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Thermal Conductivity of Metals and Alloys at Low Temperatures

A Review of the Literature

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Thermal Conductivity of Metals and Alloys at Low Temperatures

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Robert L. Powell and William A. Blanpied

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Preface

Accurate data on the thermal conductivity of materials of construction at low temperatures are essential in the design of cyrogenic equipment. Such data on pure metals also have important applications in basic physics.

This Circular is issued to satisfy the need for a complete and authoritative compilation of the useful data on thermal conductivity at low temperatures given in the widely scattered and extensive literature on the subject. Although the Circular is not primarily a critical compilation, the text indicates a method that might be used in choosing between conflicting data.

It will be noted that there are wide unexplored regions; much experimental work remains to be done. It is hoped, therefore, that this Circular will stimulate additional measurements and indicate the areas in which data are most needed.

A. V. Astin, *Director*.

Contents

Thermal Conductivity of Metals and Alloys at Low Temperatures

A Review of the Literature†

Robert L. Powell and William A. Blanpied*

An extensive compilation is given of the measured values of thermal conductivity for metals and alloys from room temperature down to approximately 0° K. The more extensive and important data are plotted in 48 graphs. The tables and graphs for the metallic elements and alloys are essentially complete for literature reference from 1900 to early 1954. For comparison, several graphs and tables are given for some representative dielectrics.

1. Introduction

1.1. Scope and Arrangement

The thermal conductivity values of three types of solids are presented: (1) metallic elements, (2) alloys, and (3) dielectrics. Very little discussion is presented on the qualitative theories or significance of the various experiments. Recent articles, as indicated under each material, usually will contain comments on these aspects of conductivity. Under "metallic elements," the materials are arranged by periodic groups, beginning with the alkali metals. Under "alloys," the materials are arranged in this same manner by major component. In group 3, several dielectrics are included for comparison. A list of the figures and tables is given in section 2.1.

The professional abstract and leading research journals were searched for references dating from 1900 to the spring of 1954. It is felt that the compilation is complete for the metals and essentially complete for the alloys, but only a few representative references are given for the dielectrics. Conductivity values were collected for the temperature range approximately 0° to 300° K. Many of the references contain information for room temperature only, and conductivity values from these are given in the tables only.

The letters at the left end of the curves are a code to the names of the authors. The symbols at the right end of the curves indicate the material tested. Conductivity values in the graphs and tables are given in units of watts per centimeter degree Kelvin (except for a few, which are in milliwatts per centimeter degree Kelvin). A table of conversion factors is given. Arrows on the bottom of the graphs indicate the normal boiling points of helium, hydrogen, and nitrogen, and the melting point of ice, respectively. A bibliography (nearly all dated after 1900) is included at the end of the Circular. It is shown in the tables when other properties of the samples have been measured, such as electrical resistance, thermal electromotive force, and specific heat, which are symbolized by R, emf, and C_p, respectively.

The units in the tables and graphs are usually watts per centimeter degree Kelvin. These may be converted to other systems of units by use of the following factors:

To convert to—	Multiply by—
Cal/cm deg K	0.239
Btu/ft hr deg F	57.8
Btu in/ft^2 hr deg F	693

The preparation of this Circular required the assistance and cooperation of many. Foremost among them was Charles A. Meizner, who plotted most of the graphs and analyzed some of the original research papers. The cooperation of the many authors and manufacturers who supplied reprints of their articles and manuals for use in this study is acknowledged.

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2. Figures and Tables

2.1. List

2.2. Metallic Elements

The variations of the thermal conductivities of metallic elements with temperature are given in figures 1 to 21. The main figures (those without a or b) have the higher temperature curves; usually the temperature range 4° to 300° K. When there is sufficient data in the liquid-helium range, there is a supplementary graph for the range from approximately 0° to 5° or 10° K. The graphs are arranged by periodic groups, beginning with the alkali metals. A summary table is included for each graph, giving for each element a list of references to research papers on the thermal conductivity of the element. The first column contains the chemical symbol and the property or composition identification on the curves if the data for the author reference are plotted on the graph.

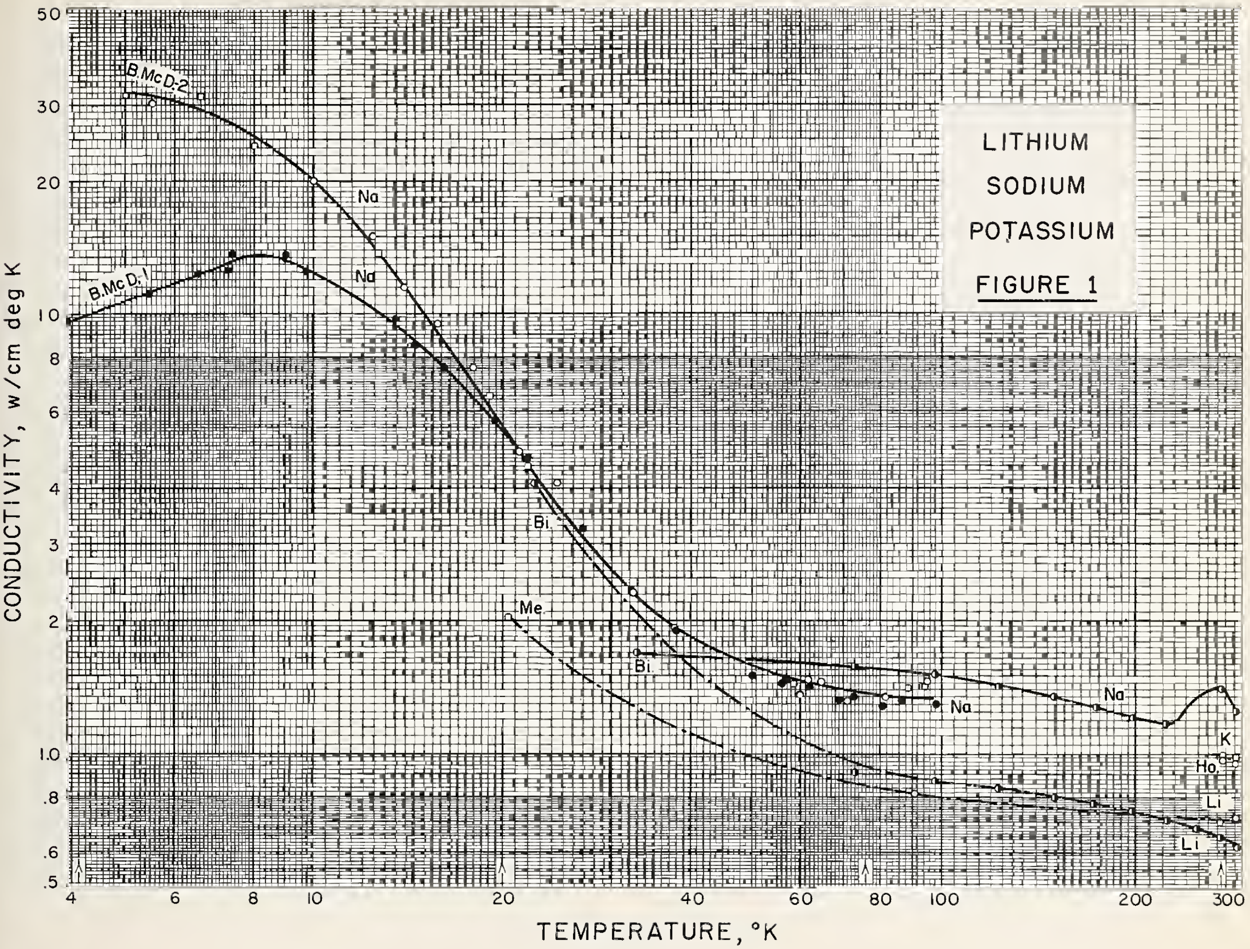
Not all the available data are plotted on graphs. If measurements were made at only 1 or 2 temperatures, representative conductivity values are usually given in the "Remarks" column in the corresponding table. When several authors report values that are nearly identical, the report that was published first is usually represented on the graph. There are exceptions to this when the results of a later author are more accurate or more extensive. In most graphs, where there are more than one curve for a given element, the graph showing the highest conductivity is considered most likely to be representative of that of the pure material. The higher values are associated with the more pure material, adequate annealing, and large crystal size.

In the commonly accepted theory for the conductivity of metals, there are two mechanisms for the conduction of heat. In pure metals nearly all of the energy transfer is by electrons. In dielectrics, there is also a transport of energy by the lattice vibrations. However, the relative contribution of this latter mechanism is insignificant except for alloys, impure metals, and the semimetals like bismuth. The transfer of energy by electrons is impeded by several scattering mechanisms. At temperatures above about 20° K the main scattering agent is the metallic lattice itself. Below that temperature the scattering due to impurity centers and lattice defects becomes increasingly more important. In the temperature range from several degrees to about 40° K, the conductivity of a pure metal may be expressed closely by the equation

$$1/k = \alpha T^2 + \beta T^{-1}.$$

The term αT^2 is characteristic of the lattice of the metal being investigated; the term βT^{-1} represents the scattering due to impurities. The latter term is related to the residual electrical resistance. Experimental values for α and β are given in the tables when the authors include these values in their research reports.

Several physical and chemical properties of the sample affect the conductivity directly. As the purity of the material is increased, the conductivity maximum rises and is shifted toward lower temperatures. The thermal resistance caused by impurities is not additive—small changes in purity can cause very large changes in the conductivity near the maximum. At higher temperatures, however, the effect is not as important. Cold-working and hardening reduce the conductivity and for that reason, other things being equal, the annealed samples will have a higher conductivity. For some single crystals the conductivity depends upon the direction of heat flow. For several metals that are anisotropic, curves are given for various crystal orientations.



LITHIUM

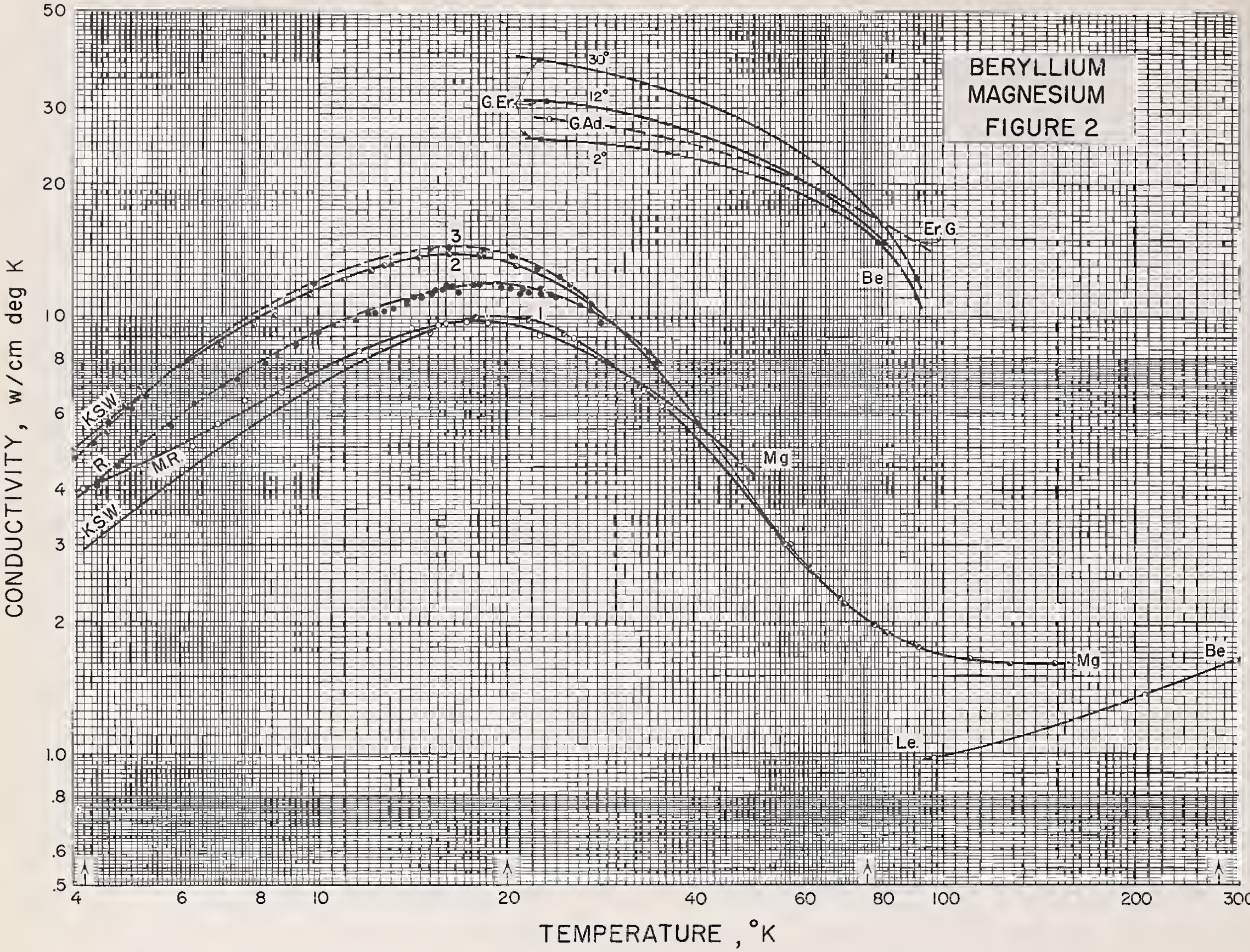
Curve	Sample source and analysis	Remarks	Reference
Me.......	Kahlbaum; "very pure".	Cold-worked; handled in CO_2 atmosphere; R.	W. Meissner (1920).
Bi.......	....	Extruded and mounted in glass tubes; cycled thermally; R.	C. C. Bidwell (1926b, 1925, 1926a).

POTASSIUM

Curve	Sample source and analysis	Remarks	Reference
Ho........	Eimer and Amend; "very pure", free of Fe, Ca, Mg, Al, trace of Na, by chemical analysis.	Melted in vacuum; cast in glass under vacuum; R.	J. W. Hornbeck (1913).

SODIUM

Curve	Sample source and analysis	Remarks	Reference
....	Eimer and Amend; "very pure" free of Fe, Ca, Mg, Al, and K by chemical analysis.	Melted in vacuum; cast in glass under vacuum; obtained $k=1.34$ at 5.7°C, 1.33 at 21.0°C; R.	J. W. Hornbeck (1913).
Bi........	....	Extruded and mounted in glass tubes; cycled thermally; R.	C. C. Bidwell (1926b, 1925, 1926a).
B.McD. 2.	British Thomson-Houston; 0.01 to 0.1% Ca and Al.	Melted, cast in vacuum; cast into soft glass; R.	R. Berman and D. K. C. MacDonald (1951).
B.McD. 2	Philips; trace of Ag.	Melted, cast in vacuum; cast into soft glass; R.	R. Berman and D. K. C. MacDonald (1951).

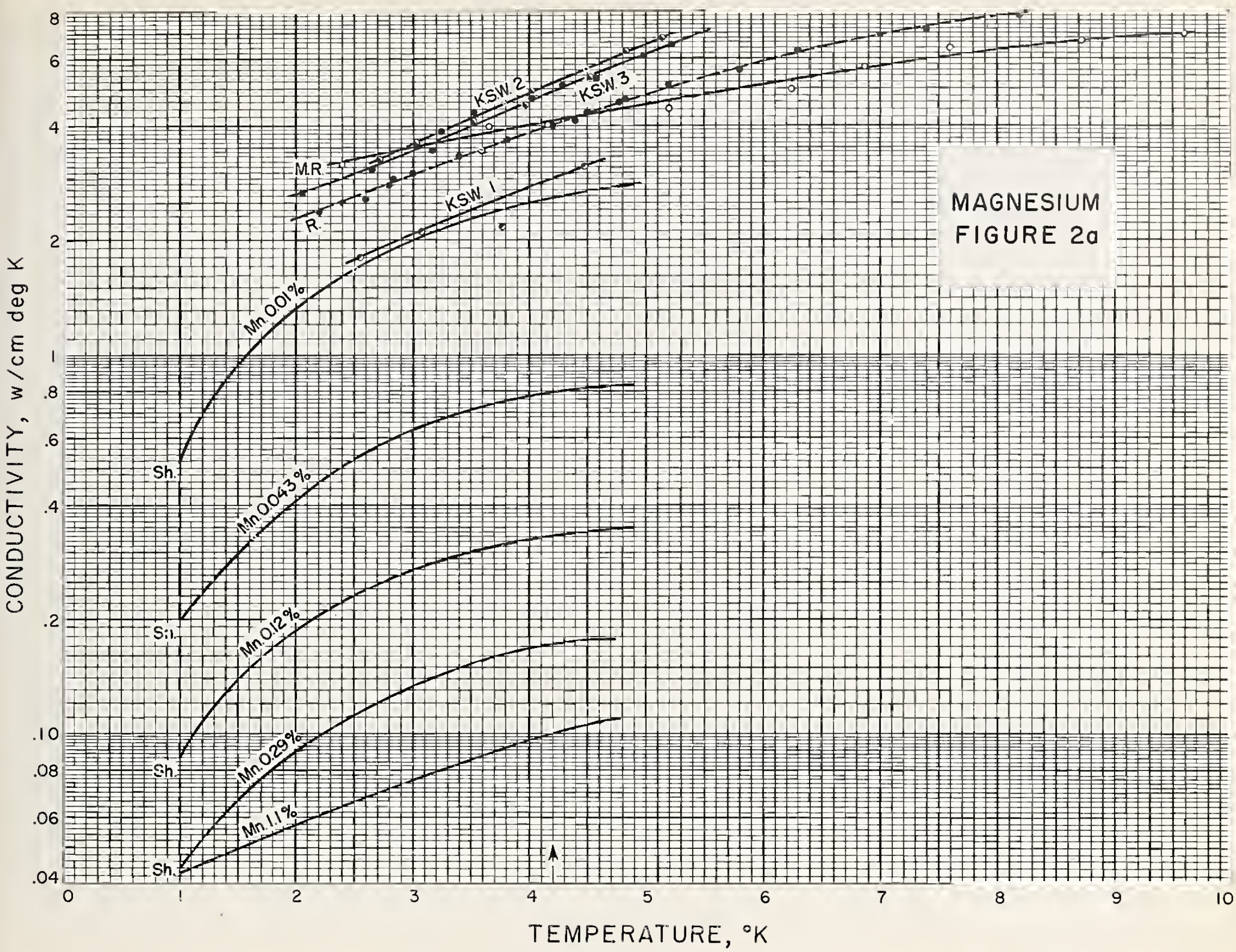


BERYLLIUM

Curve	Sample source and analysis	Remarks	Reference
Le.	Beryllium Co. Am.; comm. pure; traces of Al, Mn, Cr, Fe, Si, and Mg; total impurity ½%.	Physical imperfections noted; R, Cp, and emf.	E. J. Lewis (1929).
G. Ad.	Degussa Co.; "high purity".	Residual resistance 1% of R_{273}; single crystal with heat flow parallel to hexagonal axis; studied effect of magnetic field on R and k.	E. Grüneisen and H. Adenstedt (1938).
G. Er.	do	Same; except rod axis perpendicular to hexagonal axis; binary lateral axis inclined to rod axis by 2°, 12° and 30°; showed anisotropy.	E. Grüneisen and H.-D. Erfling (1940).
Er. G.	do	Same as G. Ad.	H.-D. Erfling and E. Grüneisen (1942).

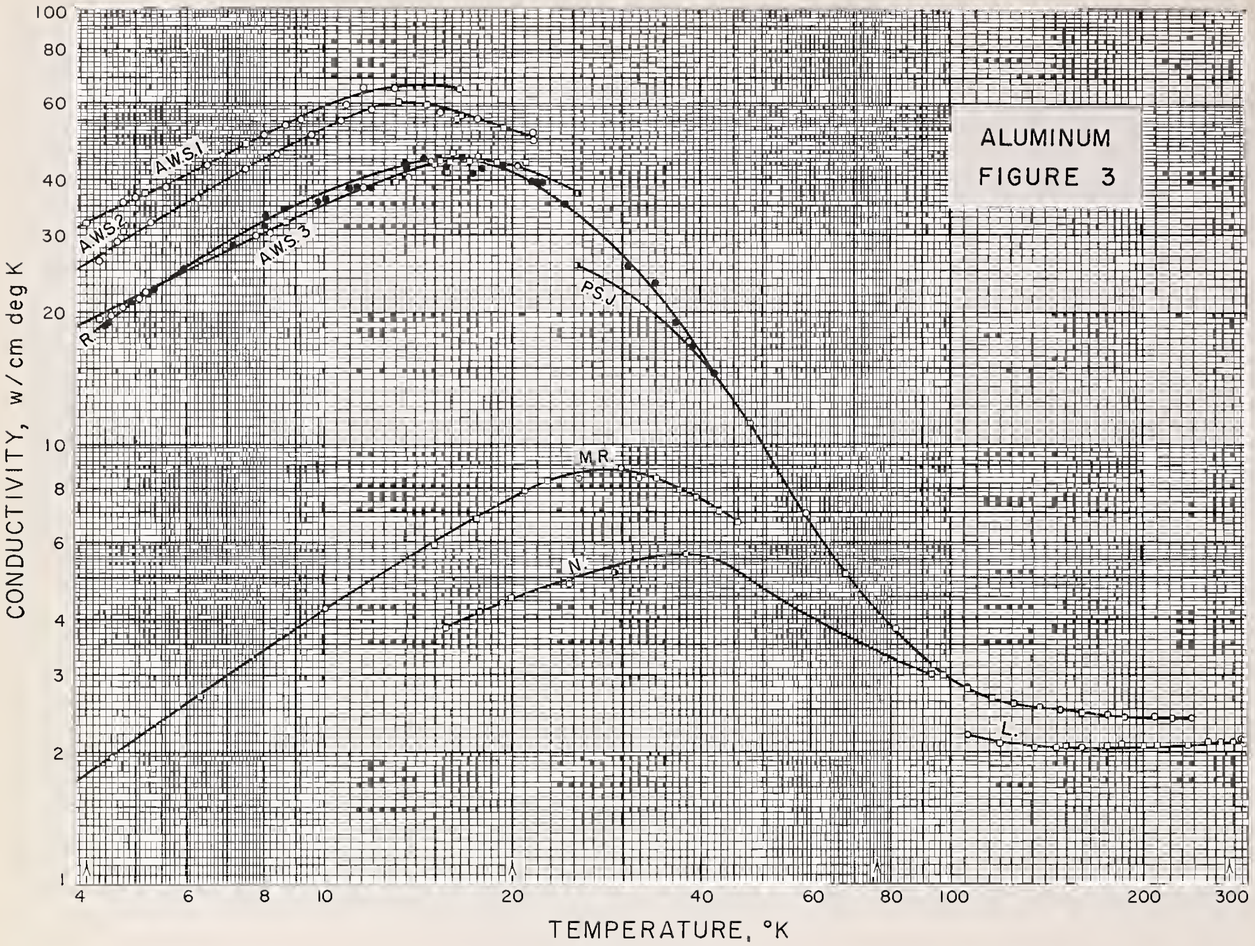
MAGNESIUM

Curve	Sample source and analysis	Remarks	Reference
	"Pure"	k=1.57 at 0 °C; R.	L. Lorenz (1881a).
	do	k=1.72 at 0°C, 2.0 at 80°K; R.	J. Staebler (1929).
	do	k=1.72 at 0°C, 1.87 at 80°K; R.	W. Mannchen (1931).
	do	k=1.60 at 18°C; R.	R. Kikuchi (1932).
M. R.	Johnson, Matthey; 99.95% pure.	Equation $\alpha=10.6\times10^{-5}$, $\beta=1.25$.	K. Mendelssohn and H. M. Rosenberg. (1952a).
	do	Equation $\alpha=8.6\times10^{-5}$, $\beta=1.05$.	H. M. Rosenberg (1954a).
S.	Dow; manganese impruities as marked on graph.	R.	E. G. Sharkoff (1952, 1953ab).



MAGNESIUM (Cont'd)

Curve	Sample source and analysis	Remarks	Reference
K. S. W. 1	Johnson, Matthey; 99.98% purity; .013% Fe, .0023% Mn, .0013% Pb, trace of Si, Cu, Ag, Ca, Na.	Cold-drawn......................	W. R. G. Kemp, A. K. Sreedhar, and G. K. White (1953).
K. S. W. 2	....do..........	Annealed in vacuum 3 hr at 350°C.	Do.
K. S. W. 3	....do..........	Same treatment as number 2......	Do.
R.........	Johnson, Matthey; 99.95% pure; .03% Mn, .0075% Fe, .004% Al.	Annealed 6 hr in vacuum at 500°C; equation $\alpha=8.5\times10^{-6}$, $\beta=1.05$.	H. M. Rosenberg (1954b).

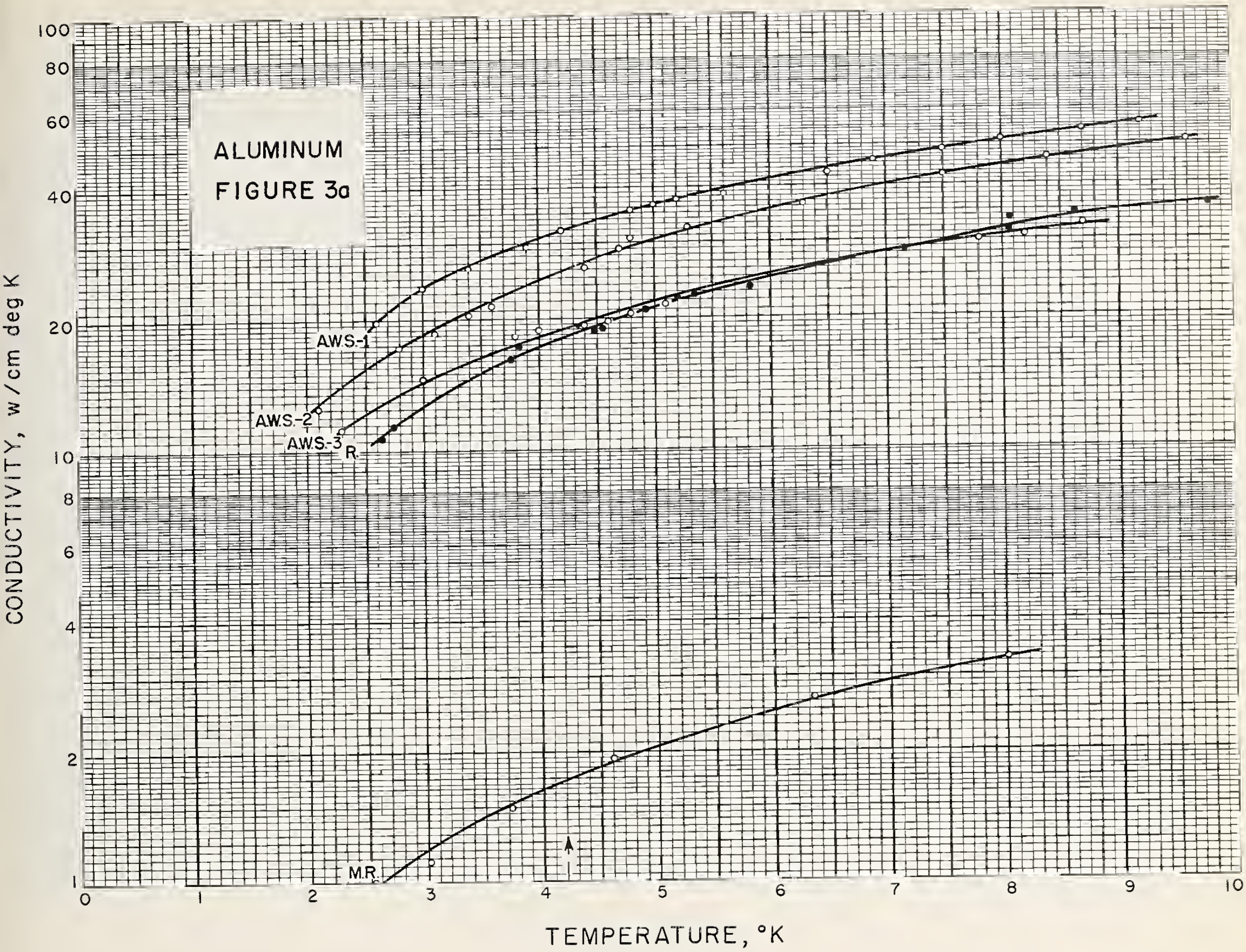


ALUMINUM

Curve	Sample source and analysis	Remarks	Reference
....	"Pure".........	Low value of k=1.43 at 0°C; R...	L. Lorenz (1881a).
....	0.5% Fe, 0.4% Cu.	k=2.01 at 18°C; R, Cp..........	W. Jaeger and H. Diesselhorst (1900).
L.........	Johnson, Matthey; 99% pure.	Lathe turned from larger sample, density of 2.70.	C. H. Lees (1908).
....	Commercial.....	k=1.93 at 0°C, 1.90 at 85°K, 1.59 at 21.4°K.	R. Schott (1916).
....	....	Measured the effect of torsion on the thermal and electrical conductivity.	J. E. Calthrop (1926).
....	5 samples ranging from pure to technical.	Measured at 20° and 80°K; results for purest samples lie just below curve of P. S. J.; studied effect of grain size and crystal boundaries.	E. Grüneisen and E. Goens (1927); E. Grüneisen (1927).
....	"Pure".........	k=2.26 at 0°C, 2.55 at 89°K; R...	J. Staebler (1929).
....	....do..........	k=2.26 at 0°C, 2.56 at 80°K; also measured R.	W. Mannchen (1931).
....	Approx. 99.7% pure; technically pure.	Two samples gave values at 0°C of k=2.26.	A. Eucken and H. Warrentrup (1935).
N........	Hadfield's......	Brinnel hardness of 17...........	J. de Nobel (1951).

