_{273} = 2.53 x 10^{-6} ohm cm
Meissner and Voigt
ρ_{273} = 2.50 x 10^{-6} ohm cm
Thomas and Mendoza
ρ_{273} = 2.50 x 10^{-6} ohm cm
Justi and Scheffers
ρ_{273} = 2.50 x 10^{-6} ohm cm
ELECTRICAL RESISTIVITY RATIO, ρ/ρ_{273}
TEMPERATURE, °K
1.5
1
.8
.6
.4
.3
.2
.1
.08
.06
.04
.03
.02
.01
.008
.006
.004
.003
.002
.001
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20
30
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80
100
200
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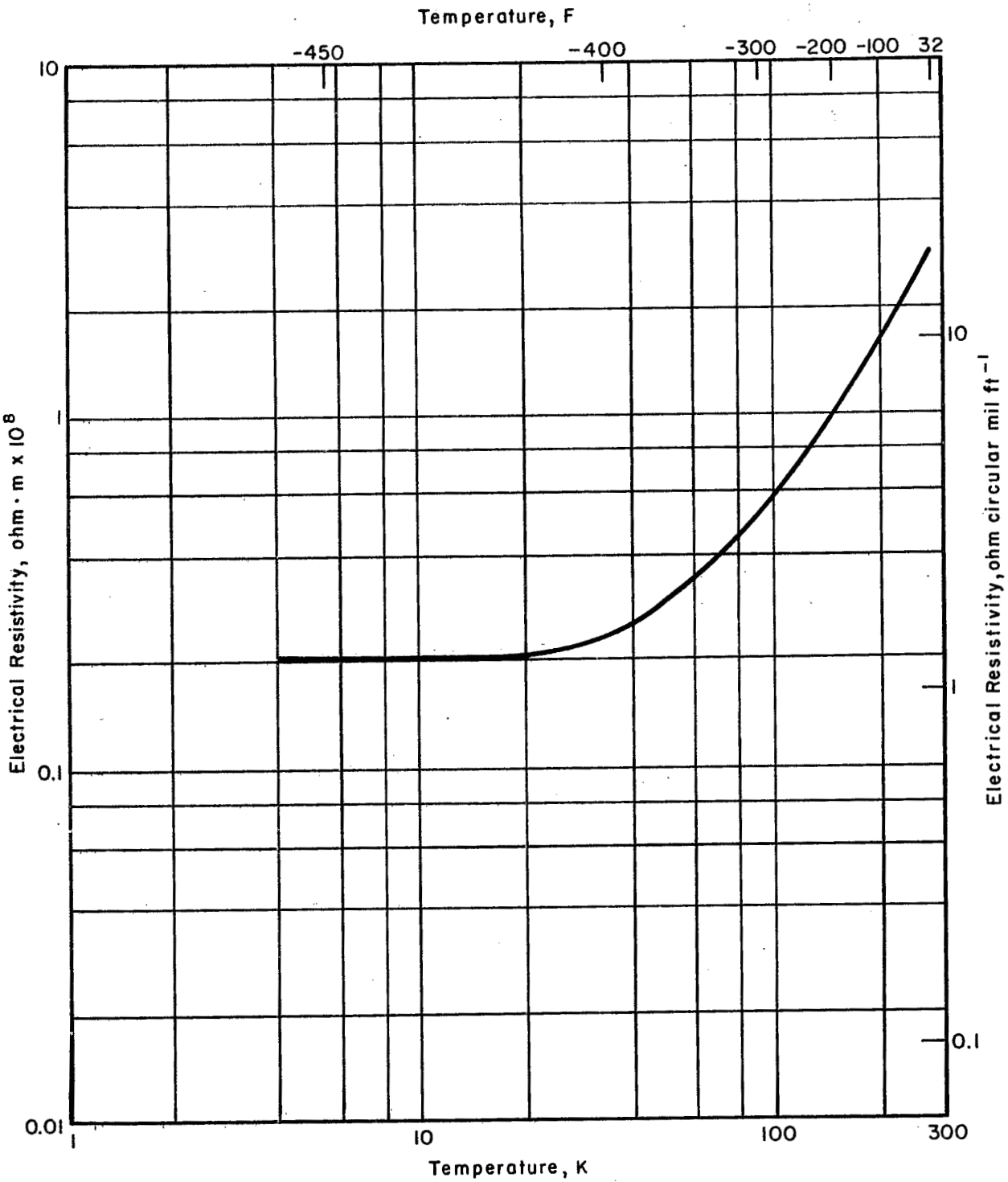

ELECTRICAL RESISTIVITY VERSUS TEMPERATURE FOR ALUMINUM ALLOY 1100-0

ELECTRICAL RESISITIVITY of BERYLLIUM, Be

(Atomic Number 4)

Source of Data:

Landolt-Börnstein Zahlenwerte und Funktionen aus Physik, Chemie, Astronomie, Geophysik und Technik, sechste Auflage, II Band, 6 Teil, Springer-Verlag, Berlin (1959) pp. 1-46

Other References:

Lewis, E. J.; Phys. Rev. 34, 1575 (1929)

Mac Donald, D. K. C. and Mendelssohn, K.; Proc. Roy. Soc. (London) A202, 523 (1950)

Meissner, W. and Voigt, B.; Ann. Physik (5) 7, 761, 892 (1930)

Powell, R. W.; Phil. Mag. 44, 645 (1953)

Comments:

Reference should be made to the preface at the beginning of the Electrical Resistivity section for an explanation of the graph. The value of electrical resistivity at 273°K (ρ_{273}) for beryllium to be used in calculating values of electrical resistivity (ρ_T) is 3.2×10^{-6} ohm-cm.

The data for this graph were taken from the reference cited above under "Source of Data". The values taken from Landolt-Börnstein tables are those reported by the authors listed above under "Other References". The original authors are used in labeling the three curves on the graph.

The data reported in Landolt-Börnstein and tabulated here are listed as ratios of electrical resistivity with respect to the resistivity at a datum temperature of 273°K. The actual value of ρ_{273} is not available for the several authors' data appearing on the graph so a datum value reported by R. W. Powell ($\rho_{273} = 3.2 \times 10^{-6}$ ohm-cm) is suggested for calculating values of resistivity from these ratios. Powell reports 0.4% impurities of unknown composition in the polycrystalline sample used in determining ρ_{273}.

The Landolt-Börnstein tables list the samples used by all of the authors as being of the polycrystalline type. No mention of impurities is made for the samples used by MacDonald and Mendelssohn; and Lewis. The sample used by Meissner and Voigt is reported to have had 2% Fe and 0.5% Bi impurities present. No mention is made of the mechanical or heat treatment of any of the samples.

ELECTRICAL RESISTIVITY of BERYLLIUM (Cont.)

Tables of Values of Electrical Resistivity

ρ = Resistivity, (ohm-cm)

ρ_{273} = Resistivity at 273°K, (ohm-cm)

Lewis	
Temp. °K	ρ/ρ_{273}
84.2	0.273
196.2	0.586
294.2	1.174

MacDonald and Mendelssohn	
Temp. °K	ρ/ρ_{290} *
4.2	0.276
20.4	0.276
90.0	0.322

Meissner and Voigt	
Temp.** °K	ρ/ρ_{273}
1.35	0.3077
2.38	0.3075
4.22	0.3075
20.44	0.3075
81.7	0.3229

* The third decimal place of the resistivity values is somewhat in doubt.

** The second decimal place of the temperature values is somewhat in doubt.

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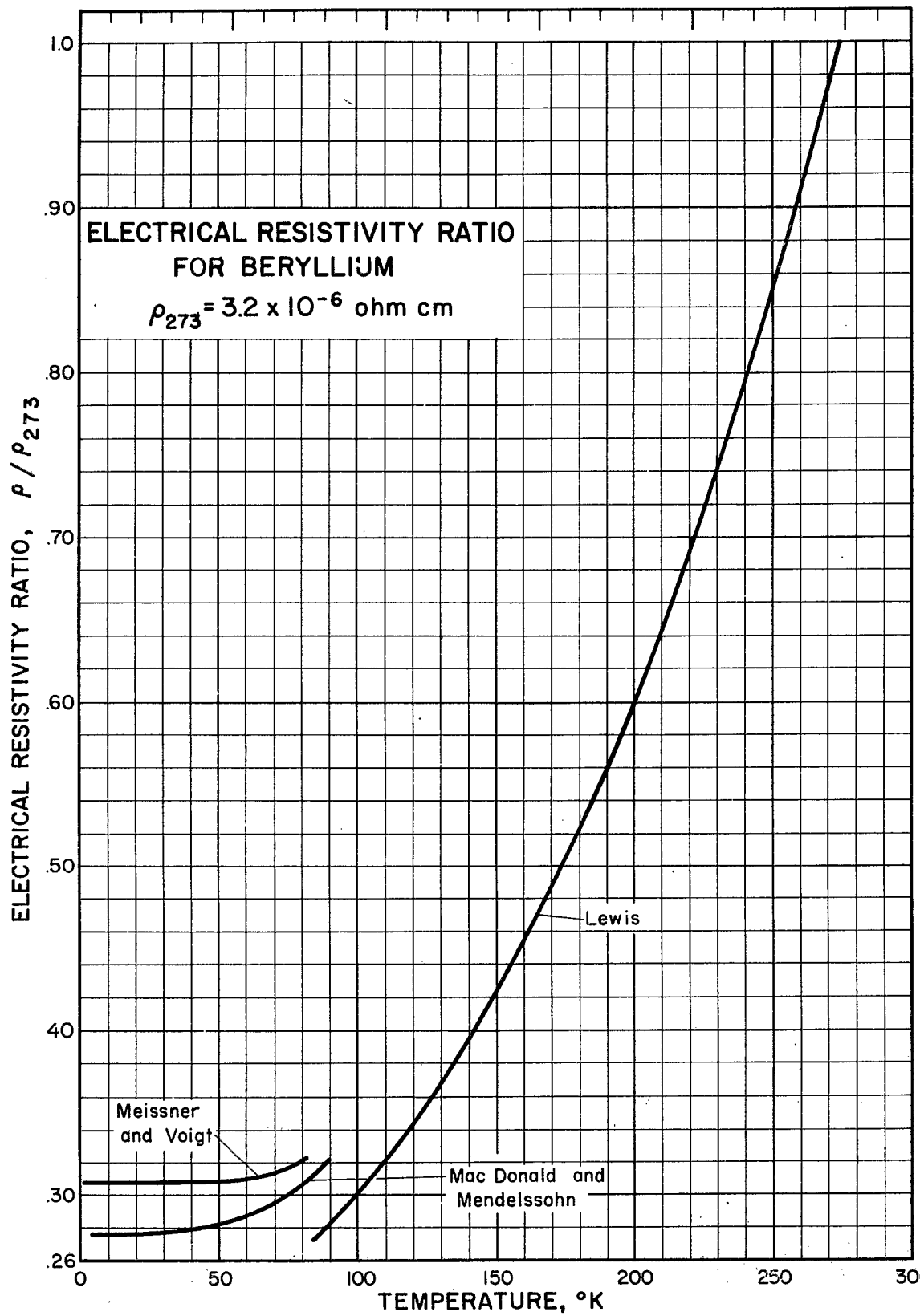
ELECTRICAL RESISTIVITY RATIO
FOR BERYLLIUM
$\rho_{273} = 3.2 \times 10^{-6}$ ohm cm
ELECTRICAL RESISTIVITY RATIO, ρ / ρ_{273}
1.0
.90
.80
.70
.60
.50
.40
.30
.26
0
50
100
150
200
250
300
TEMPERATURE, °K
Lewis
Meissner and Voigt
Mac Donald and Mendelssohn

ELECTRICAL RESISTIVITY of COBALT, Co

(Atomic Number 27)

Sources of Data:

International Critical Tables of Numerical Data, Physics, Chemistry, and Technology, VI, 1st Edition, Published for the National Research Council by the McGraw-Hill Book Co. Inc. (1929) pp. 124-135

Landolt-Börnstein Zahlenwerte und Funktionen aus Physik, Chemie, Astronomie, Geophysik und Technik, sechste Auflage, II Band, 6 Teil, Springer-Verlag, Berlin (1959) pp. 1-46

Other References:

Bridgman, P. W.; Proc. Am. Acad. Arts. Sci. 79, 149 (1940)

Meissner, W. and Voigt, B.; Ann. Physik (5) 7, 761, 892 (1930)

Schimank, H.; Ann. Physik 45, 706 (1914)

Comments:

Reference should be made to the preface at the beginning of the Electrical Resistivity section for an explanation of the graph. The value of electrical resistivity at 273°K (ρ_{273}) for cobalt to be used in calculating values of electrical resistivity (ρ_T) is 5.57×10^{-6} ohm-cm.

The data for this graph were taken from the references cited above under "Sources of Data". The values listed in the Landolt-Börnstein tables are those reported by Meissner and Voigt; and Bridgman; while those values appearing in the International Critical Tables are from Schimank. These primary sources are cited above under "Other References". The original authors are used in labeling the two curves on the graph.

The data in Landolt-Börnstein tables; the International Critical Tables and tabulated here are listed as ratios of electrical resistivity with respect to the resistivity at a datum temperature of 273°K. The actual values of ρ_{273} for the samples used by the several investigators are not available so a datum value reported by Bridgman ($\rho_{273} = 5.57 \times 10^{-6}$ ohm-cm) is suggested for calculating values of electrical resistivity from these ratios.

The Landolt-Börnstein tables list the sample used by Meissner and Voigt as an annealed, sintered polycrystalline specimen with no mention made of impurities present. The sample used by Bridgman was reported as polycrystalline with a very small amount of impurities. No information is given on the amount of impurity or nature of the Schimank sample, and no further information is available on the mechanical strain or heat treatment for any of the samples from any of the sources of data.

Tables of Values of Electrical Resistivity

ρ = Resistivity, (ohm-cm)

ρ_{273} = Resistivity at 273°K, (ohm-cm)

Meissner and Voigt	
Temp. °K	ρ/ρ_{273}
1.5	0.0431
4.2	0.0426
20.4	0.0463
77.8	0.1516
86.9	0.1829

Schimank	
Temp. °C	$100\rho/\rho_{273}$
- 80*	57.4
-100*	48.2
-120*	32.3
-160*	24.8
-180*	17.4
-192	13.5
*Values from interpolation	

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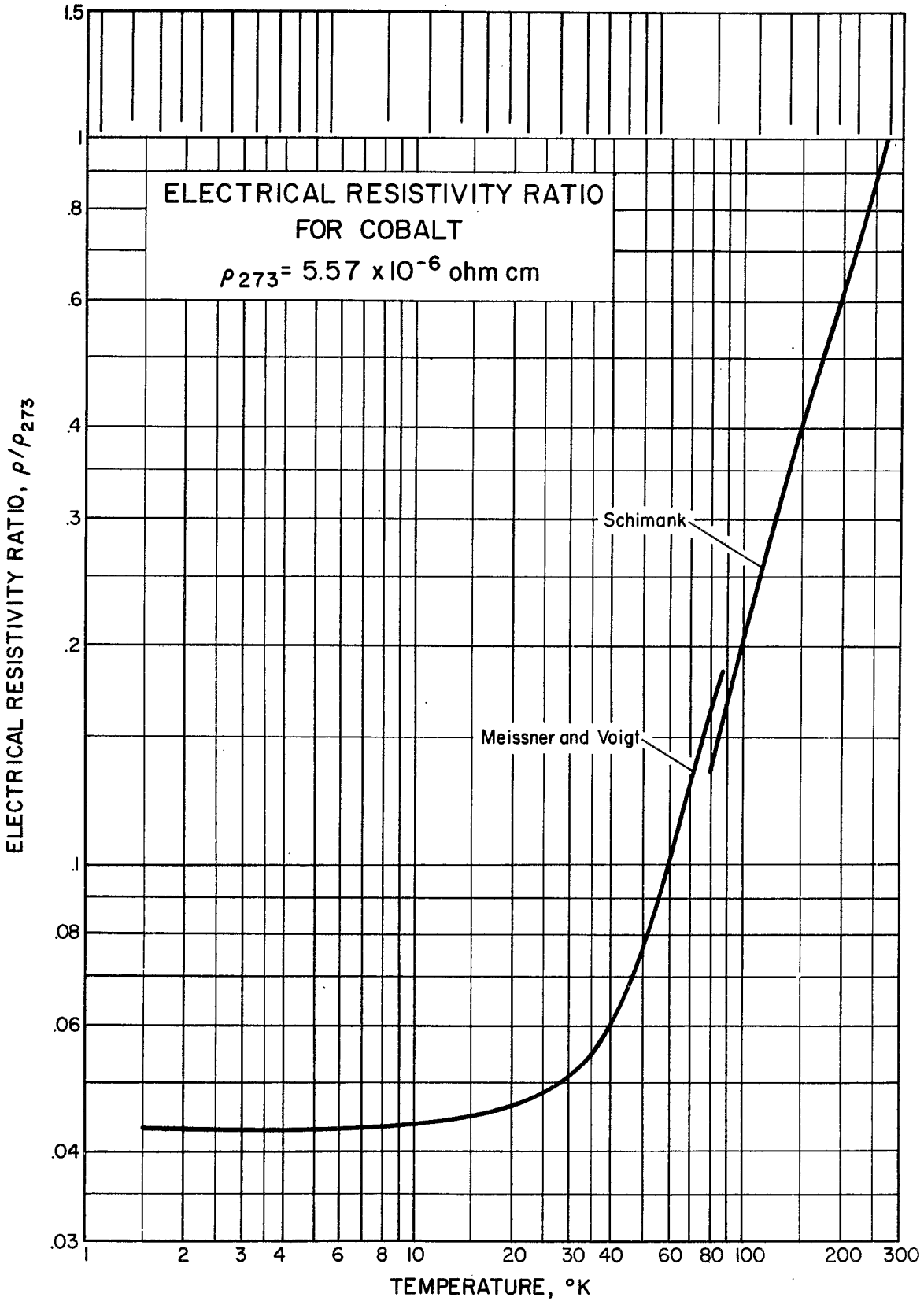
ELECTRICAL RESISTIVITY RATIO
FOR COBALT
ρ_{273}= 5.57 x10^{-6} ohm cm
Schimank
Meissner and Voigt
ELECTRICAL RESISTIVITY RATIO, ρ/ρ_{273}
TEMPERATURE, °K
1.5
1
.8
.6
.4
.3
.2
.1
.08
.06
.04
.03
1
2
3
4
6
8
10
20
30
40
60
80
100
200
300

ELECTRICAL RESISTIVITY of COPPER, Cu
(Atomic Number 29)

Sources of Data:

International Critical Tables of Numerical Data, Physics, Chemistry, and Technology, VI, 1st Edition, Published for the National Research Council by the McGraw-Hill Book Co. Inc. (1929) pp 124-135

Landolt-Börnstein Zahlenwerte und Funktionen aus Physik, Chemie, Astronomie, Geophysik und Technik, sechste Auflage, II Band, 6 Teil, Springer-Verlag, Berlin (1959) pp 1-46

Other References:

de Haas, W. J. de Boer, J. H. and Van den Berg, G. J.; Physica II, 1115 (1934)

Henning, F.; Z. Physik. 5, 264 (1921)

Holborn, L.; Ann. Physik 59, 145 (1919)

Meissner, W.; Ann. Physik (4) 47, 1001 (1915)

Meissner, W.; Physik. Z. 29, 897 (1928)

Comments:

Reference should be made to the preface at the beginning of the Electrical Resistivity section for an explanation of the graph. The value of electrical resistivity at 273°K (ρ_{273}) for copper to be used in calculating values of electrical resistivity (ρ_T) is 1.55×10^{-6} ohm-cm.

The data for this graph were taken from the references cited above under "Sources of Data". The values listed in the Landolt-Börnstein tables are those reported by de Haas, de Boer and Van den Berg; Holborn; and Meissner; while those values appearing in the International Critical Tables are from Henning. These primary sources are listed above under "Other References". The original authors are used in labeling the curves on the graph.

The data in the Landolt-Börnstein tables, the International Critical Tables and tabulated here are listed as ratios of electrical resistivity with respect to the resistivity at a datum temperature of 273°K. The actual values of ρ_{273} for the samples used by the original investigators are not available so a datum value determined by Meissner in 1915 ($\rho_{273} = 1.55 \times 10^{-6}$ ohm-cm) is suggested for calculating values of electrical resistivity from these ratios.

The Landolt-Börnstein tables report the samples used by the authors appearing in their compilation as annealed polycrystalline specimens with a small amount of impurities present. No other pertinent information is given about any of the samples in any of the sources of data.

Tables of Values of Electrical Resistivity

ρ = Resistivity, (ohm-cm)

ρ_{273} = Resistivity at 273°K, (ohm-cm)

de Haas, de Boer and Van den Berg		Henning	
Temp. °K	ρ/ρ_{273}	Temp. °C	$100\rho/\rho_{273}$
1.55	0.00117	- 76	65.739
4.23	0.00119	-183	18.868
14.26	0.00128	-252.8	0.6291
20.47	0.00176		

Holborn		Meissner	
Temp. °K	ρ/ρ_{273}	Temp.* °K	ρ/ρ_{273}**
81	0.1502	1.32	0.00029
195	0.6602	1.97	0.00028
		4.20	0.00029
		20.42	0.00078
		81.6	0.144

* The second decimal place of the temperature values is somewhat in doubt.

**The fifth decimal place of the electrical resistivity ratio values is somewhat in doubt.

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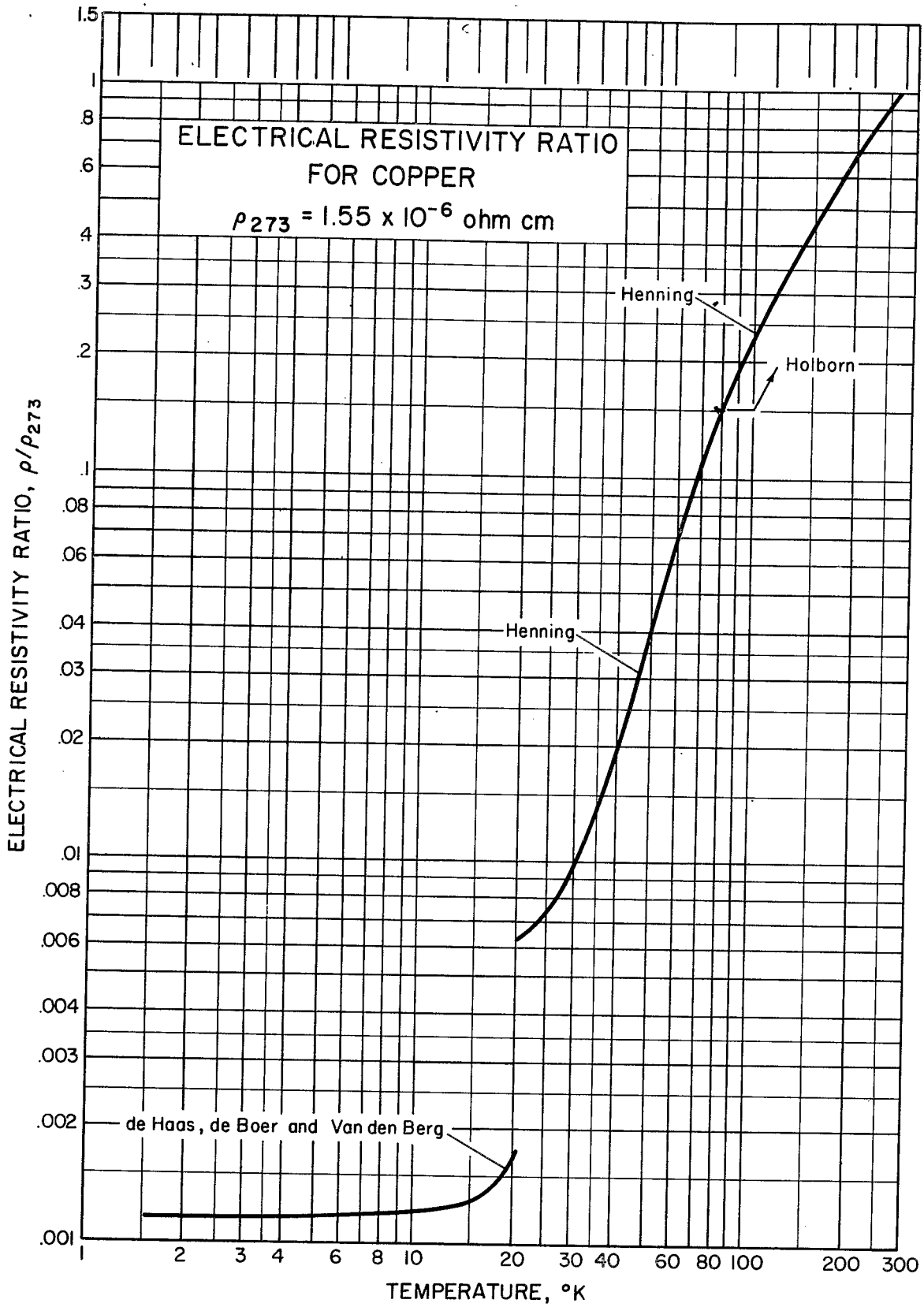
ELECTRICAL RESISTIVITY RATIO
FOR COPPER
$\rho_{273} = 1.55 \times 10^{-6}$ ohm cm
Henning
Holborn
Henning
de Haas, de Boer and Van den Berg
ELECTRICAL RESISTIVITY RATIO, ρ/ρ_{273}
1.5
1
.8
.6
.4
.3
.2
.1
.08
.06
.04
.03
.02
.01
.008
.006
.004
.003
.002
.001
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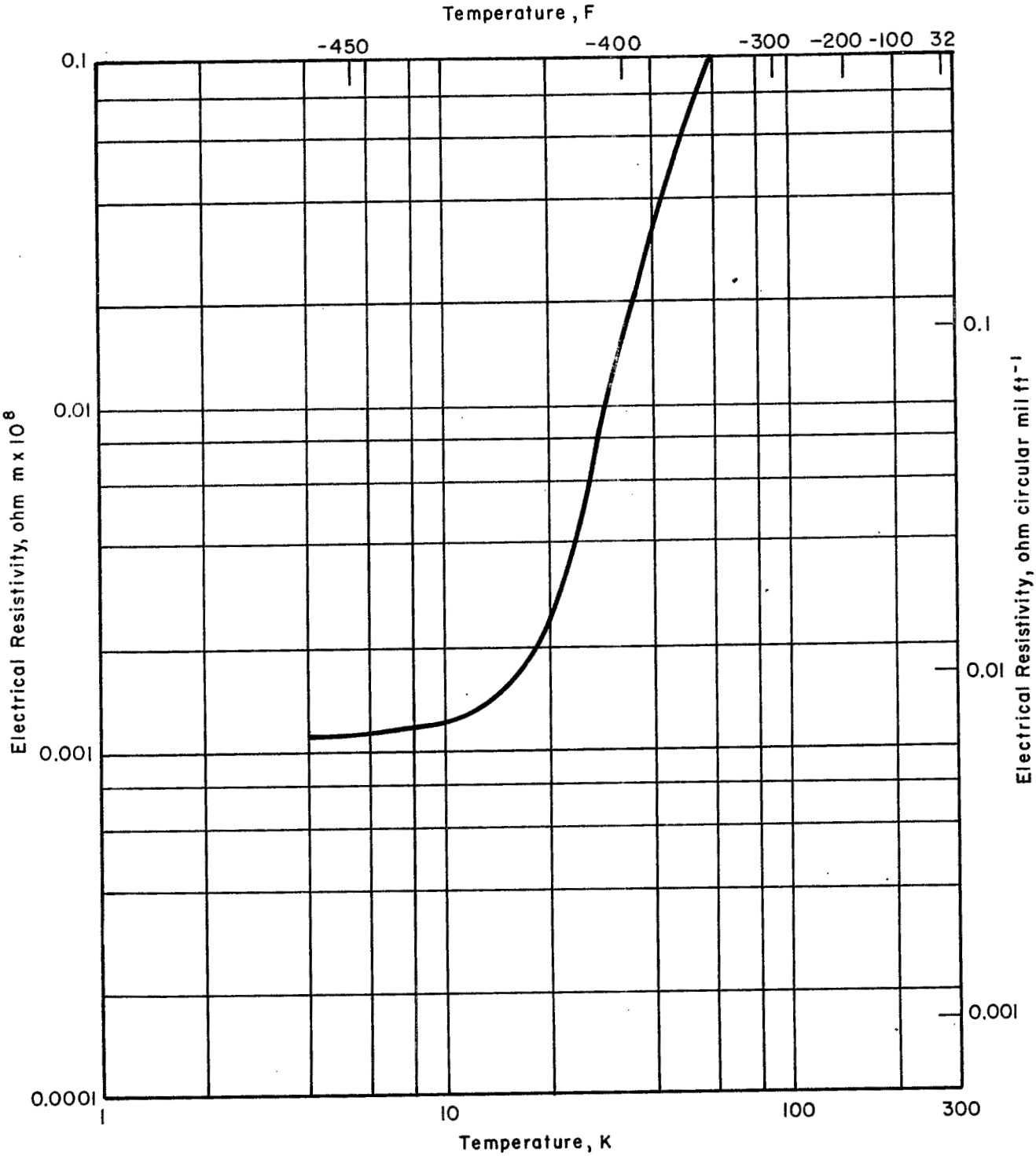
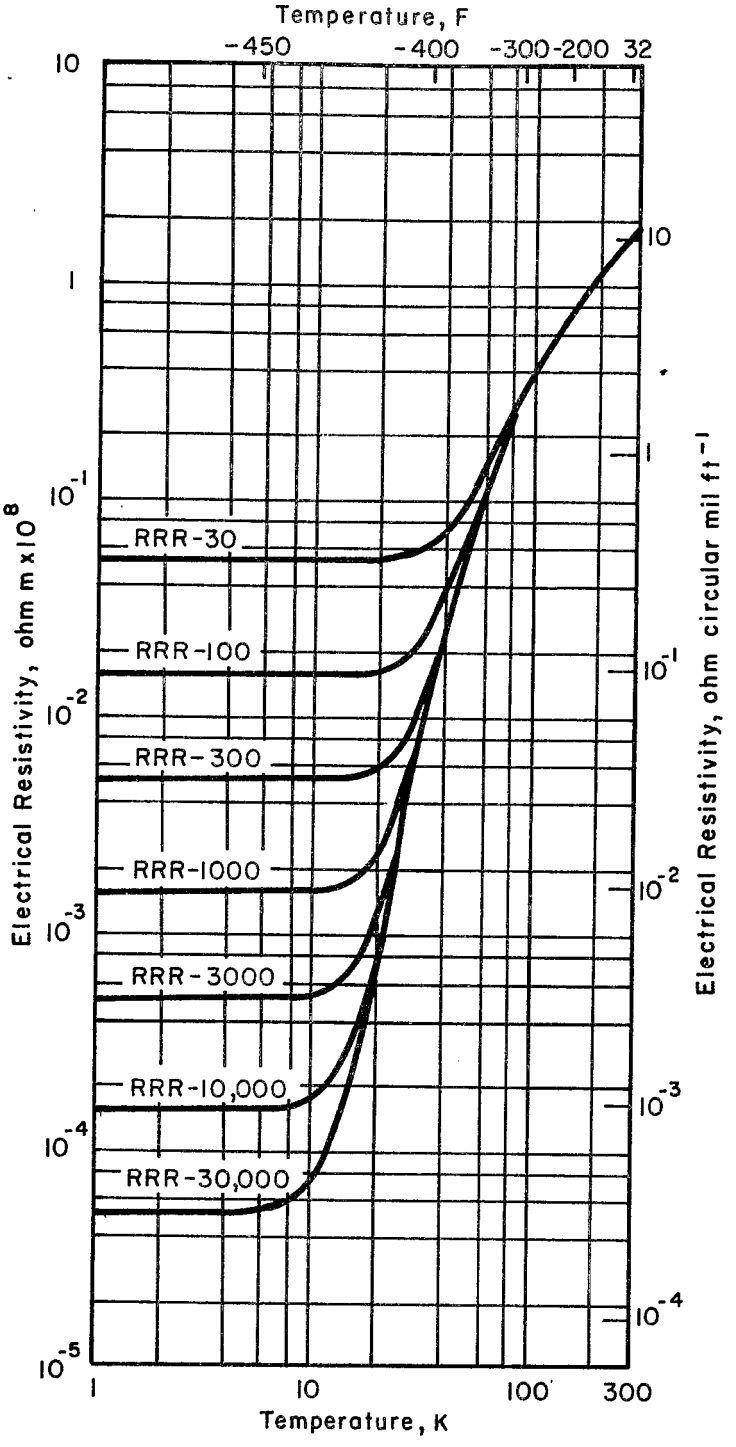
4
6
8
10
20
30
40
60
80
100
200
300
TEMPERATURE, °K



ELECTRICAL RESISTIVITY VERSUS TEMPERATURE FOR COPPER



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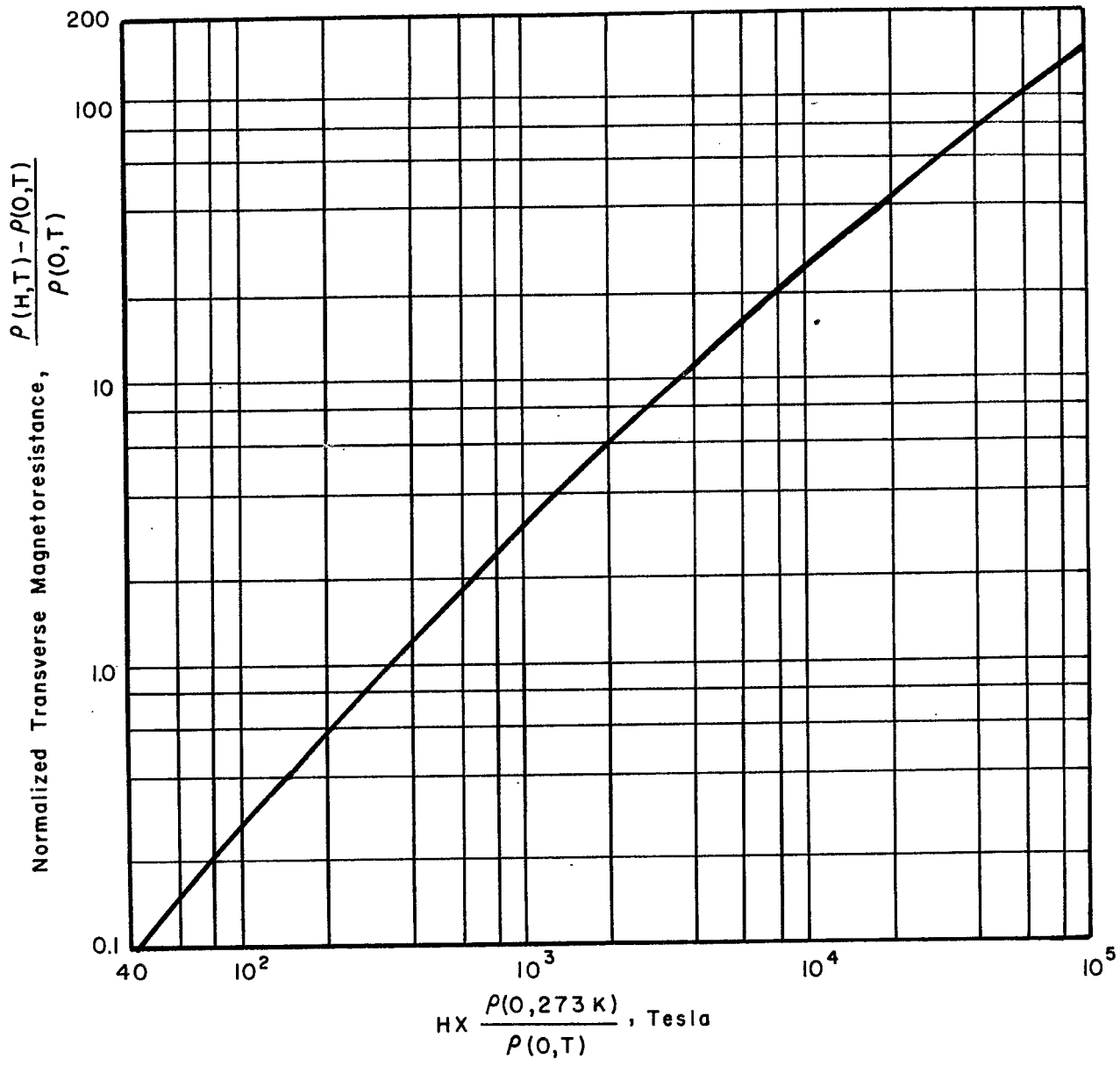
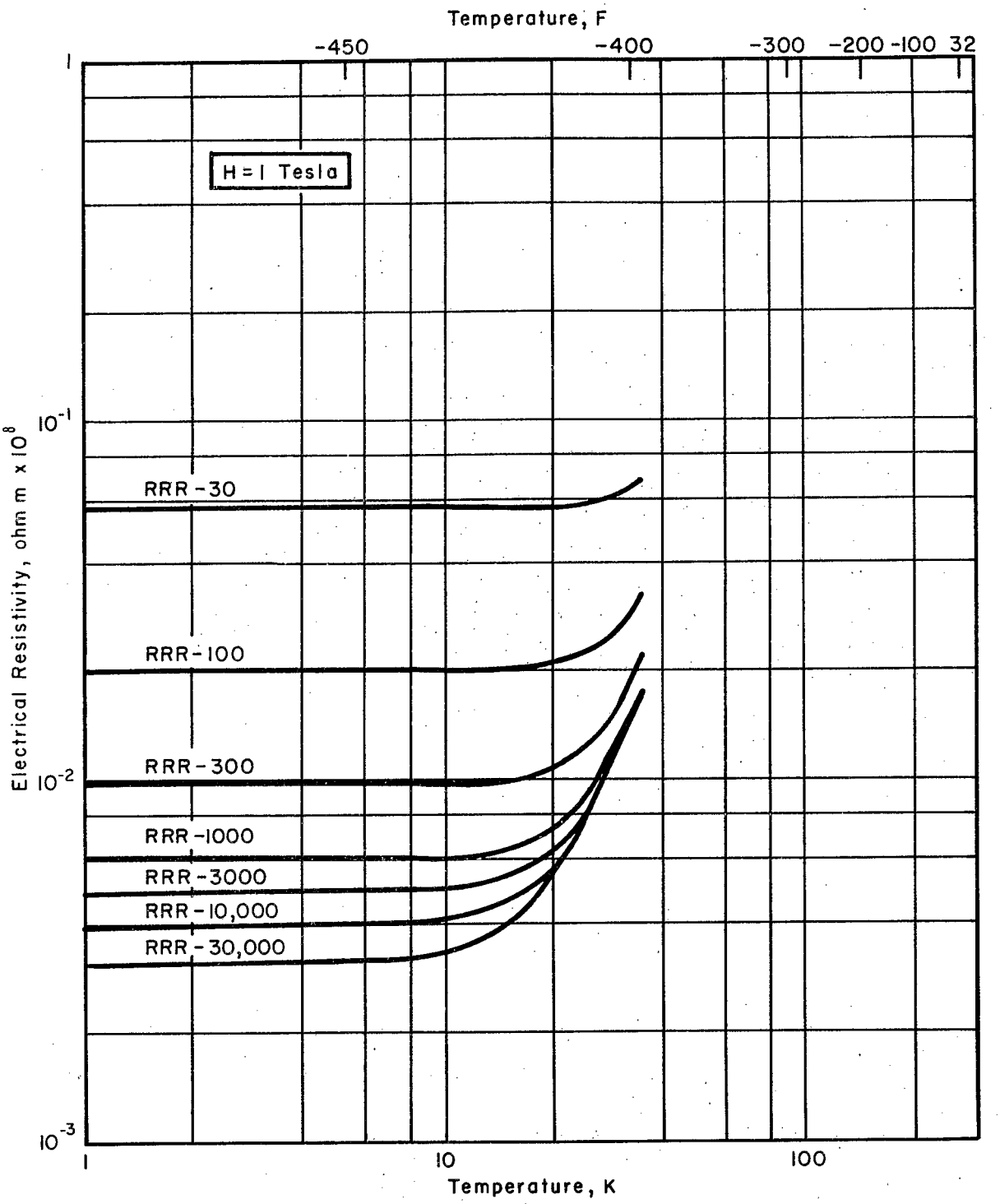
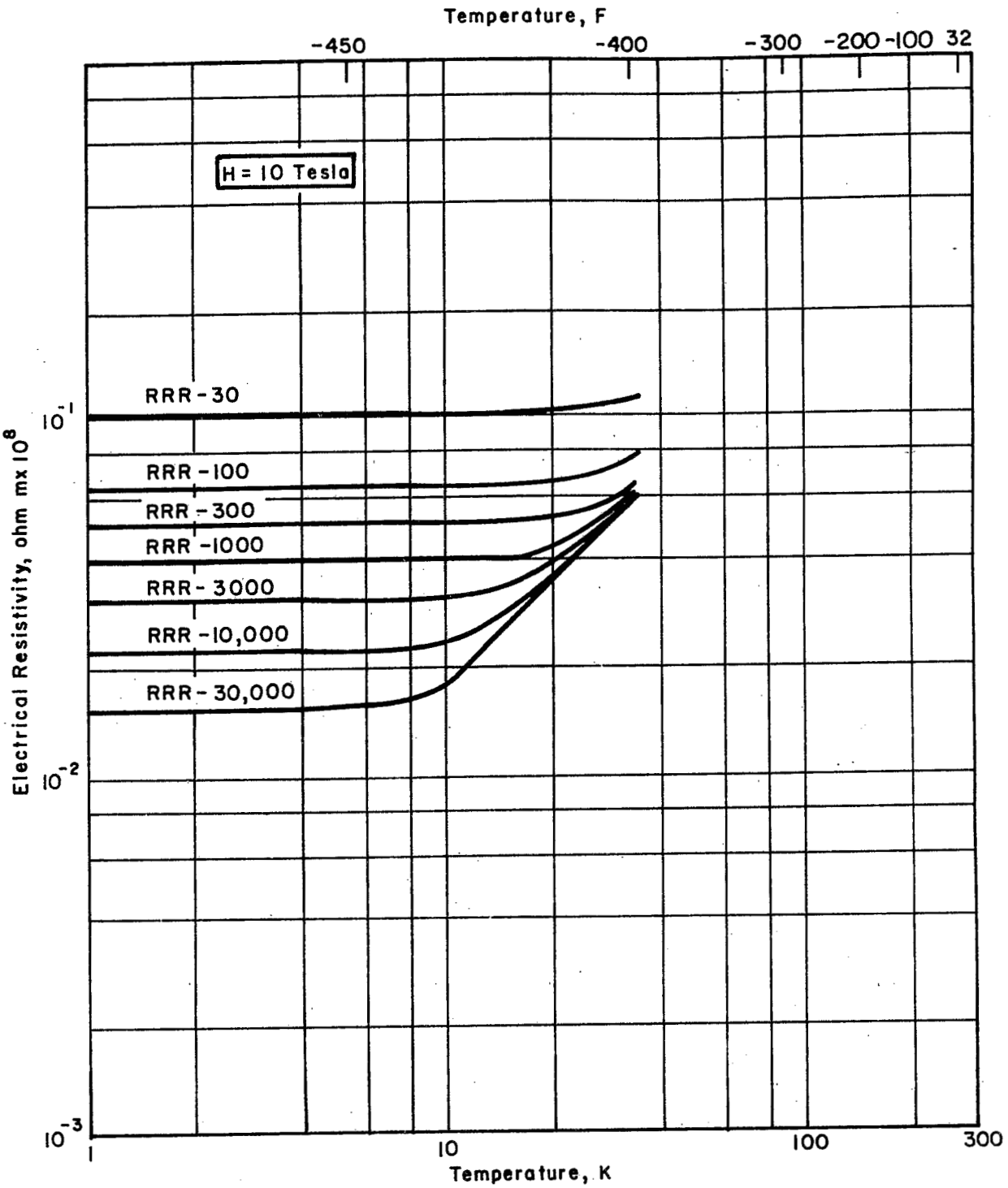