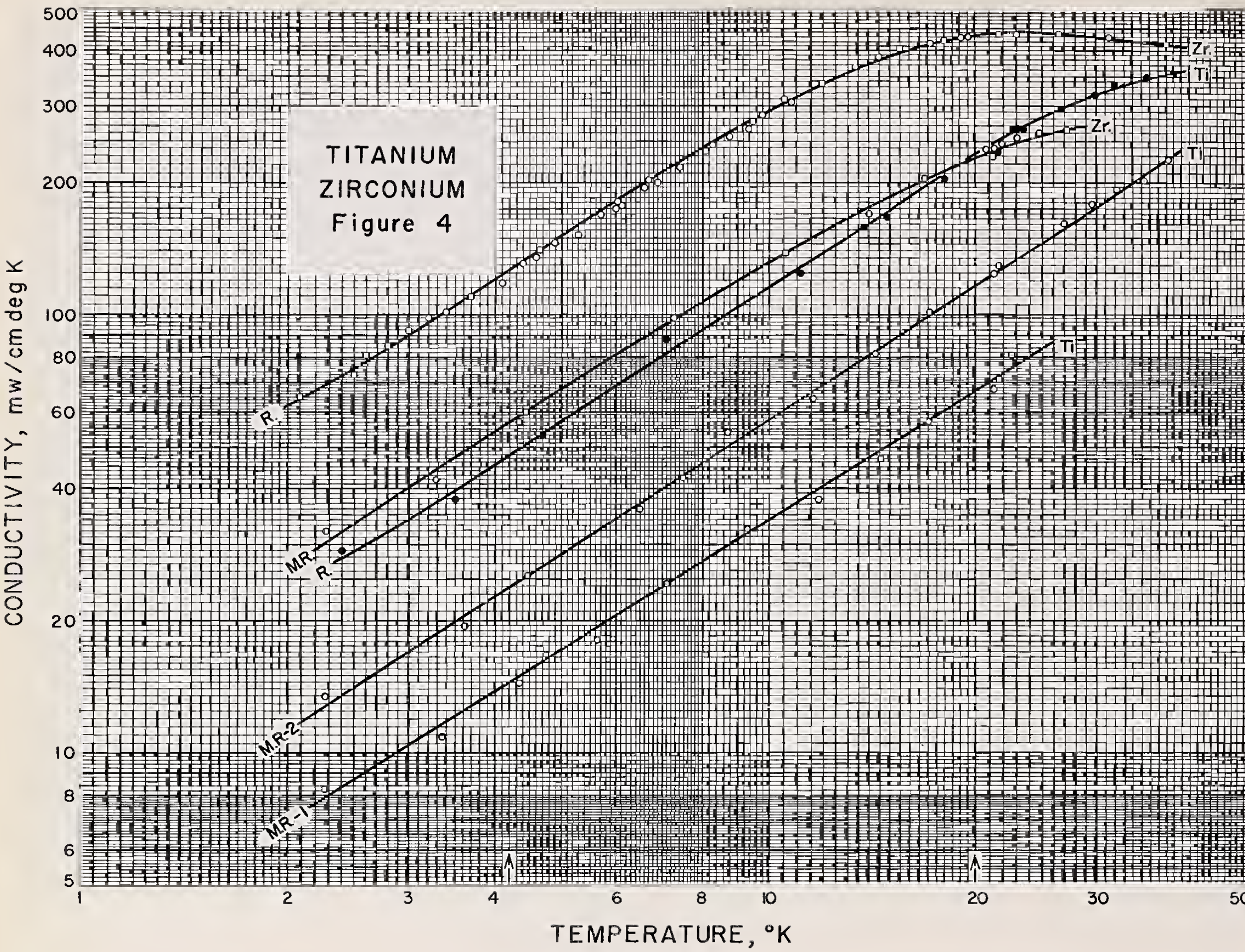
ALUMINUM (Cont'd)

Curve	Sample source and analysis	Remarks	Reference
A. W. S. 1	Alcoa; 99.996% pure, .001% Mg, .001% Si, .0006% Fe, .0004% Cu, .004% Na.	Single crystal; residual electrical resistance of 1.19×10^{-3} R_{273}; $\alpha=2.7\times10^{-5}$, $\beta=7.04$.	R. A. Andrews, R. T. Webber, and D. A. Spohr (1951).
A. W. S. 2	.....do.........	Single crystal, R = 1.48×10^{-3} R_{273}; $\alpha=2.72\times10^{-5}$, $\beta=6.06$.	Do.
A. W. S. 3.	Johnson, Matthey; 99.995% pure; .002% Mg, .001% Si, .0005% Fe, .0005% Cu, trace of Na.	Polycrystalline rod; residual resistance of 2.14×10^{-3} R_{273}; $\alpha=2.72\times10^{-5}$, $\beta=4.05$.	Do.
P. S. J.....	Alcoa; 99.99% pure.	Cold-drawn.....................	R. W. Powers, D. Schwartz, and H. L. Johnston (1951).
M. R.....	Johnson, Matthey; 99.994% pure.	Annealed polycrystal; $\alpha=2.2\times10^{-5}$, $\beta=2.3$.	K. Mendelssohn and H. M. Rosenberg (1952a).
....	....	Polycrystalline; superconducting state; representative values were .07 at 0.8°K, .015 at 0.65°K, .007 at 0.37°K.	K. Mendelssohn and C. A. Renton (1953).
R.........	....	$\alpha=3.2\times10^{-5}$, $\beta=0.23$..........	H. M. Rosenberg (1954a).



LANTHANUM

Curve	Sample source and analysis	Remarks	Reference
....	....	k=T/740 between about 2° and 20°K.	H. M. Rosenberg (1954a).

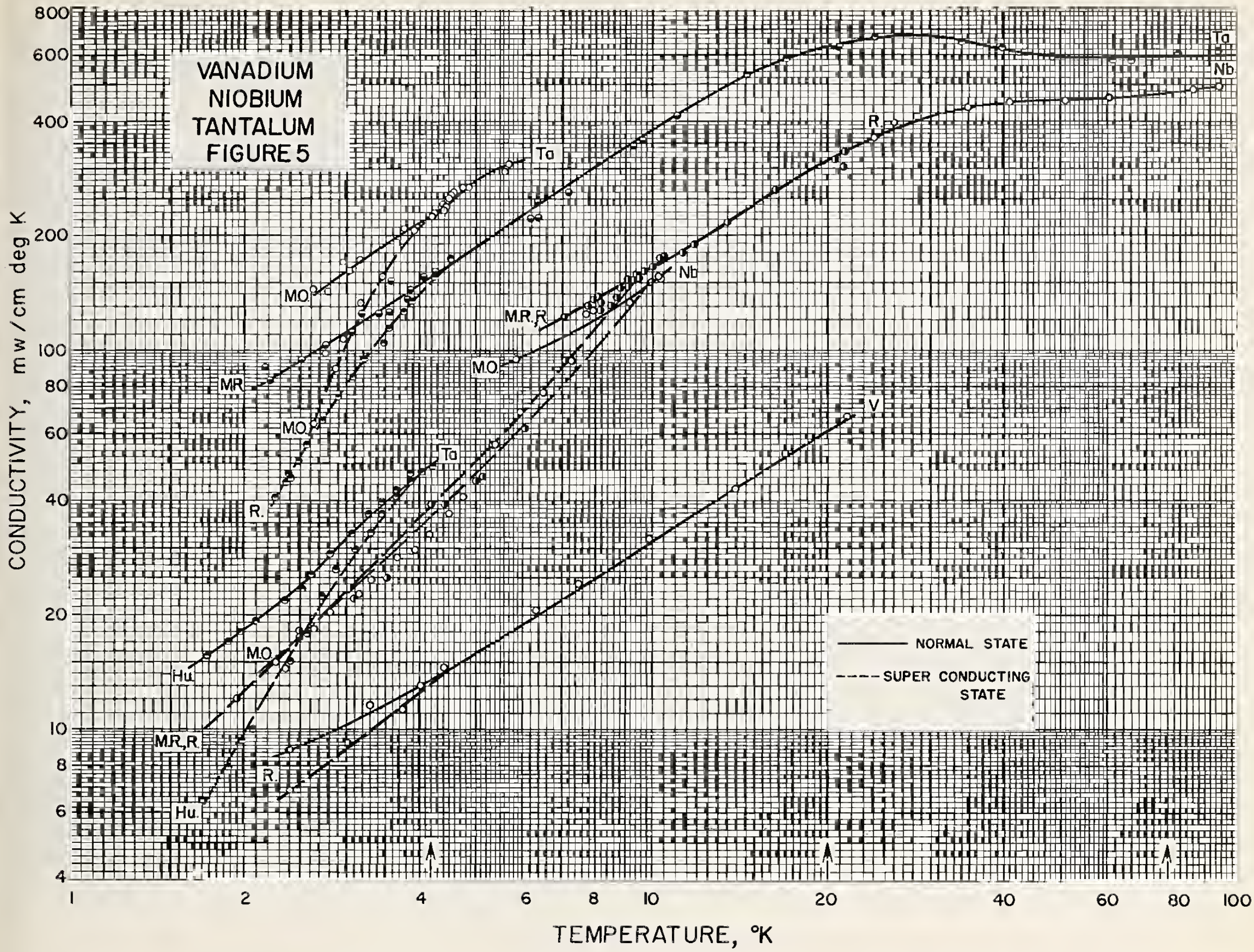


TITANIUM

Curve	Sample source and analysis	Remarks	Reference
....	Comm. pure....	Abstract only, k=0.20 at 273°K, 0.21 at 195°K, 0.18 at 90°K, 0.12 at 20°K.	C. J. Rigney and L. I. Bochstahler (1951).
M. R. 1...	Assoc. Elect. Ind. Res. Lab., England; 99.9% pure.	Unannealed; β=290............	K. Mendelssohn and H. M. Rosenberg (1952b).
M. R. 2...	Same source; 99.99% pure.	Annealed; β=170...............	Do.
R.........	....	Single crystal; conductivity constant from 50° to 100°K; α=454×10^{-5}, β=82.	H. M. Rosenberg (1954a).

ZIRCONIUM

Curve	Sample source and analysis	Remarks	Reference
M. R......	Johnson, Matthey; 98% pure.	Annealed; α= 130×10^{-5}, β=76..	K. Mendelssohn and H. M. Rosenberg (1952b).
R........	....	α=125×10^{-5}, β=34...........	H. M. Rosenberg (1954a).



VANADIUM

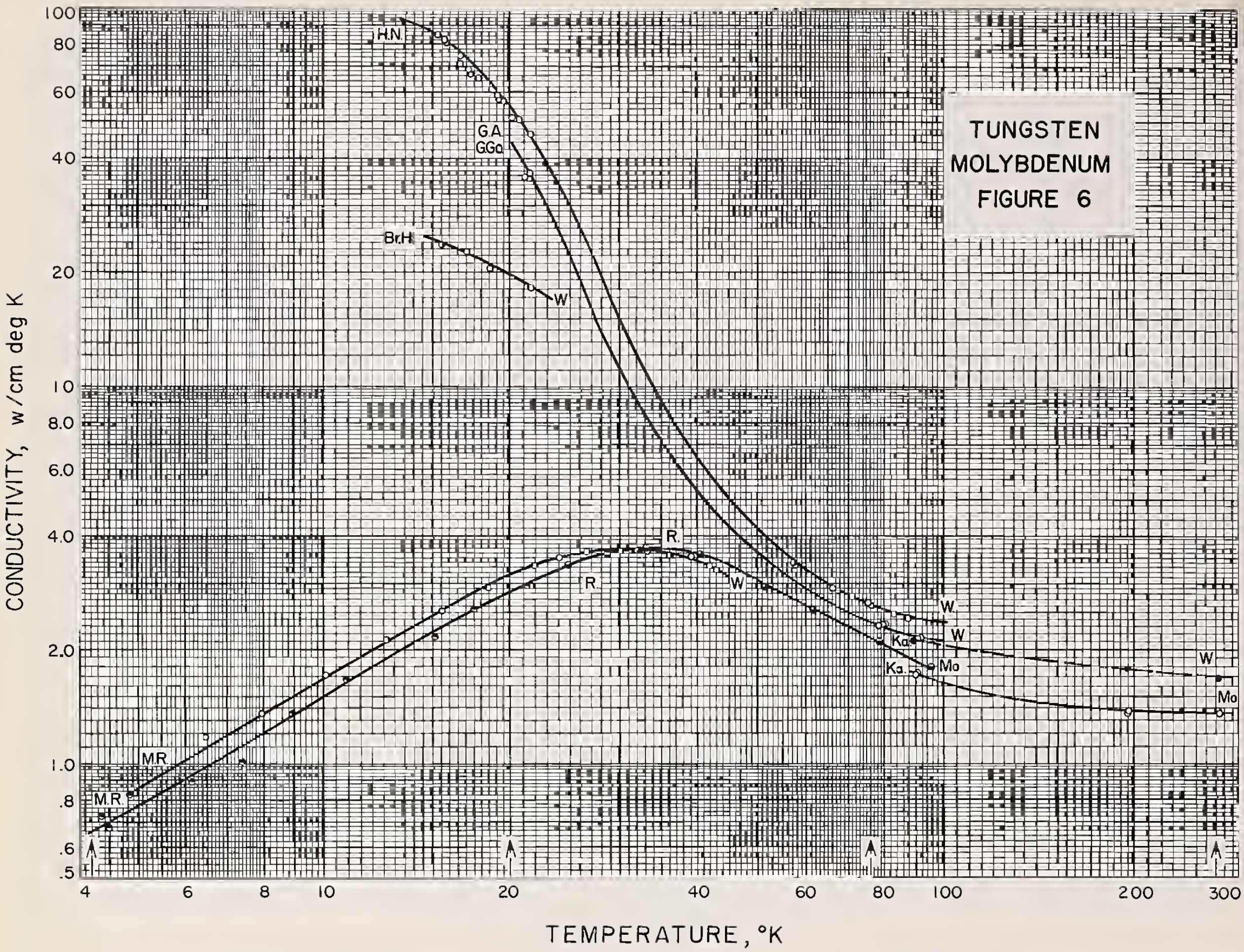
Curve	Sample source and analysis	Remarks	Reference
R..........	....	In both normal and superconducting states.	H. M. Rosenberg (1954a).

NIOBIUM

Curve	Sample source and analysis	Remarks	Reference
M. O.......	Hilger; "high purity".	In both normal and superconducting states; studied effect of magnetic field.	K. Mendelssohn and J. L. Olsen (1950a).
M. R.......	Johnson, Matthey; 99.99% pure.	In both normal and superconducting states; up to 22°K.	K. Mendelssohn and H. M. Rosenberg (1952b).
R..........	....	Continuation to temperatures above 22°K.	H. M. Rosenberg (1954a).
....	Same as M.R.	Superconducting state below 1°K..	K. Mendelssohn and C. A. Renton (1953).

TANTALUM

Curve	Sample source and analysis	Remarks	Reference
....	....	$k=0.54$ at 17°C..................	T. Barratt and R. M. Winter (1925).
....	Fansteel, 99.9% pure.	$k=0.36$ at 0°C..................	M. Cox (1943).
....	....	Measured ratio of conductivity in superconducting and normal states.	C. V. Heer and J. G. Daunt (1949).
....	....	....do..................	J. K. Hulm (1949).
M. O......	99.95% pure....	Measured in both normal and superconducting states.	K. Mendelssohn and J. L. Olsen (1950a).
Hu........	Hilger; 0.1% impurities.	Polycrystalline; impurities in solid solution; measured effect of magnetic field; both normal and superconducting states.	J. K. Hulm (1950).
M. R......	Johnson, Matthey; 99.98% purity.	Measured both normal and superconducting states; $\beta=27$.	K. Mendelssohn and H. M. Rosenberg (1952b).
....	....do..........	Measured superconducting state below 1°K.	K. Mendelssohn and C. A. Renton (1953).
R..........	....do..........	Continued M. R. curve to higher temperatures; $\alpha=79\times10^{-5}$, $\beta=25$.	H. M. Rosenberg (1954a).

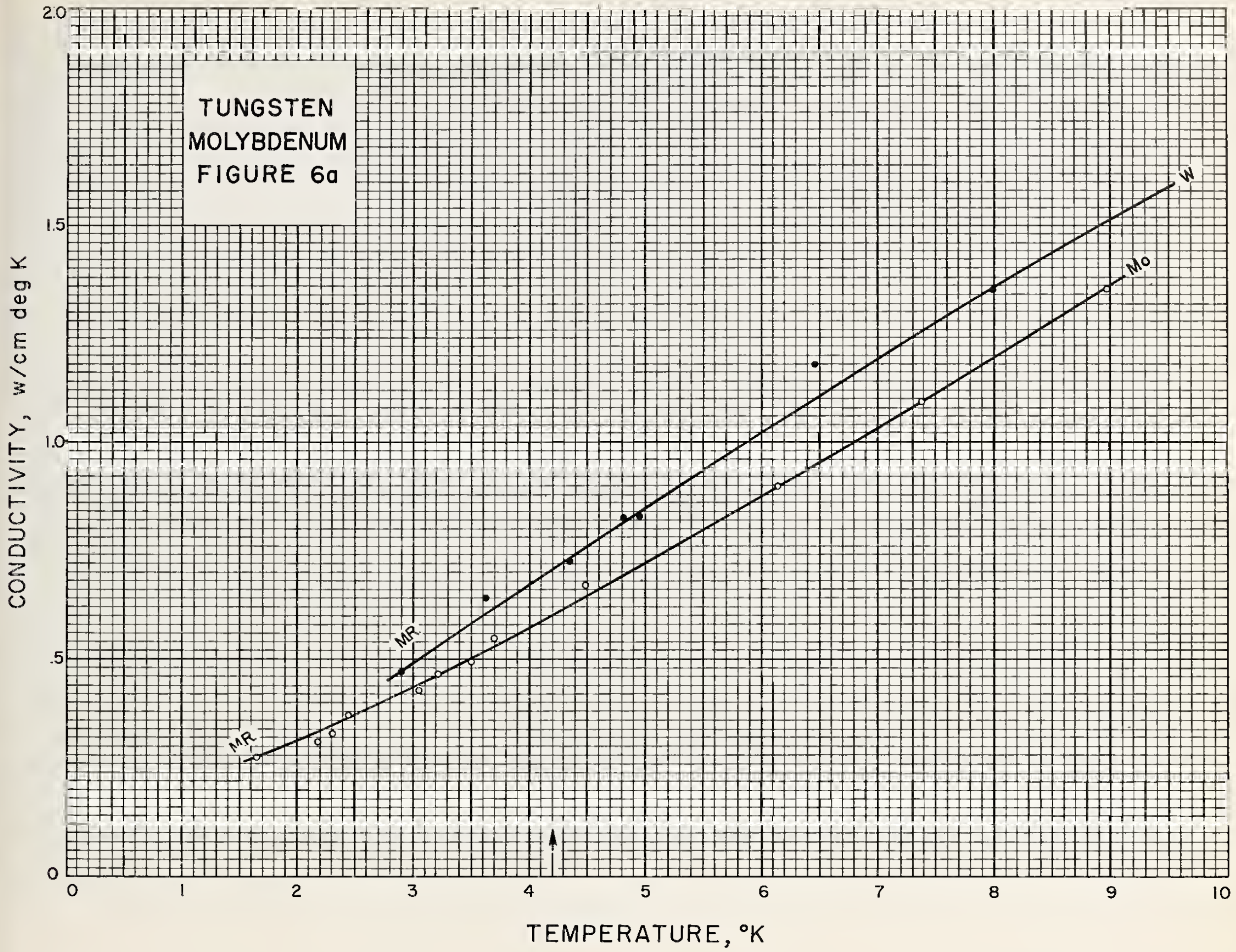


MOLYBDENUM

Curve	Sample source and analysis	Remarks	Reference
....	....	k=1.45 at 17°C....................	T. Barratt and R. M. Winter (1925).
....	Philips; "very pure".	Annealed at 900°C; k=1.44 at 0°C; R.	W. G. Kannaluik (1931).
....	Gen. Elec.......	Annealed at 220°C; k=1.32 at 0°C; R.	Do.
Ka.........	.05% Bi, Cd; .01% Al, Ge, Sn, Ti, V, W; .001% Co, Cu, Pt, Rh; trace of C.	R..............................	W. G. Kannaluik (1933).
M. R......	Johnson, Matthey; 99.95% pure.	$\alpha=7.5\times10^{-5}$, $\beta=6.7$...........	K. Mendelssohn and H. M. Rosenherg (1952h).
R.........	....do..........	Continued above work to 100°K...	H. M. Rosenberg (1954a).

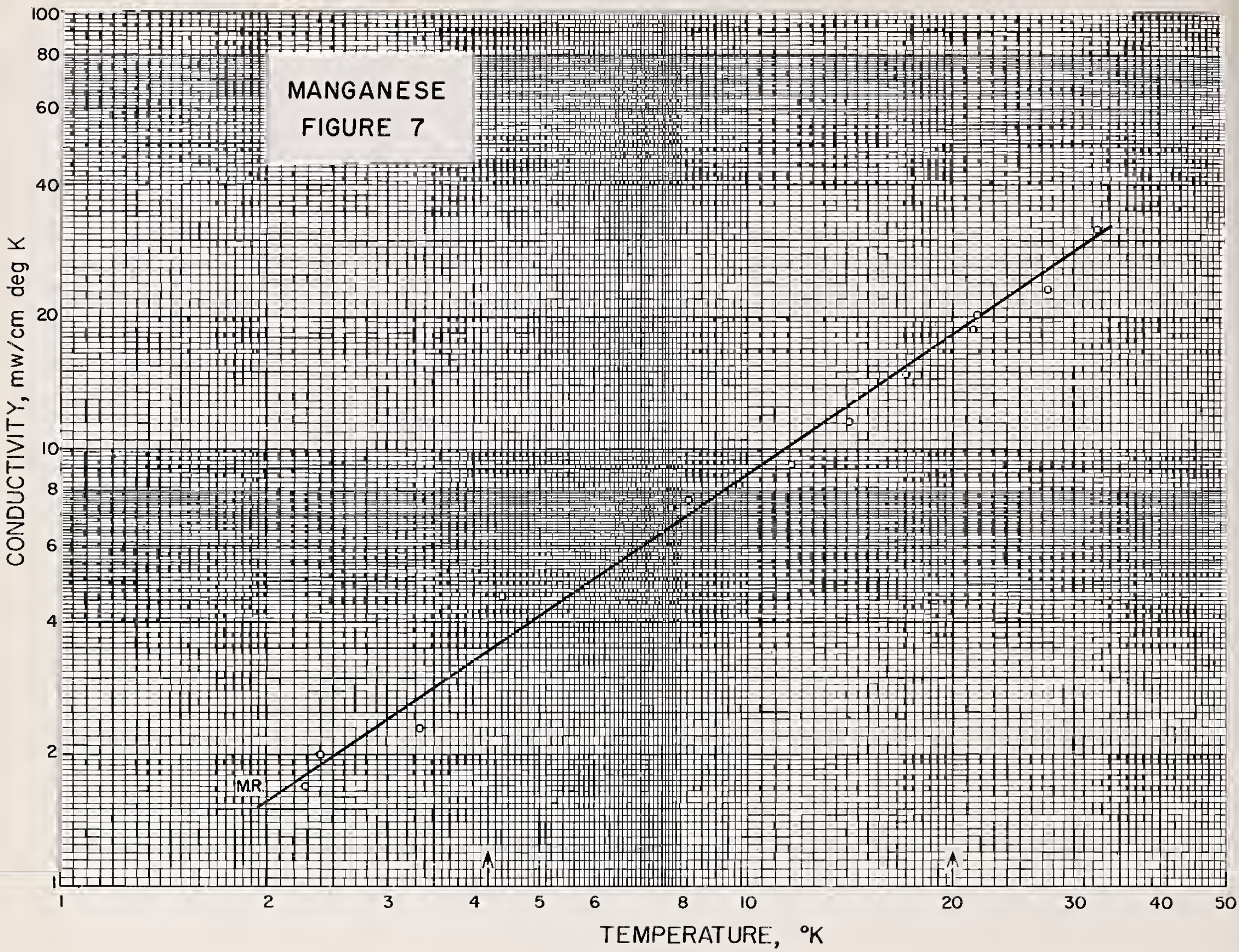
TUNGSTEN

Curve	Sample source and analysis	Remarks	Reference
....	Heraeus........	k=1.6 at 0°C....................	S. Weber (1917).
....	....	k=2 at 17°C....................	T. Barratt and R. M. Winter (1925).
....	Osram; impure..	Single crystal; k=1.83 at 83°K, 1.80 at 21°K.	E. Grüneisen and E. Goens (1927).
G. Go.....	Philips; "very pure".	Single crystal....................	Do.
....	Gen. Elec.......	One sample annealed at 220°C, k=1.64 at 08°C; another sample annealed at 1300°C, k=1.66 at 18°C.	W. G. Kannaluik (1931).
Ka........	Phillips........	Single crystals, only higher values plotted.	W. G. Kannaluik (1933).
Br. H.....	Philips.........	....	H. Bremmer and W. J. de Haas (1936).



TUNGSTEN (Cont'd)

Curve	Sample source and analysis	Remarks	Reference
....	Gen. Elec.......	$k=1.66$ at 0°C..................	I. Langmuir and J. B. Taylor (1936).
....	....	At 78°, 194°, 273°K, approx. same results as Kannaluik (1933).	W. C. Michels and M. Cox (1936).
G. A......	Same as G. Go. above.	Studied effect of magnetic field and anisotropy.	E. Grüneisen and H. Adenstedt (1937).
H. N......	Phillips.........	Siegle crystal; residual resistance of 4×10^{-4} R_{273}; measured effect of magnetic field on k and R.	W. J. de Haas and J. de Nobel (1938).
G. A......	Same as G. Go...	Single crystals; graph results are for a sample with rod axis parallel to [010] crystal axis; for another crystal with rod axis parallel to [100] axis, $k=22.2$ at 21°K; R.	E. Grüneisen and H. Adenstedt (1938).
....	Gen. Elec.......	$k=1.93$ at 77°K, 1.87 at 90°K, and 1.69 at 0°C.	M. Cox (1943)
....	Same as H. N. above.	Extended the measurements to higher magnetic fields.	J. de Nobel (1949).
M. R......	Johnson, Matthey; 99.99% pure.	Annealed; $\alpha=10.2\times10^{-5}$, $\beta=5.9$.	K. Mendelssohn and H. M. Rosenberg (1952b).
R.........	....	$\alpha=9.3\times10^{-5}$, $\beta=5.8$...........	H. M. Rosenberg (1954a).

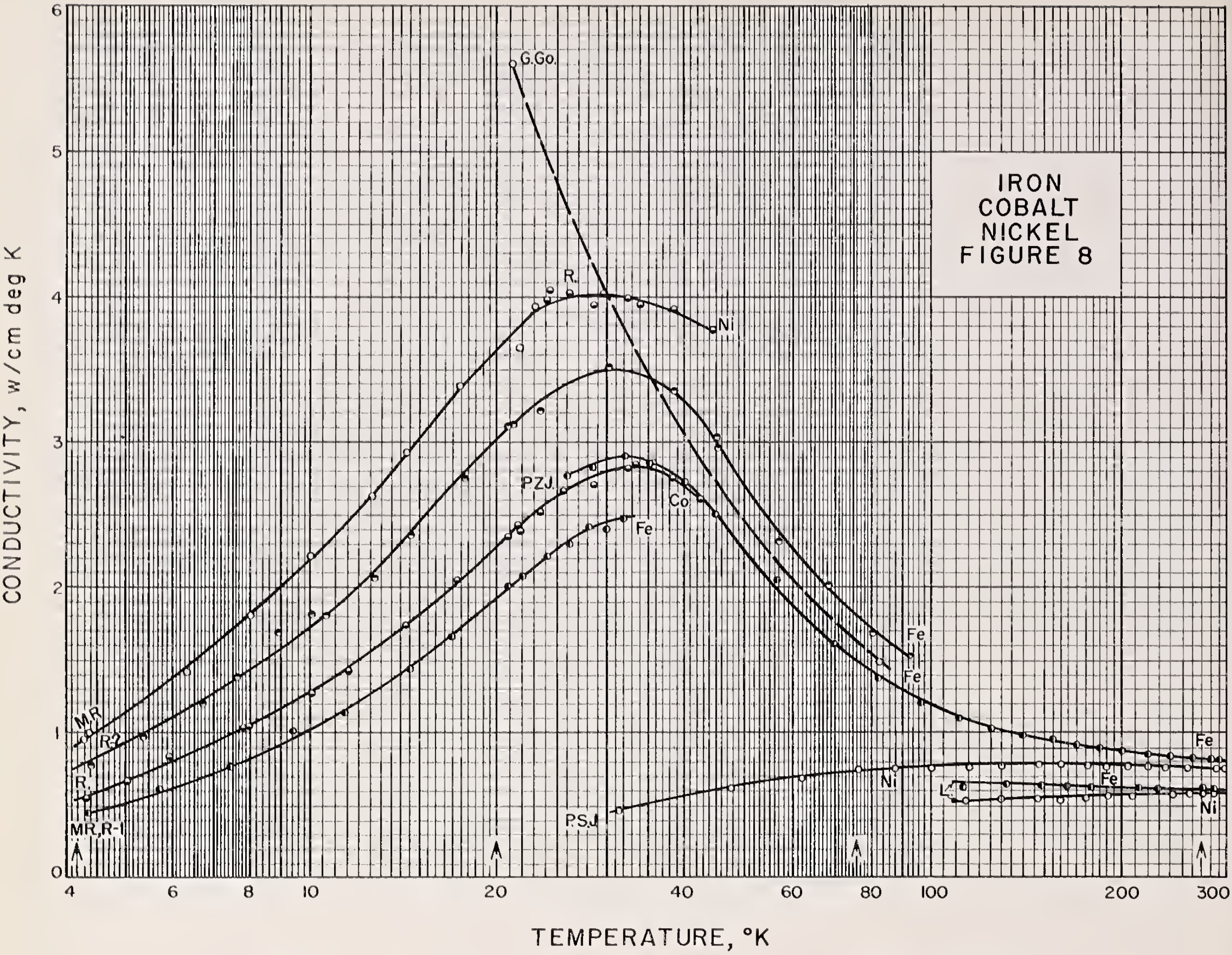

MANGANESE
FIGURE 7
CONDUCTIVITY, mw/cm deg K
TEMPERATURE, °K
MR
100
80
60
40
20
10
8
6
4
2
1
1
2
3
4
5
6
8
10
20
30
40
50

MANGANESE

Curve	Sample source and analysis	Remarks	Reference
....	....	k=0.05 at 83°K for the β phase..	H. Reddemann (1935).
M. R......	Johnson, Matthey; 99.99% pure.	Annealed; β=1200..............	K. Mendelssohn and H. M. Rosenberg (1952b).