TRANSVERSE MAGNETORESISTANCE (ELECTRICAL) OF COPPER (REDUCED KOHLER PLOT)



TRANSVERSE MAGNETORESISTANCE OF COPPER AT 1 TESLA



TRANSVERSE MAGNETORESISTANCE OF COPPER AT 10 TESLA

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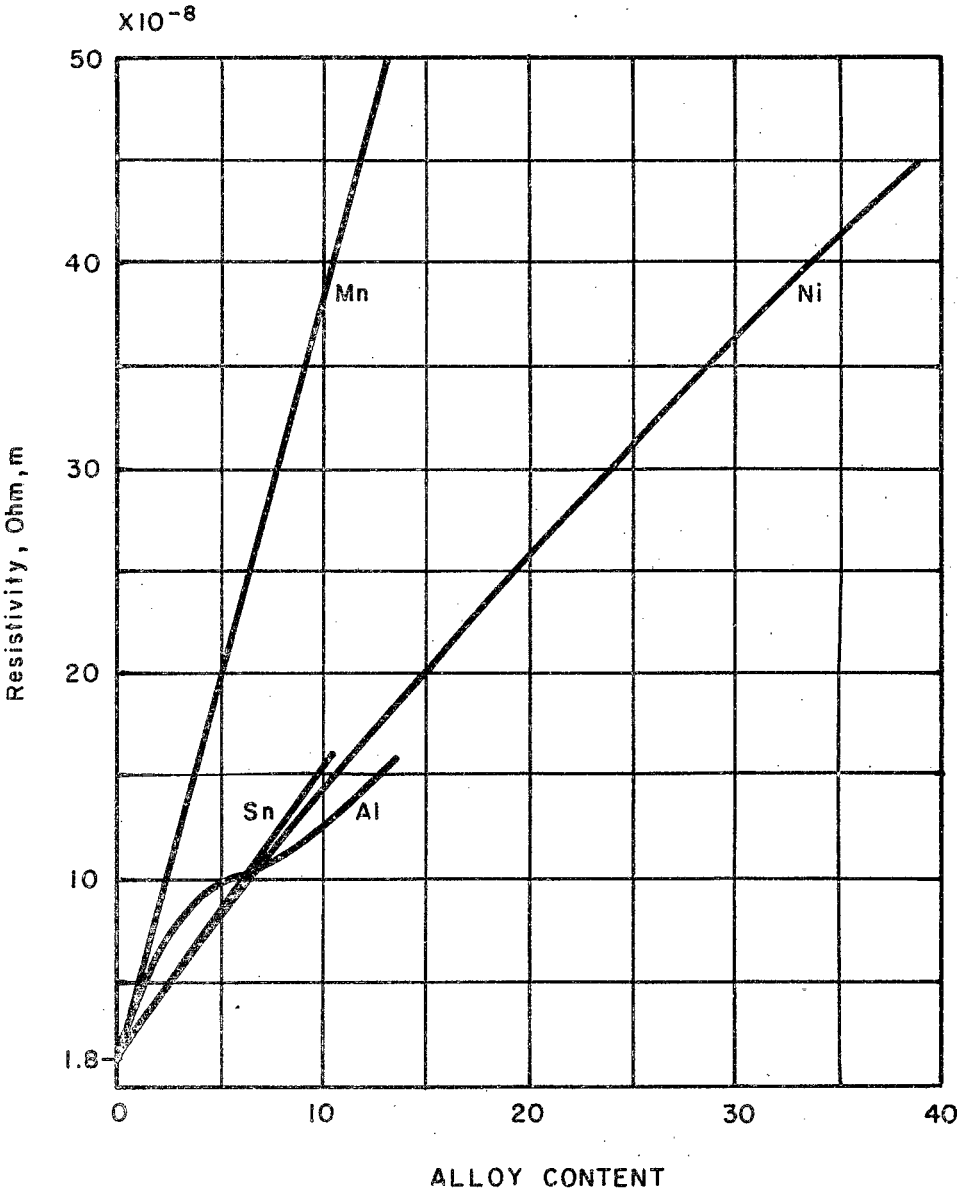
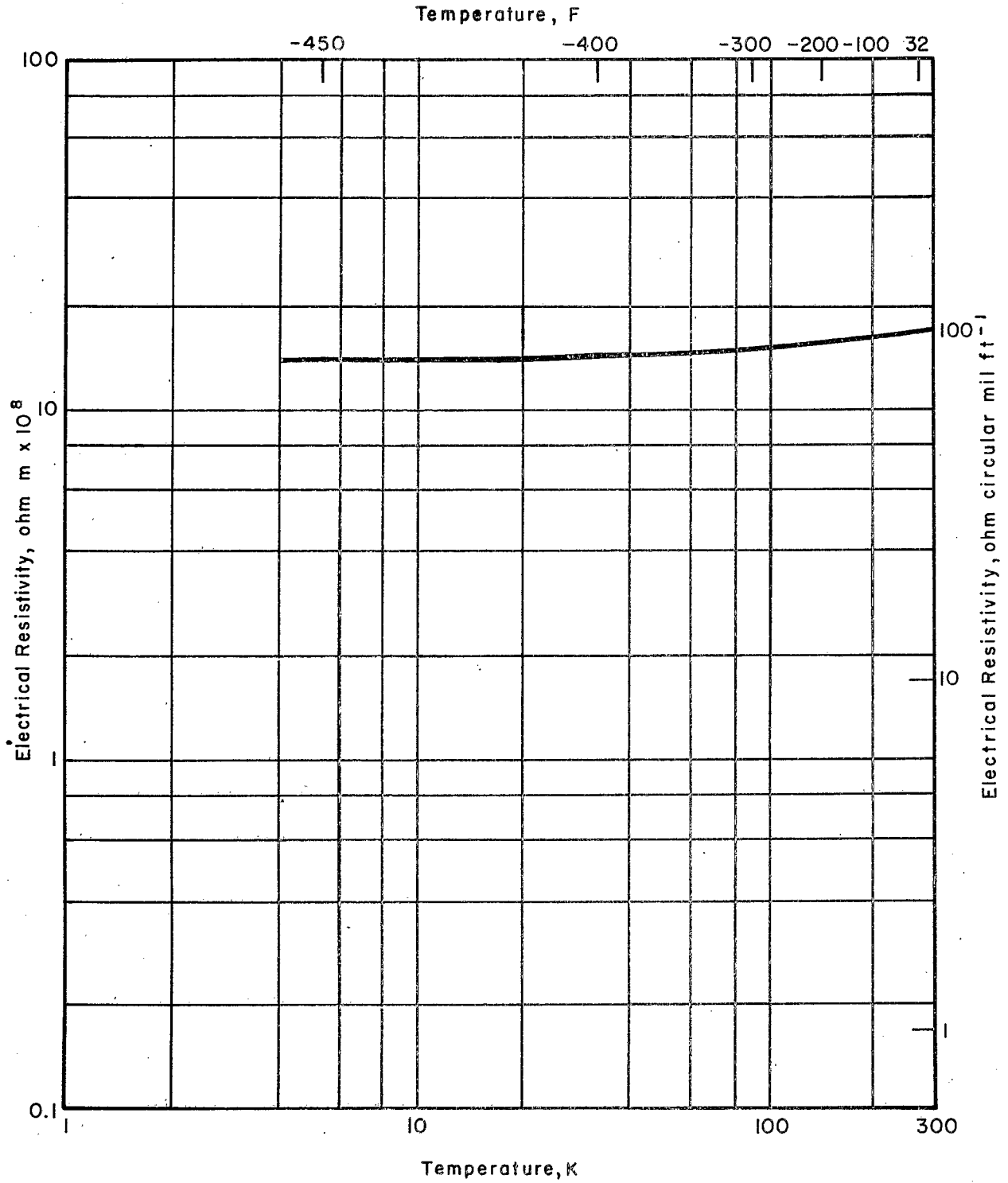


RESISTIVITY OF COPPER ALLOYS AT 300K



ELECTRICAL RESISTIVITY VERSUS
TEMPERATURE FOR COPPER
ALLOY 90 CU-10 NI

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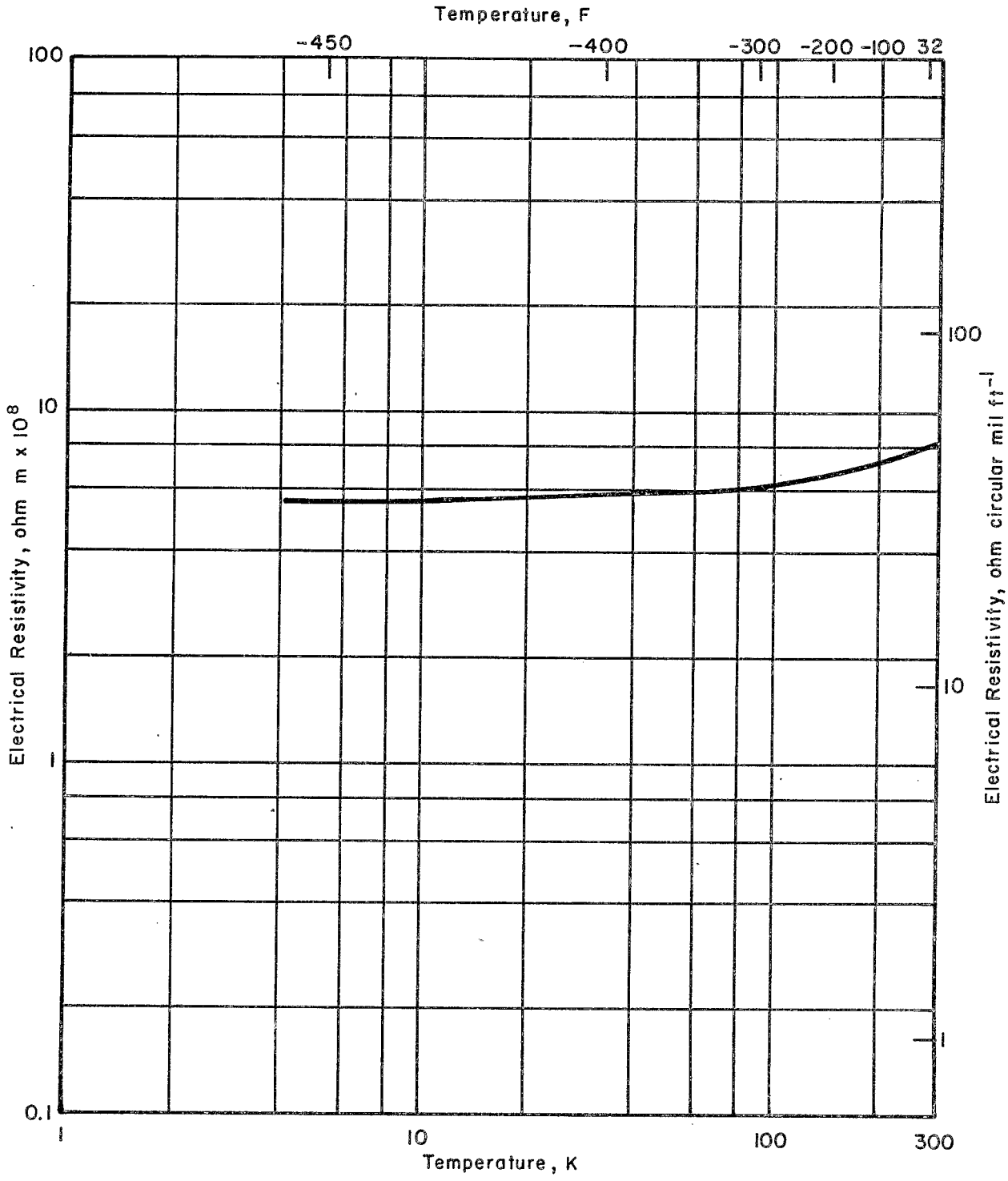

ELECTRICAL RESISTIVITY VERSUS TEMPERATURE FOR
COPPER ALLOY 98C CU-2 BE

ELECTRICAL RESISTIVITY of GOLD, Au

(Atomic Number 79)

Sources of Data:

International Critical Tables of Numerical Data, Physics, Chemistry, and Technology, VI, 1st Edition, Published for the National Research Council by the McGraw-Hill Book Co. Inc. (1929) pp 124-135

Landolt-Börnstein Zahlenwerte und Funktionen aus Physik, Chemie, Astronomie, Geophysik und Technik, sechste Auflage, II Band, 6 Teil, Springer-Verlag, Berlin (1959) pp 1-46

Other References:

Cath, P. G., Onnes, H. K. and Burgers, W. G.; Proc. Acad. Sci. Amsterdam 20, 1163 (1918)

Holborn, L.; Ann. Physik 59, 145 (1919)

Justi, E.; Physik. Z. 41, 486 (1940)

Meissner, W.; Ann. Physik (4) 47, 1001 (1915)

Meissner, W.; Physik. Z. 27, 725 (1926)

Comments:

Reference should be made to the preface at the beginning of the Electrical Resistivity section for an explanation of the graph. The value of electrical resistivity at 273°K (ρ_{273}) for gold to be used in calculating values of electrical resistivity (ρ_T) is 2.06 x 10^{-6} ohm-cm.

The data for this graph were taken from the references cited above under "Sources of Data". The values listed in the Landolt-Börnstein tables are those reported by Holborn; Justi; and Meissner; while the values appearing in the International Critical Tables are those from Cath, Onnes and Burgers. These primary sources are listed above under "Other References". The original authors are used in labeling the curves on the graph.

The data in the Landolt-Börnstein tables, the International Critical Tables and tabulated here are listed as ratios of electrical resistivity with respect to the resistivity at a datum temperature of 273°K. The actual values of ρ_{273} are not available for the samples used by the several investigators so a datum value reported by Meissner in 1915 (ρ_{273} = 2.06 x 10^{-6} ohm-cm) is suggested for calculating values of electrical resistivity from these ratios.

The Landolt-Börnstein tables report the samples used by Meissner are polycrystalline with less than 0.001% impurities present. The sample used by Meissner in the 1915 reference was a cast sample; while the sample he used in the 1926 reference was aged. The samples used by Holborn and Justi are reported as annealed polycrystalline with a small amount of impurities present. No other pertinent information is given about any of the samples in any of the sources of data.

ELECTRICAL RESISTIVITY of GOLD (Cont.)

Tables of Values of Electrical Resistivity

ρ = Resistivity, (ohm-cm)

ρ_{273} = Resistivity at 273°K, (ohm-cm)

Cath, Onnes and Burgers					
Temp. °C	$100\rho/\rho_{273}$	Temp. °C	$100\rho/\rho_{273}$	Temp. °C	$100\rho/\rho_{273}$
- 84.97	66.443	-208.18	16.365	-243.68	2.553
-102.22	59.628	-216.26	12.906	-245.80	2.039
-130.28	48.507	-222.78	10.130	-252.57	0.845
-145.86	42.273	-228.73	7.680	-255.01	0.594
-164.37	34.764	-233.62	5.804	-258.35	0.379
-183.95	26.660	-236.62	4.667	-268.88	0.223
-195.88	21.622	-240.25	3.538	-269.57	0.223
-205.31	17.596			-271.61	0.223

Holborn		Meissner		Justi	
Temp. °K	ρ/ρ_{273}	Temp. °K	ρ/ρ_{273}	Temp. °K	ρ/ρ_{273}
81	0.2375	1.6	0.00109	4.2	0.00085
195	0.6995	4.2	0.00109	14.0	0.00227
		20.4	0.00707	20.4	0.00709
		81.7	0.2341	79	0.219
		84.9	0.2480		

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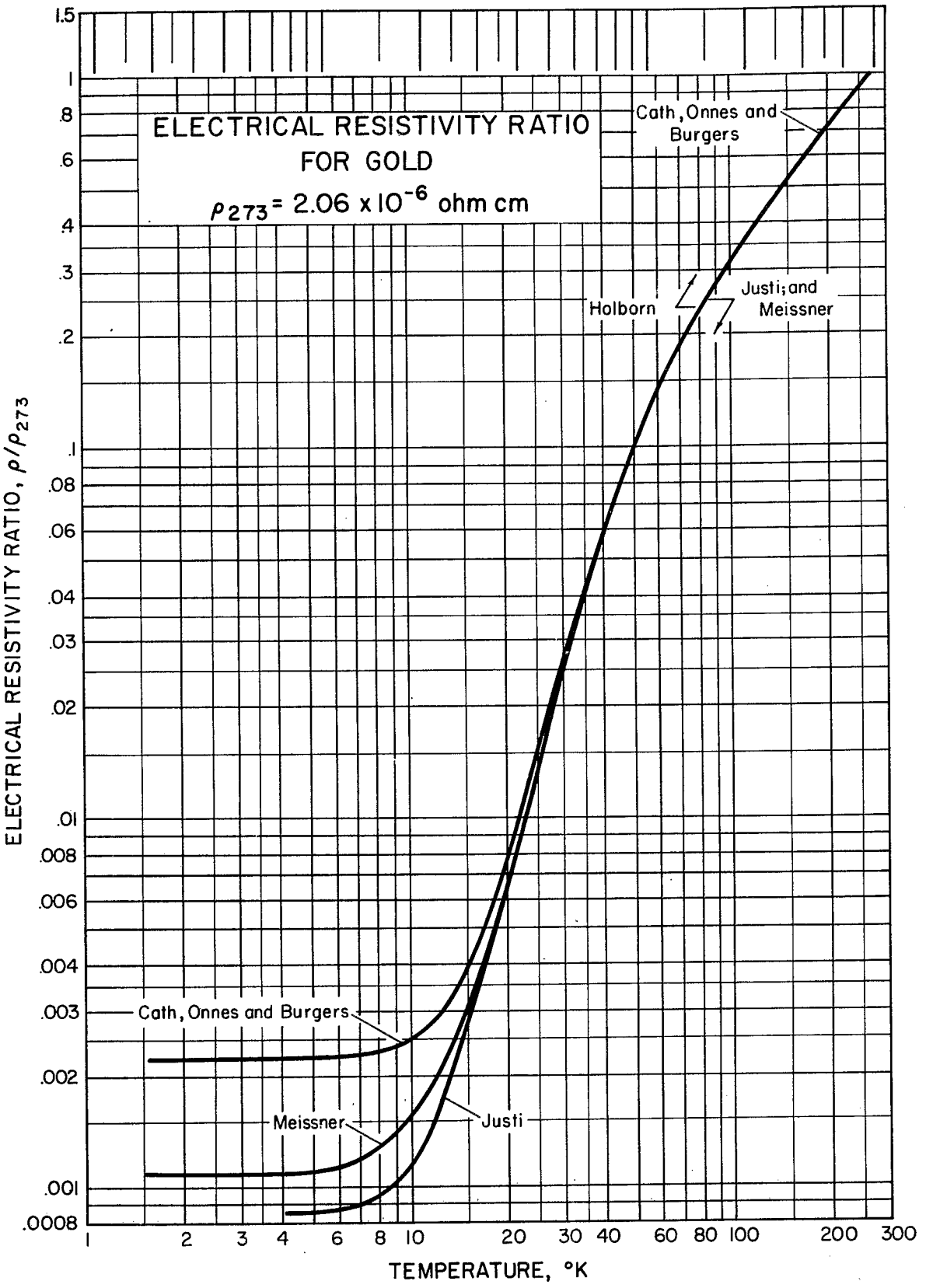
ELECTRICAL RESISTIVITY RATIO FOR GOLD
$\rho_{273} = 2.06 \times 10^{-6}$ ohm cm
Cath, Onnes and Burgers
Holborn
Justi; and Meissner
Cath, Onnes and Burgers
Meissner
Justi
ELECTRICAL RESISTIVITY RATIO, ρ/ρ_{273}
TEMPERATURE, °K
1.5
1
.8
.6
.4
.3
.2
.1
.08
.06
.04
.03
.02
.01
.008
.006
.004
.003
.002
.001
.0008
1
2
3
4
6
8
10
20
30
40
60
80
100
200
300

ELECTRICAL RESISTIVITY of INDIUM, In
(Atomic Number 49)

Sources of Data:

International Critical Tables of Numerical Data, Physics, Chemistry, and Technology, VI, 1st Edition, Published for the National Research Council by the McGraw-Hill Book Co. Inc. (1929) pp. 124-135

Landolt-Börnstein Zahlenwerte und Funktionen aus Physik, Chemie, Astronomie, Geophysik und Technik, sechste Auflage, II Band, 6 Teil, Springer-Verlag, Berlin (1959) pp. 1-46

Other References:

Meissner, W.; Franz, H. and Westerhoff, H.; Ann. Physik (5) 13, 555 (1932)

Meissner, W.; Franz, H. and Westerhoff, H.; Ann. Physik (5) 13, 505 (1932)

Meissner, W. and Voigt, B.; Ann. Physik (5) 7, 761, 892 (1930)

Tuyn, W. and Onnes, K. H.; Proc. Acad. Sci. Amsterdam 26, 504 (1923)

Comments:

Reference should be made to the preface at the beginning of the Electrical Resistivity section for an explanation of the graph. The value of electrical resistivity at 273°K (ρ_{273}) for indium to be used in calculating values of electrical resistivity (ρ_T) is 8.19×10^{-6} ohm-cm. The curves should not be extrapolated to lower temperatures since indium becomes a superconductor between 3.374 and 3.432°K.

The data for this graph were taken from the references cited above under "Sources of Data". The values listed in the Landolt-Börnstein tables are those reported by Meissner, Franz and Westerhoff; and Meissner and Voigt; while those values appearing in the International Critical Tables are from Tuyn and Onnes. These primary sources are listed above under "Other References". The original authors are used in labeling the three curves on the graph.

The data in the Landolt-Börnstein tables, the International Critical Tables and tabulated here are listed as ratios of electrical resistivity with respect to the resistivity at a datum temperature of 273°K. The actual values of ρ_{273} were not available for the samples used by Meissner and Voigt; and Tuyn and Onnes so a datum value reported by Meissner, Franz and Westerhoff ($\rho_{273} = 8.19 \times 10^{-6}$ ohm-cm) is suggested for calculating values of electrical resistivity from these ratios.

Comments: (cont.)

The Landolt-Börnstein tables list the samples of both references a polycrystalline with 0.1% impurities in the sample used by Meissne and Voigt and a very small amount of impurity in the samples used by Meissner, Franz and Westerhoff. No mention is made of the amount of impurities in the sample used by Tuyn and Onnes, and no information was given on the mechanical strain or heat treatment for any of the samples from any of the authors.

Tables of Values of Electrical Resistivity

ρ = Resistivity, (ohm-cm)

ρ_{273} = Resistivity at 273°K, (ohm-cm)

Meissner and Voigt		Meissner, Franz and Westerhoff	
Temp. °K	ρ/ρ_{273}	Temp. °K	ρ/ρ_{273}
4.21	0.0038	4.23	0.0015
20.5	0.0256	20.4	0.0216
77.8	0.2177	77.8	0.212
88.9	0.2567		

Tuyn and Onnes			
Temp. °C	$100\rho/\rho_{273}$	Temp. °C	$100\rho/\rho_{273}$
-182.79	28.75	-254.95	5.173
-194.06	24.92	-256.61	4.796
-202.07	22.20	-258.89	4.317
-209.98	19.52	-268.87	3.394
-218.30	16.71	-269.49	3.392
-252.65	5.739	-269.61	3.387

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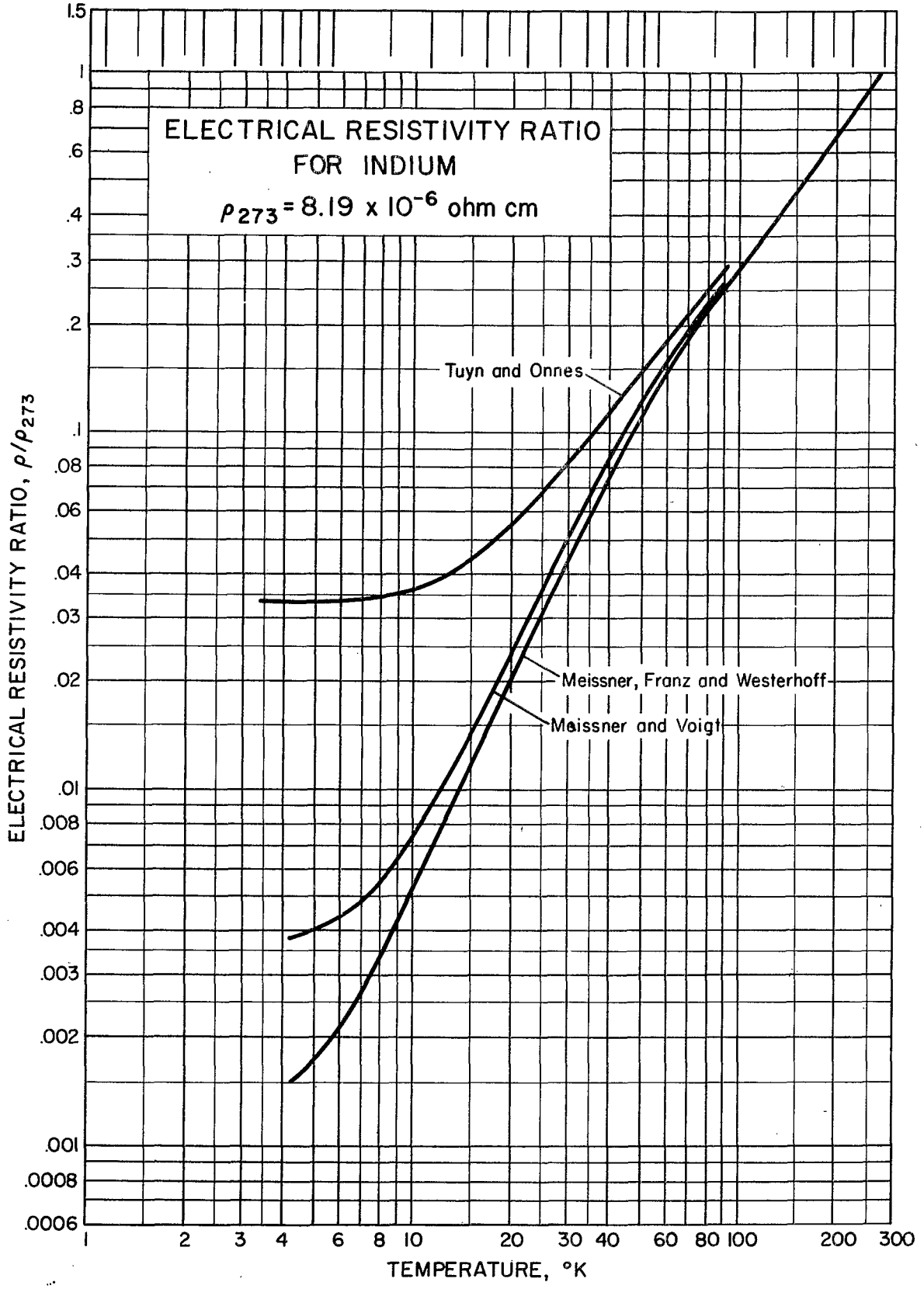
ELECTRICAL RESISTIVITY RATIO
FOR INDIUM
$\rho_{273} = 8.19 \times 10^{-6}$ ohm cm
Tuyn and Onnes
Meissner, Franz and Westerhoff
Meissner and Voigt
ELECTRICAL RESISTIVITY RATIO, ρ/ρ_{273}
1.5
1
.8
.6
.4
.3
.2
.1
.08
.06
.04
.03
.02
.01
.008
.006
.004
.003
.002
.001
.0008
.0006
1
2
3
4
6
8
10
20
30
40
60
80
100
200
300
TEMPERATURE, °K

ELECTRICAL RESISTIVITY of IRON, Fe

(Atomic Number 26)

Sources of Data:

International Critical Tables of Numerical Data, Physics, Chemistry, and Technology, VI, 1st Edition, Published for the National Research Council by the McGraw-Hill Book Co. Inc. (1929) pp 124-135

Landolt-Börnstein Zahlenwerte und Funktionen aus Physik, Chemie, Astronomie, Geophysik und Technik, sechste Auflage, II Band, 6 Teil, Springer-Verlag, Berlin (1959) pp 1-46

Other References:

Cleaves, H. E. and Hiegel, J. M.; J. Research Natl. Bur. Standards RP 1472 28, 643 (1942)

Holborn, L.; Ann. Physik 59, 145 (1919)

Meissner, W.; Physik. Z. 29, 897 (1928)

Comments:

Reference should be made to the preface at the beginning of the Electrical Resistivity section for an explanation of the graph. The value of electrical resistivity at 273°K (ρ_{273}) for iron to be used in calculating values of electrical resistivity (ρ_T) is 8.6×10^{-6} ohm-cm.

The data for this graph were taken from the references cited above under "Sources of Data". The values listed in the Landolt-Börnstein tables are those reported by Meissner; and Cleaves and Hiegel; while those values appearing in the International Critical Tables are from Holborn. These primary sources are cited above under "Other References". The original authors are used in labeling the two curves on the graph.

The data in the Landolt-Börnstein tables, the International Critical Tables and tabulated here are listed as ratios of electrical resistivity with respect to the resistivity at a datum temperature of 273°K. The actual values of ρ_{273} for the samples used by the several investigators are not available so a datum value reported by Cleaves and Hiegel ($\rho_{273} = 8.6 \times 10^{-6}$ ohm-cm) is suggested for calculating values of electrical resistivity from these ratios.

The Landolt-Börnstein tables list the sample used by Cleaves and Hiegel as an annealed polycrystalline specimen with less than 0.01% impurities. The sample used by Meissner is reported as an annealed polycrystalline specimen with a very small amount of impurities present. No other pertinent information is given on any of the samples in any of the sources of data.

Tables of Values of Electrical Resistivity

ρ = Resistivity, (ohm-cm)

ρ_{273} = Resistivity at 273°K, (ohm-cm)

Holborn			
Temp. °C	$100\rho/\rho_{273}$	Temp. °C	$100\rho/\rho_{273}$
- 78.1	57.86	-192.7	8.48
- 80 *	65.9	-200 *	6.2
-100 *	47.3	-220 *	2.7
-120 *	38.1	-240 *	1.4
-140 *	29.2	-253	1.13
-160 *	20.7		
* Values from interpolation			

Meissner	
Temp.* °K	ρ/ρ_{273}**
1.98	0.000618
4.21	0.000620
20.4	0.000761
78.2	0.0741
* The second decimal place is in doubt.	
**The fifth decimal place is in doubt.	

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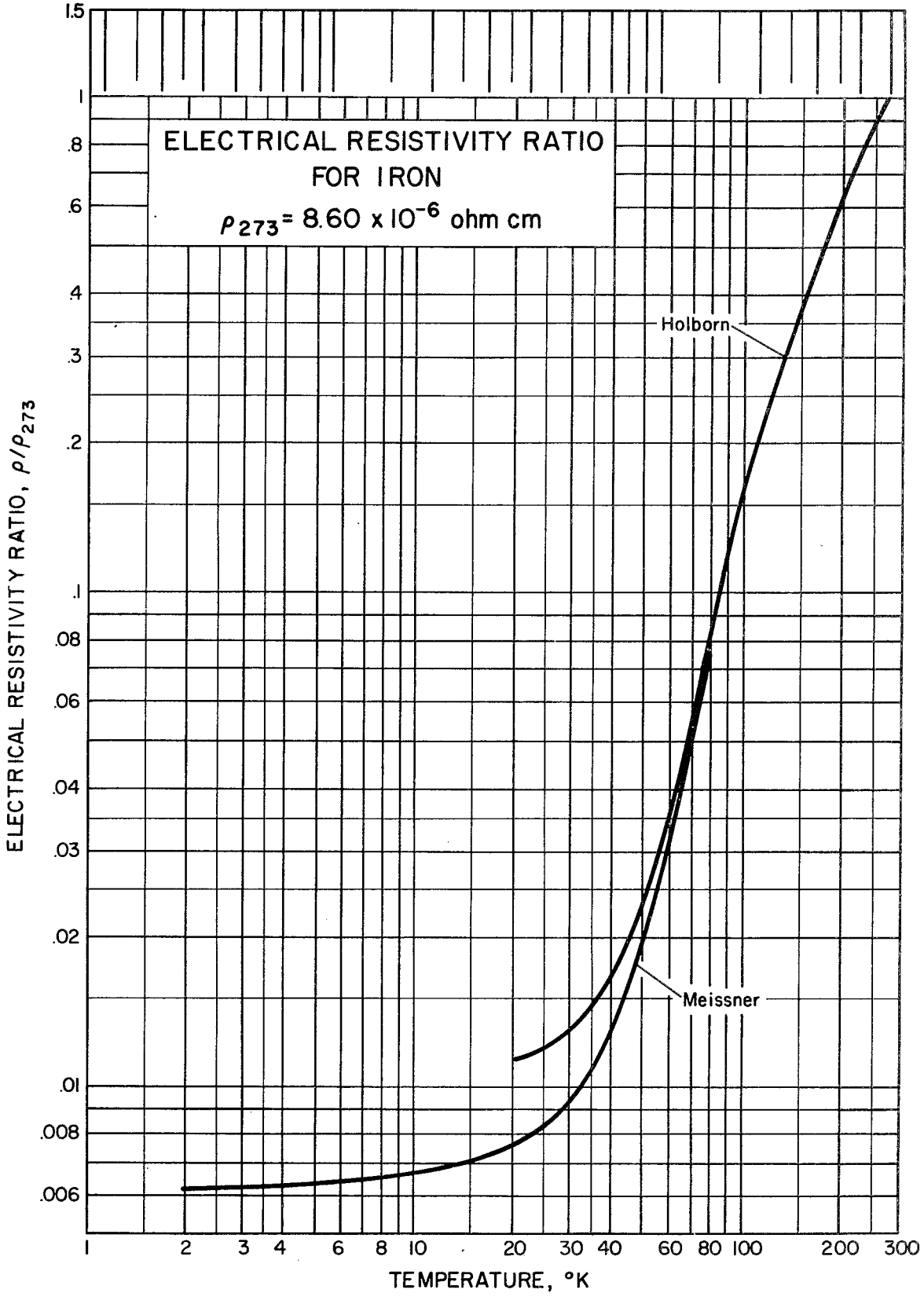
ELECTRICAL RESISTIVITY RATIO
FOR IRON
$\rho_{273} = 8.60 \times 10^{-6}$ ohm cm
Holborn
Meissner
ELECTRICAL RESISTIVITY RATIO, ρ/ρ_{273}
1.5
1
.8
.6
.4
.3
.2
.1
.08
.06
.04
.03
.02
.01
.008
.006
1
2
3
4
6
8
10
20
30
40
60
80
100
200
300
TEMPERATURE, °K

ELECTRICAL RESISTIVITY of LEAD, Pb

(Atomic Number 82)

Source of Data:

Landolt-Börnstein Zahlenwerte und Funktionen aus Physik, Chemie, Astronomie, Geophysik und Technik, sechste Auflage, II Band, 6 Teil, Springer-Berlag, Berlin (1959) pp. 1-46

Other References:

Jaeger, W. and Diesselhorst, H.; Wiss. Abhandl. physik. tech. Reichsanstalt 3, 269 (1900)

Meissner, W. and Franz, H.; Z. Physik. 65, 30 (1930)

Meissner, W.; Ann. Physik. (5) 13, 641 (1932)

Onnes, H. K. and Tuyn, W.; Communs. Kamerlingh Onnes Lab. Univ. Leiden Suppl. No. 58 (1926)

Van den Berg, G. J.; Physica 14, 111 (1948)

Comments:

Reference should be made to the preface at the beginning of the Electrical Resistivity section for an explanation of the graph. The value of electrical resistivity at 273°K (ρ_{273}) for lead to be used in calculating values of electrical resistivity (ρ_T) is 19.2 x 10^{-6} ohm-cm. The curves on the graph should not be extrapolated to lower temperatures as lead becomes a superconductor at 7.22°K.

It will be noted, however, that the data of Van den Berg extend into the superconducting region. These data below the transition temperature were based on observations of the electrical resistance with the lead subjected to a super critical magnetic field to maintain electrical resistance.