SUPPLEMENTARY DATA

Curve	Sample source and analysis	Remarks	Reference

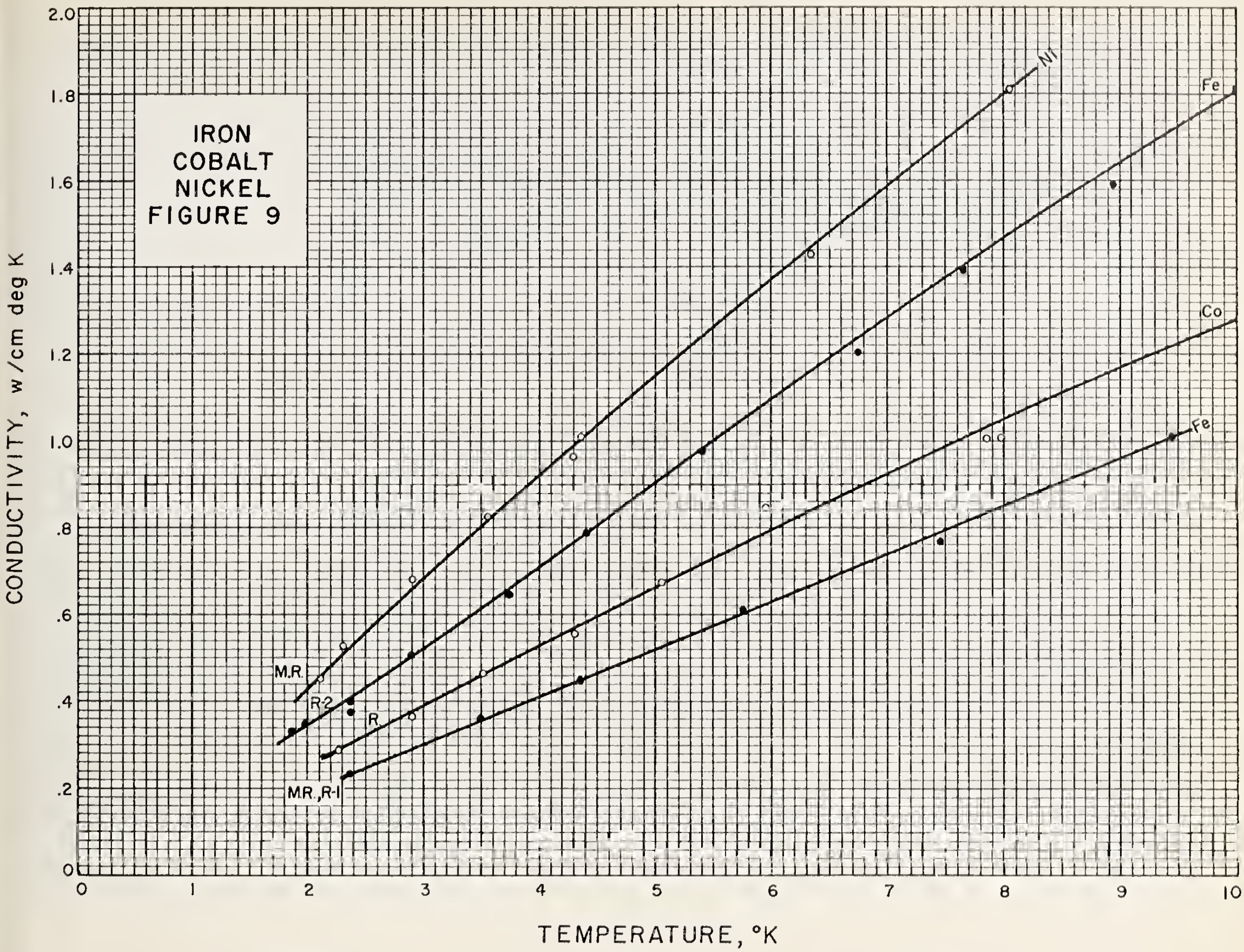


IRON

Curve	Sample source and analysis	Remarks	Reference
....	"Pure".........	k=0.70 at 0°C.................	L. Lorenz (1881a).
....	"Pure", .1% C, .06% Mn, .02% Si, .05% Cu, .03% P, .03% P, .02% .02% S.	k=0.72 at 18°C................	E. Grüneisen (1900).
....	0.1% C+metals	Also measured R, Cp, emf; k=0.67 at 18°C.	W. Jaeger and H. Diesselhorst (1900).
....	Krupp; .1% C, .2% Si, .1% Mn.	Also measured R, Cp, emf; k=0.60 at 18°C.	Do.
L.........	99.42% pure; .1% C, .15% Mn, .13% Si.	Wrought iron..................	C. H. Lees (1908).
....	....	Electrolytic; two rods with average grain sizes of 1×10^{-1} and 6×10^{-3} cm; k=0.94 and 0.90, respectively, at 0°C; k=1.84 and 1.83 at 80°K.	A. Eucken and K. Dittrich (1927).
....	Heraeus.........	Electrolytic; average grain size 2×10^{-3} cm; k=0.82 at 0°C and 1.17 at 80°K.	Do.
G. Go.....	"Double refined.	Tempered; electrolytic..........	E. Grüneisen and E. Goens (1927).

IRON (Cont'd)

Curve	Sample source and analysis	Remarks	Reference
....	"Technically pure".	Two samples untempered; electrolytic; k=1.36 and 0.91 at 83°K, 3.01 and 0.5 at 21°K.	E. Grüneisen and E. Goens (1927).
....	"Pure".........	Electrolytic; k=0.77 at 16°C.....	R. Kikuchi (1932).
....	Armco; .01% C, .02% Mn, .006% P, .026% S, .06% Cu, .02% Si.	k=0.7 at 0°C, 0.72 at 195°K, 0.94 at 90°K	W. G. Kannaluik (1933).
....	"Pure".........	Between 3° and 20°K, the values fall just below the curve marked M. R.	J. Karweil and K. Schäfer (1939).
....	Hadfield; 99.93% pure.	Forged; k=0.9 at 90°K, maximum of 1.3 at 52°K, 0.5 at 15°K.	J. de Nobel (1951).
P. Z. J.....	Johnson, Matthey; 99.99% pure.	....	R. W. Powers, J. B. Ziegler, and H. L. Johnston (1951a).
M. R......	Johnson, Matthey; 99.99% pure.	$\alpha=18\times10^{-5}, \beta=9.5$............	K. Mendelssohn and H. M. Rosenberg (1952b).
R.........	....	$\alpha=10.2\times10^{-5}, \beta=9.6$..........	H. M. Rosenberg (1954a).

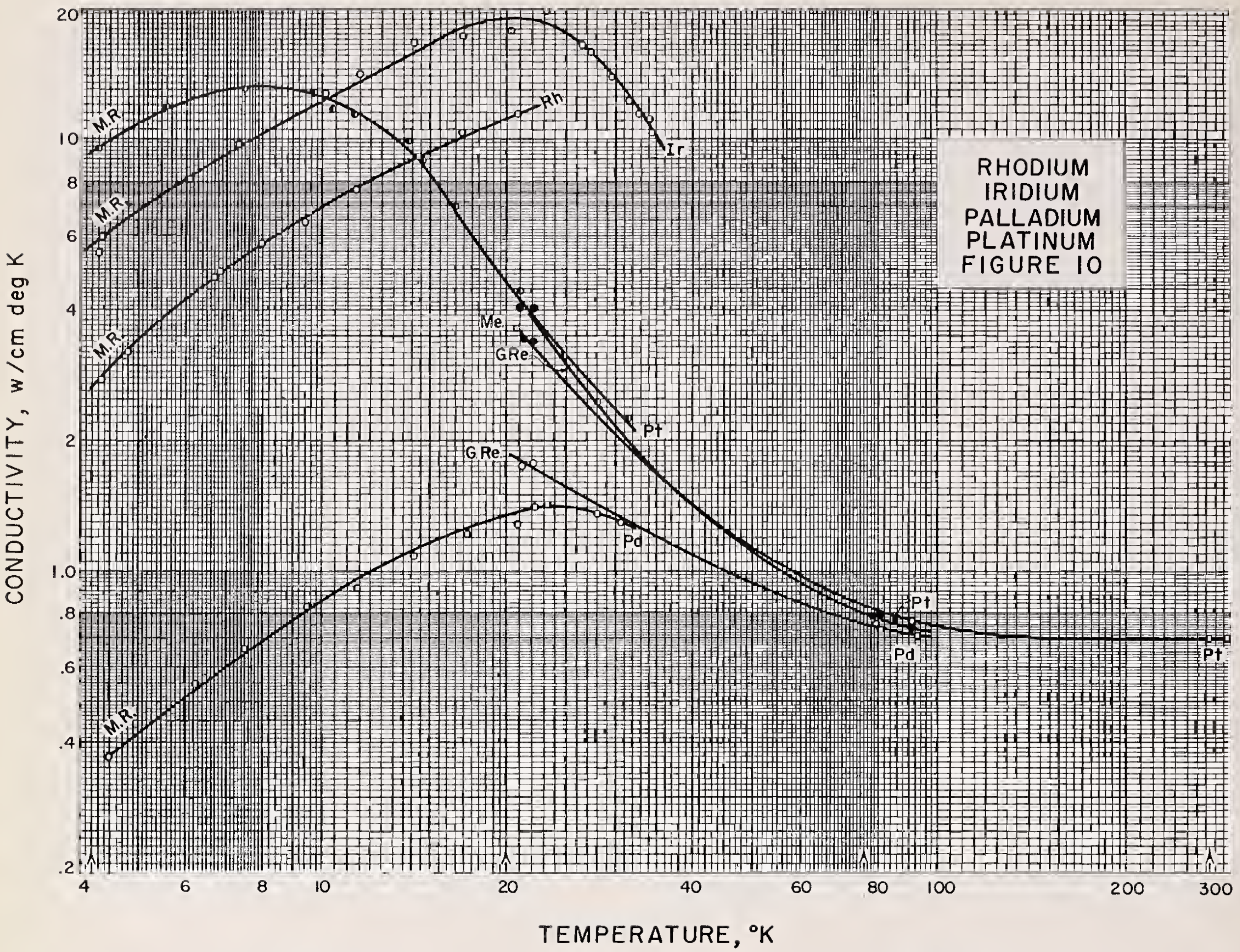


NICKEL

Curve	Sample source and analysis	Remarks	Reference
....	Basse and Selve; impure.	k=0.60 at 18°C; R, C_p, emf......	W. Jaeger and H. Diesselhorst (1900).
L.........	Johnson, Matthey; 99% pure.	Lathe turned; density 8.80........	C. H. Lees (1908).
....	Heraeus........	Drawn rod; k=0.84 at 0°C, 1.11 at 80°K.	A. Eucken and K. Dittrich (1927).
P. S. J.....	Int. Nickel; comm. pure.	....	R. W. Powers, D. Schwartz, and H. L. Johnston (1951).
....	99.4% pure.....	Forged; approx. same curve as P. S. J. from 93° to 25°K; at 15° K, k=0.18.	J. de Nobel (1951).
M. R......	Johnson, Matthey; 99.997% pure.	Annealed; $\alpha=22\times10^{-5}$, $\beta=4.4$; measured up to 22°K.	K. Mendelssohn and H. M. Rosenberg (1952b).
R.........	....do..........	Annealed; $\alpha=10.4\times10^{-5}$, $\beta=4.6$; measured up to 40°K.	H. M. Rosenberg (1954a).

COBALT

Curve	Sample source and analysis	Remarks	Reference
R.........	....	$\alpha=10.5\times10^{-5}$, $\beta=7.9$..........	H. M. Rosenberg (1954a).

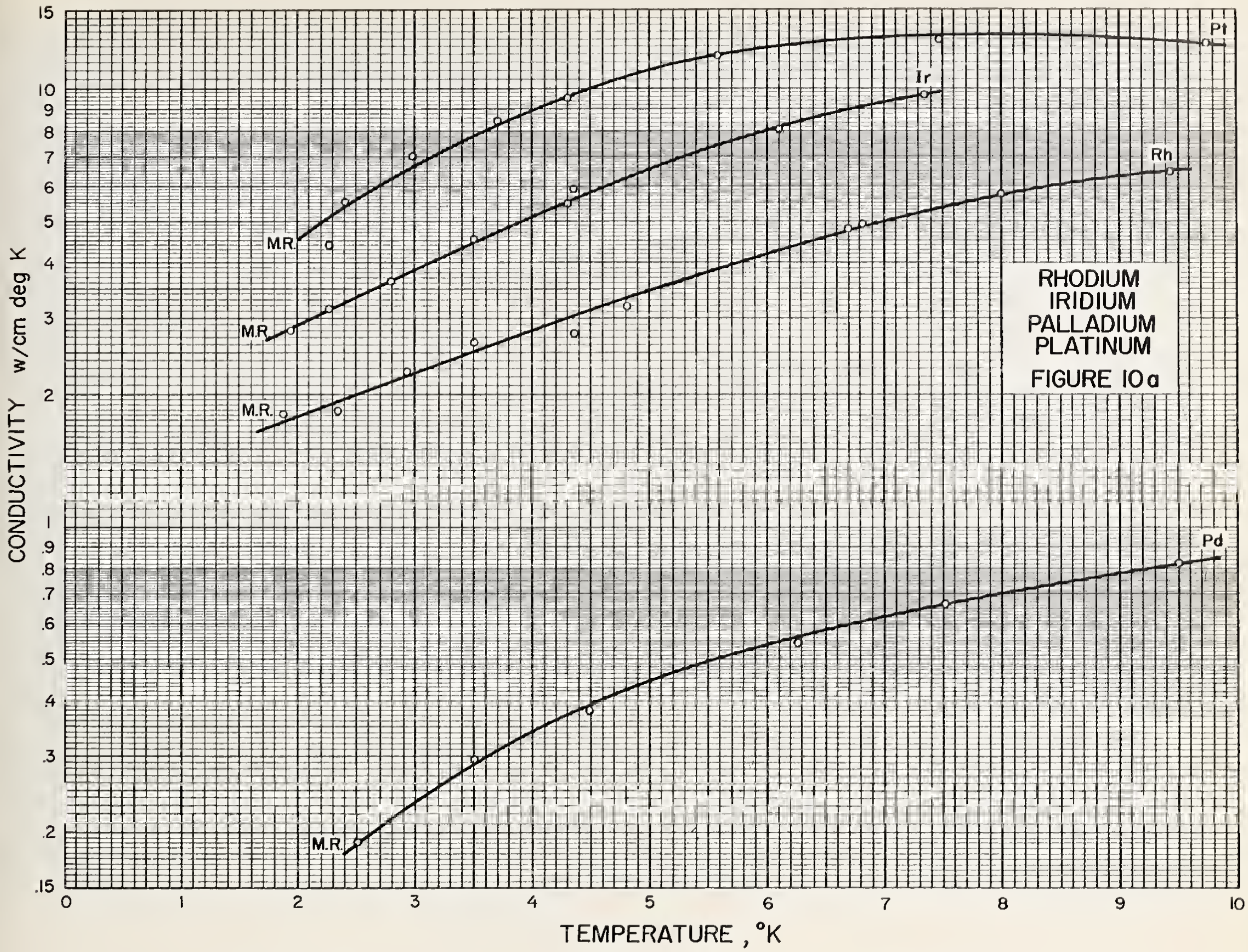


PALLADIUM

Curve	Sample source and analysis	Remarks	Reference
....	"Chem. pure"...	k=0.7 at 18°C; R, Cp, emf.......	W. Jaeger and H. Diesselhorst (1900).
....	....	k=0.42 at 17°C for commercial palladium, 0.60 at 17°C for "pure".	T. Barratt and R. M. Winter (1925).
G. Re.....	Heraeus; "pure".	Unannealed; plotted with open circles; R.	E. Grüneisen and H. Reddemann (1934).
G. Re.....	....do..........	Cold-drawn; annealed at 360°C for two hours; plotted with darkened circles; R.	Do.
M. R......	Johnson, Matthey; 99.95% pure.	Annealed; $\alpha=64\times10^{-5}$, $\beta=11$..	K. Mendelssohn and H. M. Rosenberg (1952b).
....	....	$\alpha=41\times10^{-5}$, $\beta=11.7$...........	H. M. Rosenberg (1954a).

RHODIUM

Curve	Sample source and analysis	Remarks	Reference
....	....	k=0.88 at 17°C.................	T. Barratt and R. M. Winter (1925).
....	Heraeus; "pure".	Annealed; k=2.15 at 83°K, 23.8 at 21°K, R.	E. Grüneisen and E. Goens (1927).
M. R......	Johnson Matthey; 99.95% pure.	$\alpha=22\times10^{-5}$, $\beta=1.4$...........	K. Mendelssohn and H. M. Rosenberg (1952b).
....	....	$\alpha=10.7\times10^{-5}$, $\beta=1.38$.........	H. M. Rosenberg (1954a).

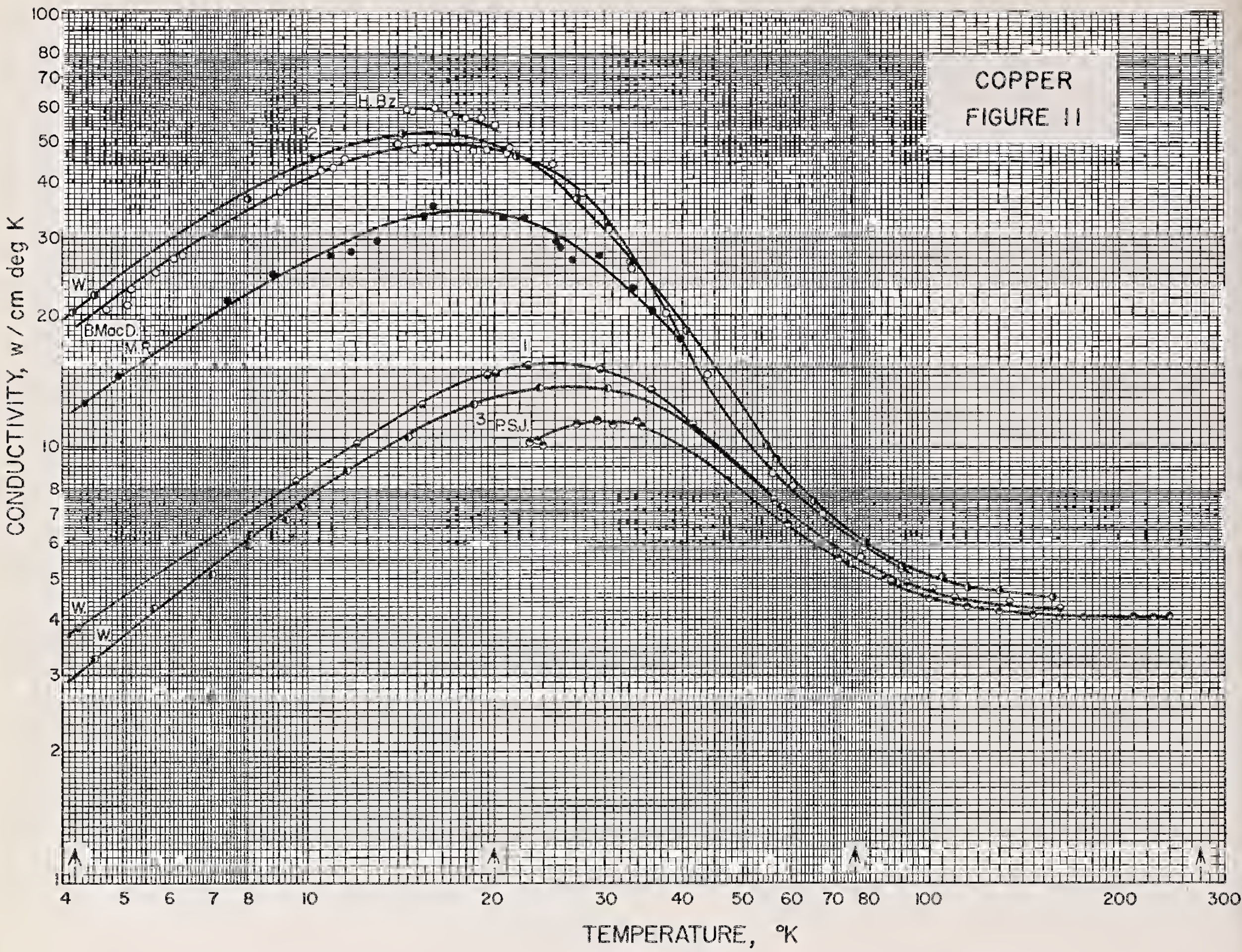


PLATINUM

Curve	Sample source and analysis	Remarks	Reference
....	"Pure".........	k=0.78 at 18°C.................	J. H. Gray (1895).
....	....do..........	k=0.7 at 18°C; R, C_p, emf.......	W. Jaeger and H. Diesselhorst (1900).
Me........	Heraeus; "very pure".	Drawn; electrically annealed......	W. Meissner (1915).
....	....do..........	Drawn; electrically annealed; obtained same results as Meissner (1915) at 21° and 83°K; R.	E. Grüneisen and E. Goens (1927).
....	Heraeus; "less pure".	k=2.96 at 21°K.................	Do.
....	Heraeus........	k=4.25 at 21°K; measured effect of magnetic field on k, R.	E. Grüneisen and H. Adenstedt (1938).
M. R......	Johnson, Matthey; 99.999% pure.	$\alpha=43\times10^{-5}$, $\beta=0.40$...........	K. Mendelssohn and H. M. Rosenberg (1952b).
....	....	$\alpha=43\times10^{-5}$, $\beta=0.35$...........	H. M. Rosenberg (1954a).

IRIDIUM

Curve	Sample source and analysis	Remarks	Reference
....	....	k=0.59 at 17°C.................	T. Barratt and R. M. Winter (1925).
M. R......	Johnson, Matthey; 99.95% pure.	Annealed; $\alpha=3.6\times10^{-5}$, $\beta=0.77$.	K. Mendelssohn and H. M. Rosenberg (1952b).
R.........	....	$\alpha=4.6\times10^{-5}$, $\beta=0.75$..........	H. M. Rosenberg (1954a).

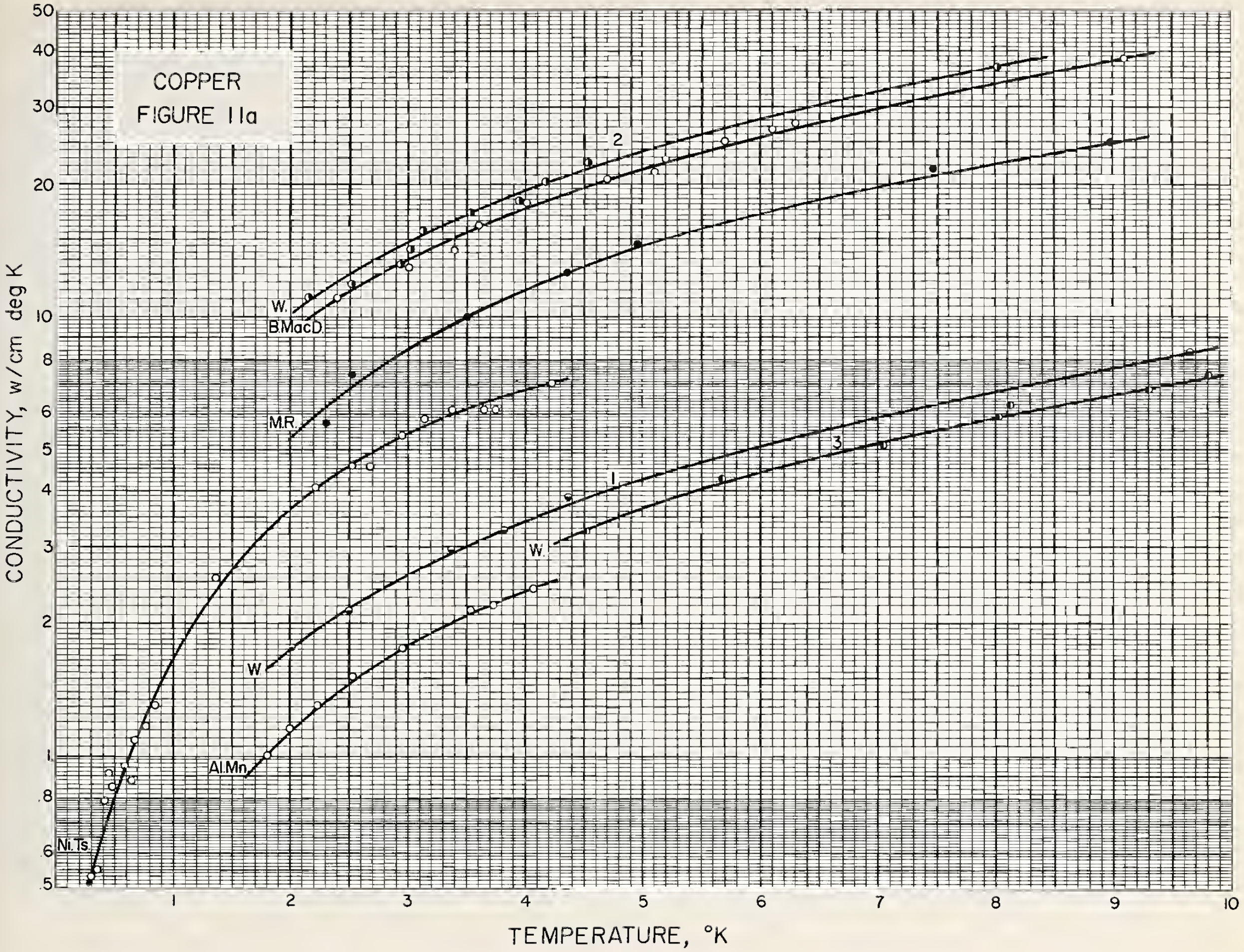


COPPER

Curve	Sample source and analysis	Remarks	Reference
	"Pure"	k=3 at 0°C	L. Lorenz (1881a).
		One sample had k=3.6 at 10°C; the second, 1.3 at 10°C.	J. H. Gray (1895).
	"Pure"	k=3.9 at 18°C	E. Grüneisen (1900).
	do.	k=3.73 at 18°C; R, C_p	W. Jaeger and H. Diesselhorst (1900).
	do.	k= 3.95 at 20°C	W. Schaufelberger (1902).
		"Soft drawn, high conductivity"; k=3.8 at 27°C; results at 100°K are close to the P.S.J. curve.	C. H. Lees (1908).
		Electrolytic copper wires; values at 21°, 91° and 273° are close to the W.-1 curve.	W. Meissner (1915).
	"Very pure"	Natural single crystal; results uncertain due to very small size of sample.	R. Schott (1916).
	"Tech. pure"	Approximately on curve of W.-3 down to 22°K.	Do.

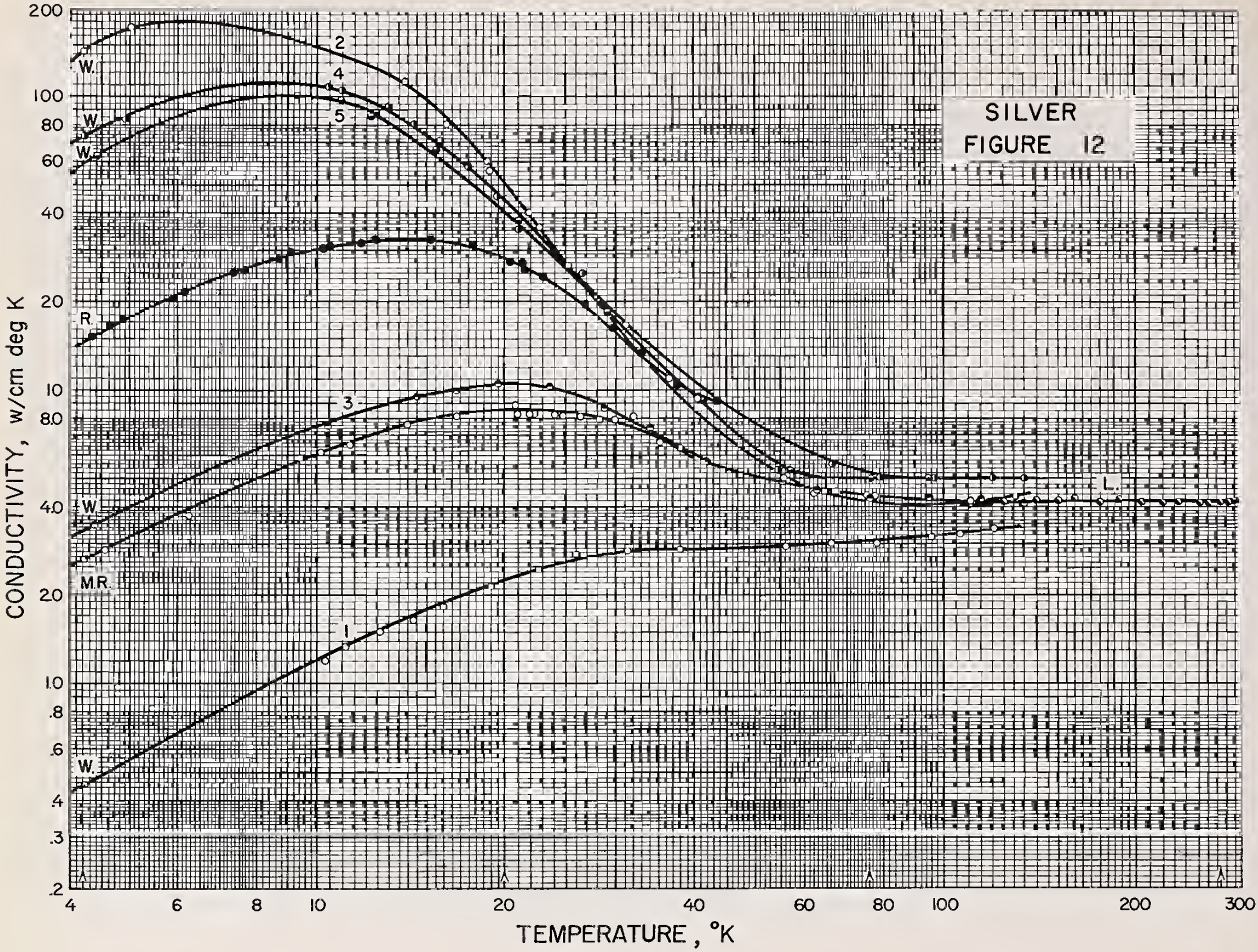
COPPER (Cont'd)

Curve	Sample source and analysis	Remarks	Reference
		Measured 18 samples of various crystal structure, purity, and annealing at 21° and 83°K; R.	E. Grüneisen and E. Goens (1927).
	Gen. Elec.	Single crystal; between 95° and 300°K, the results are close to curve W.-1.	W. G. Kannaluik and T. H. Laby (1928).
		Measured 14 different copper samples at 20° and 90°K; R.	E. Grüneisen and H. Reddemann (1934).
H. Bz.			W. J. de Haas and T. Biermasz (1936).
		Studied effect of magnetic field on k, R.	E. Grüneisen and H. Adenstedt (1938).
Al. Mn.	Johnson, Matthey; free of O_2; .003% each Ag, Ni, and Pb.	Machined and annealed	J. F. Allen and E. Mendoza (1947).
P. S. J.	Am. Brass; "O. F. H. C."	Oxygen-free, high conductivity	R. W. Powers, D. Schwartz, and H. L. Johnston (1951).



COPPER (Cont'd)

Curve	Sample source and analysis	Remarks	Reference
B. McD...	Johnson, Matthey; .0005% Ag, .0003% Ni, .0004% Pb.	Cold-drawn, then annealed 6 hr at 450°C in helium gas.	R. Berman and D. K. C. MacDonald (1952).
M. R......	Johnson, Matthey; 99.999% pure.	Annealed; $\alpha=3.2\times10^{-5}$, $\beta=0.35$.	K. Mendelssohn and H. M. Rosenberg (1952a).
Ni. Ts.....	Gen. Elec.; "comm. high purity".	Polycrystalline wire..............	J. Nicol and T. P. Tseng (1953).
W.-1......	Johnson, Matthey; 99.999% pure; same as B. MacD.	As cold-drawn; $\alpha = 2.55\times10^{-5}$, $\beta=1.15$.	G. K. White (1953c).
W.-2........	....do..........	Annealed in vacuum at 550°C for 3 hours; $\alpha=2.55\times10^{-5}$, $\beta=0.21$.	Do.
W.-3........	....do..........	As cold-drawn; same as W.-1.....	Do
R........	....	$\alpha=2.5\times10^{-5}$, $\beta=0.35$..........	H. M. Rosenberg (1954a).