The data for this graph were taken from the reference cited above under "Source of Data". The data listed in the Landolt-Börnstein tables are those reported by the authors listed above under "Other References". The original authors are used in labeling the curves on the graph.

The data reported in Landolt-Börnstein and tabulated here are listed as ratios of electrical resistivity with respect to the resistivity at a datum temperature of 273°K. The actual values of ρ_{273} are not available for the samples used by the original investigators so a datum value reported by Jaeger and Diesselhorst (ρ_{273} = 19.2 x 10^{-6} ohm-cm) is suggested for calculating values of electrical resistivity from these ratios. Jaeger and Diesselhorst report the sample used in determining ρ_{273} as polycrystalline with less than 0.05% impurities.

The Landolt-Börnstein tables report the samples used by all of the investigators as polycrystalline with a very small amount of impurities present. No other pertinent information is given about any of the samples used by any of the investigators.

Tables of Values of Electrical Resistivity

ρ = Resistivity, (ohm-cm)

ρ_{273} = Resistivity at 273°K, (ohm-cm)

Meissner and Franz	
Temp.* °K	ρ/ρ_{273}
7.26	0.0007
14.02	0.0104
20.32	0.0292

Meissner	
Temp. °K	ρ/ρ_{273}
1.3	1.55×10^{-4}+
4.2	1.75×10^{-4}+

Onnes and Tuyn	
Temp.* °K	ρ/ρ_{273}
7.26	0.0010
14.32	0.0113
20.52	0.0301
73.11	0.2321
88.56	0.2895

Van den Berg	
Temp.* °K	ρ/ρ_{273}***
2.30	0.00013+
3.22	0.00015+
4.24	0.00019+
7.22	0.00083
9.38	0.0025
20.32	0.0301

* The second decimal place of the temperature values is somewhat in doubt.

** The fifth decimal place of the electrical resistivity ratio values is somewhat in doubt.

\+ These measurements were made with the aid of a supercritical magnetic field at temperatures at which lead is normally a superconductor. (For a more detailed explanation see the preface of the electrical resistivity section.)

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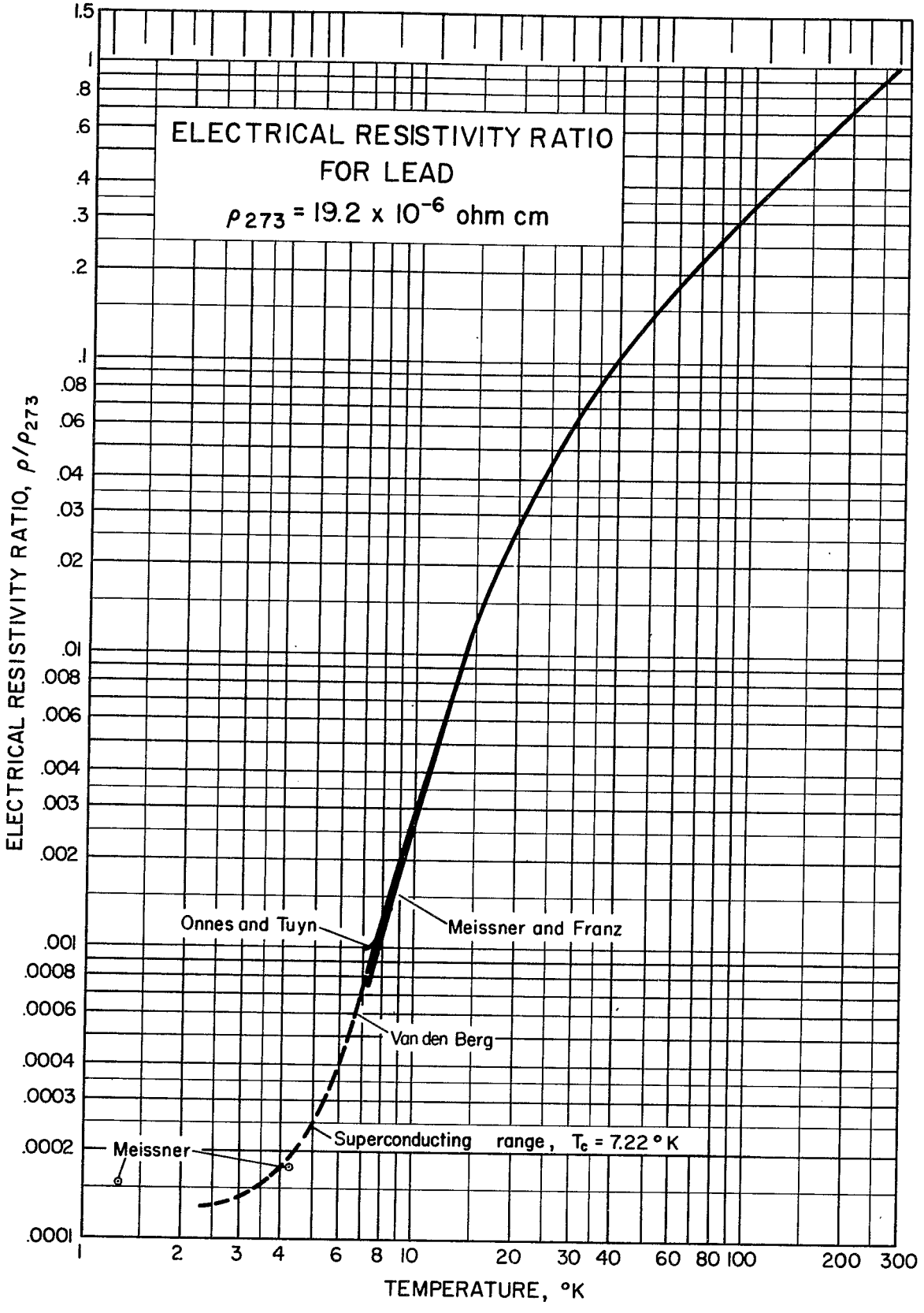

ELECTRICAL RESISTIVITY RATIO
FOR LEAD
$\rho_{273} = 19.2 \times 10^{-6}$ ohm cm
ELECTRICAL RESISTIVITY RATIO, ρ/ρ_{273}
1.5
1
.8
.6
.4
.3
.2
.1
.08
.06
.04
.03
.02
.01
.008
.006
.004
.003
.002
.001
.0008
.0006
.0004
.0003
.0002
.0001
Onnes and Tuyn
Meissner and Franz
Van den Berg
Superconducting range, $T_c = 7.22°K$
Meissner
1
2
3
4
6
8
10
20
30
40
60
80
100
200
300
TEMPERATURE, °K

ELECTRICAL RESISTIVITY of MAGNESIUM, Mg
(Atomic Number 12)

Sources of Data:

Landolt-Börnstein Zahlenwerte und Funktionen aus Physik, Chemie, Astronomie, Geophysik und Technik, sechste Auflage, II Band, 6 Teil, Springer-Verlag, Berlin (1959) pp. 1-46

International Critical Tables of Numerical Data, Physics, Chemistry, and Technology, VI, 1st Edition, Published for the National Research Council by the McGraw-Hill Book Co. Inc. (1929) pp. 124-135

Other References:

Dewar, J. and Fleming, J. A.; Phil. Mag. (5) 36, 271 (1893)

Meissner, W. and Voigt, B.; Ann. Physik (5) 7, 761, 892 (1930)

Niccolai, G.; Physik. Z. 9, 367 (1908)

Rosenberg, H. M.; Phil. Mag. 45, 73 (1954)

Yntema, G. B.; Phys. Rev. 91, 1388 (1953)

Comments:

Reference should be made to the preface at the beginning of the Electrical Resistivity section for an explanation of the graph. The value of electrical resistivity at 273°K (ρ_{273}) for magnesium to be used in calculating values of electrical resistivity (ρ_T) is 4.31 x 10^{-6} ohm-cm.

The data for this graph were taken from the references cited above under "Sources of Data". The values listed in the Landolt-Börnstein tables are those reported by Meissner and Voigt; Niccolai; Rosenberg; and Yntema; while those values listed by the International Critical Tables are from Dewar and Fleming. Those primary sources are listed above under "Other References". The original authors are used in labeling the curves on the graph.

The data reported in the Landolt-Börnstein tables, the International Critical Tables, and tabulated here are listed as ratios of electrical resistivity with respect to the resistivity at a datum temperature of 273°K. The actual values of ρ_{273} are not available for the samples used by the several investigators so a datum value reported by Niccolai (ρ_{273} = 4.31 x 10^{-6} ohm-cm) is suggested for calculating values of electrical resistivity from these ratios.

The sample used by Meissner and Voigt is reported by Landolt-Börnstein as polycrystalline and annealed in a vacuum at 250°C. The sample used by Yntema was of a polycrystalline nature with less than 0.02% impurities present. The Yntema sample was also annealed but no mention is made of conditions. The samples used by Rosenberg and Niccolai are reported as polycrystalline with very few impurities present. No other pertinent information was given about any of the samples used by any of the authors.

Tables of Values of Electrical Resistivity

ρ = Resistivity, (ohm-cm)

ρ_{273} = Resistivity at 273°K (ohm-cm)

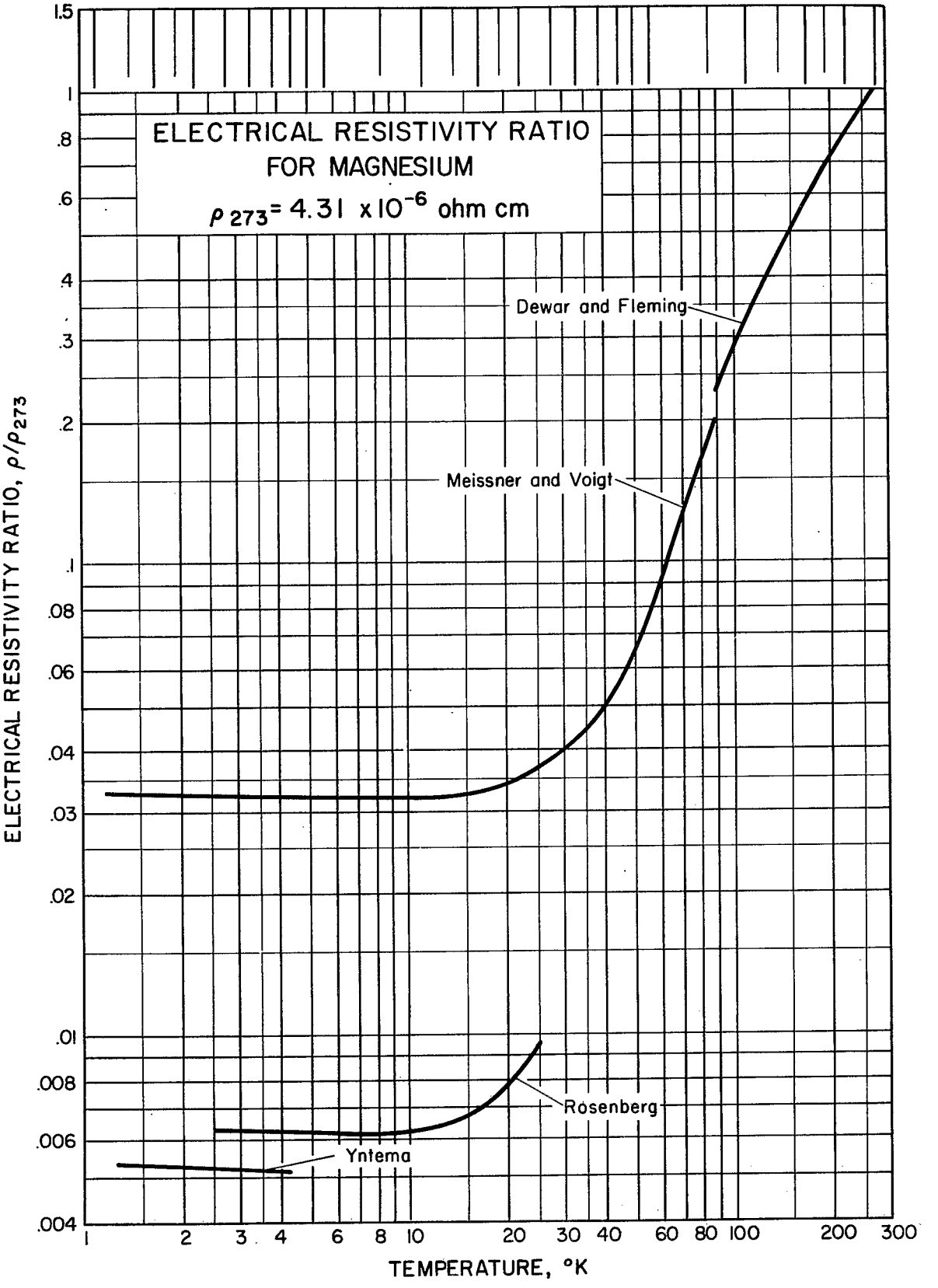
Meissner and Voigt		Rosenberg	
Temp.* °K	ρ/ρ_{273}	Temp. °K	ρ/ρ_{273}**
1.27	0.0329	2.5	0.00630
3.16	0.0326	5	0.00623
4.20	0.0323	10	0.00632
20.46	0.0344	15	0.0068
77.6	0.1576	25	0.0096
88.2	0.2006		

* The second decimal place is in doubt.

** The fifth decimal place is in doubt.

Yntema		Dewar and Fleming	
Temp. °K	ρ/ρ_{273}	Temp. °C	$100\rho/\rho_{273}$
1.30	0.00537	- 78.3*	68.2*
4.21	0.00516	- 80	67.4
		-100	59.0
		-120	50.5
		-140	41.9
		-160	33.2
		-180	24.4
		-182.9*	23.0*

* Results of actual observations.
All other values from interpolations.


ELECTRICAL RESISTIVITY RATIO
FOR MAGNESIUM
$\rho_{273} = 4.31 \times 10^{-6}$ ohm cm
Dewar and Fleming
Meissner and Voigt
Rosenberg
Yntema
ELECTRICAL RESISTIVITY RATIO, ρ/ρ_{273}
TEMPERATURE, °K
1.5
1
.8
.6
.4
.3
.2
.1
.08
.06
.04
.03
.02
.01
.008
.006
.004
1
2
3
4
6
8
10
20
30
40
60
80
100
200
300

ELECTRICAL RESISTIVITY of MOLYBDENUM, Mo

(Atomic Number 42)

Sources of Data:

International Critical Tables of Numerical Data, Physics, Chemistry, and Technology, VI, 1st Edition, Published for the National Research Council by the McGraw-Hill Book Co., Inc. (1929) pp. 124-135

Landolt-Börnstein Zahlenwerte und Funktionen aus Physik, Chemie, Astronomie, Geophysik und Technik, sechste Auflage, II Band, 6 Teil, Springer-Verlag, Berlin (1959) pp. 1-46

Other References:

Blom, E. C.; Phys. Rev. 13, 308 (1919)

Holborn, L.; Ann. Physik. 59, 145 (1919)

Meissner, W. and Voigt, B.; Ann. Physik. (5) 7, 761, 892 (1930)

Comments:

Reference should be made to the preface at the beginning of the Electrical Resistivity section for an explanation of the graph. The value of electrical resistivity at 273°K (ρ_{273}) for molybdenum to be used in calculating values of electrical resistivity (ρ_T) is 4.4×10^{-6} ohm-cm.

The data for this graph were taken from the references cited above under "Sources of Data". The values listed in the Landolt-Börnstein tables are those reported by Meissner and Voigt; and Blom; while those values listed by the International Critical Tables are from Holborn. These original authors are used in labeling the two curves on the graph.

The data in the Landolt-Börnstein tables, the International Critical Tables and tabulated here are listed as ratios of electrical resistivity with respect to the resistivity at a datum temperature of 273°K. The actual values of ρ_{273} for the samples used by the several investigators are not available so a datum value reported by Blom ($\rho_{273} = 4.4 \times 10^{-6}$ ohm-cm) is suggested for calculating values of electrical resistivity from these ratios.

The Landolt-Börnstein tables list the samples used by both authors as polycrystalline with no mention made of impurities present. No reference is made as to the nature of the sample used by Holborn, and no information is available on mechanical strain or heat treatment for any of the samples from any of the sources of data.

ELECTRICAL RESISTIVITY of MOLYBDENUM (Cont.)

Tables of Values of Electrical Resistivity

ρ = Resistivity, (ohm-cm)

ρ_{273} = Resistivity at 273°K, (ohm-cm)

Holborn	
Temp. °C	$100\rho/\rho_{273}$
- 78.2	66.60
- 80*	65.9
-100*	57.4
-120*	48.9
-140*	40.5
-160*	32.2
-180*	24.2
-192.5	19.11
* Values from interpolation	

Meissner and Voigt	
Temp. °K	ρ/ρ_{273}
1.5	0.0462
4.2	0.0455
20.4	0.0448
77.8	0.1370
86.9	0.1701

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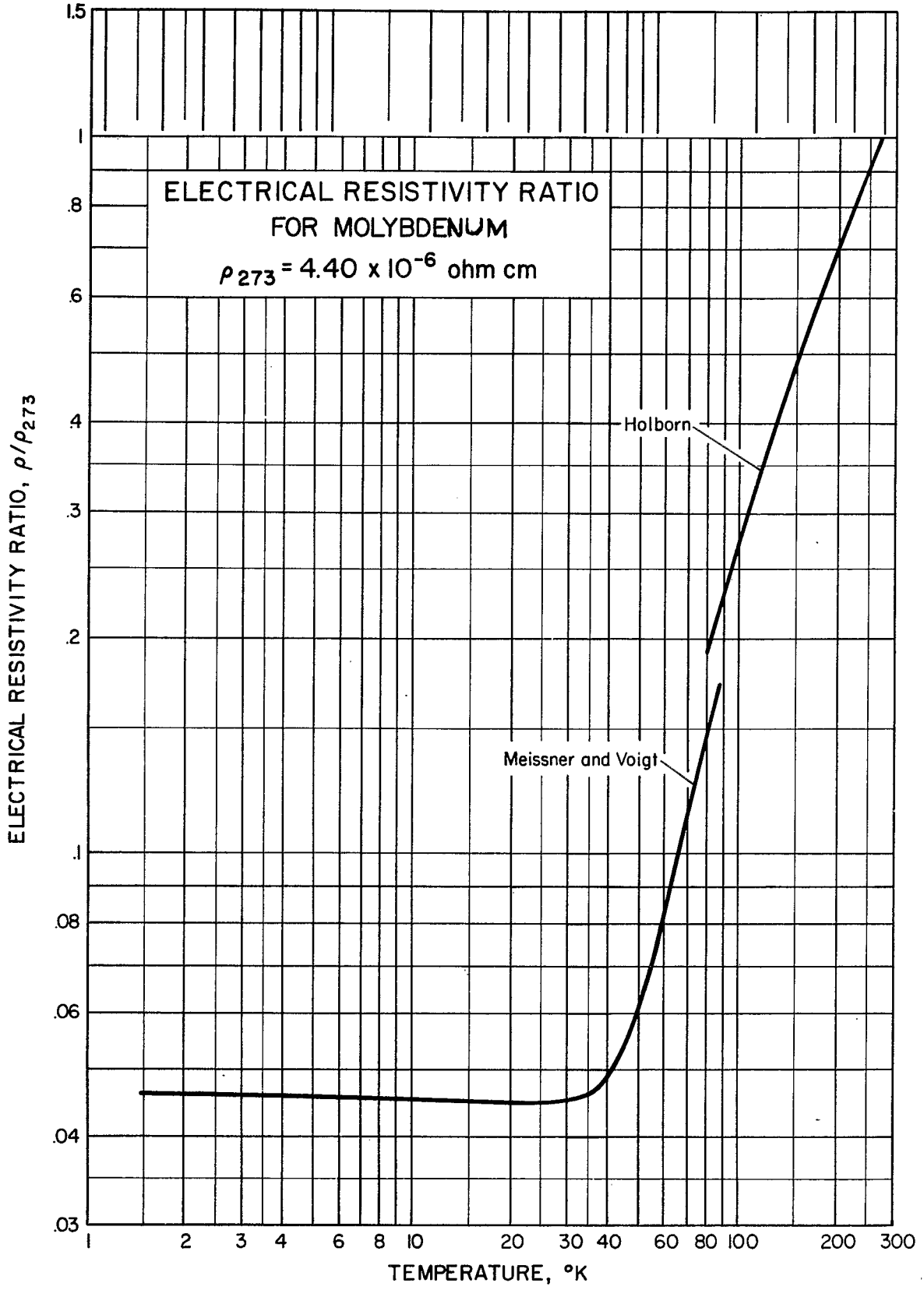
ELECTRICAL RESISTIVITY RATIO FOR MOLYBDENUM
$\rho_{273} = 4.40 \times 10^{-6}$ ohm cm
Holborn
Meissner and Voigt
ELECTRICAL RESISTIVITY RATIO, ρ/ρ_{273}
1.5
1
.8
.6
.4
.3
.2
.1
.08
.06
.04
.03
1
2
3
4
6
8
10
20
30
40
60
80
100
200
300
TEMPERATURE, °K

ELECTRICAL RESISTIVITY of NICKEL, Ni

(Atomic Number 28)

Sources of Data:

International Critical Tables of Numerical Data, Physics, Chemistry, and Technology, VI, 1st Edition, Published for the National Research Council by the McGraw-Hill Book Co. Inc. (1929) pp 124-135

Landolt-Börnstein Zahlenwerte und Funktionen aus Physik, Chemie, Astronomie, Geophysik und Technik, sechste Auflage, II Band, 6 Teil, Springer-Verlag, Berlin (1959) pp 1-46

Other References:

Fleming, J. A.; Proc. Roy. Soc. (London) 66, 50 (1900)

Dewar, J.; Proc. Roy. Soc. (London) 73, 244 (1904)

Meissner, W.; Physik. Z. 27, 725 (1926)

Wise, E. M.; Proc. Inst. Radio Engrs. 25, 714 (1937)

Comments:

Reference should be made to the preface at the beginning of the Electrical Resistivity section for an explanation of the graph. The value of electrical resistivity at 273°K (ρ_{273}) for nickel to be used in calculating electrical resistivity is 6.14×10^{-6} ohm-cm.