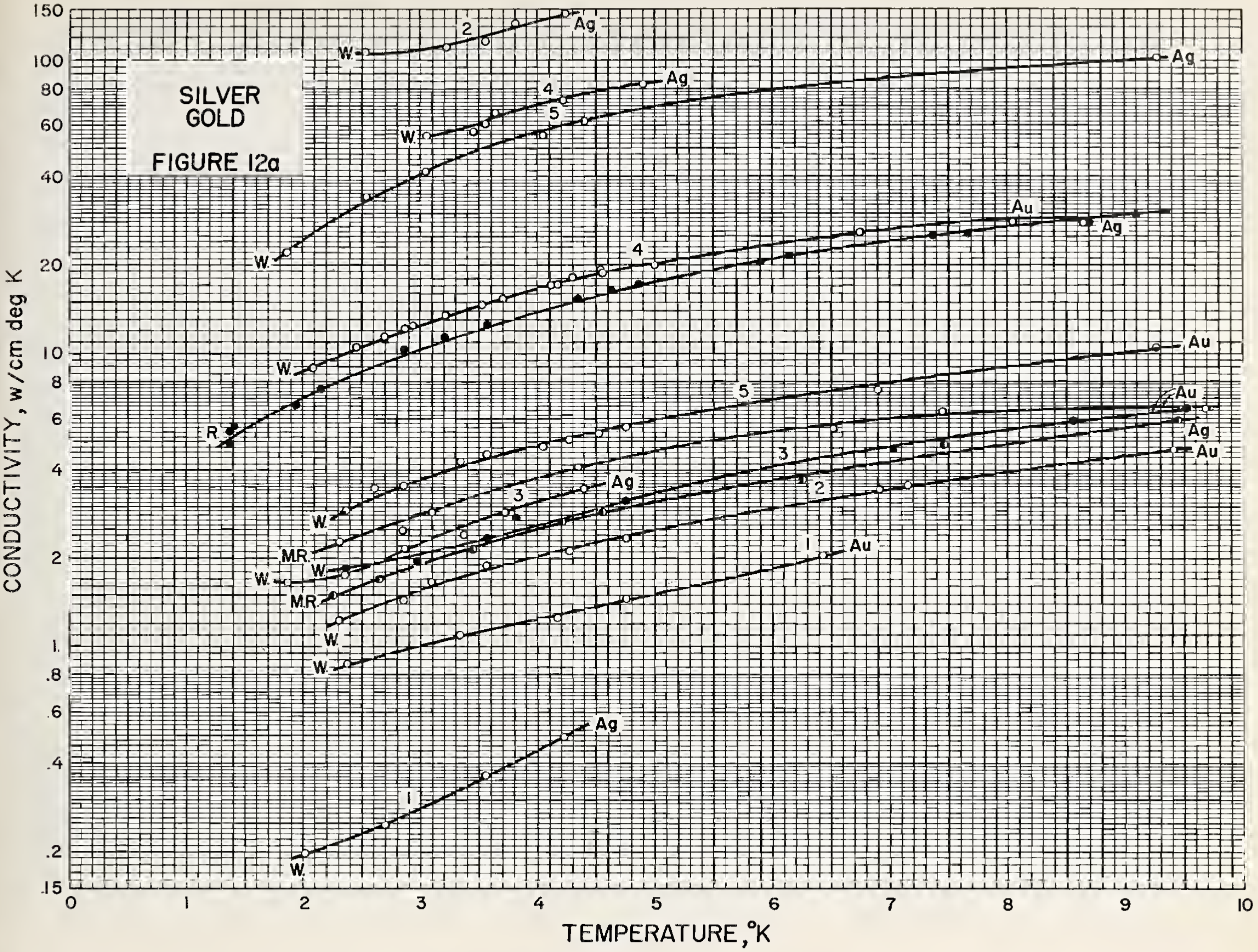


SILVER

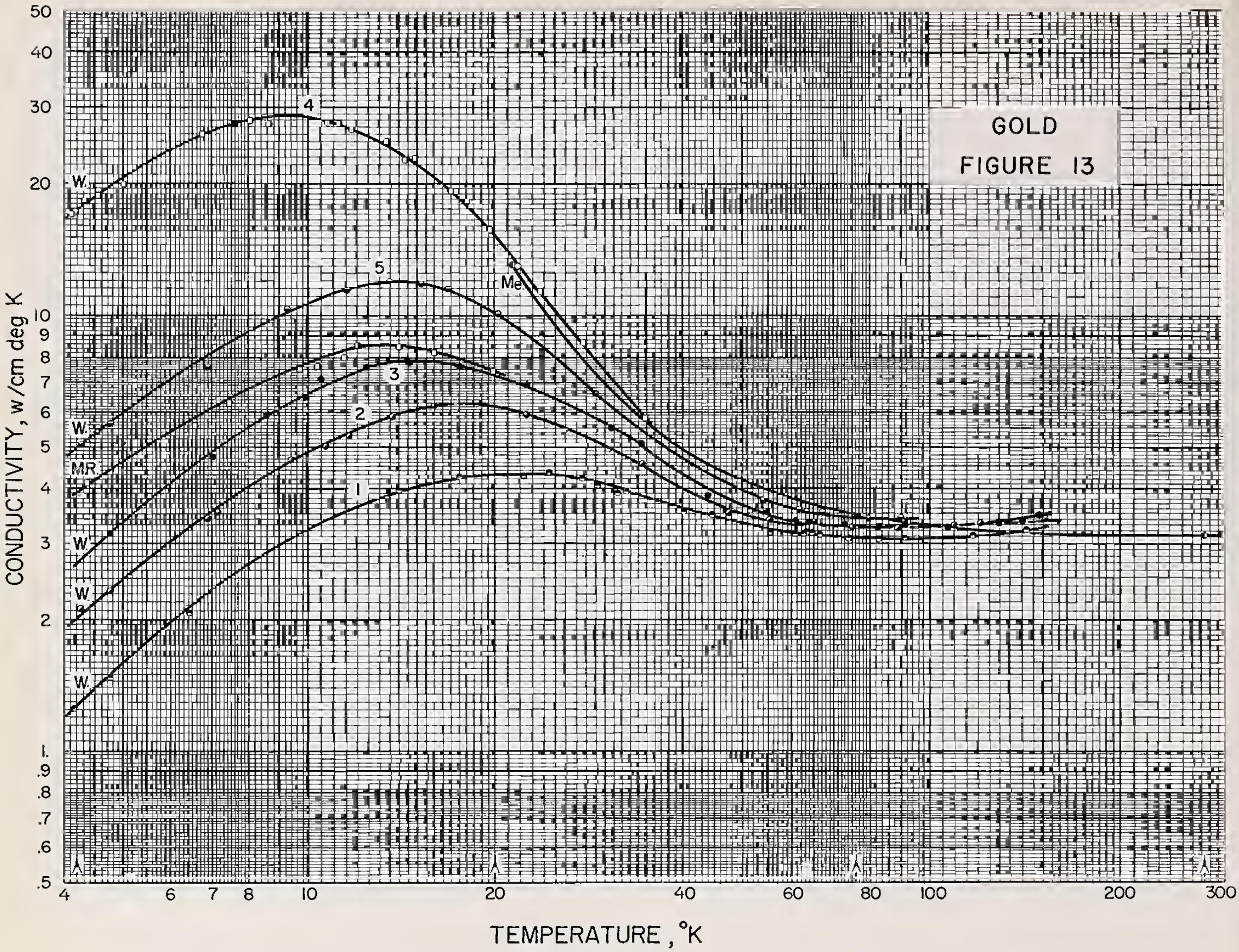
Curve	Sample source and analysis	Remarks	Reference
....	....	Silver wire; $k=4.02$ at 18°C......	J. H. Gray (1895).
....	99.98% pure....	$k=4.21$ at 18°C; also measured R, Cp, and emf.	W. Jaeger and H. Diesselhorst (1900).
L.........	Johnson, Matthey; 99.9% pure.	Lathe-turned from a larger rod....	C. H. Lees (1908).
....	....	Two silver wires had $k=4.11$ and 4.04 at 0°C.	W. G. Kannaluik (1931).
....	Hilger; trace of Cu, Pb, Bi, Mg, Ca, Na, Si.	At 90°, 195°, and 273°K values are somewhat higher than those of Lees (1908).	W. G. Kannaluik (1933).
....	....	Five rods of silver, varied in composition, annealing, crystal structure. At 20° and 90°K pure rods had values close to curve W.-3; R.	E. Grüneisen and H. Reddemann (1934).

SILVER (Cont'd)

Curve	Sample source and analysis	Remarks	Reference
....	Hönig-schmid...	Annealed; electrolytic; $k=31.4$ at 21°K; measured effect of magnetic field on k and R.	E. Grüneisen and H. Adenstedt (1938).
M. R......	Johnson, Matthey; 99.99% pure.	$\alpha=9.0\times10^{-5}$, $\beta=1.6$..........	K. Mendelssohn and H. M. Rosenberg (1952a).
....	....do..........	Measured effect of magnetic field..	K. Mendelssohn and H. M. Rosenberg (1953).
W. 1-5....	Johnson, Matthey; 99.999% pure.	No. 1 was unannealed; #2, annealed at 650°C, grain size 0.1 mm; #3, cold-drawn; #4, the previous one annealed; #5, a rerun of #4.	G. K. White (1953b).
R.........	Johnson, Matthey.	$\alpha=5\times10^{-5}$, $\beta=0.3$............	H. M. Rosenberg (1954a).



(See next page for the table on GOLD.)

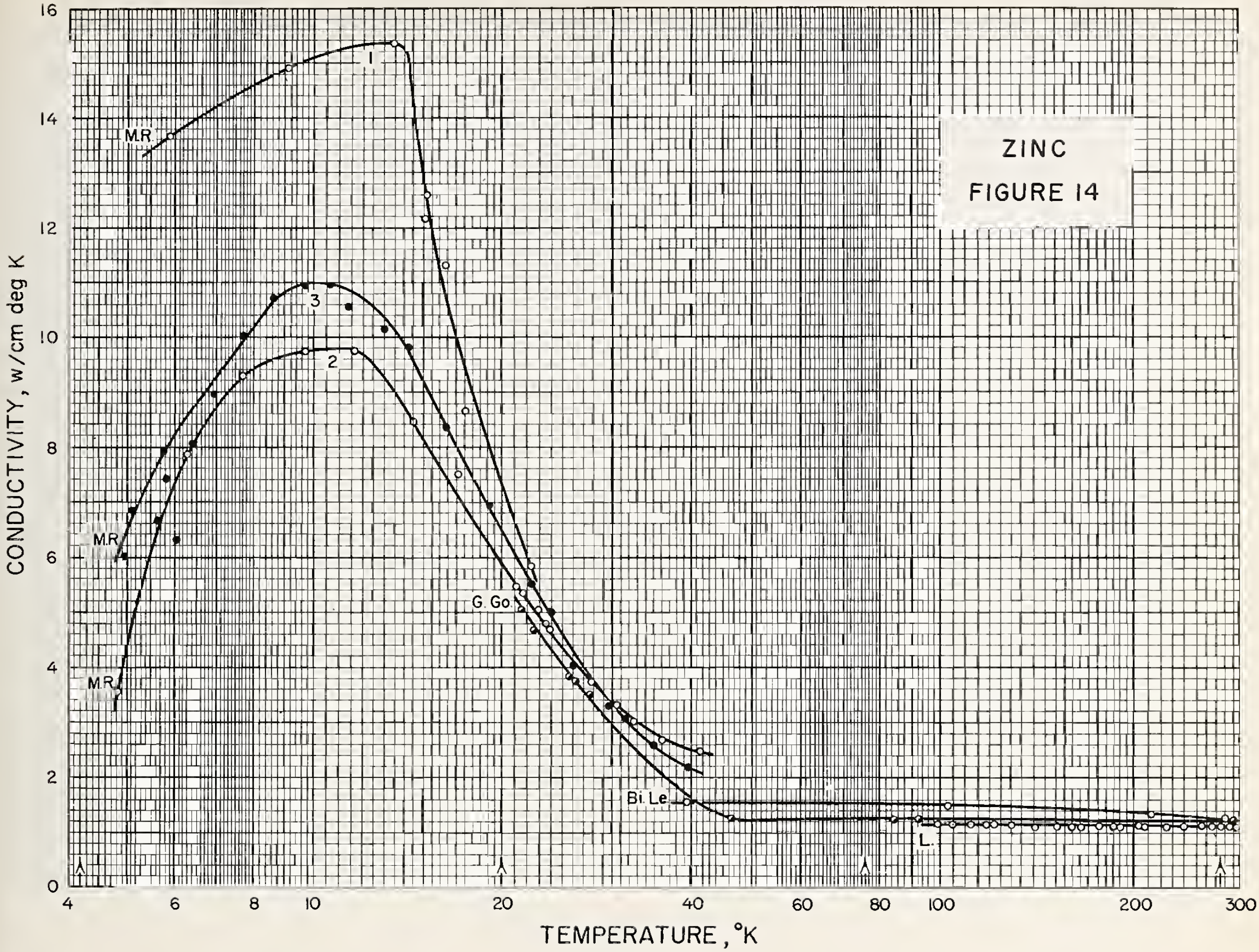


GOLD

Curve	Sample source and analysis	Remarks	Reference
		k= 3.14 at 18°C	J. H. Gray (1895).
	"Pure"	k= 2.93 at 18°C; a less pure sample had k=1.79 at 18°C; R, Cp, emf.	W. Jaeger and H. Diesselhorst (1900).
Me	Mylius; 99.999% pure.	Cold-drawn; annealed	W. Meissner (1915).
		k=2.95 at 17°C	T. Barratt and R. M. Winter (1925).
		k=2.98 at 24°C	H. Masumoto (1927).
		Six samples of various composition, annealing; R. Results for "very pure" gold at 21° and 83° K fall close to curve W.-4.	E. Grüneisen and E. Goens (1927).
		k=3.06 at 0°C	W. G. Kannaluik (1931).

GOLD (Cont'd)

Curve	Sample source and analysis	Remarks	Reference
M. R.	Johnson, Matthey; 99.999% pure.	$\alpha=18\times10^{-5}$, $\beta=1.15$	K. Mendelssohn and H. M. Rosenberg (1952a).
W. 1, 2	Garrett, Davidson, Matthey; 99.9% pure (comm.); Ag, trace of Pt, Fe, Pb, Cu, Sn.	No. 1 sample unannealed; #2, annealed.	G. K. White (1953a).
W. 3, 4, 5	Johnson, Matthey; 99.999% pure; trace of Ag, Cu; faint trace of Cd, Fe, Mg, Na, Ca, Zn.	No. 3 sample cold-drawn; #4, annealed in vacuum at 700°C for 3 hours; #5 was the fourth redrawn.	Do.
		$\alpha=19\times10^{-5}$, $\beta=1.13$	H. M. Rosenberg (1954a).

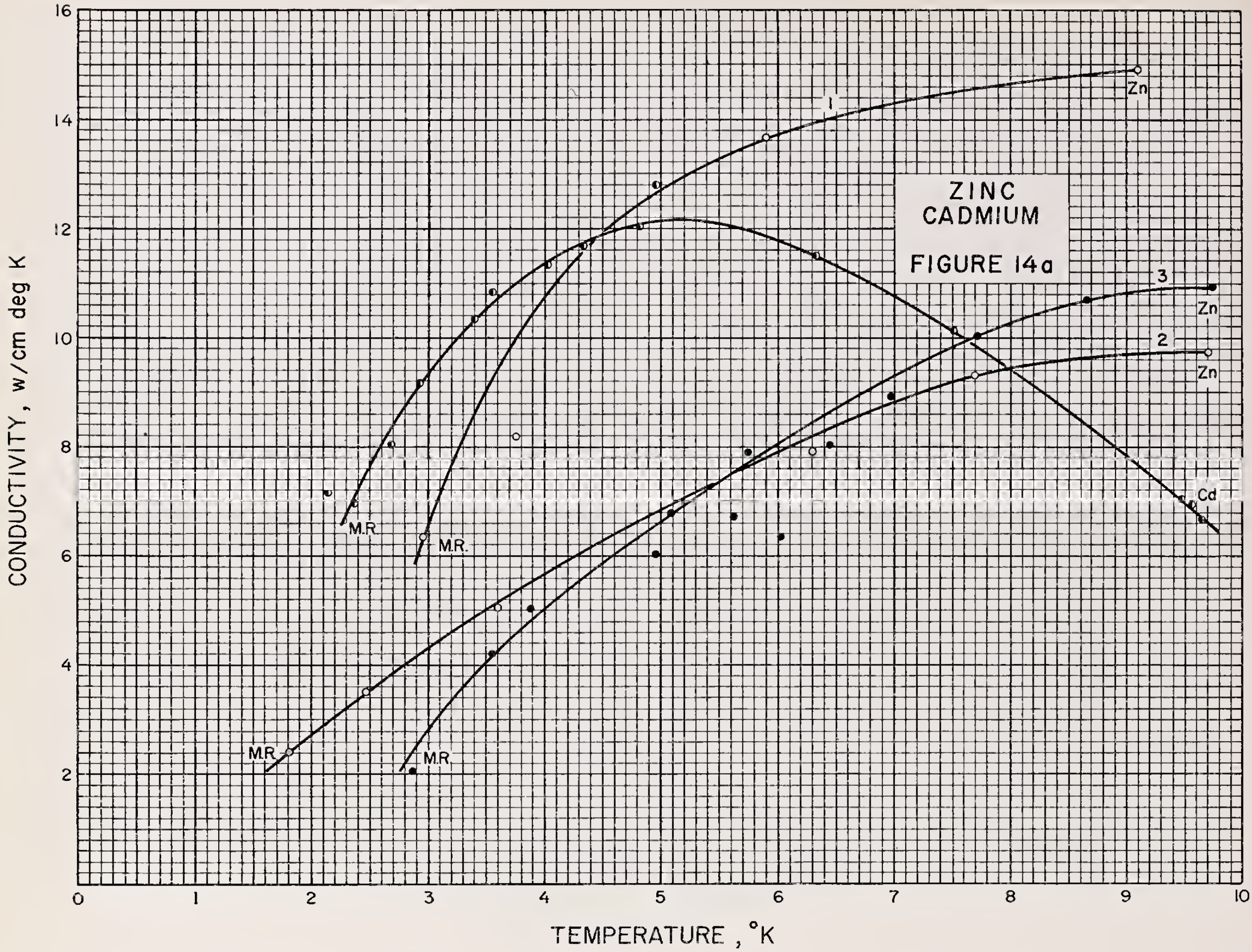


ZINC

Curve	Sample source and analysis	Remarks	Reference
....	"Pure".........	k=1.1 at 18°C; R, Cp, emf.......	W. Jaeger and H. Diesselhorst (1900).
L.........	"Pure redistilled".	Lathe-turned from a cast stick....	C. H. Lees (1908).
Bi. Le.....	99.993% pure...	Single crystal; also measured polycrystalline samples.	C. C. Bidwell and E. J. Lewis (1929); also E. J. Lewis and C. C. Bidwell (1928).
....	Kahlbaum......	k=1.26 at 83°K and 1.25 at 0°C...	J. Staebler (1929).
G. Go.....	Kahlbaum; "pure".	Single crystals each with rod axis parallel to main crystal axis. Another sample with axes perpendicular had a conductivity 10% lower.	E. Goens and E. Grüneisen (1932).

ZINC (Cont'd)

Curve	Sample source and analysis	Remarks	Reference
M. R. 1...	Hilger; 99.995% pure.	Polycrystalline; $\alpha = 21 \times 10^{-5}$, $\beta = 0.4$.	K. Mendelssohn and H. M. Rosenberg (1952a).
M. R. 2, 3.	Imperial Smelting; 99.997%.	No. 2 had rod axis inclined 80° to hexagonal crystal axis, $\alpha = 34 \times 10^{-5}$, $\beta = 0.7$; #3, inclined 13°, $\alpha = 31 \times 10^{-5}$, $\beta = 0.6$.	Do.
....	Same as M. R. 1, 2, 3.	Measured effect of magnetic field..	K. Mendelssohn and H. M. Rosenberg (1953).
....	....	$\alpha = 30 \times 10^{-5}$, $\beta = 0.6$............	H. M. Rosenberg (1954a).



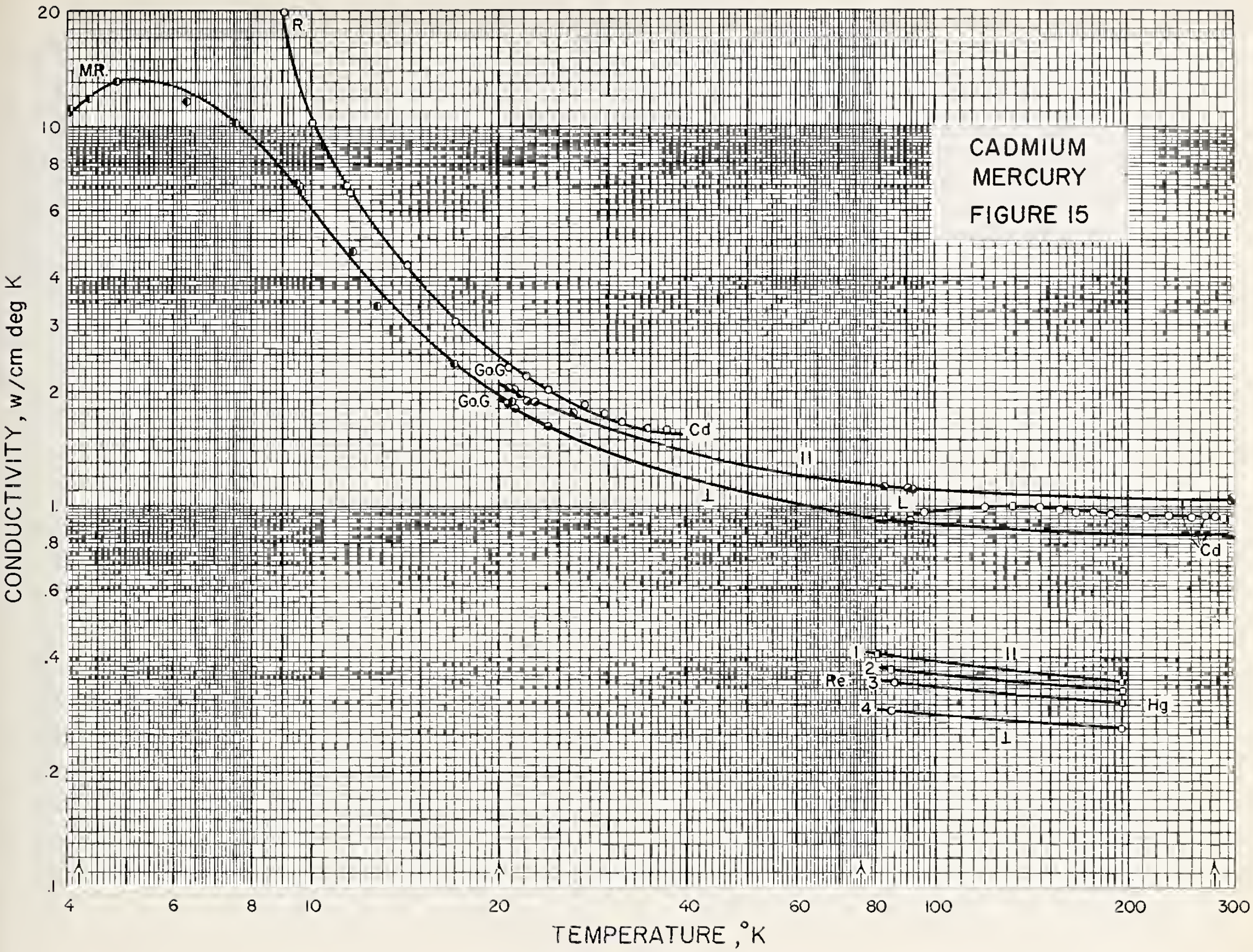
(See previous page for the table on ZINC.)

CADMIUM

Curve	Sample source and analysis	Remarks	Reference
....	"Pure..........	k=0.92 at 0°C..................	L. Lorenz (1881).
....	.....do.........	k=0.93 at 18°C; R, Cp, emf.......	W. Jaeger and H. Diesselhorst (1900).
L.........	"Pure redistilled".	Lathe-turned from a cast stick....	C. H. Lees (1908).
....	Kahlbaum; "pure".	k=1.02 at 273° and 194°K, 1.23 at 83°K.	A. Eucken and G. Gehlhoff (1912).
....	Kahlbaum; "chem. pure".	At 20° and 273°K values fall just below upper curve of Go. G.	R. Schott (1916).

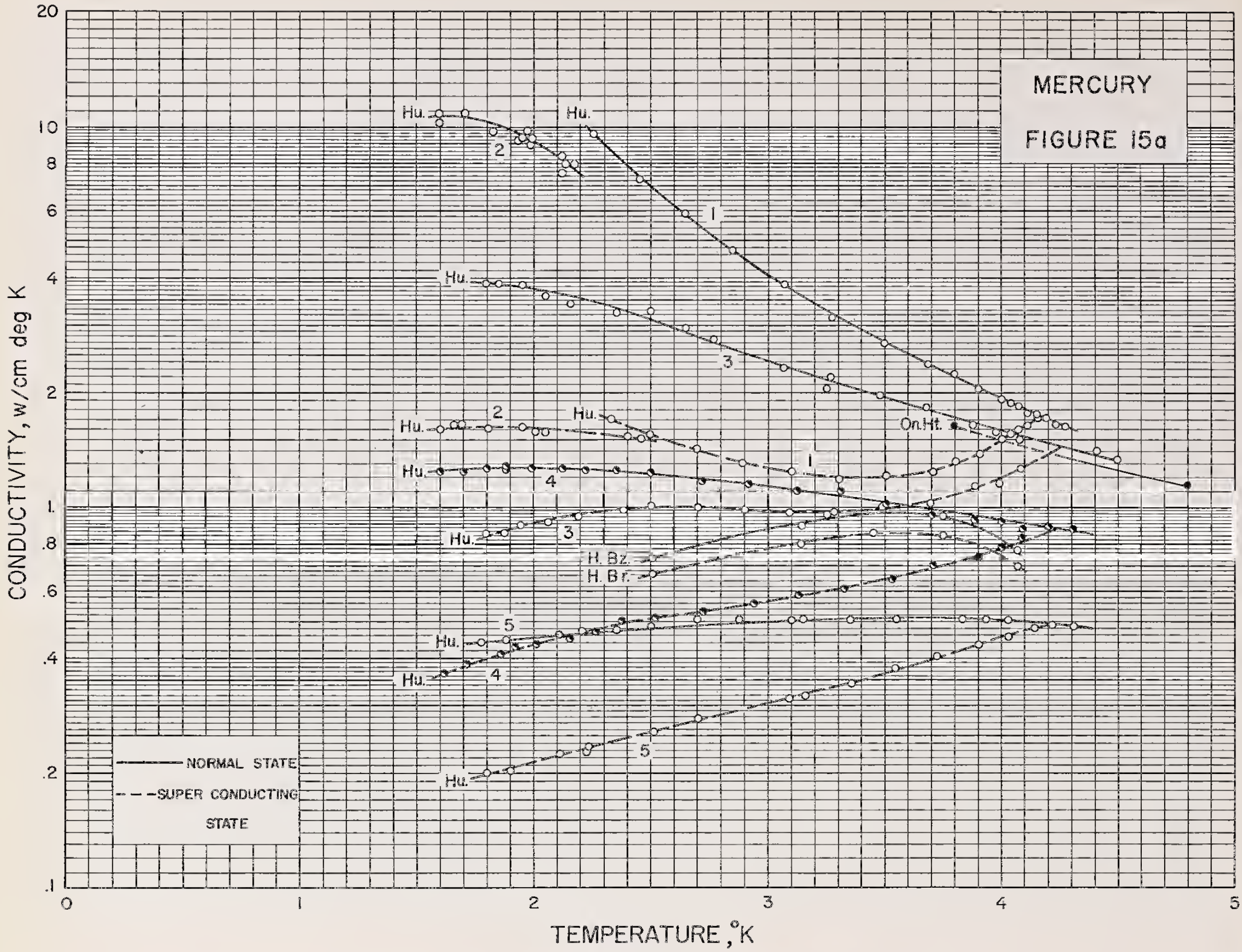
CADMIUM (Cont'd)

Curve	Sample source and analysis	Remarks	Reference
Go. G..... ‖	Kahlbaum; "pure".	Two single crystals, each with main crystal and rod axes parallel.	E. Goens and E. Grüneisen (1932).
Go. G..... ⊥	....do..........	Single crystal with main crystal and rod axes perpendicular.	Do.
....	Hilger; 99.999% pure.	Measured effect of magnetic field..	K. Mendelssohn and H. M. Rosenberg (1951).
M. R......	Hilger; 99.9999% pure.	Cast in glass; $\alpha = 140 \times 10^{-5}$, $\beta = 0.5$.	K. Mendelssohn and H. M. Rosenberg (1952a).
....	.....do.........	Measured effect of magnetic field..	K. Mendelssohn and H. M. Rosenberg (1953).
R.........	....	Maximum conductivity of 88 between 4° and 5°K; α=122$\times 10^{-5}$, β=0.02.	H. M. Rosenberg (1954a).



MERCURY

Curve	Sample source and analysis	Remarks	Reference
On. Ht.	....	Cp........	H. Kamerlingh Omnes (1914).
....	....	Measured in the liquid state and in solid state near melting.	G. Gehlhoff and F. Neumeier (1919).
Re.	....	Measured ten single crystal rods; fall into four groups. No. 1, rod axis parallel to crystal axis; #2, axes inclined 25°; #3, axes inclined 45°; #4, axes perpendicular.	H. Reddemann (1932).
H. Br.	....	Measured in both normal and superconducting states.	W. J. de Haas and H. Bremmer (1936).
Hu. 1-5	Basic rod (#1) from Johnson, Matthey; #2, .002% Cd; #3, .007% Cd; #4, .10% In; #5, .39% In.	Homogeneous solid solutions; polycrystalline, but large crystals; measured in both normal and superconducting state.	J. K. Hulm (1950).
....	....	Measured in the intermediate state near 4°K.	R. T. Webber and D. A. Spohr (1953).