The data for this graph were taken from the references cited above under "Sources of Data". The values listed in the Landolt-Börnstein tables are those reported by Meissner and Wise; while those values appearing in the International Critical Tables are from Dewar and Fleming. These primary references are cited above under "Other References". The original authors are used in labeling both curves on the graph.

The data in the Landolt-Börnstein tables, the International Critical Tables and tabulated here are listed as ratios of electrical resistivity with respect to the resistivity at a datum temperature of 273°K. The actual values of ρ_{273} for the samples used by the several investigators are not available so a datum value reported by Wise ($\rho_{273} = 6.14 \times 10^{-6}$ ohm-cm) is suggested for calculating values of electrical resistivity from these ratios.

The Landolt-Börnstein tables list the sample used by Wise as polycrystalline with 0.01% impurities of unknown composition. The sample used by Meissner is reported as a polycrystalline and annealed in a hydrogen atmosphere. No further pertinent information is available on any of the samples from any of the sources of data.

Tables of Values of Electrical Resistivity

ρ = Resistivity, (ohm-cm)

ρ_{273} = Resistivity at 273°K, (ohm-cm)

Dewar and Fleming			
Temp. °C	$100\rho/\rho_{273}$	Temp. °C	$100\rho/\rho_{273}$
- 78.3	61.3	-180 +	21.7
- 80 +	60.5	-182.9	20.8
-100 +	51.8	-200 +	15.6
-120 +	43.7	-220 +	11.2
-140 +	36.1	-240 +	8.9
-160 +	28.7	-252.7	8.5
+ Values are from interpolation			

Meissner	
Temp.** °K	ρ/ρ_{273}*
1.34	0.00503
4.21	0.00508
20.40	0.00662
78.8	0.0919
87.4	0.1179
** The second decimal place is in doubt.	
* The fifth decimal place is in doubt.	

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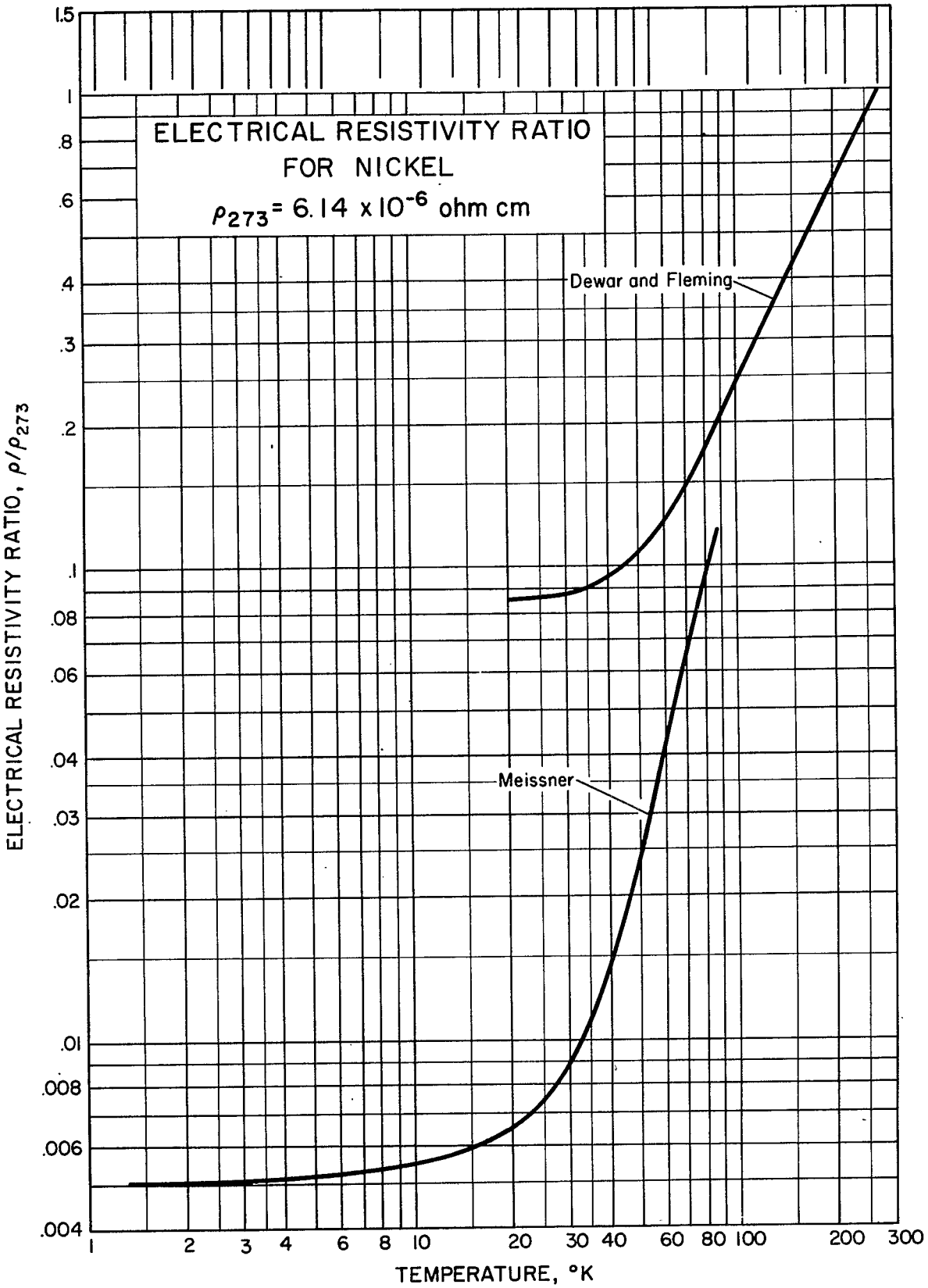
ELECTRICAL RESISTIVITY RATIO
FOR NICKEL
$\rho_{273} = 6.14 \times 10^{-6}$ ohm cm
Dewar and Fleming
Meissner
ELECTRICAL RESISTIVITY RATIO, ρ/ρ_{273}
1.5
1
.8
.6
.4
.3
.2
.1
.08
.06
.04
.03
.02
.01
.008
.006
.004
1
2
3
4
6
8
10
20
30
40
60
80
100
200
300
TEMPERATURE, °K

ELECTRICAL RESISTIVITY of NIOBIUM, Nb

(Atomic Number 41)

Source of Data:

Landolt-Börnstein Zahlenwerte und Funktionen aus Physik, Chemie, Astronomie, Geophysik und Technik, sechste Auflage, II Band, 6 Teil, Springer-Verlag, Berlin (1959) pp 1-46

Other References:

Meissner, W., Franz, H. and Westerhoff, H.; Ann Physik (5) 17, 593 (1933)

Reimann, A. L. and Grant, K.; Phil. Mag. (7) 22, 34 (1936)

Comments:

Reference should be made to the beginning of the Electrical Resistivity section for an explanation of the data. The value of the electrical resistivity at 273°K (ρ_{273}) for Niobium to be used in calculating values of electrical resistivity (ρ_T) is 16.1 x 10^{-6} ohm-cm. This data should not be extrapolated to lower temperatures as Niobium becomes a superconductor between 8.7 and 8.9°K.

The data presented here were taken from the reference cited above under "Source of Data". The values listed in the Landolt-Börnstein tables are those reported by Meissner, Franz and Westerhoff; and Reimann and Grant, cited above under "Other References".

The data reported in the Landolt-Börnstein tables and tabulated here are listed as ratios of electrical resistivity with respect to the resistivity at a datum temperature of 273°K. The actual value of ρ_{273} is not available for the sample used by Meissner, et al. so a datum value reported by Reimann and Grant (ρ_{273} = 16.1 x 10^{-6} ohm-cm) is suggested for calculating values of resistivity from these ratios.

The Landolt-Börnstein tables list the samples used by Meissner, et al. as polycrystalline with 0.08% O_2 and 0.02% Ta impurities present. No other pertinent information is given about either of the samples.

Table of Values of Electrical Resistivity

ρ = Resistivity, (ohm-cm)

ρ_{273} = Resistivity at 273°K, (ohm-cm)

Meissner, Franz and Westerhoff	
Temp. °K	ρ/ρ_{273}
9.33	0.035
20.4	0.0617
78	0.2416

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ELECTRICAL RESISTIVITY of PLATINUM, Pt

(Atomic Number 78)

Sources of Data:

International Critical Tables of Numerical Data, Physics, Chemistry, and Technology, VI, 1st Edition, Published for the National Research Council by the McGraw-Hill Book Co. Inc. (1929) pp 124-135

Landolt-Börnstein Zahlenwerte und Funktionen aus Physik, Chemie, Astronomie, Geophysik und Technik, sechste Auflage, II Band, 6 Teil, Springer-Verlag, Berlin (1959) pp 1-46

Other References:

Henning, F.; Handbuch der Physik IX, Berlin, Springer-Verlag (1926)

Holborn, L.; Ann. Physik. 59, 145 (1919)

Meissner, W.; Ann. Physik (4) 47, 1001 (1915)

Meissner, W.; Physik Z. 27, 725 (1926)

Meissner, W. and Grassmann, P.; Physik Z. 34, 516 (1933)

Onnes, H. K. and Tuyn, W.; Communs. Phys. Lab. Univ. Leiden Suppl. No. 58 (1926)

Van der Horst, H. D.; Tuyn, W. and Onnes, K. H.; Private communication with the editors of the International Critical Tables of Numerical Data, Physics, Chemistry, and Technology, VI, (1929)

Comments:

Reference should be made to the preface at the beginning of the Electrical Resistivity section for an explanation of the graph. The value of electrical resistivity at 273°K (ρ_{273}) for platinum to be used in calculating values of electrical resistivity (ρ_T) is 9.81×10^{-6} ohm-cm.

The data for this graph were taken from the references cited above under "Sources of Data". The values listed in the Landolt-Börnstein tables are those reported by Holborn; Meissner; and Meissner and Grassmann; while those values appearing in the International Critical Tables are from Henning; Tuyn and Onnes; and Van der Horst, Tuyn and Onnes. These primary sources are listed above under "Other References". The original authors are used in labeling the several curves on the graph.

The data in the Landolt-Börnstein tables, the International Critical Tables and tabulated here are listed as ratios of electrical resistivity with respect to the resistivity at a datum temperature of 273°K. The actual values of ρ_{273} for the samples used by the various investigators are not available so a datum value reported by Meissner ($\rho_{273} = 9.81 \times 10^{-6}$ ohm-cm) is suggested for calculating values of electrical resistivity from these ratios.

Comments: (cont.)

The sample used by Holborn is reported in the Landolt-Börnstein tables as cast polycrystalline with a very small amount of impurities present. The samples used by Meissner are reported as polycrystalline with a very small amount of impurities present. The Meissner sample from the 1915 reference is reported to have been annealed. The sample used by Meissner and Grassmann is reported as an annealed polycrystalline sample with less than 0.001% of Cu and Pb impurities present. No other pertinent information is given on any of the samples fron any of the sources of data.

Tables of Values of Electrical Resistivity

ρ = Resistivity, (ohm-cm)

ρ_{273} = Resistivity at 273°K, (ohm-cm)

Holborn		Meissner		Meissner and Grassmann	
Temp. °K	ρ/ρ_{273}	Temp.* °K	ρ/ρ_{273}**	Temp.* °K	ρ/ρ_{273}**
20	0.0060	1.35	0.00165	1.35	0.00031
81	0.2060	4.21	0.00168	4.2	0.00031
195	0.6860	20.40	0.00607	20.4	0.00425
		91.4	0.250		

* The second decimal place is in doubt.

** The fifth decimal place is in doubt.

Table of Values of Electrical Resistivity

ρ = Resistivity, (ohm-cm)

ρ_{273} = Resistivity at 273°K, (ohm-cm)

Temp. °C	Tuyn and Onnes $100\rho/\rho_{273}$	Van der Horst et al. $100\rho/\rho_{273}$	Henning $100\rho/\rho_{273}$
- 80	68.158	68.017	67.782
- 90	64.113	63.955	63.688
-100	60.053	59.874	59.576
-120	51.863	51.650	51.295
-140	43.595	43.337	42.928
-160	35.213	34.904	34.463
-180	26.709	26.356	25.885
-200	18.176	17.750	17.268
-210	14.009	13.563	--
-220	--	9.587	--
-230	--	6.030	--
-240	--	3.252	--
-250	--	1.571	--
-255	1.5885	1.1263	0.5706
-260	1.335	0.894	--
-265	1.239	0.810	--
-270	1.225	0.7863	--

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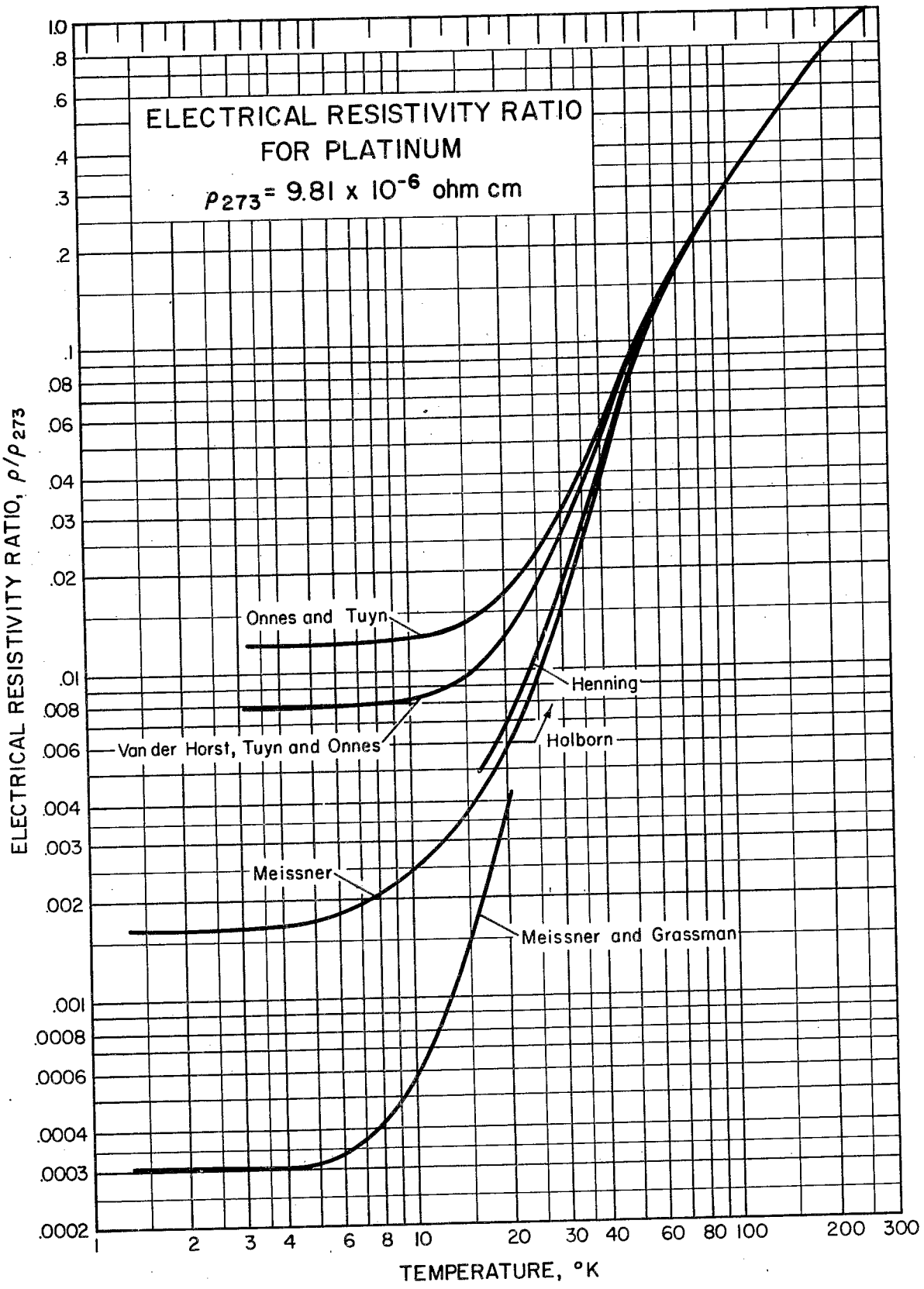
ELECTRICAL RESISTIVITY RATIO FOR PLATINUM
ρ_{273} = 9.81 x 10^{-6} ohm cm
ELECTRICAL RESISTIVITY RATIO, ρ/ρ_{273}
1.0
.8
.6
.4
.3
.2
.1
.08
.06
.04
.03
.02
.01
.008
.006
.004
.003
.002
.001
.0008
.0006
.0004
.0003
.0002
1
2
3
4
6
8
10
20
30
40
60
80
100
200
300
TEMPERATURE, °K
Onnes and Tuyn
Henning
Holborn
Van der Horst, Tuyn and Onnes
Meissner
Meissner and Grassman

ELECTRICAL RESISTIVITY of SILVER, Ag
(Atomic Number 47)

Sources of Data:

International Critical Tables of Numerical Data, Physics, Chemistry, and Technology, VI, 1st Edition, Published for the National Research Council by the McGraw-Hill Book Co. Inc. (1929) pp 124-135

Landolt-Börnstein Zahlenwerte und Funktionen aus Physik, Chemie, Astronomie, Geophysik und Technik, sechste Auflage, II Band, 6 Teil, Springer-Verlag, Berlin (1959) pp 1-46

Other References:

Dewar, J. and Fleming, J. A.; Phil. Mag. J. Sci. (5) 36, 271 (1893)

Holborn, L.; Ann. Physik 59, 145 (1919)

de Haas, W. J. and Van den Berg, G. J.; Physica 3, 440 (1936)

Meissner, W.; Physik. Z. 27, 725 (1926)

Onnes, K. H. and Clay, J. Proc. Acad. Sci. Amsterdam 10, 207 (1908)

Comments:

Reference should be made to the preface at the beginning of the Electrical Resistivity section for an explanation of the graph. The value of electrical resistivity at 273°K (ρ_{273}) for silver to be used in calculating values of electrical resistivity is 1.47×10^{-6} ohm-cm.

The data for this graph were taken from the references cited above under "Sources of Data". The values listed in the Landolt-Börnstein tables are those reported by Dewar and Fleming; Holborn; de Haas and Van den Berg; and Meissner; while those values appearing in the International Critical Tables are from Onnes and Clay. These primary sources are listed above under "Other References". The original authors are used in labeling the curves on the graph.