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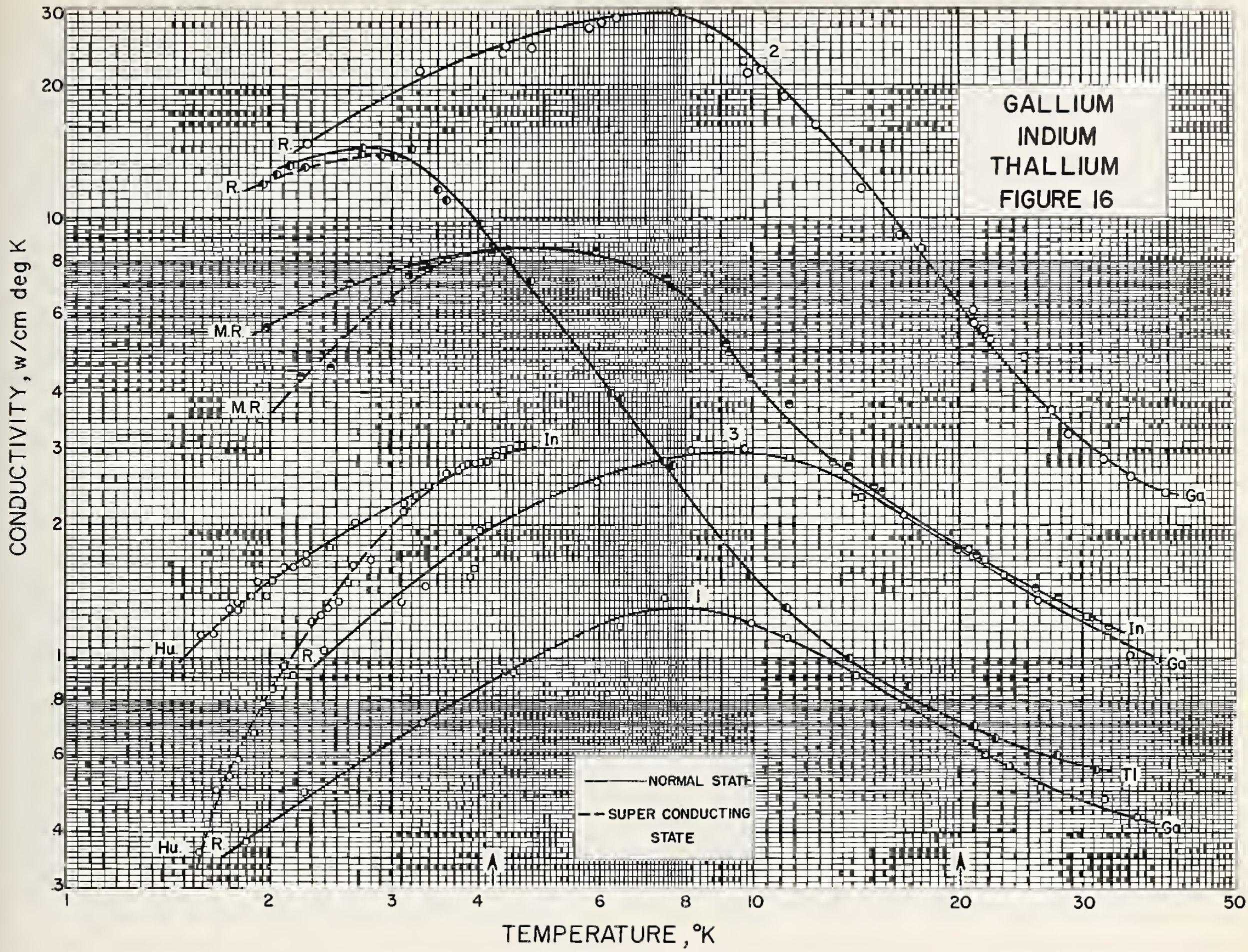


GALLIUM

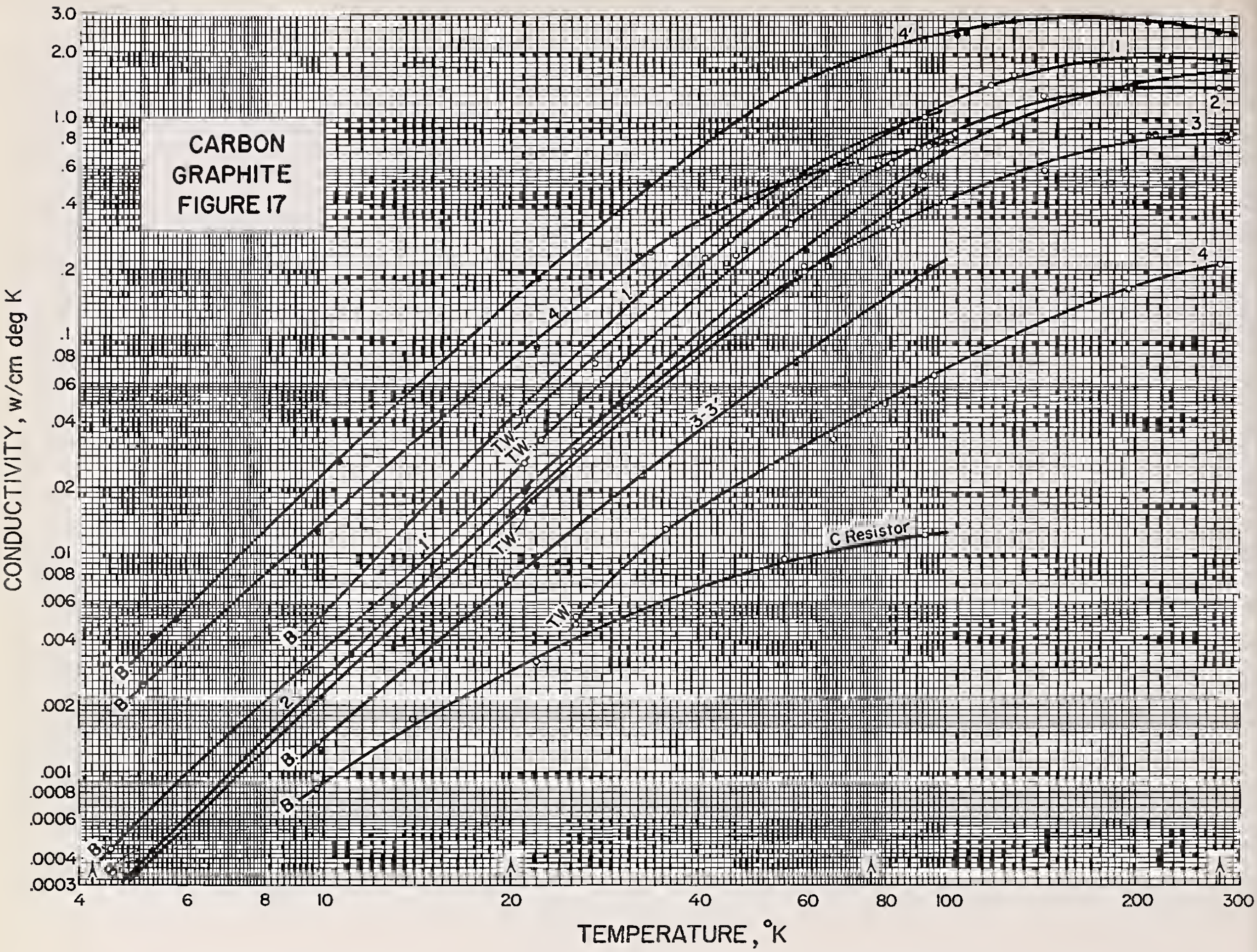
Curve	Sample source and analysis	Remarks	Reference
R.		Three single crystals of different orientation; No. 1 $\alpha=160\times10^{-5}$, $\beta=4.7$; #2, $\alpha=23\times10^{-5}$, $\beta=0.165$; #3, $\alpha=87\times10^{-5}$, $\beta=2.22$.	H. M. Rosenberg (1954a).

THALLIUM

Curve	Sample source and analysis	Remarks	Reference
	Kahlbaum	Drawn; $k=0.51$ at 0°C and 0.64 at 80°K.	A. Eucken and K. Dittrich (1927).
	Johnson, Matthey; 99.99% pure.	Annealed; polycrystalline; measured effect of magnetic field.	K. Mendelssohn and H. M. Rosenberg (1953).
	do.	Annealed; polycrystalline; measured conductivity below 1°K; between 0.3° and 0.65°K, conductivity was of form $\ln k=aT$; $k=0.2$ at 0.62°K, 0.0015 at 0.3°K.	K. Mendelssohn and C. A. Renton (1953).
R.	do.	$\alpha=537\times10^{-5}$, $\beta=0.1$	H. M. Rosenberg (1954a).

INDIUM

Curve	Sample source and analysis	Remarks	Reference
	Hilger	Absolute values were not determined.	W. J. de Haas and H. Bremmer (1932a).
Hu.	Johnson, Matthey; 0.1% impurity.	$\alpha=189\times10^{-5}$, $\beta=1.38$	J. K. Hulm (1950).
	Johnson, Matthey.	Single crystal; measured conductivity in intermediate state.	D. P. Detwiler and H. A. Fairbank (1952a, b).
M. R.	Johnson, Matthey; 99.993% pure.	$\alpha=190\times10^{-5}$, $\beta=0.4$; measured in both normal and superconducting state.	K. Mendelssohn and H. M. Rosenberg (1952a).
	do.	Measured effect of magnetic field.	K. Mendelssohn and H. M. Rosenberg (1953).
	do.	Measured conductivity below 1°K; between 0.2° and 0.7°K, conductivity equation was $k=2.5\times10^{-2}\,T^3$; $k=.019$ at 0.8°K, .003 at 0.46°K.	K. Mendelssohn and C. A. Renton (1953).
R.		$\alpha=185\times10^{-5}$, $\beta=0.35$ for normal state conductivity.	H. M. Rosenberg (1954a).



CARBON (Graphite)

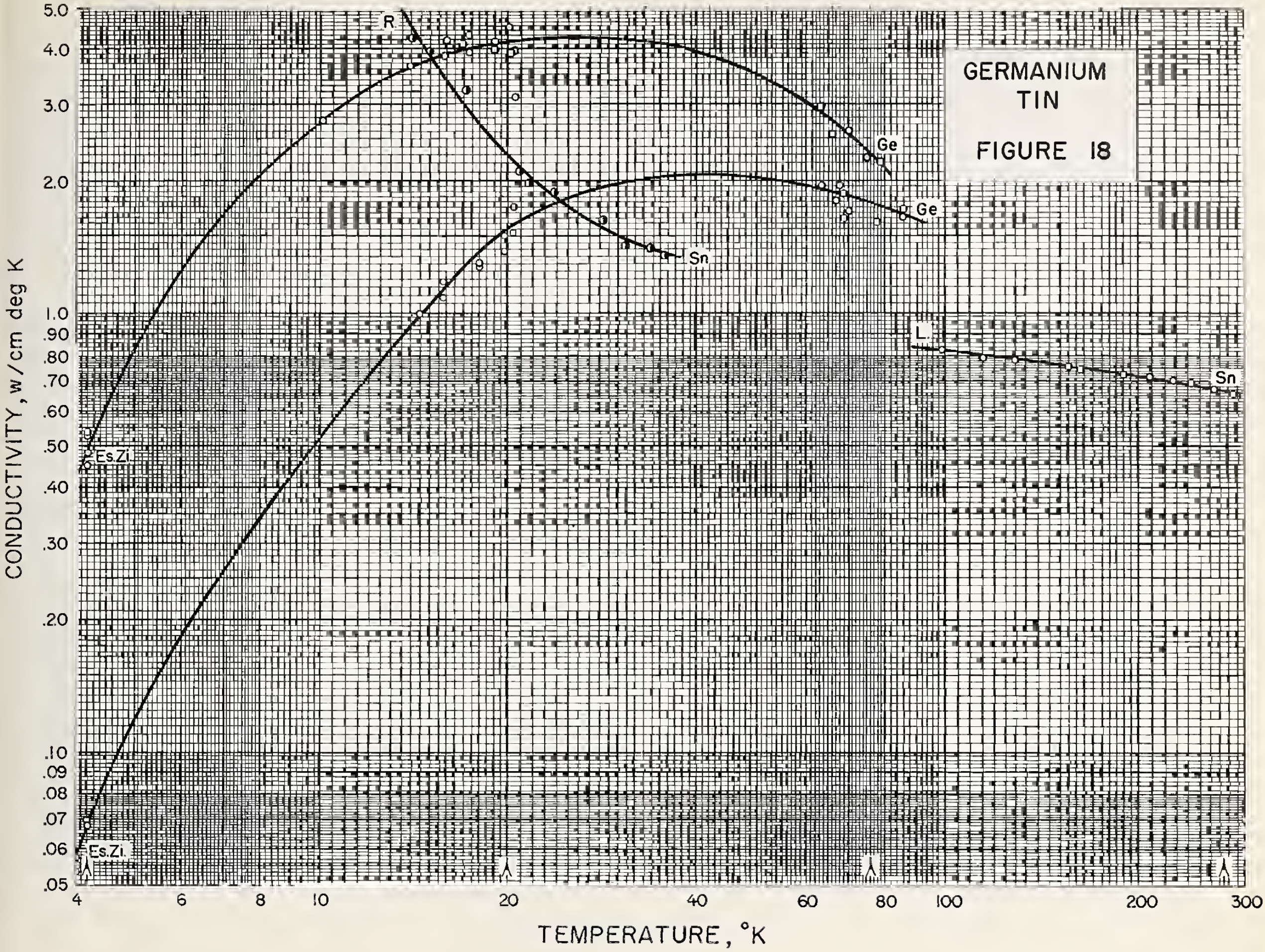
Curve	Sample source and analysis	Remarks	Reference
....	....	Pencil lead; density of 2.11 g/cm³; k=0.15 at 18°C.	T. Barratt and R. M. Winter (1925).
....	Acheson graphite.	k=1.78 at 122°K, 1.72 at 300°K...	A. P. Crary (1933).
....	Carbon; 80% petroleum coke, 20% lampblack.	k=0.016 at 0°C..................	R. W. Powell, F. H. Schofield (1939).
....	Acheson graphite.	Two rods gave k=1.21 and 1.67 at 0°C.	Do.
....	National Carbon; Acheson graphite.	For a sample with rod axis parallel to extrusion direction, k=1.76 at 0°C, 2.5 at 82°K; for a second sample with rod axis perpendicular to extrusion, k=1.13 at 0°C; 1.76 at 82°K.	R. A. Buerschaper (1944).
....	National Carbon; carbon electrode.	k=0.06 at 0°C, 0.01 at 82°K......	Do.
....	....	Measured conductivities of graphite and amorphous carbon.	S. Mizushima and J. Okada (1951).
....	....	Measured effect of crystal size....	S. Mrozowski (1952).

CARBON (Graphite) (Cont'd)

Curve	Sample source and analysis	Remarks	Reference
B. 1-3, 1'-3'.	Atomic Energy Res. Establish.	Artificial graphite rods; very anisotropic; unprimed numbers refer to rods with axes parallel to direction of extrusion; primed numbers refer to rods with axes perpendicular to the extrusion; densities were respectively 1.79, 1.60, and 1.77 g/cm³; crystal sizes 2000, 1000, and 300 A.	R. Berman (1952).
B. 4, 4'....	Natural graphite.	Density 2.25 g/cm³; crystal size, 2000 A; unprimed number refers to sample with its rod axis parallel to preferred c-axis; primed number, perpendicular.	Do.
T. W. 1, 2.	National Carbon; graphite.	Densities were 1.70 g/cm³; rod axes were respectively perpendicular and parallel to the preferred c-axes.	W. W. Tyler and A. C. Wilson (1953).
T. W. 3...	Natural graphite.	Molded; density of 1.80; rod axis perpendicular to preferred c-axis.	Do.
T. W. 4...	Lampblack.....	Molded; density of 1.65; rod axis parallel to preferred c-axis.	Do.
....	....	Abstract only; data not given.....	A. W. Smith (1954).

SILICON

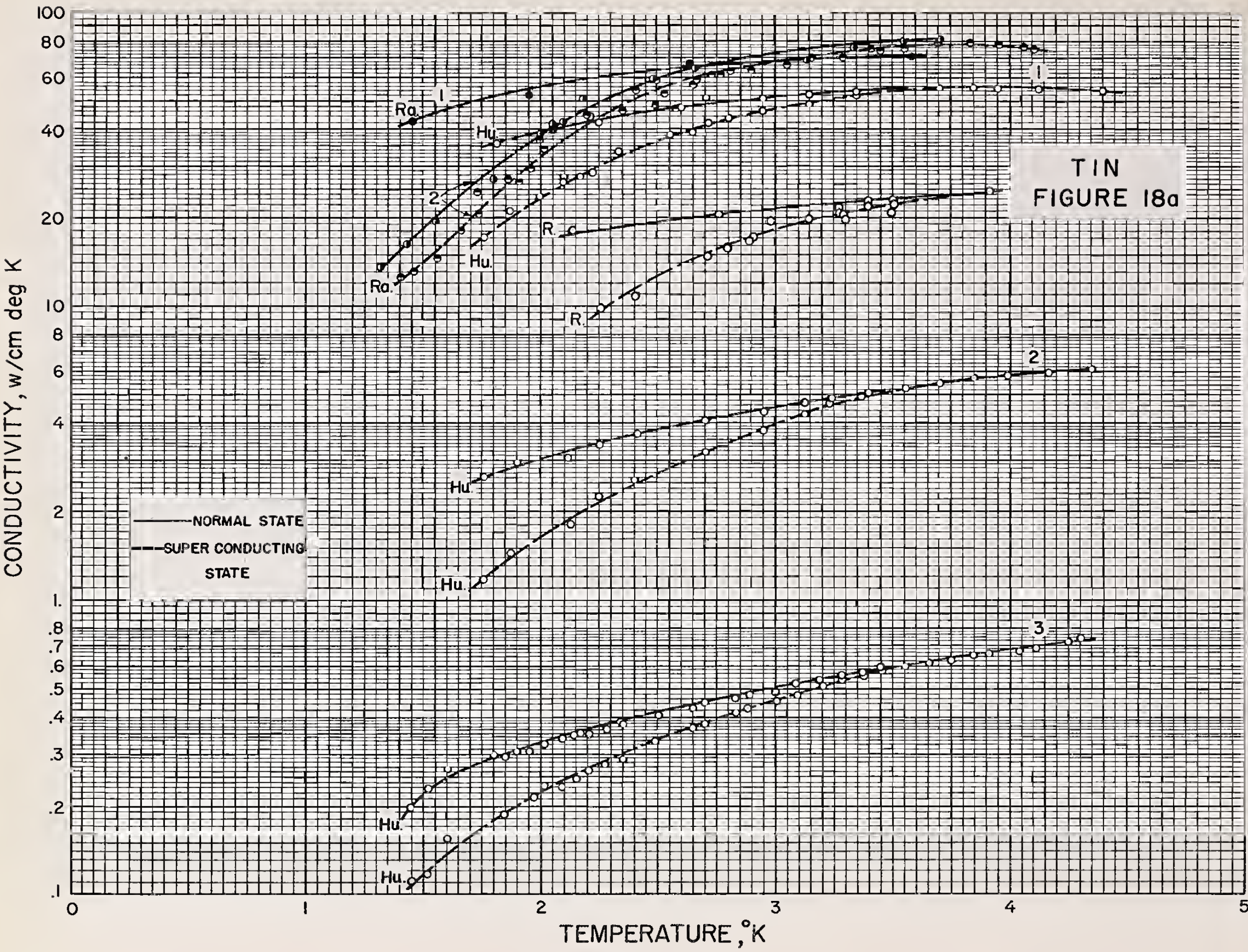
Curve	Sample source and analysis	Remarks	Reference
....	Impurities of 1 $\times 10^{-6}$ percent as shown by Hall effect.	"Filament cut from a crystal pulled in [100] direction;" k=1.48 at 0°C, 9 at 80°K, 19.5 at 30°K.	G. W. Hull and T. H. Geballe (1954).



(See next page for table on TIN.)

GERMANIUM

Curve	Sample source and analysis	Remarks	Reference
Es. Zi.....	"High purity"..	Cast; higher of two Ge curves on figures 18 and 19a.	I. Estermann and J. E. Zimmerman (1951).
Es. Zi.....	0.006 atomic % of Al.	Cast; lower of two Ge curves on figures 18 and 19a.	Do.

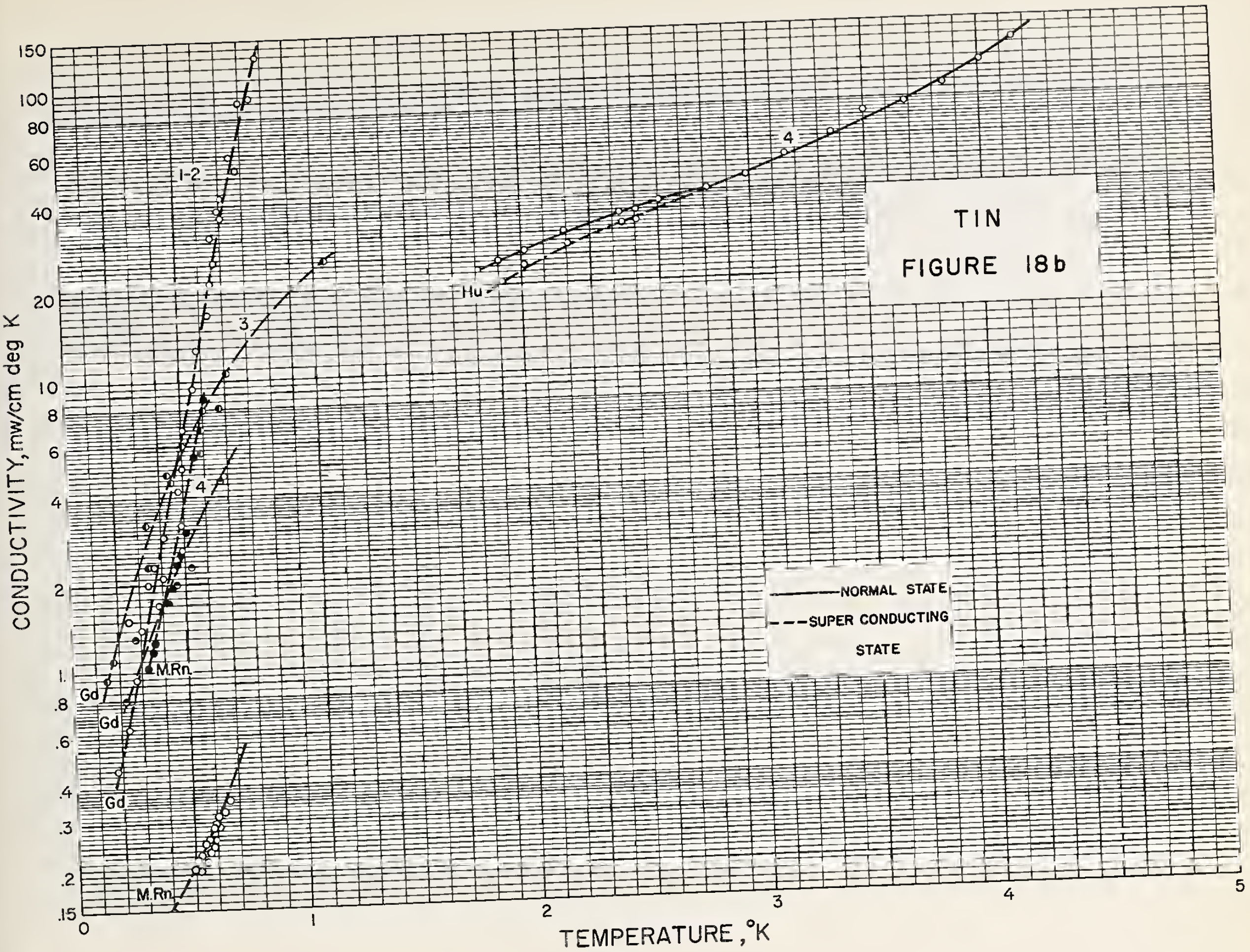


TIN

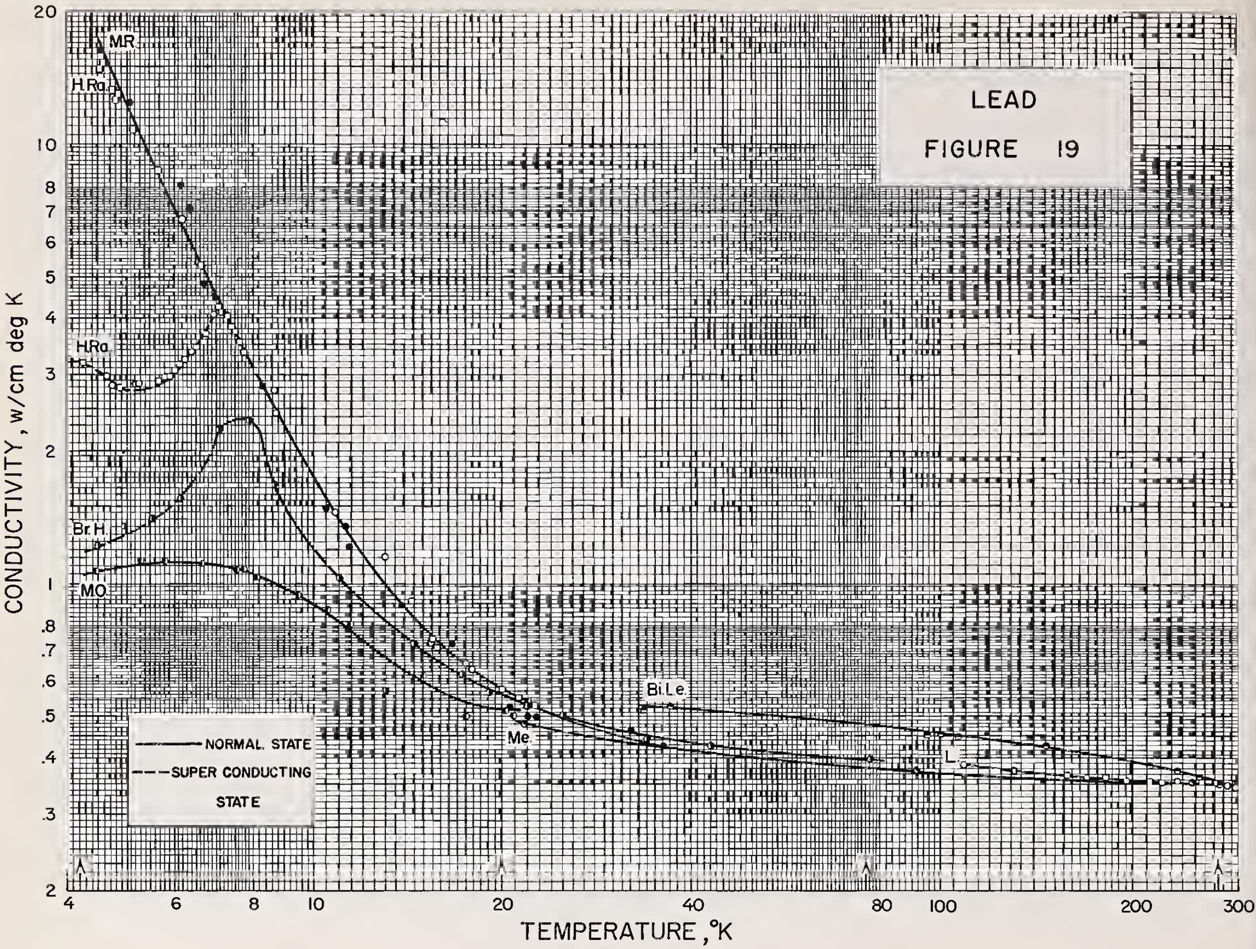
Curve	Sample source and analysis	Remarks	Reference
....	"Pure".........	$k=0.64$ at 0°C..................	L. Lorenz (1881).
....	"Pure" .03% Ph.	$k=0.61$ at 18°C.................	W. Jaeger and H. Diesselhorst (1900).
L.........	Kahlbaum; "pure".	Lathe-turned from a rod.........	C. H. Lees (1908).
....	....	Measured the relative change in conductivity at low temperatures, absolute values not given.	W. J. de Haas, S. Aoyama, and H. Bremmer (1931) and W. J. de Haas and H. Bremmer (1931a).
Hu. 1-4...	Johnson, Matthey; No. 1, 99.996% pure; #2, .03% Hg added; #3, .3% Hg added; #4, 4.1% Hg added.	Samples 1-3 were homogeneous solid solutions; #4 was two-phase; both normal and superconducting state measured.	J. K. Hulm (1949, 1950).

TIN (Cont'd)

Curve	Sample source and analysis	Remarks	Reference
....	....	Measured relative change upon becoming superconducting.	C. V. Heer and J. G. Daunt (1949).
Ra. 1, 2...	Chempur; 99.992% pure.	Single crystals with tetragonal axis inclined 85° to rod axis.	A. Rademakers (1949).
....	Johnson, Matthey; 99.996% pure.	Measured conductivity in the intermediate state.	D. P. Detwiler H. A. Fairhank (1952a,h).
....	Johnson, Matthey; 99.997%.	Single crystal; measured the effect of a magnetic field; for zero field, $k=25.1$ at 4.4°K, 19.6 at 3.0°K, 18.0 at 2.4°K, in normal state.	K. Mendelssohn H. M. Rosenberg (1953).
M. Rn....	.....do.........	Single crystal; npper curve in figure 18b; superconducting state.	K. Mendelssohn C. A. Renton (1953).
M. Rn.....	.....do.........	Polycrystalline; lower curve on figure 18h; superconducting state.	Do.
R.........	.....do.........	$\alpha=60\times10^{-5}$, $\beta=0.12$...........	H. M. Rosenherg (1954a).
Gd. 1-5....	No. 1 and 2, "spect. pure"; #3, 0.3% In; #4 and 5, 3% In.	Polycrystalline; crystal sizes about 1 to 3 mm; cast in glass.	B. B. Goodman (1953).



TIN
FIGURE 18b
NORMAL STATE
SUPER CONDUCTING STATE
CONDUCTIVITY, mw/cm deg K
TEMPERATURE, °K
1-2
3
4
Hu
Gd
M.Rn.

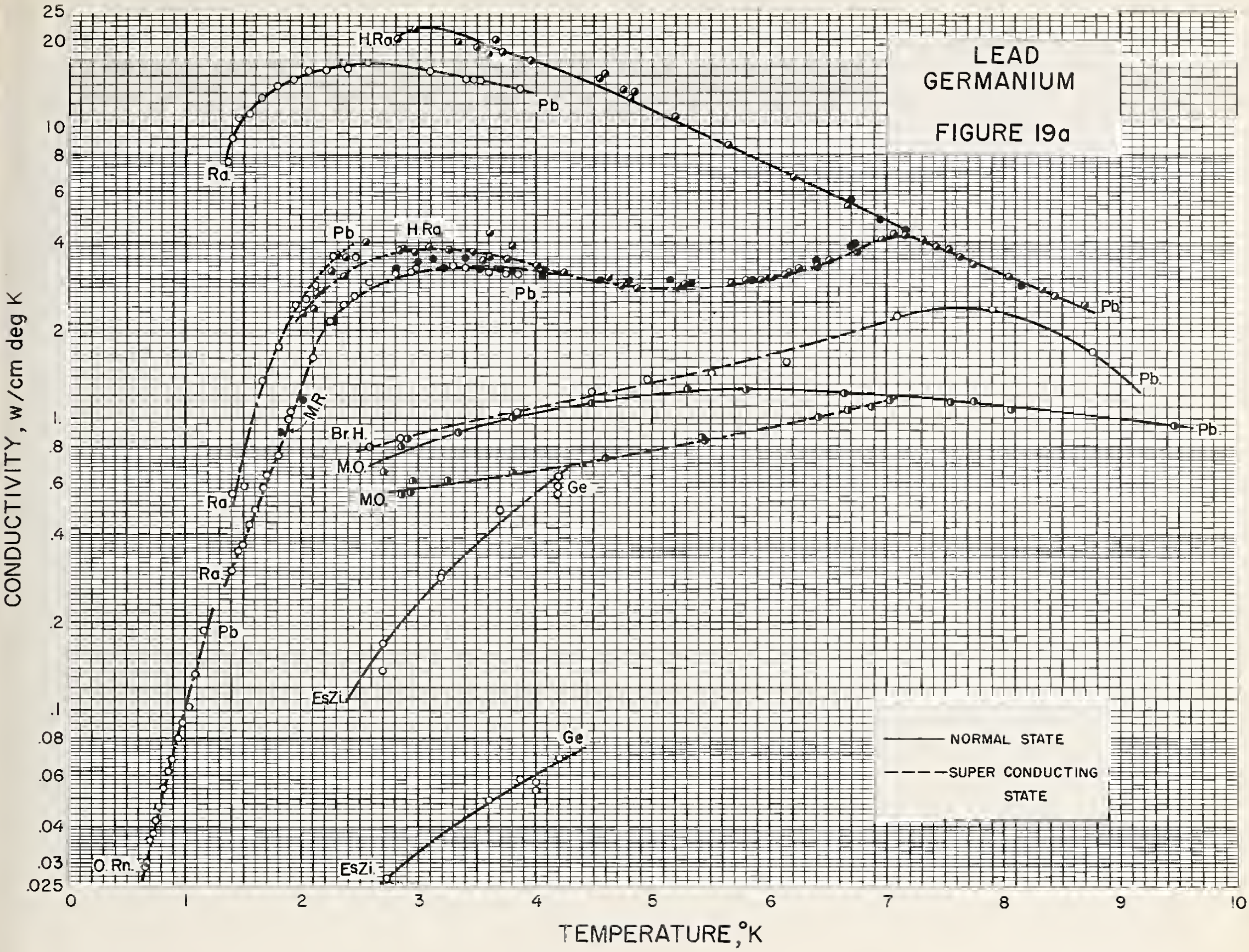


LEAD

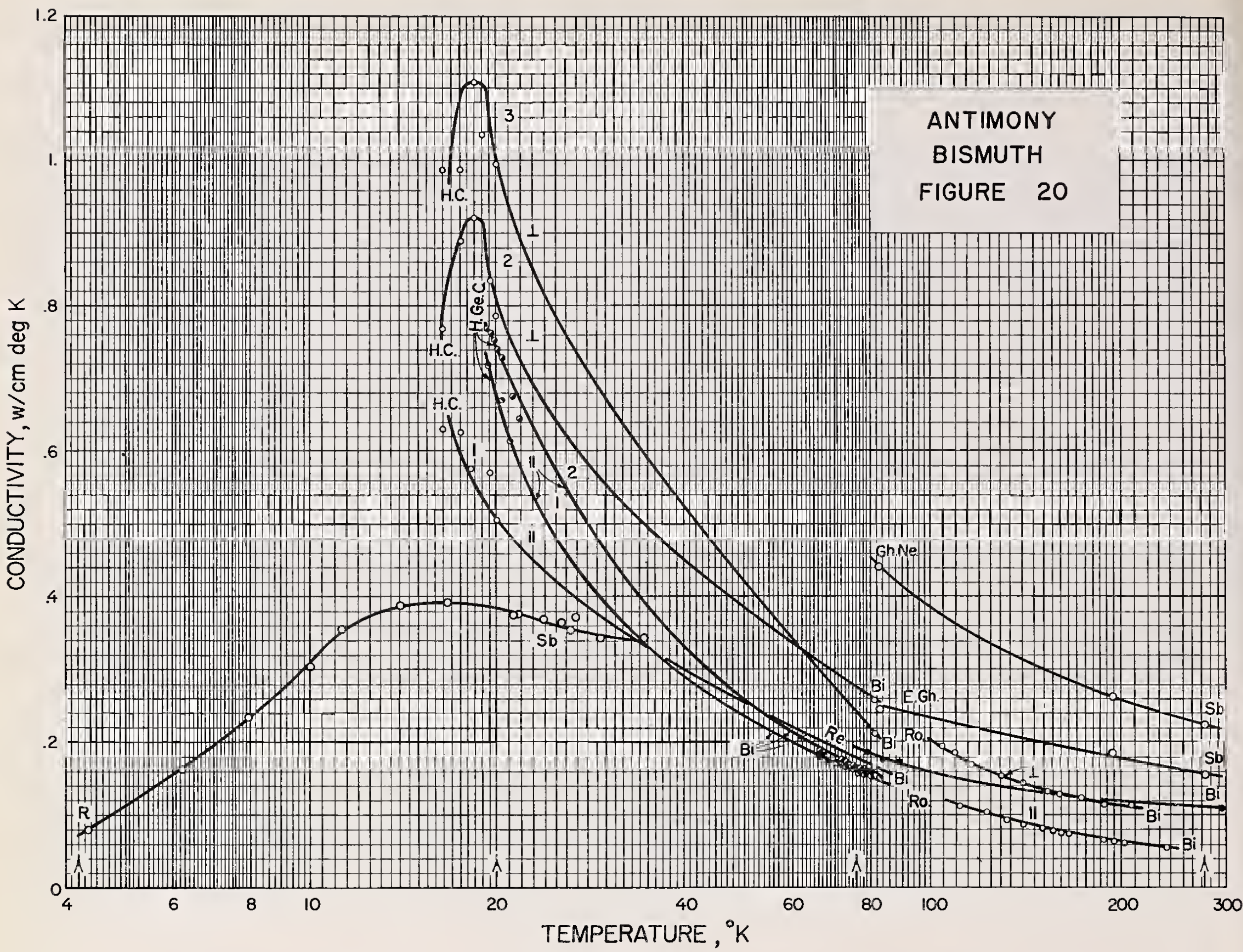
Curve	Sample source and analysis	Remarks	Reference
....	"Pure".........	k= 0.35 at 0°C..................	L. Lorenz (1881).
....	.....do.........	k= 0.35 at 18°C................	W. Jaeger and H. Diesselhorst (1900).
....	....	k=0.35 at 25°C, 0.45 at 90°K.....	P. Macchia (1907).
L.........	Baxendale; "pure".	Lathe-turned from a bar.........	C. H. Lees (1908).
Me........	Kahlbaum; 99.-998% pure.	Cold-drawn.....................	W. Meissner (1915).
....	Kahlbaum; "pure".	Results agree with Meissner (1915).	R. Schott (1916).
....	....	k= 0.38 at 12°C, 0.36 at 23°C.....	T. Peczalski (1917).
Bi. Le.....	....	....	C. C. Bidwell and E. J. Lewis (1929).
....	....	Measured relative temperature variation.	W. J. de Haas and H. Bremmer (1931).
Br. H.....	....	Measured in both normal and superconducting states.	H. Bremmer and W. J. de Haas (1936).
....	Hilger; 99.999% pure.	Measured changes in conductivity during superconducting transition.	K. Mendelssohn and R. B. Pontius (1937).

LEAD (Cont'd)

Curve	Sample source and analysis	Remarks	Reference
H. Ra.....	Hilger..........	Melted under vacuum; single crystal; in both normal and superconducting states.	W. J. de Haas and H. Rademakers (1940).
Ra........	.....do.........	Two single crystals..............	A. Rademakers (1949).
M. O......	0.02% Bi.......	In both normal and superconducting states.	K. Mendelssohn and J. L. Olsen (1950c).
....	....	Studied conductivity in intermediate state.	R. T. Webber and D. A. Spohr (1951).
M. R......	Tadenae, 99.-998% pure.	Single crystal; measured in both normal and superconducting states; normal curve gives α= 325×10^{-5}, β= 0.10; same curve on graph as H. Ra.; experimental points marked by filled circles.	K. Mendelssohn and H. M. Rosenberg (1952b).
O. Rn.....	....	Single crystal..................	J. L. Olsen and C. A. Renton (1952).
....	Tadenac........	Measured effect of magnetic field..	K. Mendelssohn and H. M. Rosenberg (1953).
....	Same as M.R...	k=25 at 3.1°K, 28 at 2.7°K; continuation of work of Mendelssohn, Rosenberg (1952b); α= 290×10^{-5}, β=0.10.	H. M. Rosenberg (1954a).



(For GERMANIUM, see the table under figure 18, page 31.)

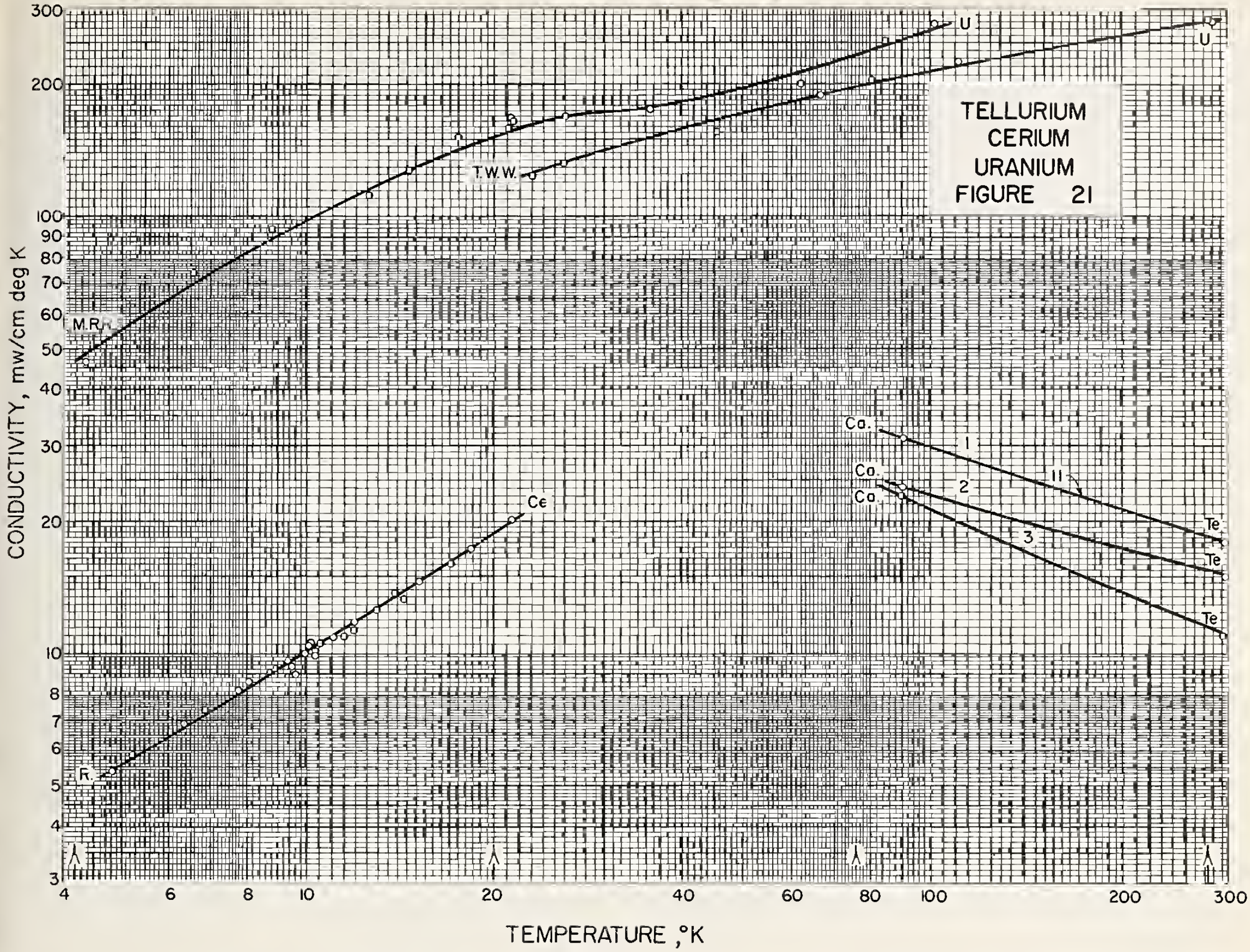


ANTIMONY

Curve	Sample source and analysis	Remarks	Reference
....	....	k=0.19 at 0°C..................	L. Lorenz (1881).
E. Gb.....	Kahlbaum......	Cold-drawn.....................	A. Eucken and G. Gehlhoff (1912).
Gb. Ne....	Kahlbaum; "pure".	R..............................	G. Gehlhoff and F. Neumeier (1913a).
....	Kahlbaum; "chem. pure".	Measured effect of grain size; sample witb largest grains had a conductivity close to the Gh. Ne. curve.	A. Eucken and O. Neumann (1924).
....	Kahlbaum; "pure".	Measured effect of magnetic field on k and R for single and polycrystalline rods; at 80° and 90°K results agree with those of Gh. Ne. curve.	K. Rauscb (1947).
R.........	....	....	H. M. Rosenberg (1954a).

BISMUTH

Curve	Sample source and analysis	Remarks	Reference
....	....	k=0.074 at 0°C..................	L. Lorenz (1881).
....	"Pure".........	k=0.081 at 18°C; R, C_p, emf.	W. Jaeger and H. Diesselhorst (1900).
....	....	At 87°, 194°, and 291°K results are close to Rodine's upper eurve.	E. Giebe (1903).
....	Kahlbaum; "pure".	Drawn; at 83°, 194°, and 273°K results are close to Rodine's upper curve.	G. Gehlhoff and F. Neumeier (1913a).
....	.....do.........	Measured pressed powders; k= 0.21 at 83°K, 0.08 at 0°C.	G. Geblhoff and F. Neumeier (1913b).
....	0.02% Pb, traee Fe.	Single erystals, measured anistropy.	G. W. C. Kaye and J. K. Roberts (1923).
....	....	Measured effect of grain size......	A. Eucken and O. Neumann (1924).
....	....	Measured effeet of magnetic field on conductivity in single crystals.	G.W.C.Kaye and W. F. Higgins (1929).



BISMUTH (Cont'd)

Curve	Sample source and analysis	Remarks	Reference
Re........	Kahlbaum; "pure".	Rod axis inclined 80° to crystal axis; studied effect of magnetic field; R.	H. Reddemann (1934).
Ro........	....	Measured two single crystals, one with rod axis parallel to trigonal crystal axis, one perpendicular.	M. T. Rodine (1934).
H. C. 1, 2, 3.	Hilger; 99.995% pure, trace of silver.	Single crystals; No. 1, rod axis parallel to main crystal axis; #2, rod axis parallel to binary axis; #3, rod axis parallel to bissectrix of binary axes.	W. J. de Haas and W. H. Capel (1934a, b).
....	....	At 83° and 90°K results are close to the ones above; measured effect of magnetic field on *k* and R.	E. Grüneisen and J. Gielessen (1936).
H. Ge. C...	Hilger; .002% silver, trace of Pb.	Single crystal; rod axis parallel to main crystal axis; measured effect of magnetic field.	W. J. de Haas, A. N. Gerritsen, and W. H. Capel (1936).
....	....	Measured *k* between 2.3° and 77.4°K.	S. Shalyt (1947).
....	....	Measured effect of magnetic field..	E. Grüneisen, K. Rausch, and K. Weiss (1950).

TELLURIUM

Curve	Sample source and analysis	Remarks	Reference
Ca........	99.999% pure...	No. 1, a single crystal with rod axis parallel to main crystal axis; #2 and #3 are polycrystalline; also measured R, emf.	C. H. Cartwright (1933).

CERIUM

R.........	....	k=T/900 from 4° to 20°K........	H. M. Rosenberg (1954a).

URANIUM

T. W. W...	....	Quenched; also measured R, emf..	W. W. Tyler, A. C. Wilson, and G. J. Wolga (1952).
M. R......	Assoc. Elec. Ind Res. Lab.	α=750×10^{-5}, β= 95...........	K. Mendelssohn and H. M. Rosenberg (1952b).
R.........	.....do.........	α=790×10^{-5}, β= 93...........	H. M. Rosenberg (1954a).

2.3 Alloys and Commercial Metals

The values for conductivities of experimental and commercial alloys are given in figures 22 through 29a and in the following tables, arranged according to periodic group of the major component. In several instances a particularly large class of alloys has been separately presented, i. e., copper-nickel alloys. Many of the experimental results are for a limited temperature range, so more of the data are presented in tables than in section 2.2 on metals. This section is also not as complete as section 2.2 because many of the data were published in now unavailable journals or institute reports. As for the preceding tables the following tables contain columns indicating the curve identifying marks, composition, conductivity, remarks, and reference. In addition, they occasionally contain information on trade designation or symbols and manufacturing tempers. The names or numbers and the arrangement within a group are based upon the corresponding arrangements in Metals Handbook.[1] The composition limits for many of the alloys are also taken from the Metals Handbook. The tables listed below, which quote "company or trade manuals", are all based on room-temperature values.

In pure metals the greater part of the energy transfer is by electrons, whereas in alloys the transfer by the lattice vibration is very significant and may be the predominant mode. For that reason the conductivity is not as sensitive to small differences in composition as it is in nearly pure metals. It will be noted in the following graphs that the conductivity curves of alloys with similar compositions are usually parallel to each other and seldom intersect.

[1]Metals Handbook, 1948 ed., Am. Soc. for Metals, Cleveland, Ohio.

ALKALI METAL ALLOYS

Nominal Composition (%)	Conductivity and remarks	Reference
	w/cm deg K	
Sodium-potassium; 50-50 by atomic percent.	k=0.29 at −8.9°C, 0.30 at −10.6°C	J. W. Hornbeck (1913).

BERYLLIUM

Commercially pure; Beryllium Co. of America.	See figure 2, under "Metallic Elements"	E. J. Lewis (1929).
Copper-beryllium	See "Copper Alloys"	

MAGNESIUM ALLOYS

0.5 Mn	k=1.60 at 273°K, 1.34 at 87°K [1]	J. Staebler (1929).
0.8 Mn	k=1.58 at 273°K, 1.22 at 87°K [1]	Do.
2 Mn	k=1.18 at 273°K, 0.67 at 87°K [1]	Do.
3.54 Mn	k=1.02 at 273°K, 0.57 at 87°K [1]	Do.
6 Al	k=0.80 at 273°K, 0.59 at 87°K [1]	Do.
8 Al	k=0.65 at 273°K, 0.42 at 87°K [1]	Do.
12 Al	k=0.59 at 273°K, 0.33 at 87°K [1]	Do.
0.7 Si	k=1.48 at 273°K, 1.10 at 87°K [1]	Do.
1.5 Si	k=1.40 at 273°K, 0.95 at 87°K [1]	Do.
8 Ce	k=1.25 at 273°K, 1.06 at 87°K [1]	Do.
12 Ce	k=1.03 at 273°K, 0.81 at 87°K [1]	Do.
8 Cu	k=1.25 at 273°K, 0.88 at 87°K [1]	Do.
8 Zn	k=1.19 at 273°K, 0.89 at 87°K [1]	Do.
8 Cd	k=1.42 at 273°K, 1.30 at 87°K [1]	Do.
2 Si, 6 Al	k=0.69 at 273°K, 0.48 at 87°K [1]	Do.
2 Si, 8 Al	k=0.61 at 273°K, 0.38 at 87°K [1]	Do.
2 Si, 10 Al	k=0.55 at 273°K, 0.29 at 87°K [1]	Do.
2 Si, 12 Al	k=0.54 at 273°K, 0.28 at 87°K [1]	Do.

[1] Chill-cast; also measured R.

MAGNESIUM ALLOYS (Cont'd)

Nominal Composition (%)	Conductivity and Remarks	Reference
	w/cm deg K	
15 Cu	k=1.54 at 273°K, 1.51 at 87°K; chill-cast	W. Mannchen (1931).
20 Cu, 3 Si	k=1.08 at 273°K, 0.89 at 87°K; chill-cast	Do.
2.2 Ag	k=1.31 at 25°C [2]	R. Kikuchi (1932).
6.0 Ag	k=1.16 at 27°C [2]	Do.
2.1 Al	k=0.88 at 27°C [2]	Do.
4.2 Al	k=0.69 at 22°C [2]	Do.
6.2 Al	k=0.56 at 22°C [2]	Do.
8.2 Al	k=0.51 at 18°C [2]	Do.
10.3 Al	k=0.45 at 19°C [2]	Do.
12.2 Al	k=0.39 at 23°C [2]	Do.
2.4 Cu	k=1.39 at 20°C° [2]	Do.
6.3 Cu	k=1.31 at 24°C [2]	Do.
1.9 Ni	k=1.36 at 20°C [2]	Do.
5.8 Ni	k=1.26 at 24°C [2]	Do.
2.2 Sn	k=1.06 at 21°C [2]	Do.
6.4 Sn	k=0.74 at 22°C [2]	Do.
2.1 Zn	k=1.26 at 26° [2]	Do.
6.1 Zn	k=1.09 at 26°C [2]	Do.
4 Zn, 0.5 Cu	"Elektron" k=1.14 at 26° C°[2]	Do.
4 Al, 1 Zn, 1 Cd, 1 Sn.	k=0.56 at 22°C [2]	Do.
6 Al, 3 Zn, 0.4 Cu	"Dow metal" k=0.61 at 29°C [2]	Do.
4 Al, 0.5 Zn, 2 Cd, 1 Sn.	k=0.63 at 22°C [2]	Do.
4 Al, 3 Cd, 1 Sn	k=0.69 at 22°C [2]	Do.
4 Al, 2 Cd, 2 Sn	k=0.56 at 30°C° [2]	Do.

[2] Vacuum-annealed.

MAGNESIUM ALLOYS (Cont'd)
COMPANY AND TRADE MANUALS

ASTM designation	Trade designations	Nominal composition (%)	Conductivity
			w/cm deg K
A 8	Dowmetal A; Mazlo AM 241; British DTD 59A, DTD 289, Elektron A8, Elektron A8K.	8 Al, 0.2 Mn	0.75
A 10	Dowmetal G; Mazlo AM 240; AM-C59S; British DTD 259; Elektron VI.	10 Al, 0.1 Mn	.71
AM 80 A		See A 8	
AM 100 A		See A 10	
AZ 31X, A, B.	Dowmetal FS-1; Mazlo AM-C52S; Whitelight FS-1; British DTD 120A; Elektron AZ 31.	3 Al, 1 Zn, 0.3 Mn.	.96
AZ 51 X	Dowmetal JS-1	5 Al, 1 Zn, 0.25 Mn.	.88
AZ 61 X, A, B.	Dowmetal J-1; Mazlo AM-C57S; Whitelight J-1; British DTD 88B, DTD 120A, DTD 259; Elektron AZM.	6 Al, 1 Zn, 0.2 Mn.	.80
AZ 63, A	Dowmetal H; Mazlo AM 265; British DTD 59A, DTD 289; Elektron AZG.	6 Al, 3 Zn, 0.2 Mn.	.75
AZ 80 X, A	Dowmetal 0-1; Mazlo AM-C58S; Whitelight 0-1; British DTD 88B; Elektron AZ 855.	8.5 Al, 0.5 Zn, .15 Mn.	.75
AZ 91 A, B, C.	Dowmetal R, RC; Mazlo AM 263; British DTD 136A; Elektron AZ 91.	9 Al, 0.7 Zn, 0.2 Mn.	.71
AZ 92, A	Dowmetal C; Mazlo AM 260	9 Al 2 Zn, 0.1 Mn.	.71
M 1 A, B	Dowmetal M; Mazlo AM403, AM 3S; Whitelight M; British DTD 142, 118, 140A; Elektron AM 503.	1.5 Mn	1.26
	Mazlo AM 244	4 Al, 0.2 Mn	0.96
	Dowmetal EK 30A	3 rare earths, 0.35 Zr, 0.3 Zn.	.27

ALUMINUM ALLOYS

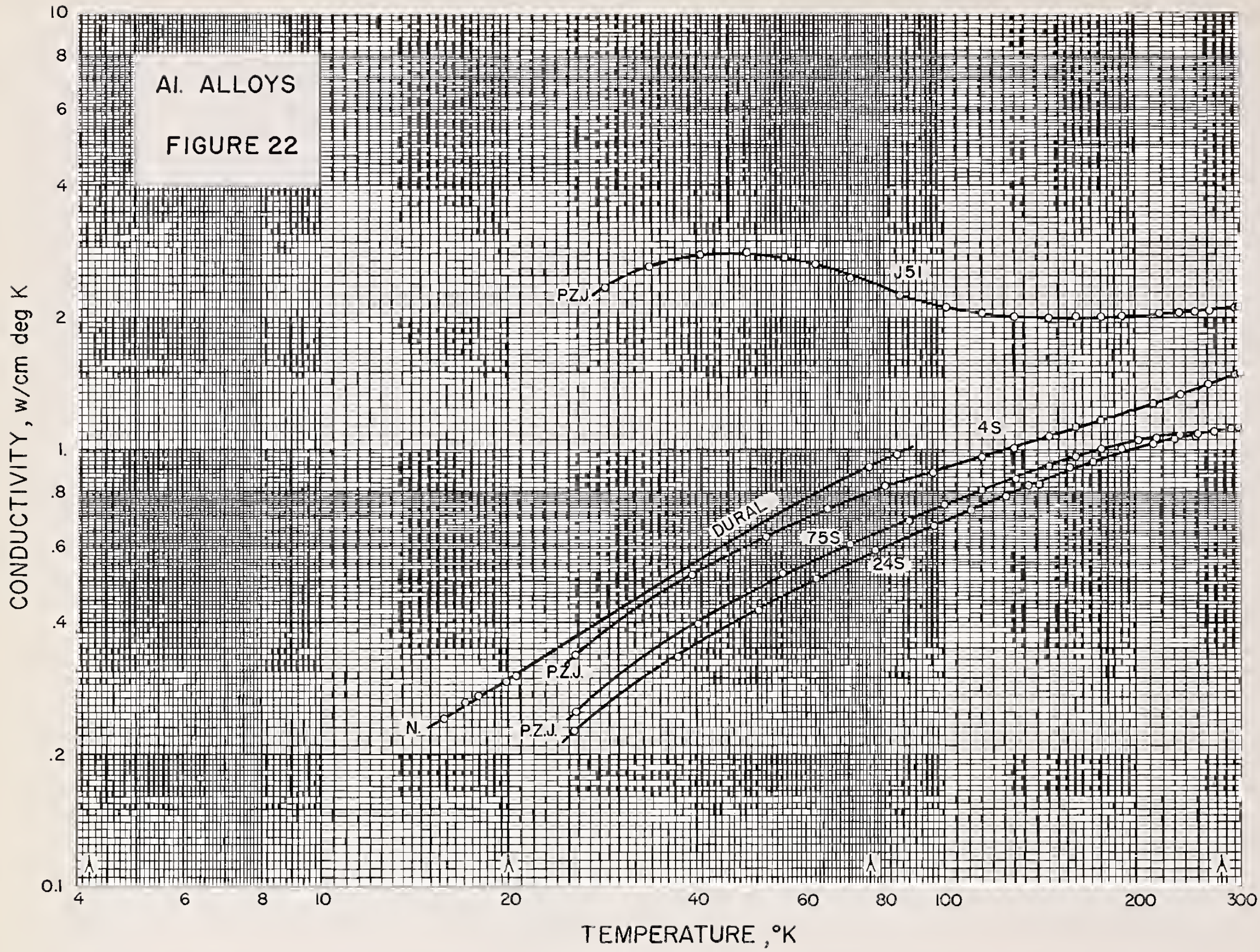
Composition (%)	Conductivity and remarks	Reference
	w/cm deg K	
0.5 Fe, 0.4 Cu	k=2.01 at 18° C	W. Jaeger and H. Diesselhorst (1900).
Commercial	k=1.93 at 0°C, 1.90 at 85°K, 1.59 at 21.4°K.	R. Schott (1916).

Composition (%) [1]	Conductivity [1]	State [1]
	w/cm deg K	
12.2 Cu, 0.3 Si, 0.6 Fe [2]	1.24 1.48	Cast. Annealed.
12.2 Cu, 0.2 Si, 0.6 Fe, 1 Mn [2]	0.93 1.33	Cast. Annealed.
10.5 Cu, 0.3 Si, 0.8 Fe, 1 Ni, 3 Sn [2].	1.35 1.59	Cast. Annealed.
8.4 Cu, 0.3 Si, 0.7 Fe, 0.7 Mn [2]	1.02 1.35	Cast. Annealed.
8.1 Cu, 0.4 Si, 0.6 Fe [2]	1.39 1.67	Cast. Annealed.
6.9 Cu, 0.3 Si, 0.7 Fe, 1.2 Sn [2]	1.47 1.66	Cast. Annealed.

ALUMINUM ALLOYS (Cont'd)

Composition (%) [1]	Conductivity [1]	State [1]
	w/cm deg K	
5.3 Cu, 0.5 Si, 0.8 Fe, 0.5 Mn, 1.2 Mg.[2]	1.18 1.52	Cast. Annealed.
4.3 Cu, 0.4 Si, 0.9 Fe, 0.6 Mn, 0.4 Mg.[2]	1.22 1.52	Cast. Annealed.
2.5 Cu, 0.4 Si, 0.9 Fe, 1.8 Ni, 0.9 Mg.[2]	1.44 1.63	Cast. Annealed.
4.4 Cu, 0.5 Si, 0.7 Fe, 2.1 Ni, 0.9 Mg.[2]	1.30 1.47	Cast. Annealed.
3.8 Cu, 6.1 Si, 0.9 Fe, 0.6 Mn, 1.6 Mg.[2]	1.00 1.36	Cast. Annealed.
2.7 Cu, 0.4 Si, 0.6 Fe, 12.0 Zn [2].	1.32 1.33	Cast. Annealed.
2.6 Cu, 0.4 Si, 0.6 Fe, 20.3 Zn [2].	1.07 1.08	Cast. Annealed.
2.5 Cu, 0.3 Si, 0.8 Fe, 0.5 Mn, 2.6 Zn.[2]	1.26 1.45	Cast. Annealed.
1.9 Cu, 0.1 Si, 1 Fe, 1.5 Mg [2]	1.57 1.65	Cast. Annealed.
1.8 Cu, 0.4 Si, 0.9 Fe, 0.9 Cr [2]	1.05 1.09	Cast. Annealed.
1.8 Cu, 0.3 Si, 0.6 Fe, 1 Ni, 1.6 Mg.[2]	1.48 1.65	Cast. Annealed.
11.9 Si, 0.8 Fe [2]	1.31 1.78	Cast. Annealed.
0.1 Si, 0.6 Fe [2]	1.86 2.00	Cast. Annealed.
8.1 Cu, 0.4 Si, 0.6 Fe [3]	1.33 1.32	Quenched. Aged.
5.3 Cu, 0.5 Si, 0.8 Fe, 0.5 Mn, 1.2 Mg.[3]	1.23 1.23	Quenched. Aged.
2.5 Cu, 0.4 Si, 0.9 Fe, 1.8 Ni, 0.9 Mg.[3]	1.38 1.33	Quenched. Aged.
3.8 Cu, 6.1 Si, 0.9 Fe, 0.6 Mn, 1.6 Mg.[3]	1.16 1.14	Quenched. Aged.
2.6 Cu, 0.4 Si, 0.6 Fe, 20.3 Zn [3].	0.98 0.98	Quenched. Aged.
2.5 Cu, 0.3 Si, 0.9 Fe, 0.5 Mn, 2.6 Zn.[3]	1.32	Quenched.
1.9 Cu, 0.1 Si, 1 Fe, 1.5 Mg [3]	1.59	Quenched.
1.8 Cu, 0.3 Si, 0.6 Fe, 1.0 Ni, 1.6 Mg.[3]	1.45	Quenched.
5.3 Cu, 0.5 Si, 0.8 Fe, 0.5 Mn, 1.2 Mg.[4]	1.36 1.60	Drawn. Annealed.
4.3 Cu, 0.4 Si, 0.9 Fe, 0.4 Mn, 0.6 Mg.[4]	1.48 1.73	Drawn. Annealed.
11.9 Si, 0.8 Fe [4]	1.73 1.81	Drawn. Annealed.
0.1 Si, 0.5 Fe [4]	2.06 2.07	Drawn. Annealed.