The data in the Landolt-Börnstein tables, the International Critical Tables and tabulated here are listed as ratios of electrical resistivity with respect to the resistivity at a datum temperature of 273°K. The actual values of ρ_{273} are not available for the samples used by the several investigators so a datum value reported by Dewar and Fleming ($\rho_{273} = 1.47 \times 10^{-6}$ ohm-cm) is suggested for calculating values of electrical resistivity from these ratios.

The samples used by the investigators appearing in Landolt-Börnstein are all reported as polycrystalline with a small amount of impurities present. The samples used by Holborn; and de Haas and Van den Berg were annealed. The sample used by Meissner was aged. No other pertinent information was listed for any of the samples in any of the sources of data.

Tables of Values of Electrical Resistivity

ρ = Resistivity, (ohm-cm)

ρ_{273} = Resistivity at 273°K, (ohm-cm)

Onnes and Clay					
Temp. °C	$100\rho/\rho_{273}$	Temp. °C	$100\rho/\rho_{273}$	Temp. °C	$100\rho/\rho_{273}$
- 80 +	67.8	-140 +	43.2	-204.67	15.528
-100 +	59.6	-160 +	34.8	-220 +	9.2
-103.81	58.087	-180 +	26.3	-240 +	2.6
-120 +	51.4	-183.57	24.679	-252.92	0.8913
-139.87	43.282	-195.17	19.703	-259.22	0.6942
		-200 +	17.6		

Holborn		Meissner		de Haas and Van den Berg	
Temp. °K	ρ/ρ_{273}	Temp.* °K	ρ/ρ_{273}**	Temp. °K	ρ/ρ_{273}
20	0.0054	1.34	0.00679	4.2	0.00266
81	0.2071	4.21	0.00682	6.0	0.00268
195	0.6841	20.4	0.01000	8.4	0.00274
		78.8	0.1974	10.8	0.00288
		87.4	0.2349	20.4	0.00543

* The second decimal place of the temperature values is somewhat in doubt.

** The fifth decimal place of the electrical resistivity ratio values is somewhat in doubt.

\+ Values from interpolation.

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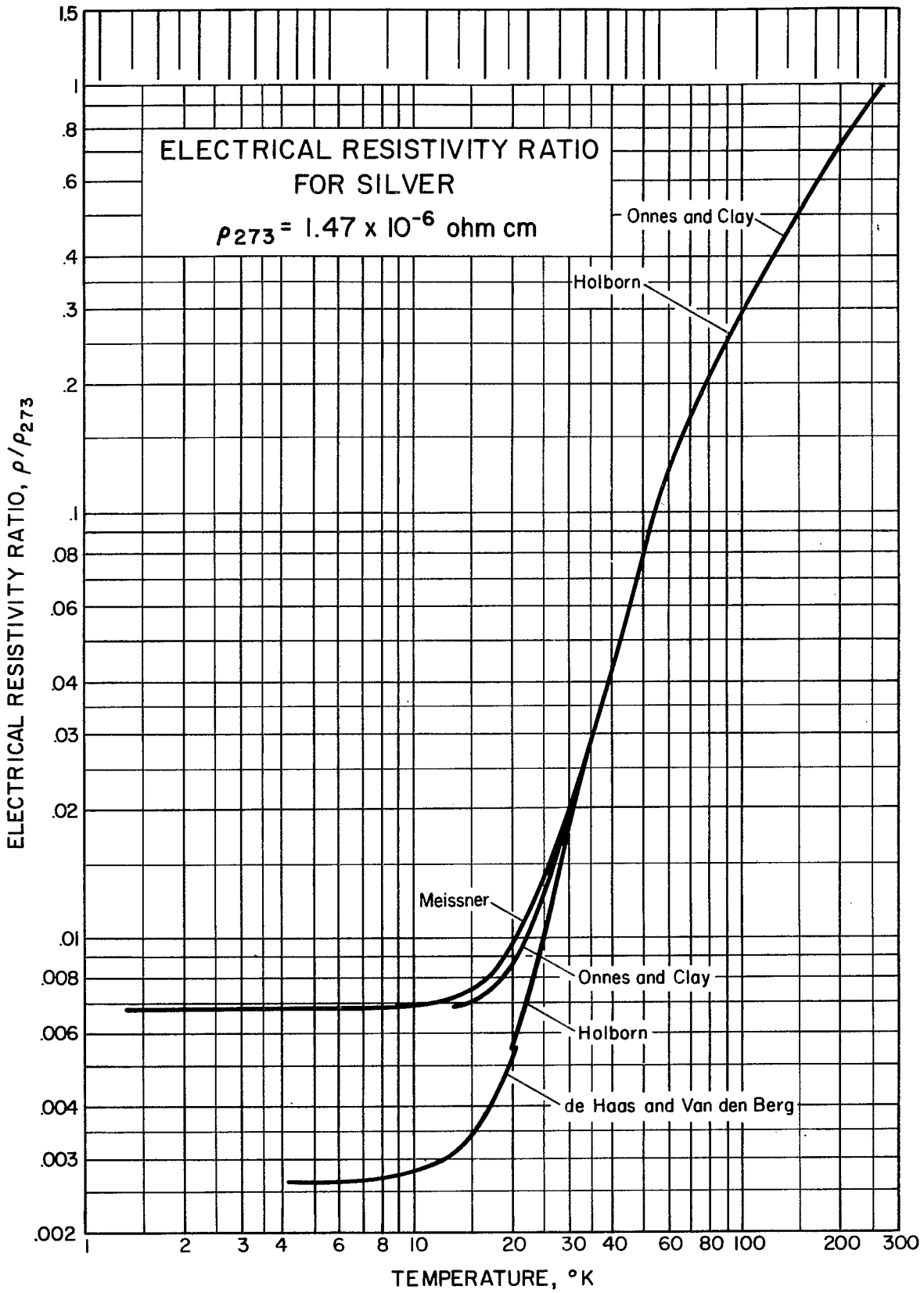
ELECTRICAL RESISTIVITY RATIO FOR SILVER
ρ_{273} = 1.47 x 10^{-6} ohm cm
Onnes and Clay
Holborn
Meissner
Onnes and Clay
Holborn
de Haas and Van den Berg
ELECTRICAL RESISTIVITY RATIO, ρ/ρ_{273}
1.5
1
.8
.6
.4
.3
.2
.1
.08
.06
.04
.03
.02
.01
.008
.006
.004
.003
.002
1
2
3
4
6
8
10
20
30
40
60
80
100
200
300
TEMPERATURE, °K

ELECTRICAL RESISTIVITY of TANTALUM, Ta
(Atomic Number 73)

Sources of Data:

International Critical Tables of Numerical Data, Physics, Chemistry, and Technology, VI, 1st Edition, Published for the National Research Council by the McGraw-Hill Book Co. Inc. (1929) pp 124-135

Landolt-Börnstein Zahlenwerte und Funktionen aus Physik, Chemie, Astronomie, Geophysik und Technik, sechste Auflage, II Band, 6 Teil, Springer-Verlag, Berlin (1959) pp 1-46

Other References:

Burgers, W. G. and Basart, J. C. M.; Z. Anorg. Allgem. Chem. 216, 223 (1934)

Holborn, L.; Ann. Physik 59, 145 (1919)

McLennan, J. C., Howlett, L. E. and Wilhelm, J. O.; Trans. Roy. Soc. Can. 23, III, 287 (1930)

Meissner, W. and Voigt, B.; Ann. Physik (5) 7, 761, 892 (1930)

Comments:

Reference should be made to the preface at the beginning of the Electrical Resistivity section for an explanation of the graph. The value of electrical resistivity at 273°K (ρ_{273}) for tantalum to be used in calculating values of electrical resistivity (ρ_T) is 12.4 x 10^{-6} ohm-cm. The curves on this graph should not be extrapolated to lower temperatures as tantalum becomes a superconductor at 4.38 degrees.

The data for this graph were taken from the references cited above under "Sources of Data". The values listed in the Landolt-Börnstein tables are those reported by Burgers and Basart; McLennan, Howlett and Wilhelm; and Meissner and Voigt; while those values appearing in the International Critical Tables are from Holborn. These primary sources are cited above under "Other References". The names of the original authors are used in labeling the curves on the graph.

The data in the Landolt-Börnstein tables, the International Critical Tables and tabulated here are listed as ratios of electrical resistivity with respect to the resistivity at a datum temperature of 273°K. The actual values of ρ_{273} are not available for the samples used by the several investigators so a datum value reported by Burgers and Basart (ρ_{273} = 12.4 x 10^{-6} ohm-cm) is suggested for calculating values of electrical resistivity from these ratios.

The samples used by the investigators appearing in Landolt-Börnstein are reported as polycrystalline with no mention made of impurities. No other pertinent information is given about any of the samples from any of the sources of data.

Tables of Values of Electrical Resistivity

ρ = Resistivity, (ohm-cm)

ρ_{273} = Resistivity at 273°K, (ohm-cm)

Holborn			
Temp. °C	$100\rho/\rho_{273}$	Temp. °C	$100\rho/\rho_{273}$
- 78.2	72.98	-140 +	49.6
- 80 +	72.4	-160 +	41.9
-100 +	64.9	-180 +	34.3
-120 +	57.3	-192.6	29.55

Meissner and Voigt		McLennan, Howlett and Wilhelm	
Temp.* °K	ρ/ρ_{273}	Temp. °K	ρ/ρ_{273}
4.29	0.00019	4.3	0.029
4.49	0.0099	20.6	0.033
20.44	0.0140	80.0	0.230
77.61	0.2037		
88.30	0.2511		

* The second decimal place of the temperature values is somewhat in doubt.

\+ Values from interpolation.

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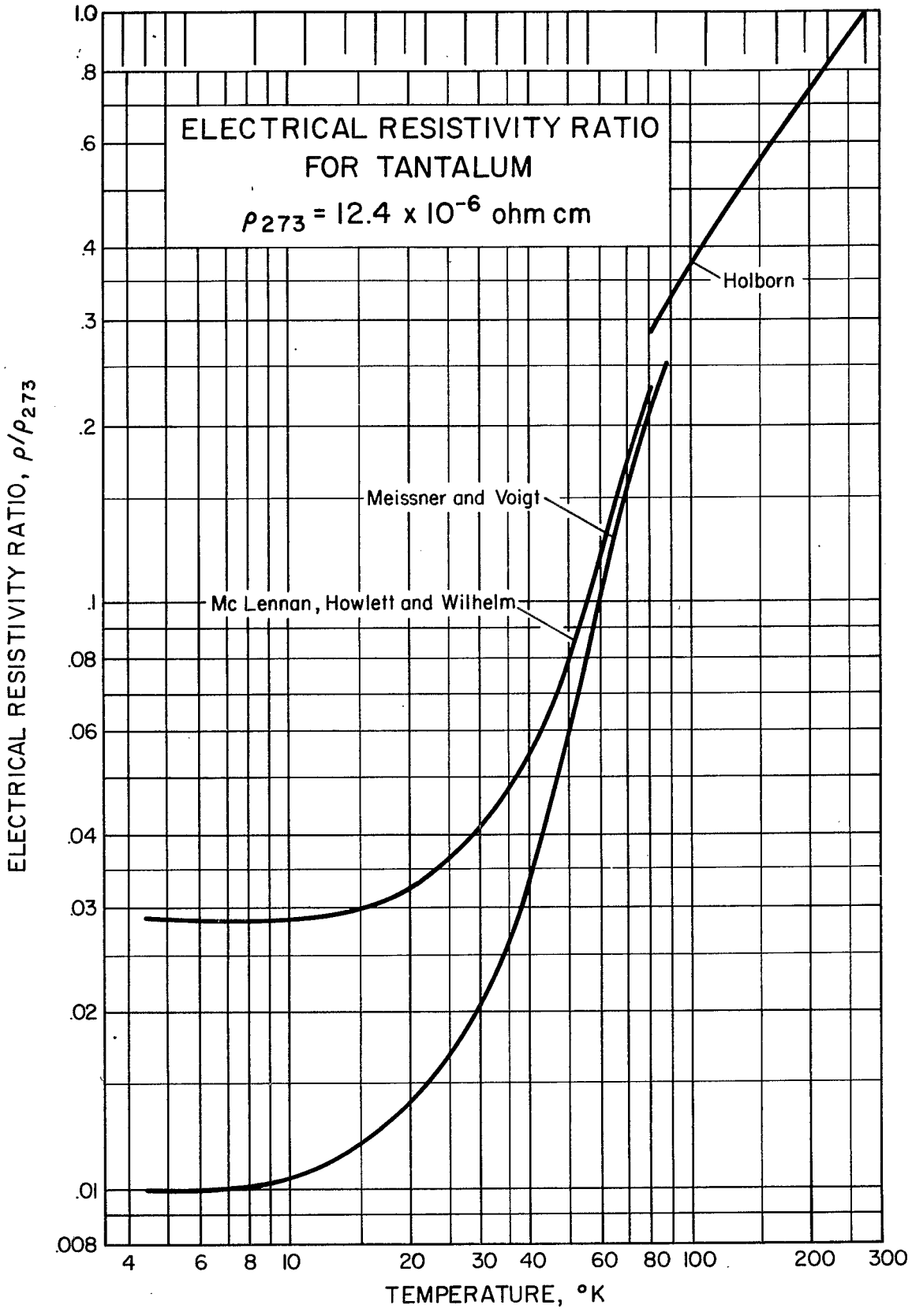
ELECTRICAL RESISTIVITY RATIO
FOR TANTALUM
$\rho_{273} = 12.4 \times 10^{-6}$ ohm cm
Holborn
Meissner and Voigt
Mc Lennan, Howlett and Wilhelm
ELECTRICAL RESISTIVITY RATIO, ρ/ρ_{273}
1.0
.8
.6
.4
.3
.2
.1
.08
.06
.04
.03
.02
.01
.008
4
6
8
10
20
30
40
60
80
100
200
300
TEMPERATURE, °K

ELECTRICAL RESISTIVITY of TIN, Sn

(Atomic Number 50)

Sources of Data:

International Critical Tables of Numerical Data, Physics, Chemistry, and Technology, VI, 1st Edition, Published for the National Research Council by the McGraw-Hill Book Co. Inc. (1929) pp 124-135

Landolt-Börnstein Zahlenwerte und Funktionen aus Physik, Chemie, Astronomie, Geophysik und Technik, sechste Auflage, II Band, 6 Teil, Springer-Verlag, Berlin (1959) pp 1-46

Other References:

Jaeger, W. and Diesselhorst, H.; Wiss. Abhandl. physik. tech. Reichsanstalt, 3, 269 (1900)

Meissner, W.; Physik. Z. 26, 689 (1925)

Onnes, K. H. and Tuyn, W.; Proc. Roy. Acad. Sci. Amsterdam 25, 443 (1923)

Comments:

Reference should be made to the preface at the beginning of the Electrical Resistivity section for an explanation of the graph. The value of the electrical resistivity at 273°K (ρ_{273}) for tin to be used in calculating values of electrical resistivity (ρ_T) is 11.15 x 10^{-6} ohm-cm. The curves should not be extrapolated to lower temperatures as tin becomes a superconductor at 3.74°K.

The data for this graph were taken from the references cited above under "Sources of Data". The values listed in the Landolt-Börnstein tables are those reported by Jaeger and Diesselhorst; and Meissner; while those values appearing in the International Critical Tables are from Onnes and Tuyn. These primary sources are listed above under "Other References".

The data in the Landolt-Börnstein tables, the International Critical Tables and tabulated here are listed as ratios of electrical resistivity with respect to the electrical resistivity at a datum temperature of 273°K. The actual values of ρ_{273} for the samples used by both the investigators are not available so a datum value reported by Jaeger and Diesselhorst (ρ_{273} = 11.15 x 10^{-6} ohm-cm) is suggested for calculating values of electrical resistivity from these ratios. Jaeger and Diesselhorst report less than 0.03% Pb impurity in the polycrystalline sample used in the determination of ρ_{273}.

The Landolt-Börnstein tables list the samples of Meissner as polycrystalline with no mention of impurities present. The sample used by Onnes and Tuyn is reported as polycrystalline with less than 0.01% impurities of unknown composition. No information was given on the mechanical or heat treatment of any of the samples from any of the sources of data.

Tables of Values of Electrical Resistivity

ρ = Resistivity, (ohm-cm)

ρ_{273} = Resistivity at 273°K, (ohm-cm)

Onnes and Tuyn			
Temp. °C	$100\rho/\rho_{273}$	Temp. °C	$100\rho/\rho_{273}$
-102.13	57.36	-209.98	14.67
-115.14	52.16	-218.30	11.45
-127.50	47.25	-252.65	1.162
-141.06	41.90	-254.95	0.836
-158.74	34.91	-256.61	0.637
-182.80	25.44	-258.89	0.409
-194.07	20.98	-269.33	0.099
-202.07	17.79		

Meissner	
Temp. °K	ρ/ρ_{273}
4.2	0.00078
20.4	0.0120
88.2	0.2457

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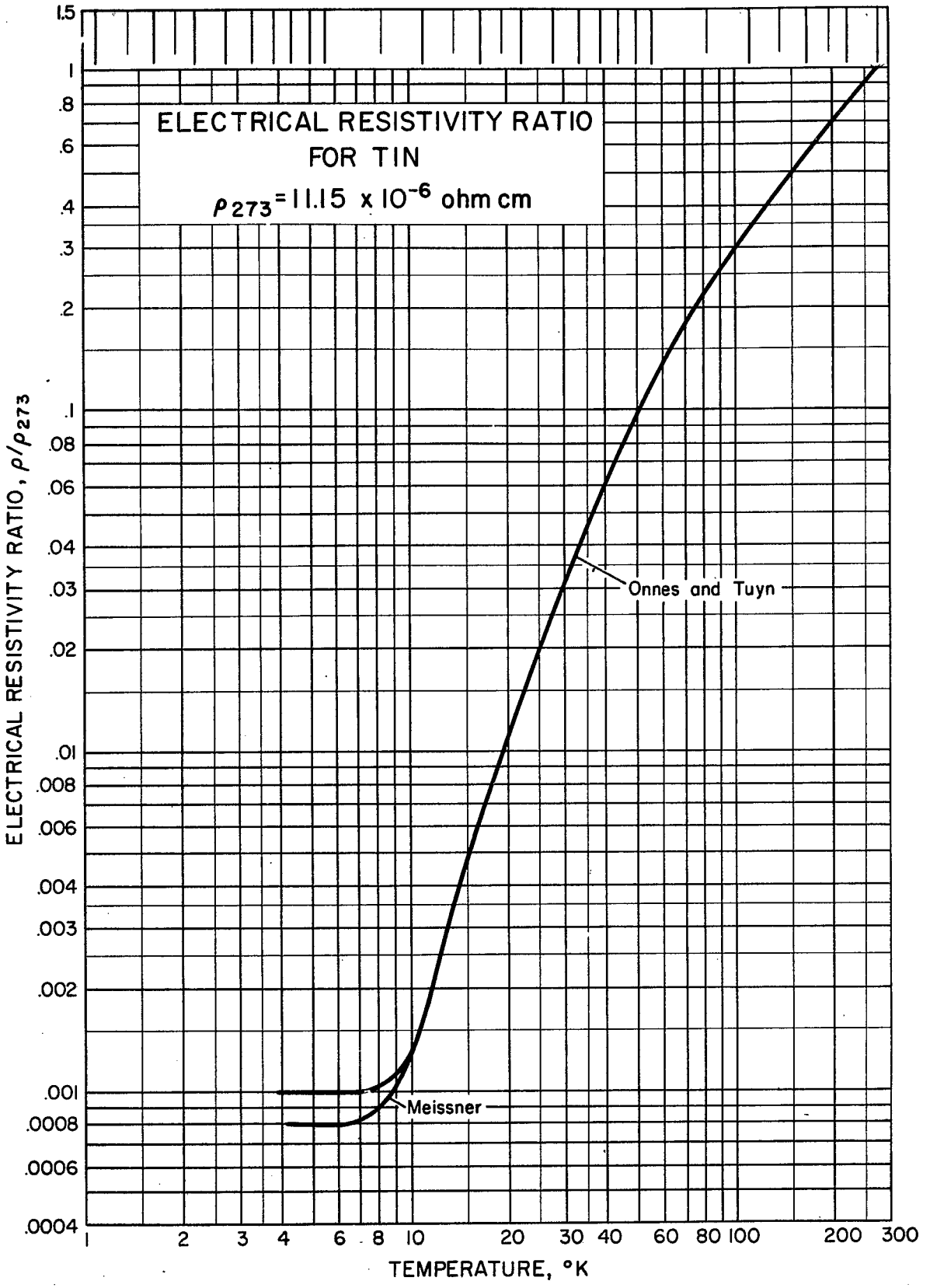
ELECTRICAL RESISTIVITY RATIO
FOR TIN
$\rho_{273} = 11.15 \times 10^{-6}$ ohm cm
Onnes and Tuyn
Meissner
ELECTRICAL RESISTIVITY RATIO, ρ/ρ_{273}
TEMPERATURE, °K
1.5
1
.8
.6
.4
.3
.2
.1
.08
.06
.04
.03
.02
.01
.008
.006
.004
.003
.002
.001
.0008
.0006
.0004
1
2
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6
8
10
20
30
40
60
80
100
200
300

ELECTRICAL RESISTIVITY of SOME COMMERCIAL ALLOYS at LOW TEMPERATURES

Sources of Data:

Low Temperature Electrical Resistance of Fifteen Commercial Conductors, O.E. Park, M.M. Fulk, M.M. Reynolds. NBS Report 3517, Pages 101 & 102, (1954)

Engineering Alloys, 3rd ed., Norman E. Woldman, American Society for Metals, (1954)

Other References:

E.F. Burton et al, Phenomena at the Temperature of Liquid Helium (245-281) Reinhold Publishing Corporation, New York (1940)

Bruce Chalmers, Progress in Metal Physics, Vol. 3 "Properties of metals at low temperatures" by D.K.C. MacDonald, Interscience Publishing Company, (1952)

Comments:

ADVANCE

Composition: 54-55 Cu, 44-46 Ni

Manufacturer: Driver Harris Co., Harrison, N.J.