[1] Results by H. Masumoto (1925) at 27°C.
[2] The samples were chill cast in an iron mold, then annealed for 30 minutes at 450°C.
[3] Chill-cast in an iron mold, annealed, then heated for 30 minutes at about 500°C, quenched in water, and later aged two weeks.
[4] Chill-cast in an iron mold, forged, then cold-drawn to 60% of original diameter, and later annealed for 30 minutes at 500°C.



ALUMINUM ALLOYS (Cont'd)

Nominal composition (%)	Conductivity and remarks	Reference
	w/cm deg K	
8 Cu	k=1.32 at 273°K; 0.88 at 87°K	W. Mannchen (1931).
Do	k=1.31 at 273°K; 0.90 at 87°K	Do.
15 Cu	k=1.48 at 273°K; .90 at 87°K	Do.
8 Mg	k=1.00 at 273°K; .73 at 87°K	Do.
Do	k=1.05 at 273°K; 77 at 87°K; thermally treated.	Do.
12 Mg	k=0.77 at 273°K; .56 at 87°K	Do.
14 Mg	k=0.69 at 273°K; .44 at 87°K; thermally treated.	Do.
20 Si	k=1.59 at 273°; 1.21 at 87°K; "Alusil".	Do.
4 Cu, 2 Ni, 1.5 Mg; "Y" Alloy	k=1.62 at 273°K; 1.12 at 87°K	Do.
Do	k=1.53 at 273°K; 1.38 at 87°K; thermally treated.	Do.
Mg, Mn, Sb; K-S Alloy 245	k= 1.07 at 273°K; 1.00 at 87°K	Do.
Mn, Mg, Sb; K-S Alloy 280	k=1.00 at 273°K; 0.80 at 87°K	Do.
Mn, Mg, Sb; K-S Alloy Special	k= 1.39 at 273°K; 1.14 at 87°K	Do.
Cu, Mn, Mg; Nelson-Kolben 10.	k= 1.60 at 273°K; 1.32 at 87°K	Do.
Cu; Nelson-Kolben Vn 1	k= 1.43 at 273°K; 1.18 at 87°K	Do.
Cu; Nelson-Kolben	k=1.59 at 273°K; 1.30 at 87°K	Do.
3-5 Cu, 0.5 Mg	k=1.60 at 273°K; 0.89 at 87°K	Do.

ALUMINUM ALLOYS (Cont'd)

Curve	Composition (%)	Remarks	Reference
N.-"Dural"	0.57 Mg, 0.42 Fe, 4.10 Cu, 94.0 Al.	As stamped; "Duraluminium".	J. de Nobel (1951).
P. Z. J.-J51	0.29 Cu, 0.56 Mg, 0.02 Mn, 0.56 Fe, 0.30 Si, 0.01 Cr, 0.01 Ti.		R. W. Powers, J. B. Ziegler, and H. L. Johnston (1951).
P. Z. J.-4S	0.16 Cu, 1.02 Mg, 1.20 Mn, 0.52 Fe, 0.13 Si, 0.02 Cr, 0.02 Ti.		Do.
P. Z. J.-75S	1.5 Cu, 5.5 Zn, 2.5 Mg, 0.2 Mn, 0.3 Cr.		Do.
P. Z. J.-24S	4.49 Cu, 0.01 Zn, 1.47 Mg, 0.66 Mn, 0.34 Fe, 0.13 Si, 0.01 Cr, 0.02 Ti.		Do.

ALUMINUM ALLOYS (Cont'd)
COMPANY AND TRADE MANUALS

ASTM designation	Trade designation	Nominal compositions (%)	Conductivity	State
			w/cm deg K	
....	EC	99.45 Al	2.34	Annealed.
A2	2S; British BS 2L	99 Al	2.22	....
			2.18	H 18
		WROUGHT ALLOYS		
MI	3S	1.2 Mn	1.93	O
			1.63	H 12
			1.59	H 14
			1.55	H 18
....	4S	1.2 Mn, 1 Mg	1.63	O
			1.63	H 38
CP 21	11S; British BS 6L1	5.5 Cu, 0.5 Pb, 0.5 Bi.	1.55	T 3
CS 41	14S; British DTD 364.	4.4 Cu, 0.8 Si, 0.8 Mn, 0.4 Mg.	1.93	O
			1.55	T 6
			1.21	T4
CM 21	17S; British BS 6L1	4 Cu, 0.5 Mg, 0.5 Mn.	1.72	O
			1.21	T 4
....	A 17S	2.5 Cu, 0.3 Mg	1.55	T 4
....	18S; British BS 4L25, BS 2L42.	4 Cu, 2 Ni, 0.5 Mg	1.93	O
			1.55	T 61
....	B18S	4 Cu, 1.5 Mg, 2.0 Ni.	1.93	O
			1.72	T 72
CG 21	24S; British BS2L40, DTD 273.	4.5 Cu, 1.5 Mg, 0.6 Mn.	1.88	O
			1.21	T 4
....	25S	4.5 Cu, 0.8 Mn, 0.8 Si.	1.55	T 6
			1.93	O
....	32S	12.5 Si, 1.0 Mg, 0.9 Cu, 0.9 Ni.	1.55	O
			1.38	T 6
....	50S	1.2 Mg	1.93	O
			1.93	H 38
....	C50S	1.3 Mg	1.55	....
....	A 51 S	1.0 Si, 0.6 Mg, 0.25 Cr.	2.09	O
			1.72	T 4
GR 1	52S	2.5 Mg, 0.25 Cr	1.38	O
			1.38	H 38
....	53S	1.3 Mg, 0.7 Si, 0.25 Cr.	1.72	O
			1.55	T 4
....	56S; British DTD 303.	5.2 Mg, 0.1 Mn, 0.1 Cr.	1.17	O
			1.09	H 18
GS 21	61S	1 Mg, 0.6 Si, 0.25 Cu, 0.25 Cr.	1.72	O
			1.55	T 4
....	62S	0.25 Cu, 0.6 Si, 1 Mg.	1.72	O
			1.55	T 4
....	63S	0.4 Cu, 0.7 Mg	1.93	T 42
			2.09	T 5
ZG 42	75S	5.5 Zn, 2.5 Mg, 1.5 Cu, 0.3 Cr, 0.2 Mn.	1.21	T 6
....	R 301	1 Mg, 0.7 Si, 0.5 Mn	1.93	O
			1.21	T 4
			1.55	T 6
....	R 317	4 Cu, 0.5 Mn, 0.5 Mg, Pb, 0.5 Bi.	1.72	O
			1.21	T 4
		CASTING ALLOYS		
S5	13	12 Si	1.55 to 1.21	....
S4	43	5 Si	1.47	....
			1.67	Annealed.
SC 2	85	5 Si, 4 Cu	1.17	....
....	108	4 Cu, 3 Si	1.21	Cast.
			1.47	Annealed.
SC 8	Allcast	5 Si, 3 Cu	1.05	Cast.
			1.17	Relieved.
			1.13	Aged.
			1.38	T 7
SC 1	A108	5.5 Si, 4.5 Cu	1.42	....
....	112	7 Cu, 1.7 Zn	1.17	....
			1.47	Annealed.
CS 22	113	7 Cu, 2 Si, 1.7 Zn	1.17	....
			1.47	Annealed.
CS 22	C113	7 Cu, 3.5 Si	1.09	
CG 1	122	10 Cu, 0.2 Mg	1.59	T 2
			1.30	T 61
			1.34	....

ALUMINUM ALLOYS (Cont'd)
COMPANY AND TRADE MANUALS

ASTM designation	Trade designation	Nominal compositions (%)	Conductivity	State
			w/cm deg K	
SC 41	A 132	12 Si, 2.5 Ni, 1.2 Mg, 0.8 Cu.	1.17	T 551
....	D 132	9 Si, 3.5 Cu, 0.8 Mg, 0.8 Ni.	1.09	T 5
....	138	10 Cu, 4 Si, 0.3 Mg	1.05	....
CN 21	142	4 Cu, 2 Ni, 1.5 Mg	1.67	T 21
			1.34	T 571
			1.51	T 77
			1.30	T 61
C 1	195	4.5 Cu	1.38	T 4
			1.47	T 62
CS 4	B 195	4.5 Cu, 2.5 Si	1.38	T 4
			1.42 to 1.88	T 6
....	212	8 Cu, 1.2 Si	1.17	....
G 1	214; British DTD 165.	3.8 Mg	1.38	....
			1.38	Annealed.
....	A 214	3.8 Mg, 1.8 Zn	1.34	....
....	B 214	3.8 Mg, 1.8 Si	1.47	....
....	F 214	3.8 Mg, 0.5 Si	1.42	....
....	218	8 Mg	0.96	....
....	220	10 Mg	.88	T 4
SC 8	319	6 Si, 3.5 Cu	1.13	....
....	333	9 Si, 3.8 Cu	1.05	F
			1.21	T 5
			1.17	T 6
			1.42	T 7
SC 21	355	5 Si, 1.3 Cu, 0.5 Mg	1.67	T 51
			1.42	T 6
			1.47	T 61
			1.63	T 7
			1.51	Chill T 6.
SG 1	356	7 Si, 0.3 Mg	1.67	T 51
			1.55	T 6
			1.59	T 7
			1.63	Chill T6.
....	360, A360	9.5 Si	1.13 to 1.47	....
....	380, A380	9 Si, 3.5 Cu	0.96 to 1.09	....
....	384	12 Si, 3.8 Cu	0.96	....
....	A612	6.5 Zn, 0.7 Mg, 0.5 Cu.	.96	....
....	C 612	6.5 Zn, 0.5 Cu, 0.4 Mg.	1.59	....
....	750	6.5 Sn, 1 Cu, 1.0 Ni.	1.80	....

TITANIUM ALLOYS

Curve	Composition (%)	Conductivity and Remarks	Reference
		w/cm deg K	
....	2.8 Cr, 1 Fe	Abstract only; $k=0.13$ at 273°K, 0.10 at 195°K, 0.06 at 80°K.	C. J. Rigney and L. I. Bockstahler (1951).
Fig. 29; T.W.-Ti.	Rem-Cru Titanium, RC 130-B; 4.7 Mn, 3.99 Al, 0.14 C.	R, emf	W. W. Tyler and A. C. Wilson (1952).

TUNGSTEN

Composition	Conductivity and remarks	Reference
	w/cm deg K	
"Impure"	Single crystal; $k=1.83$ at 83°K, 1.80 at 21°K.	E. Grüneisen and E. Goens (1927).

CHROMIUM
COMPANY AND TRADE MANUALS

Composition	Conductivity
	w/cm deg K
Commercial......	k=0.67 at 20°C.

IRON

See figures 8 and 9 under "METALLIC ELEMENTS"

STEELS

The tables for steels are arranged into groups where the principal alloying metals are as follows: carbon; silicon; copper, chromium, cobalt, manganese, molybdenum, nickel, tungsten, vanadium; and aluminum.

CARBON STEELS

Composition (%)	Conductivity and remarks	Reference
	w/cm deg K	
0.1 C............	k=0.67 at 18°C; wrought iron............	W. Jaeger and H. Diesselhorst (1900).
1 C..............	k=0.45 at 18°C, wrought iron............	Do.
0.1 C, 0.06 Mn, 0.05 Cu, 0.02 Si, S, 0.03 P.	k=0.72 at 18°C........................	E. Grüneisen (1900).
0.57 C, 0.2 Si, 0.1 Mn, 0.04 S, 0.03 Cu, 0.01 P.	k=0.52 at 18°C........................	Do.
0.99 C, 0.1 Mn, 0.06 Si, 0.03 S, Cu.	k=0.51 at 18°C........................	Do.
1.5 C, 0.2 Mn, 0.05 Si, 0.03 Cu, S, 0.01 P.	k=0.50 at 18°C........................	Do.
1 C; "silver steel"..	See figure 23, curve with initial L..........	C. H. Lees (1908).

CARBON STEELS (Cont'd)

Composition (%)[1]	Conductivity[1]	State[1]
	w/cm deg K	
0.1 C, 0.4 Mn, 0.02 P, 0.02 S............	0.60	....
0.4 C, 0.3 Si, 0.4 Mn, 0.02 P, 0.02 S.......	.44	....
0.7 C, 0.3 Si, 0.2 Mn, 0.03 P, 0.02 S.......	.45	....
0.9 C, 0.3 Si, 0.2 Mn, 0.03 P, 0.02 S.......	.42	....
1.0 C, 0.3 Si, 0.2 Mn, 0.03 P, 0.02 S.......	.42	....
1.2 C, 0.3 Si, 0.2 Mn, 0.03 P, 0.02 S.......	.40	....
1.5 C, 0.2 Si, 0.2 Mn, 0.03 P, 0.02 S.......	.39	....
2.41 C, 0.12 Si, 0.05 Mn, 0.04 P, 0.09 S....	.32	As cast.
	.33	Annealed 1,000°C, 2 hr.
	.33	6 hr.
	.33	8 hr.

CARBON STEELS (Cont'd)

Composition (%)[1]	Conductivity[1]	State[1]
	w/cm deg K	
2.53 C, 0.05 Si, 0.02 Mn, 0.01 P, 0.03 S....	.31	As cast.
2.67 C, 0.11 Si, 0.02 Mn, 0.03 P, 0.05 S....	.30	Do.
	.32	1,000°C annealed, 2 hr.
	.32	6 hr.
	.32	8 hr.
3.12 C, 0.06 Si, 0.05 Mn, 0.02 P, 0.06 S....	.26	As cast.
3.14 C, 0.01 Si, 0.03 Mn, 0.02 P, 0.03 S....	.26	Do.
3.17 C, 0.21 Si, 0.08 Mn, 0.04 P, 0.06 S....	.25	Do.
	.26	Annealed 1,000°C, 2 hr.
	.26	6 hr.
	.27	8 hr.
3.53 C, 0.04 Si, 0.05 Mn, 0.01 P, 0.05 S....	.23	As cast.
3.64 C, 0.16 Si, 0.04 Mn, 0.02 P, 0.02 S....	.21	Do.
	.23	Annealed 1,000°C, 2 hr.
	.23	6 hr.
	.23	8 hr.
3.93 C, 0.15 Si, 0.04 Mn, 0.02 P, 0.05 S....	.20	As cast.
3.96 C, 0.2 Si, 0.06 Mn, 0.01 P, 0.02 S.....	.19	As cast.
	.21	Annealed 1,000°C, 2 hr.
	.26	6 hr.
	.50	8 hr.
4.13 C, 0.10 Si, 0.03 Mn, 0.02 P, 0.02 S....	.18	As cast.
	.20	Annealed 1,000°C, 2 hr.
4.26 C, 0.10 Si, 0.03 Mn, 0.02 P, 0.02 S....	.17	As cast.
	.19	Annealed 1,000°C, 2 hr.
4.35 C, 0.35 Si, 0.08 Mn, 0.02 P, 0.02 S....	.15	As cast.
	.57	Annealed 1,000°C, 2 hr.
4.40 C, 0.34 Si, 0.03 Mn, 0.02 P, 0.08 S....	.15	As cast.
	.17	Annealed 1,000°C, 2 hr.
4.61 C, 0.37 Si, 0.03 Mn, 0.02 P, 0.04 S....	.13	As cast.
	.15	Annealed 1,000°C, 2 hr
4.63 C, 0.54 Si, 0.08 Mn, 0.02 P, 0.07 S....	.13	As cast.
	.56	Annealed 1,000°C, 2 hr.
3.82 C, 1.24 Si, 0.09 Mn, 0.01 P, 0.06 S....	.13	As cast.
	.20	Annealed 800°C, 1 hr.
3.81 C, 1.96 Si, 0.05 Mn, 0.05 S...........	.13	As cast.
	.35	Annealed 800°C, 1 hr.
	.40	Add. annealed 1,000°C 1 hr.
3.84 C, 1.98 Si, 0.06 Mn, 0.01 S...........	.43	As cast.
	.52	Annealed 800°C, 1 hr.

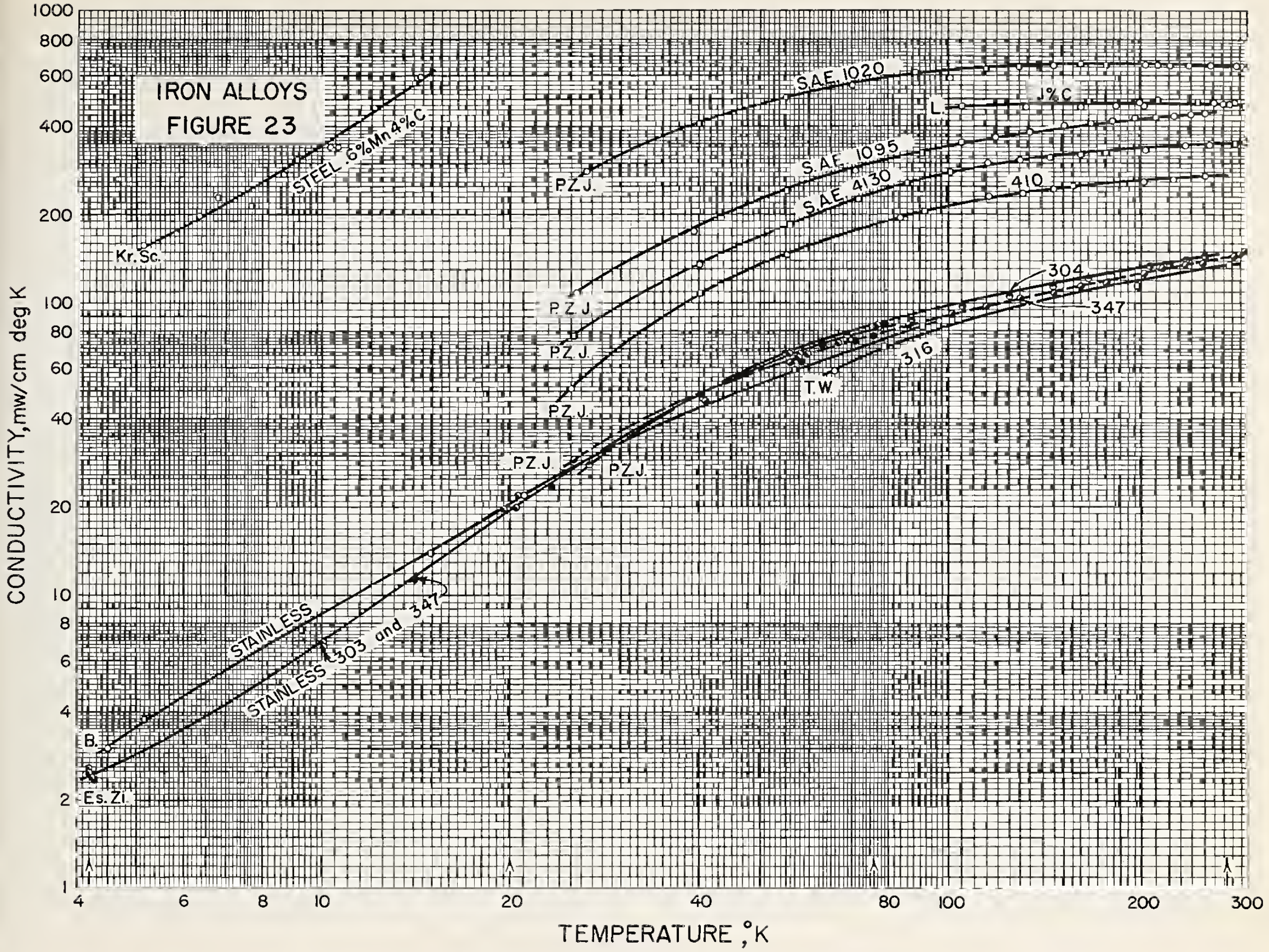
[1] Results by H. Masumoto (1927) at 25°C.

CARBON STEELS (Cont'd)

Curve	Composition (%)	Remarks	Reference
Fig. 24; Mild..	0.14 C, 0.08 Si, 0.07 Mn...	"Mild steel"; heated to 800°C and furnace-cooled.	J. de Nohel (1951).
Fig. 23; P. Z. J.- SAE 1020.	0.33 Mn, 0.18 C, 0.014 Si..	....	R. W. Powers, J. B. Ziegler, H. L. Johnston (1951a).
Fig. 23; P. Z. J.- SAE 1095.	0.93 C, 0.34 Mn, 0.26 Si, 0.1 Ni, Cr, 0.05 Mo.	....	Do.

CARBON STEELS (Cont'd)
COMPANY AND TRADE MANUALS

Composition (%)	Conductivity
	w/cm deg K
0.08 C, 0.045 Cr, 0.07 Ni, 0.31 Mn, 0.02 Mo....................	0.59
0.23 C, trace Cr, 0.074 Ni, 0.635 Mn, 0.13 Cu..................	.52
0.415 C, traee Cr, 0.063 Ni, 0.643 Mn, 0.12 Cu.................	.52
0.80 C, 0.11 Cr, 0.13 Ni, 0.32 Mn, 0.07 Cu, 0.01 Mo............	.49
1.22 C, 0.11 Cr, 0.13 Ni, 0.35 Mn, 0.01 Mo, 0.08 Cu............	.45



Specific references can be found under the type of steel.

SILICON STEELS

Composition (%)	Conductivity and remarks	Reference
	w/cm deg K	
0.2 Si, 0.1 C, 0.1 Mn, trace of P, S, and Cu.	k=0.60 at 18°C..........	W. Jaeger and H. Diesselhorst (1900).

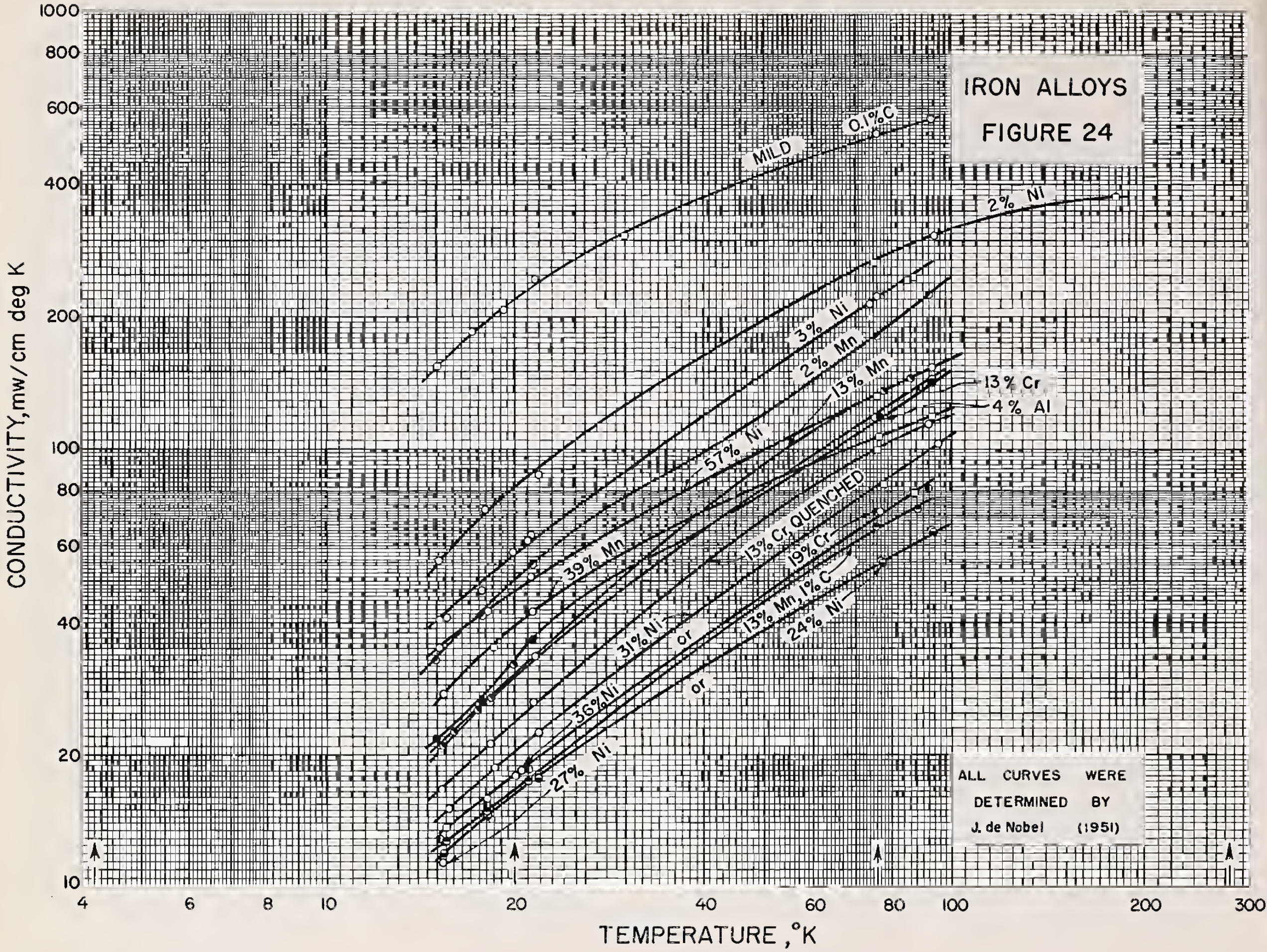
CORROSION RESISTING STEELS

(Copper, chromium, cobalt, manganese, molybdenum, nickel, tungsten, and vanadium)

Curve	Composition (%)	Remarks	Reference
Fig. 23; Kr. Sc.	0.6 Mn, 0.4 C, 0.3 Si, 0.03 S, 0.3 P.	....	J. Karweil and K. Schāfer (1939).
....	"Stainless"..........	k=7 mw/cm deg K at 10°K, 11 at 15° K, 15 at 20°K.	K. R. Wilkinson and J. Wilks (1949).

CORROSION RESISTING STEELS (Cont'd)

Curve	Composition (%)	Remarks	Reference
Fig. 24; 2% Ni.	1.92 Ni, 0.72 Mn, 0.21 Si, 0.14 C.	Heated to 800°C and furnace-cooled.	J. de Nobel (1951).
24% Ni......	24.30 Ni, 6.05 Mn, 1.18 C..	Heated to 1,050°C and water-quenehed.	Do.
27% Ni......	27.30 Ni, 14.6 Cr, 3.5 W, 1.62 Si, 1.34 Mn, 0.44 C.	Heated to 1,000°C and water-quenched, "era/ATV".	Do.
31% Ni......	31.4 Ni, 0.82 Mn, 0.7 C...	Heated to 800°C and furnace-cooled.	Do. Do.
36% Ni......	36.17 Ni, 0.92 Mn, 0.16 C, 0.09 Si.	Heated to 1,050°C and water-quenched.	Do.
57% Ni......	57.5 Ni, 1.31 Mn, 0.34 C, 0.14 Si.	As forged; "A.M.F.".	Do.
2% Mn......	2.23 Mn, 0.41 C, 0.07 Si...	Heated to 800°C and furnace-cooled.	Do.
13% Mn, 1% C.	12.69 Mn, 1.27 C, 0.12 Si..	Heated to 2,000°C and water-quenched, "manganese steel".	Do. Do.
13% Mn.....	12.95 Mn, 0.10 S, 0.12 Si, 0.09 C, 0.05 P.	Heated to 1,000°C and water-quenched.	Do.
39% Mn.....	38.9 Mn, 0.7 Si, 0.2 C, 0.06 S, 0.04 P.	.....do............	Do.



Specific references can be found under the type of steel.

CORROSION RESISTING STEELS (Cont'd)

Curve	Composition (%)	Remarks	Reference
13% Cr......	13.5 Cr, 0.36 C, 0.22 Si, 0.13 Mn.	Heated to 800°C and furnace-cooled.	J. de Nobel (1951).
13% Cr, quenched.	.....do..................	Heated to 950°C, oil quenched, reheated to 450°C, air-cooled.	Do. Do.
19% Cr......	18.8 Cr, 8.1 Ni, 0.43 Si, 0.24 Mn, 9.12 C.	Heated to 1,150°C and water-quenched.	Do.
3% Ni.......	2.61 Ni, 0.75 Mo, 0.49 Cr, 0.45 Mn, 0.27 C, 0.11 Si, 0.03 P, 0.01 S.	Heated to 850°C, oil-quenched, reheated to 650°C, water-quenched.	Do.
Fig. 23; P.Z.J.-SAE 4130.	0.99 Cr, 0.52 Mn, 0.33 C, 0.2 Si, Ni, and Mo each.	....	R. W. Powers, J. B. Ziegler, and H. L. Johnston (1951a).
P. Z. J.-410...	12.6 Cr, 0.36 Si, 0.32 Mn, 0.12 Ni, 0.09 C, 0.06 Cu, 0.03 N, 0.01 P.	....	Do.

CORROSION RESISTING STEELS (Cont'd)

Curve	Composition (%)	Remarks	Reference
P.Z.J.-347....	17.88 Cr, 10.28 Ni, 1.24 Mn, 0.85 Nb, 0.57 Si, 0.26 Cu, 0.06 C, 0.03 N, 0.02 P.	....	R. W. Powers, J. B. Ziegler, and H. L. Johnston (1951a).
P. Z. J.-304...	18.68 Cr, 8.84 Ni, 1.12 Mn, 0.43 Si, 0.06 Cu, 0.05 C, 0.03 N, 0.02 P.	....	Do.
Fig. 23; B.-Stainless.	7.9 Ni, 18.9 Cr, 1 Ti, 0.7 Si, 0.1 C.	Austenite grains about 0.01 mm across.	R. Berman (1951b).
Fig. 23; Es. Zi.-303.	18 Cr, 9 Ni, 0.15 C.......	....	I. Estermann and J. E. Zimmerman (1952).
Es. Zi.-347....	18 Cr, 10 Ni, 0.5 Nb, 0.08 C.	....	Do.
T.W.-316.....	17 Cr, 12 Ni, 2.5 Mo, 0.1 C.	25% cold reduction..	W. W. Tyler and A. C. Wilson (1952).