Temp. (^{o}K)	ρ (ohm-cm)
19.7	4.36×10^{-5}
76.0	4.62×10^{-5}
193.0	4.73×10^{-5}
273.2	4.76×10^{-5}

CHROMEL A

Composition: 80 Ni, 20 Cr

Manufacturer: Hoskins Mfg. Co., Detroit, Mich.

Temp. (^{o}K)	ρ (ohm-cm)
19.7	1.02×10^{-4}
76.0	1.03×10^{-4}
193.0	1.04×10^{-4}
273.2	1.05×10^{-4}

CUPRON

Composition: 55 Cu, 45 Ni

Manufacturer: Wilbur B. Driver Co., Newark, N.J.

Temp. (^{o}K)	ρ (ohm-cm)
19.7	4.31×10^{-5}
76.0	4.57×10^{-5}
193.0	4.70×10^{-5}
273.2	4.74×10^{-5}

EVANOHM

Composition: 20 Cr, 75 Ni, 2.75 Al, 2.75 Cu

Manufacturer: Wilbur B. Driver Co., Newark, N.J.

Temp. (^{o}K)	ρ (ohm-cm)
19.7	1.32×10^{-4}
193.0	1.33×10^{-4}
273.2	1.33×10^{-4}

MANGANIN

Composition: 84 Cu, 12 mn, 4 Ni
10.5-13.5 Mn, 1-2 Ni, bal. Cu

Manufacturer: Wilbur B. Driver Co., Newark, N.J.
Driver Harris, Co., Harrison, N.J.

Temp. (^{o}K)	ρ (ohm-cm)
19.8	4.24×10^{-5}
76.0	4.44×10^{-5}
193.0	4.69×10^{-5}
273.2	4.73×10^{-5}

NILSTAIN (SS Type 304)

Composition: 0.11 Max. C, 17-19 Cr, 7-11 Ni, bal.Fe

Manufacturer: Several

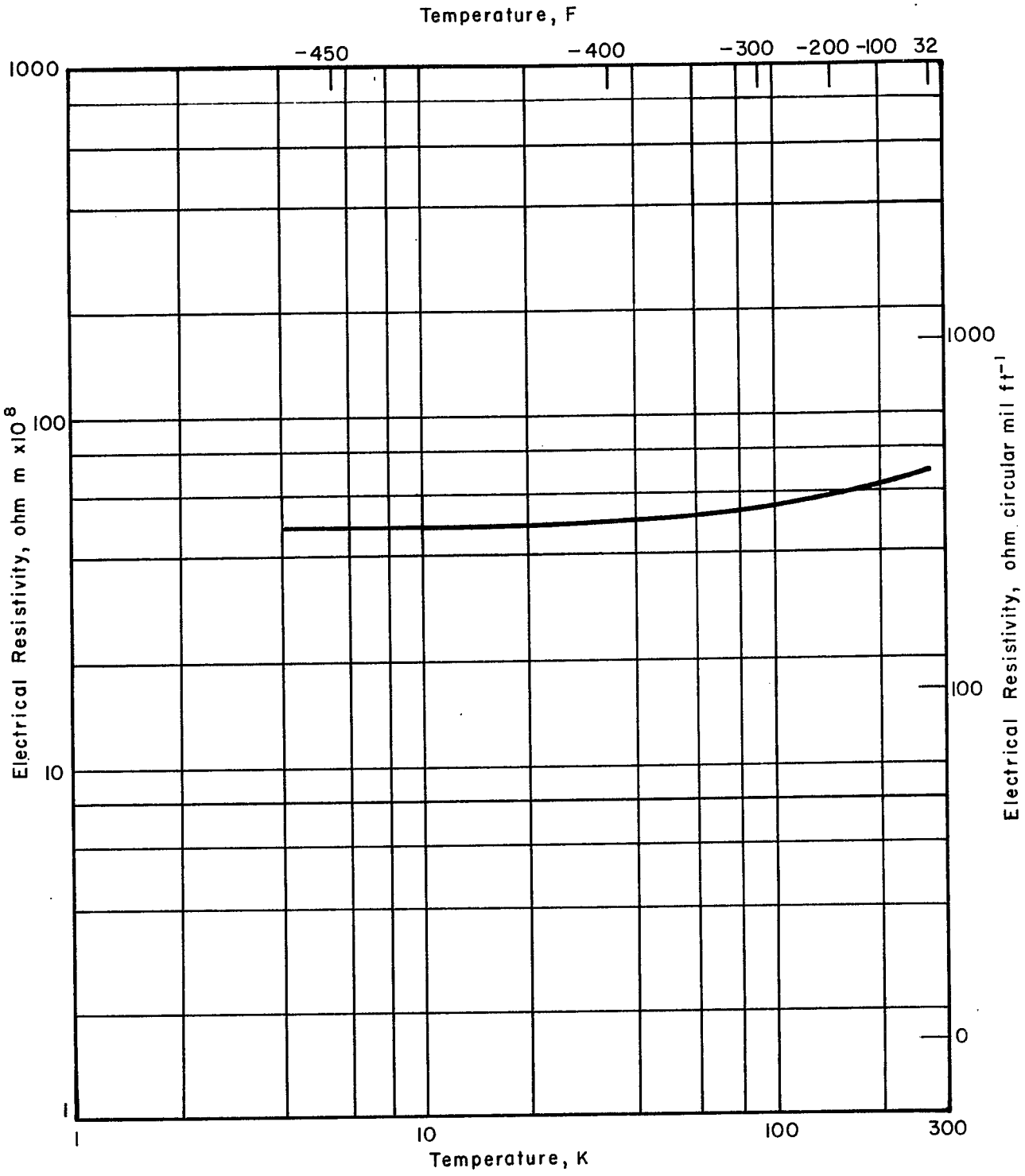
Temp. (^{o}K)	ρ (ohm-cm)
19.7	5.52×10^{-5}
76.0	5.60×10^{-5}
193.0	7.07×10^{-5}
273.2	1.02×10^{-4}

TROPHET A

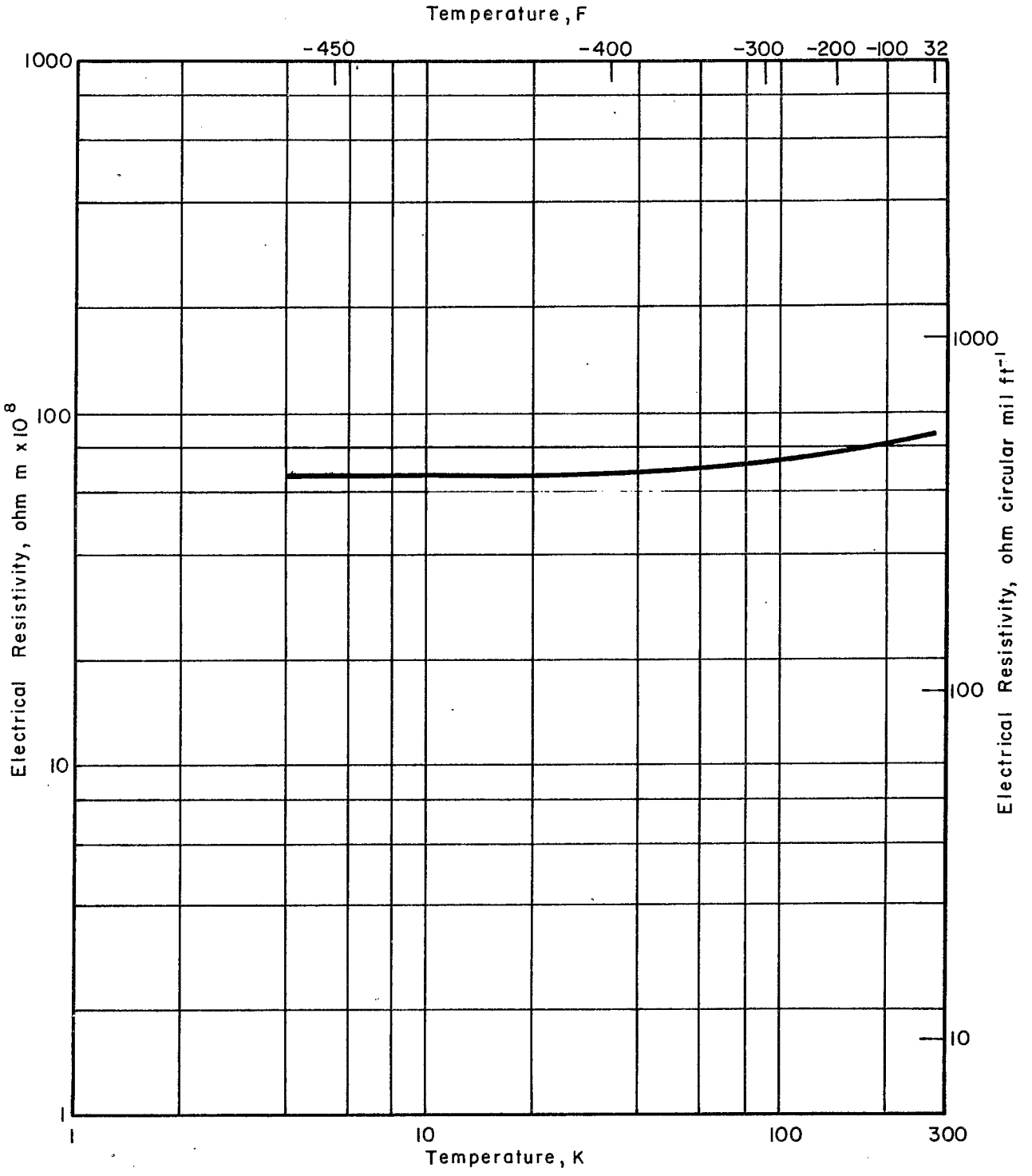
Composition: 80 Ni, 20 Cr

Manufacturer: Wilbur B. Driver Co., Newark, N.J.

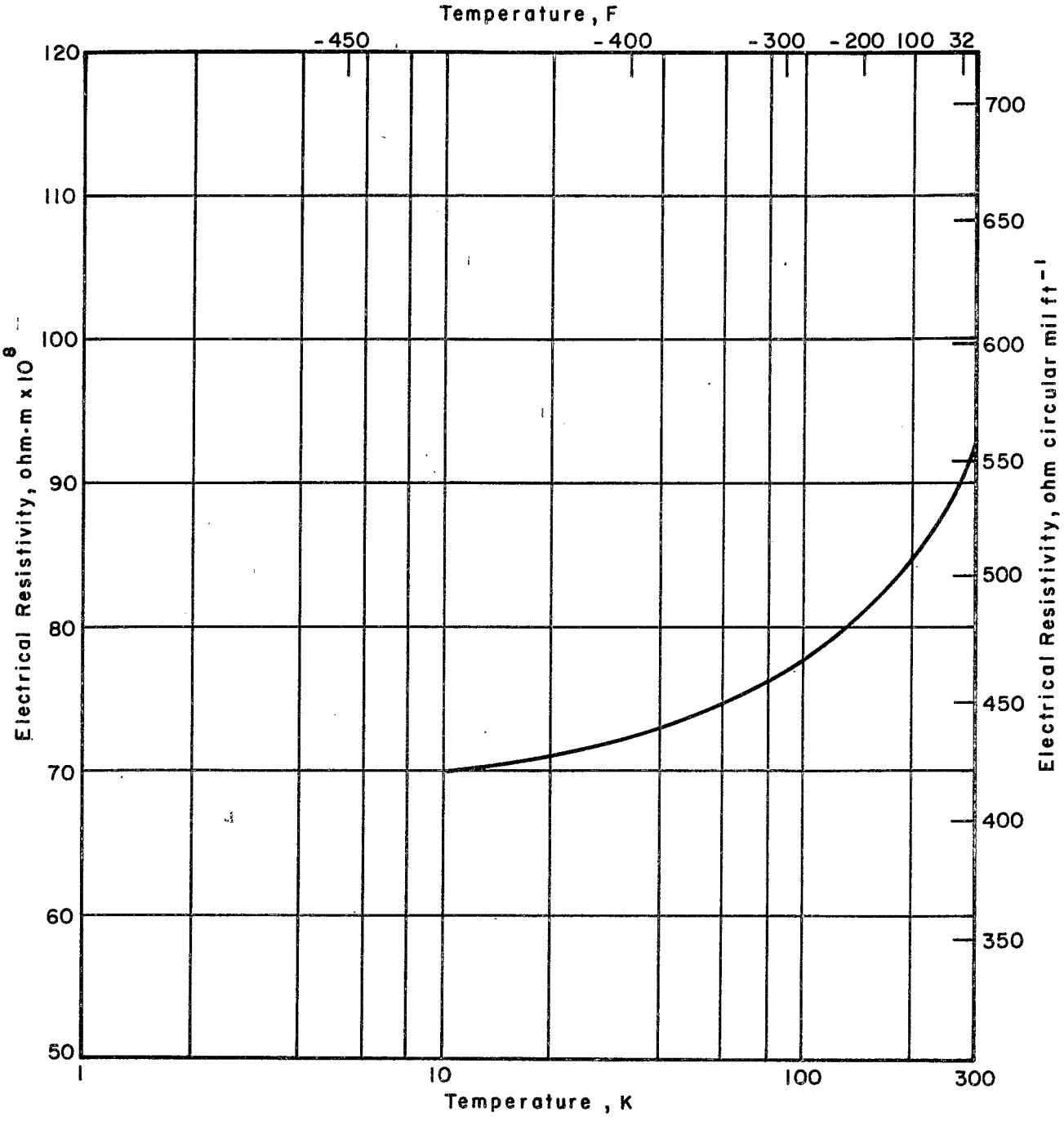
Temp. (^{o}K)	ρ (ohm-cm)
19.7	1.09×10^{-4}
76.0	1.09×10^{-4}
193.0	1.09×10^{-4}
273.2	1.11×10^{-4}



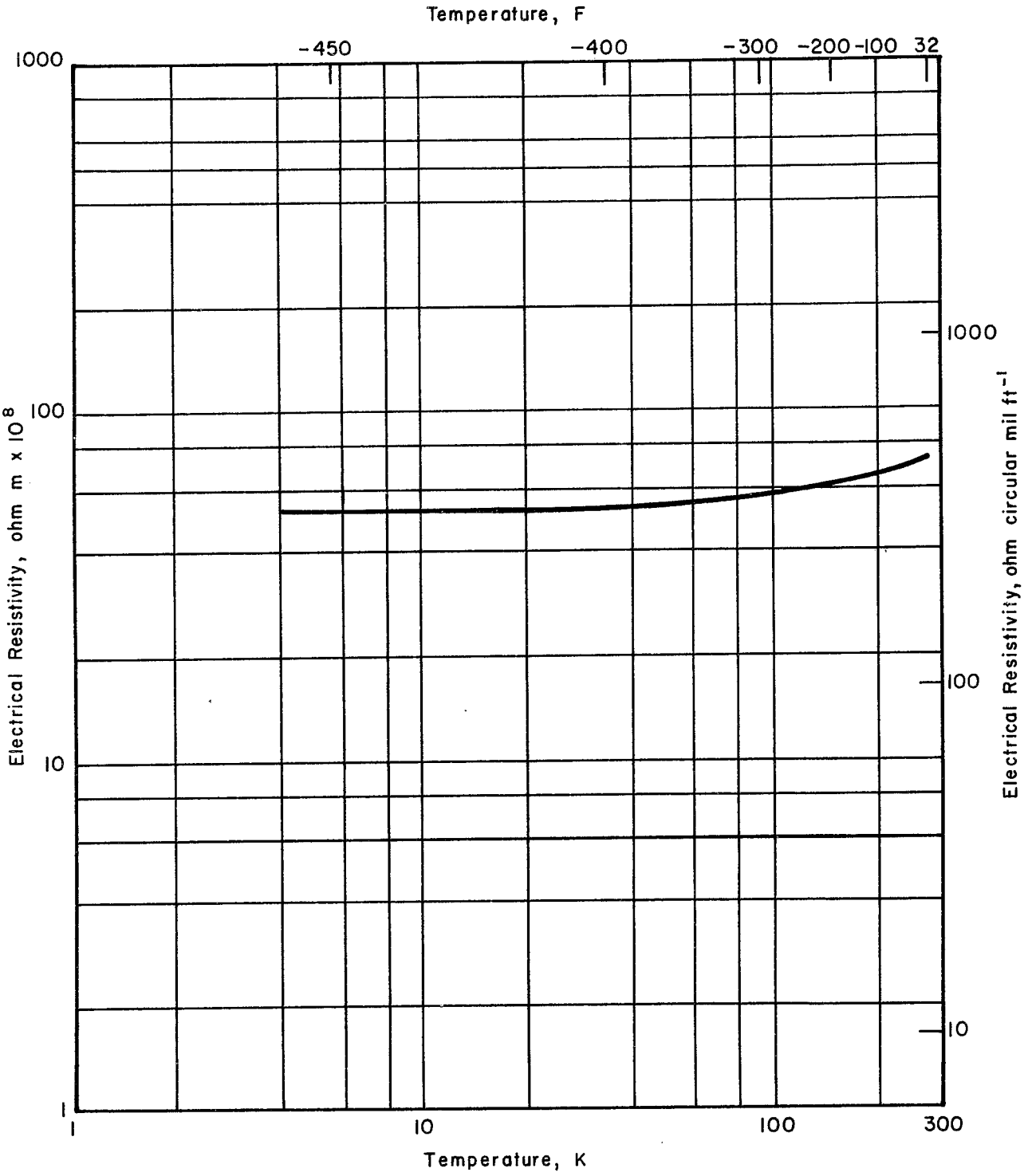
ELECTRICAL RESISTIVITY VERSUS TEMPERATURE FOR TYPE 304L STAINLESS STEEL



ELECTRICAL RESISTIVITY VERSUS TEMPERATURE FOR
TYPE 310 STAINLESS STEEL



ELECTRICAL RESISTIVITY VERSUS TEMPERATURE FOR
TYPE 310S STAINLESS STEEL



ELECTRICAL RESISTIVITY TEMPERATURE VERSUS FOR
TYPE 321 STAINLESS STEEL