CORROSION RESISTING STEELS (Cont'd)
COMPANY AND TRADE MANUALS

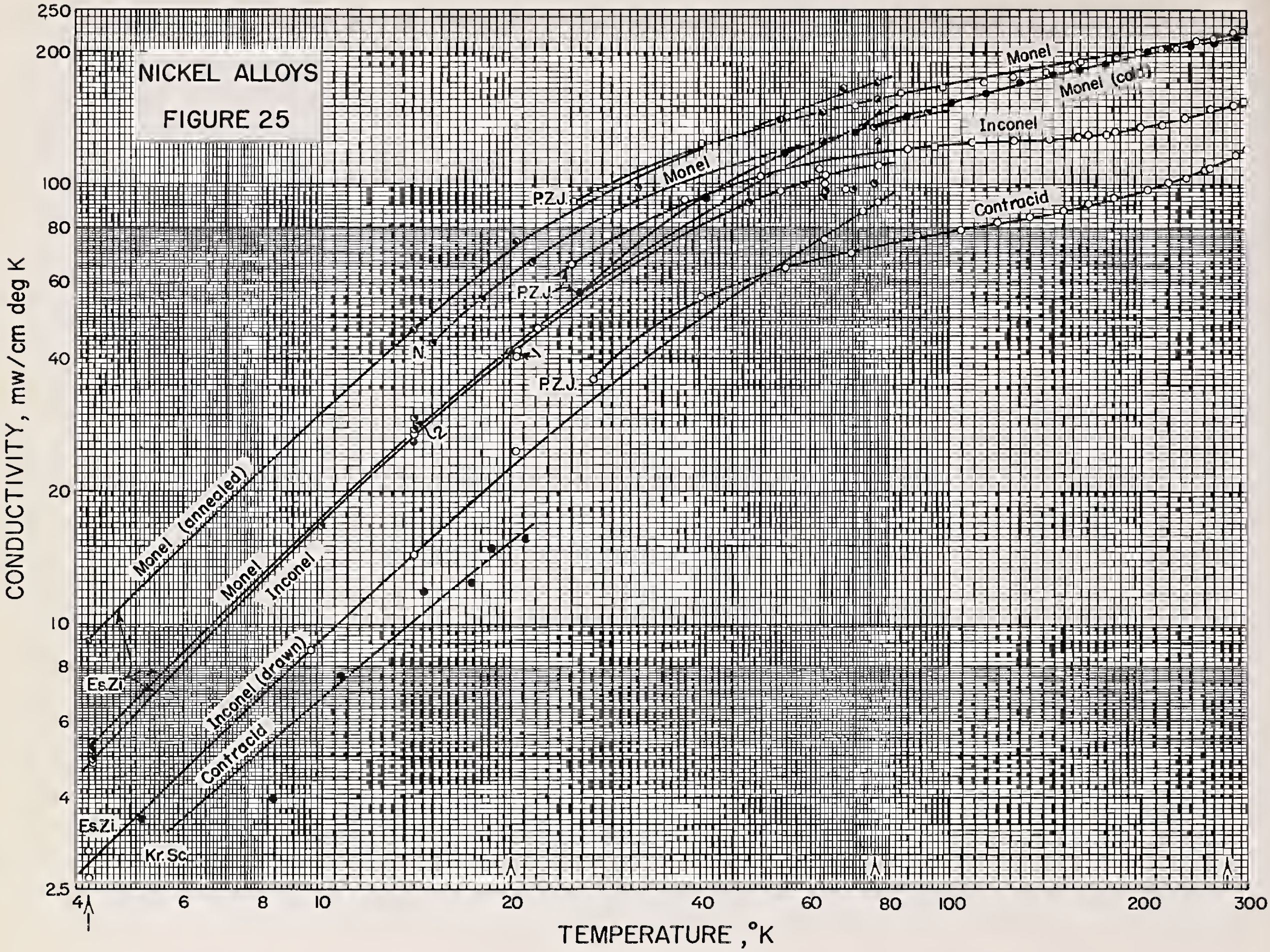
AISI No.	Nominal composition (%)	Conductivity
		w/cm deg K
....	0.08 C, .045 Cr, .07 Ni, .31 Mn, .02 Mo	0.59
....	0.23 C, trace Cr, .074 Ni, .635 Mn, .13 Cu	.52
....	0.415 C, trace Cr, .063 Ni, .643 Mn, .12 Cu	.52
....	0.325 C, .17 Cr, 3.47 Ni, 0.55 Mn, .09 Cu, .04 Mo	.37
....	0.34 C, 0.78 Cr, 3.53 Ni, 0.55 Mn, .39 Mo, .05 Cu	.33
....	0.315 C, 1.09 Cr, 0.073 Ni, .69 Mn, .012 Mo, .07 Cu	.48
....	0.35 C, .88 Cr, .26 Ni, .59 Mn, .2 Mo, .12 Cu	.43
....	5 Cr, 0.5 Mo	.37
....	1.22 C, 0.03 Cr, .07 Ni, 13.0 Mn, 0.22 Si, .07 Cu	.13
....	0.28 C, trace Cr, 28.37 Ni, 0.89 Mn,.15 Si, .03 Cu	.13
....	0.08 C, 19.11 Cr, 8.14 Ni, 0.37 Mn, .68 Si, .6 W, .03 Cu.	.16
....	0.13 C, 12.95 Cr, 0.14 Ni, .25 Mn, .17 Si, .06 Cu, .01 V.	.27
....	0.27 C, 13.69 Cr, 0.21 Ni, .28 Mn, .25 W, .02 V	.26
....	0.715 C, 4.26 Cr, 0.067 Ni, .25 Mn, 18.45 W, 1.08 V	.25
302	0.14 C, 18 Cr, 9 Ni, 2 Mn	.22
303	0.15 C, 18 Cr, 9 Ni, 0.07 P, S, Se each, .6 Zr, Mo each	.22
309	0.20 C, 23 Cr, 13 Ni, 2 Mn	.19
410	0.15 C, 12.5 Cr	.40
416	0.15 C, 13 Cr, 0.07 P, S, Se each, .6 Zr, Mo each	.40
420	0.15 C or more, 13 Cr	.33
430	0.12 C, 16 Cr	.30
440	0.7 C, 17 Cr, 0.75 Mo	.25
....	15 Cr, 35 Ni	.13

DEOXIDIZED STEELS
(Aluminum)

Curve	Composition (%)	Remarks	Reference
Fig. 24; 4% Al.	4.11 Al, 0.13 Si, 0.08 Mn, 0.03 C, 0.01 S.	Heated to 800°C and furnace-cooled.	J. de Nobel (1951).

NICKEL ALLOYS
COMPANY AND TRADE MANUALS

Trade Designation	Nominal composition (%)	Conductivity
		w/cm deg K
A Nickel	99.4 Ni+Co, 0.2 Mn, .15 Fe, .1 Cu, .1 C	0.61
D Nickel	95 Ni, 4.5 Mn	.48
Monel	67 Ni, 30 Cu, 1.4 Fe, 1 Mn, 0.15 C, .1 Si	.26
K Monel	66 Ni, 29 Cu, 2.75 Al, 0.9 Fe, .75 Mn, .5 Si, .15 C	.19
Hastelloy A	57 Ni, 20 Mo, 20 Fe	.17
Hastelloy B	62 Ni, 30 Mo, 5 Fe	.11
Hastelloy C	58 Ni, 17 Mo, 15 Cr, 5 W, 5 Fe	.13
Hastelloy D	85 Ni, 10 Si, 3 Cu	.21
Inconel	80 Ni, 14 Cr, 6 Fe	.15
Illium G	58 Ni, 22 Cr, 6 Cu, Mo, Fe each	.12
....	80 Ni, 20 Cr	.56
....	60 Ni, 24 Fe, 16 Cr	.14
....	35 Ni, 50 Fe, 15 Cr	.13
Constantan	45 Ni, 55 Cu	.23

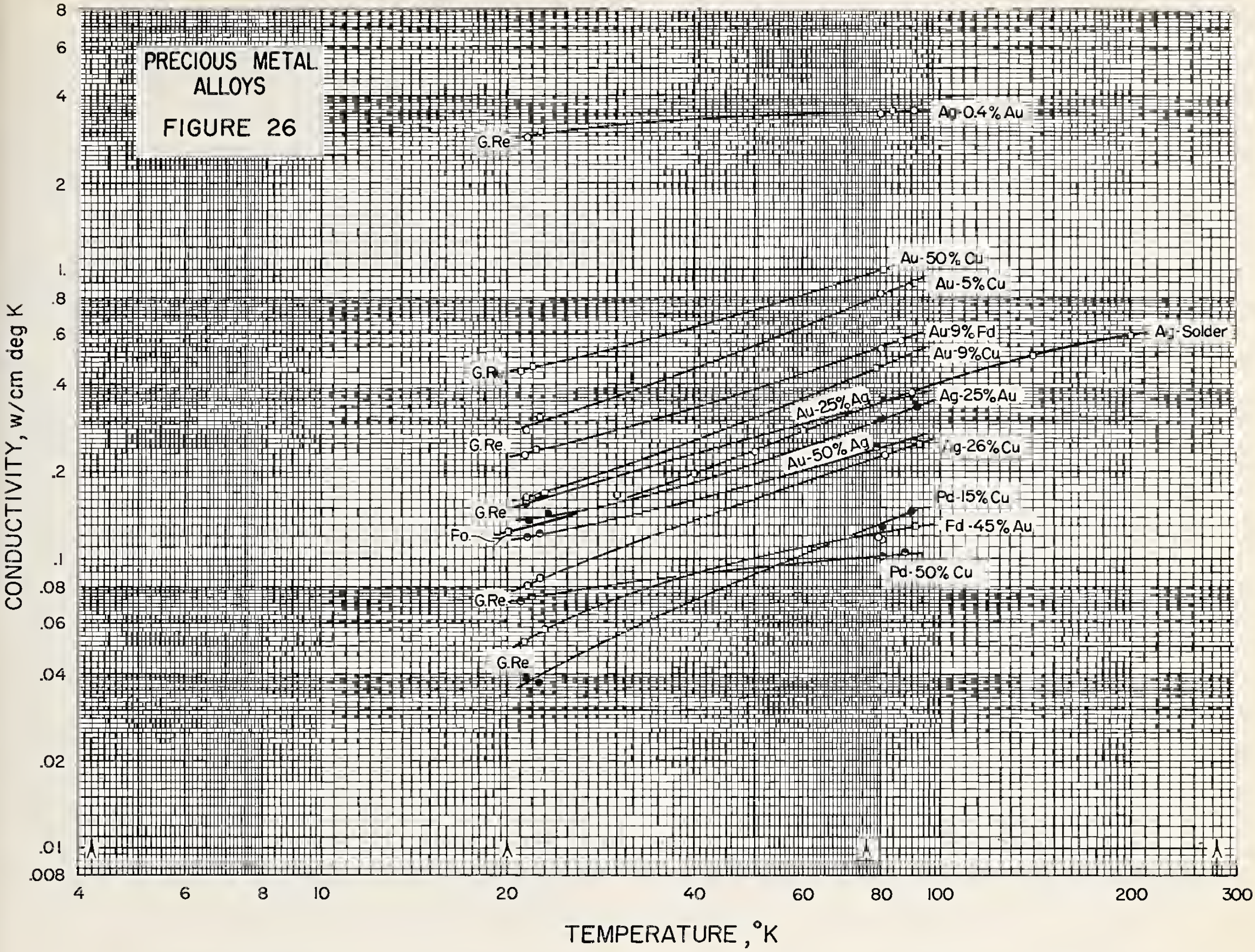


NICKEL ALLOYS (Cont'd)

Curve	Composition (%)	Conductivity and remarks	Reference
		w/cm deg K	
....	97.0 Ni, 1.4 Co, 1 Mn, 0.4 Fe.	k=0.59 at 18°C.....	W. Jaeger and H. Diesselhorst (1900).
....	80 Ni, 20 Cr; "nichrome"..	k=0.31 above room temperature.	R. Kikuchi (1932).
....	70 Ni, 18 Cr, 12 Fe.......	k=0.28 above room temperature.	Do.
Fig. 25; Kr. Sc.-Contracid.	60 Ni, 15 Cr, 16 Fe, 7 Mo..	....	J. Karweil and K. Schäfer (1939).
P.Z.J.-Inconel.	80 Ni, 14 Cr, 6 Fe........	....	R. W. Powers, J. B. Ziegler, and H. L. Johnston (1951c).
P.Z.J.-Contracid.	60.05 Ni, 14.74 Cr, 15.82 Fe, 7.2 Mo, 2.14 Mn, 0.05 C.	....	Do.
P. Z. J. Monel.	67 Ni, 30 Cu, 1.4 Fe, 1.0 Mn, 0.15 C, .1 Si, .01 S.	Hot-rolled.........	Do.
P.Z.J.-Monel, cold.	.....do..................	Cold-rolled........	Do.

NICKEL ALLOYS (Cont'd)

Curve	Composition (%)	Conductivity and remarks	Reference
		w/cm deg K	
....	Commercial; 99.4 Ni......	See Fig. 8 and Nickel Table under "Metallic Elements".	J. de Nobel (1951).
N.-Monel.....	67 Ni, 30.2 Cu...........	As forged...........	Do.
Fig. 24; 57% Ni.	57.5 Ni, 1.31 Mn, 0.34 C, .14 Si; remainder Fe, approx. 40.	As forged...........	Do.
Fig. 25; Es. Zi.-Inconel (drawn).	Inconel..................	Hard-drawn.........	I. Estermann and J. E. Zimmerman (1952).
Es. Zi.-Inconel, #1.	.....do..................	Annealed...........	Do.
Es. Zi.-Inconel, #2.	.....do..................	Hot-rolled..........	Do.
Es.Zi.-Monel.	Monel....................	Hard-drawn.........	Do.
Es.Zi.-Monel, (annealed).	Monel....................	Annealed...........	Do.



PRECIOUS METAL ALLOYS

See also the tables given under "SILVER ALLOYS" and "GOLD ALLOYS".

PALLADIUM ALLOYS

Composition (%)	Conductivity and remarks	Reference
	w/cm deg K	
90 Pd, 10 Ag	k=0.48 at 25°C	F. A. Schulze (1911).
80 Pd, 20 Ag	k=0.37 at 25°C	Do.
70 Pd, 30 Ag	k=0.32 at 25°C	Do.
60 Pd, 40 Ag	k=0.27 at 25°C	Do.
50 Pd, 50 Ag	k=0.32 at 25°C	Do.
90 Pd, 10 Au	k=0.52 at 25°C	Do.
80 Pd, 20 Au	k=0.42 at 25°C	Do.
70 Pd, 30 Au	k=0.40 at 25°C	Do.
60 Pd, 40 Au	k=0.36 at 25°C	Do.
50 Pd, 50 Au	k=0.36 at 25°C	Do.
90 Pd, 10 Pt	k=0.56 at 25°C	Do.
80 Pd, 20 Pt	k=0.44 at 25°C	Do.
70 Pd, 30 Pt	k=0.40 at 25°C	Do.
60 Pd, 40 Pt	k=0.38 at 25°C	Do.
50 Pd, 50 Pt	k=0.37 at 25°C	Do.

PALLADIUM ALLOYS (Cont'd)

Composition (%)	Conductivity and remarks	Reference
	w/cm deg K	
Commercial	k=0.42 at 17°C	T. Barratt and R. M. Winter (1925).
85.5 Pd, 14.5 Cu	Polycrystalline; see Fig. 26, "Pd-15% Cu"	E. Grüneisen and H. Reddemann (1934).
50 Pd, 50 Cu	Annealed; see Fig. 26, "Pd-50% Cu"	Do.
55 Pd, 45 Au	Annealed 2 hr. at 800°C; see Fig. 26, "Pd-45% Au".	Do.

PLATINUM ALLOYS

Composition (%)	Conductivity and remarks	Reference
"Impure"	k=0.516 at 18°C	W. Jaeger and H. Diesselhorst (1900).
90 Pt, 10 Pd	k=0.43 at 25°C	F. A. Schulze (1911).
80 Pt, 20 Pd	k=0.42 at 25°C	Do.
70 Pt, 30 Pd	k=0.36 at 25°C	Do.
60 Pt, 40 Pd	k=0.34 at 25°C	Do.
50 Pt, 50 Pd	k=0.37 at 25°C	Do.

PLATINUM ALLOYS (Cont'd)

Composition (%)	Conductivity and remarks	Reference
	w/cm deg K	
90 Pt, 10 Ir	k=0.31 at 17°C	T. Barratt and R. M. Winter (1925).
85 Pt, 15 Ir	k=0.23 at 17°C	Do.
80 Pt, 20 Ir	k=0.18 at 17°C	Do.
90 Pt, 10 Rh	k=0.30 at 17°C	Do.
96 atomic % Pt, 4 atomic % Au.	k=0.46 at 18°C	C. H. Johansson and J. O. Linde (1930).
90 atomic % Pt, 10 atomic % Au.	k=0.35 at 18°C	Do.
75 atomic % Pt, 25 atomic % Au.	k=0.24 at 18°C	Do.
55 atomic % Pt, 45 atomic % Au.	k=0.21 at 18°C	Do.

COPPER ALLOYS

See also the "COPPER-NICKEL ALLOY" graph and and tables.

Curve	Composition (%)	Conductivity and remarks	Reference
		w/cm deg K	
	About 62 Cu, 15 Ni, 22 Zn.	"Neusilber"; k=0.29 at 0°C.	L. Lorenz (1881).
	About 82 Cu, 18 Zn	"Red brass"; k=1.03 at 0°C.	Do.
	About 65 Cu, 35 Zn	"Yellow brass"; k=0.85 at 0°C.	Do.
	0.34 P	k=0.95 at 15°C	A. Rietzsch (1900).
	0.87 P	k=0.61 at 15°C	Do.
	1.79 P	k=0.53 at 15°C	Do.
	2.08 P	k=0.34 at 15°C	Do.
	2.35 P	k=0.27 at 15°C	Do.
	5.25 P	k=0.15 at 15°C	Do.
	1.04 As	k=1.14 at 15°C	Do.
	1.80 As	k=0.82 at 15°C	Do.
	2.66 As	k=0.54 at 15°C	Do.
	3.00 As	k=0.54 at 15°C	Do.
	5.02 As	k=0.20 at 15°C	Do.
	85.7 Cu, 7.15 Zn, 6.39 Sn, 0.6 Ni.	"Red brass"; k=0.60 at 18°C.	W. Jaeger and H. Diesselhorst (1900).
	84 Cu, 12 Mn, 4 Ni	k=0.22 at 18°C	Do.
Fig. 27; L.-Brass.	70 Cu, 30 Zn		C. H. Lees (1908).
Fig. 27; L.-Ger. silv.	62 Cu, 22 Zn, 15 Ni	"German silver"	Do.
L.-Plat.	Approx. same as above.	"Platinoid"	Do.
L.-Manganin.	84 Cu, 12 Mn, 4 Ni	"Manganine"	Do.
	82 Cu, 18 Zn	"Red brass"; "fine" crystals; k=1.27 at 273°K, 0.66 at 90°K.	A. Eucken and O. Neumann (1924).
	do	"Red brass"; "large" crystals; k=1.30 at 273°K, 0.65 at 90°K.	Do.

COPPER ALLOYS (Cont'd)

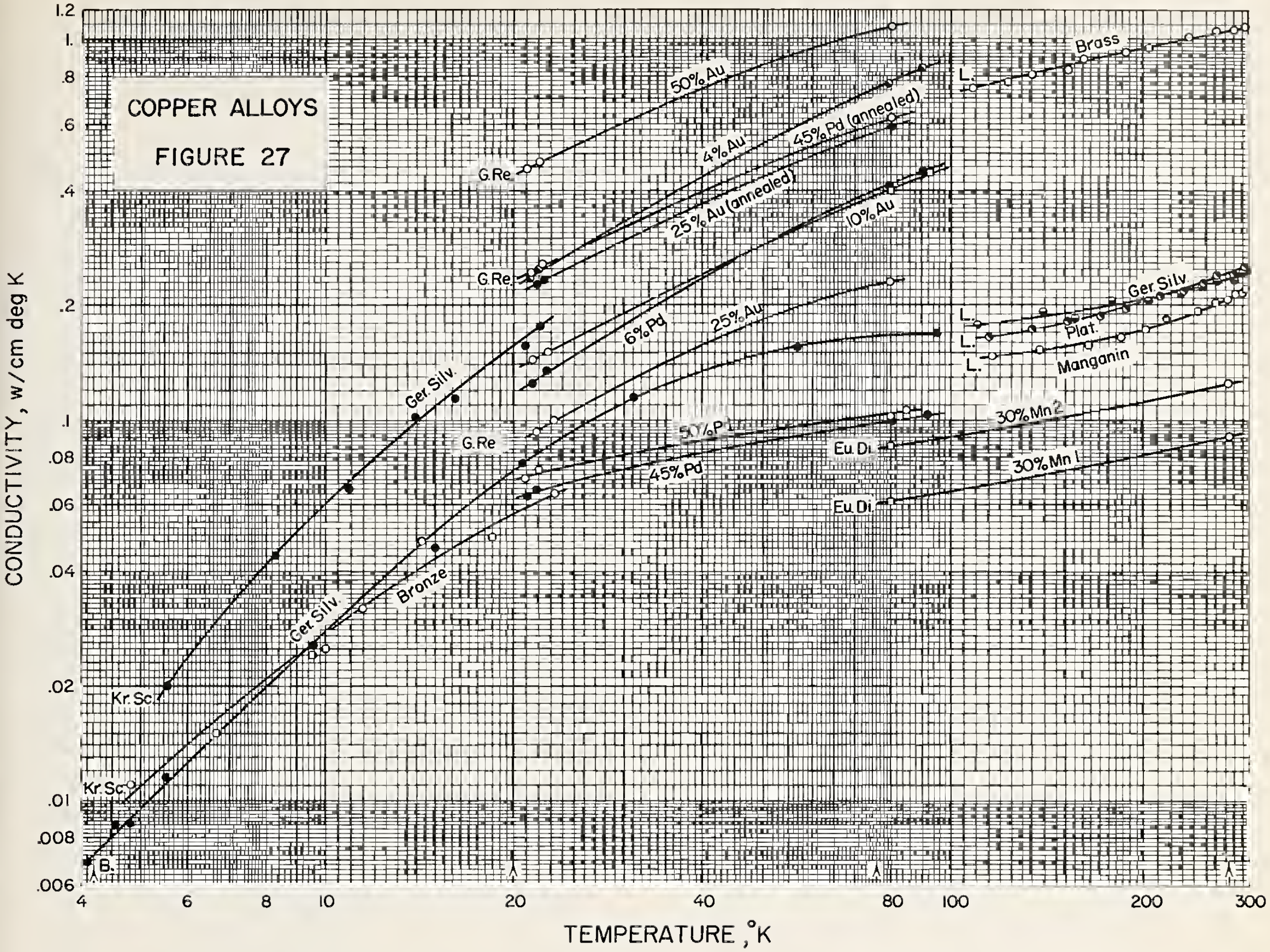
Curve	Composition (%)	Conductivity and remarks	Reference
		w/cm deg K	
Eu. Di.-Cu-50% Mn, 1.	70 Cu, 30 Mn	About 48 crystals per centimeter.	A. Eucken and K. Dittrich (1927).
Eu. Di.-Cu-50% Mn, 2.	do	About 112 crystals per centimeter.	Do.
	3 Ag	Unannealed; k=3.57 at 83° and 21°K.	E. Grüneisen and E. Goens (1927).
	do	Annealed 3 hr at 390°C; k=4.06 at 83°K, 6.19 at 21°K.	Do.
Fig. 27; G. Re.-4% Au.	95.5 Cu, 4.5 Au	Polycrystalline; unannealed.	E. Grüneisen and H. Reddemann (1934).
G. Re.-10% Au.	90.3 Cu, 9.7 Au	Polycrystalline; unannealed.	Do.
	75.1 Cu, 24.9 Au	Quenched from 800°C; k=0.34 at 83°K.	Do.
	do	Annealed 20 hr at 400°C; k=0.61 at 83°K.	Do.
	do	Annealed 32 hr at 360°C; k=0.63 at 83°K.	Do.
	do	Same as above except later annealed 2 hr at 820°C, then quenched; k=0.23 at 83°K.	Do.
G. Re.-25% Au.	do	Same as above except later annealed 5 months at room temperature.	Do.
G. Re.-25% Au, annealed.	do	Same as above except additionally annealed 30 hr at 320°C.	Do.
G. Re.-Cu-50% Au.	49.9 Cu, 50.1 Au	Annealed 30 hr at 320°C	Do.
G. Re.-Cu-50% Pd.	49.9 Cu, 50.1 Pd	Annealed	Do.
G. Re.-6% Pd.	93.6 Cu, 6.4 Pd	Polycrystalline; unannealed.	Do.
	55 Cu, 45 Pd	Annealed; k=0.67 at 83°K.	Do.
G. Re.-45% Pd.	do	Annealed 2 hr at 800°C	Do.
G. Re.-45% Pd, (annealed).	do	Further annealed 30 hr at 320°C.	Do.

COPPER ALLOYS (Cont'd)

Composition (%) [1]	Conductivity [1]
	w/cm deg K
99.986 Cu, 0.0016 Fe, .02 O_2	3.93 [2]
99.80 Cu, 0.19 Si, .02 Fe	2.13 [2]
99.78 Cu, 0.23 Si, .02 Fe	1.92 [2]
99.65 Cu, 0.32 Si, .032 Fe	1.65 [2]
99.53 Cu, 0.45 Si, .03 Fe	1.29 [2]
99.06 Cu, 1.00 Si, 0.03 Fe	0.82 [2]
98.09 Cu, 1.98 Si, 0.05 Fe	0.51 [2]
96.00 Cu, 3.91 Si, 0.02 Fe	0.34 [2]

[1] These values were determined by C. S. Smith (1935) at 20°C. Sometimes the composition percentages add up to more than 100.

[2] The copper-silicon alloys were hot-rolled, cold-drawn and annealed at 700°C and were in the homogeneous α solid solution.



COPPER ALLOYS (Cont'd)

Composition (%) [1]	Conductivity [1]
	w/cm deg K
99.95 Cu, 0.07 Al, .01 Fe	3.52 [2]
99.77 Cu, 0.22 Al, .01 Fe	2.91 [2]
99.47 Cu, 0.47 Al, .02 Fe	2.35 [2]
99.20 Cu, 0.71 Al, .09 Fe	1.75 [2]
98.08 Cu, 1.89 Al, 0.03 Fe	1.23 [2]
95.25 Cu, 4.61 Al, 0.14 Fe	0.83 [2]
92.15 Cu, 7.72 Al, 0.13 Fe	0.72 [2]
90.56 Cu, 9.37 Al, 0.07 Fe	0.65 [2]
89.88 Cu, 9.90 Al, 0.22 Fe	0.66 [2]
87.76 Cu, 12.15 Al, 0.09 Fe	0.54 [2]
99.94 Cu, 0.07 Mn, .01 Fe, .02 Mg	3.62 [3]
99.88 Cu, 0.14 Mn, .01 Fe, .01 Mg	3.28 [3]
99.55 Cu, 0.43 Mn, .01 Fe, .01 Mg	2.26 [3]
99.05 Cu, 1.05 Mn, 0.01 Fe, .01 Mg	1.50 [3]
98.27 Cu, 1.77 Mn, 0.03 Fe, .01 Mg	1.02 [3]
95.34 Cu, 4.55 Mn, 0.06 Fe, .02 Mg	0.49 [3]
90.25 Cu, 9.53 Mn, 0.18 Fe, .02 Mg, .021 C	0.26 [3]
80.03 Cu, 19.82 Mn, 0.09 Fe, .02 Mg, .035 C	0.15 [3]

[1] These values were determined by C. S. Smith (1935) at 20°C. Sometimes the composition percentages add up to more than 100.

[2] The copper-aluminum alloys were rolled and annealed at 700°C and were in the α solid solution (except the 12% Al, which was δ).

[3] The copper-manganese alloys were deoxidized with magnesium, hot-rolled, and annealed at 700°C.

COPPER ALLOYS (Cont'd)

Composition (%) [1]	Conductivity [1]	State [1]
	w/cm deg K	
99.986 Cu, 0.002 Fe, .02 O_2	3.94 [2]	
66.24 Cu, 33.72 Zn, 0.03 Pb, .01 Fe, .001 S	1.20 [2]	
96.94 Cu, 3.04 Zn, 0.02 Fe	2.68 [2]	
95.21 Cu, 4.77 Zn, 0.02 Fe	2.42 [2]	
97.49 Cu, 0.06 Fe, .27 Ni, 2.24 Be	0.86 [2]	Quenched.
97.49 Cu, 0.06 Fe, .27 Ni, 2.24 Be	1.03 [2]	Reheated.
97.49 Cu, 0.06 Fe, .27 Ni, 2.24 Be	0.74 [2]	Quenched, cold-drawn.
97.49 Cu, 0.06 Fe, .27 Ni, 2.24 Be	0.82 [2]	Reheated.
85.10 Cu, 12.97 Zn, 1.88 Pb, 0.05 Fe	1.60 [2]	
61.85 Cu, 34.79 Zn, 3.29 Pb, 0.07 Fe	1.08 [2]	
65.99 Cu, 29.18 Zn, 4.02 Pb, 0.01 Fe	1.11 [2]	
88.07 Cu, 3.70 Zn, 3.77 Sn, 3.83 Pb, 0.03 Fe	0.90 [2]	
88.08 Cu, 4.09 Zn, 3.76 Sn, 3.80 Pb, 0.02 Fe, .25 P	0.56 [2]	
60.41 Cu, 37.09 Zn, 1.03 Sn, 1.12 Pb, 0.02 Fe, .18 Al, .21 Si.	1.00 [2]	Chill-cast.
56.01 Cu, 25.93 Zn, 0.18 mn, 17.95 Ni, 0.08 Fe, .02 C.	0.30 [2]	
63.76 Cu, 19.79 Zn, 0.18 Mn, 16.29 Ni, 0.14 Fe	.34 [2]	
65.51 Cu, 23.86 Zn, 0.18 Mn, 10.36 Ni, 0.08 Fe, .01 C.	.46 [2]	
59.76 Cu, 29.88 Zn, 0.15 Mn, 10.13 Ni, 0.04 Fe, .04 Mg.	.42 [2]	
64.04 Cu, 30.50 Zn, 5.41 Ni, 0.05 Fe	.59 [2]	

[1] These values were determined by C. S. Smith (1935) at 20°C. Sometimes the composition percentages add up to more than 100.

[2] The miscellaneous alloys were extensively worked, annealed, and slowly cooled except where noted.

COPPER ALLOYS (Cont'd)

Composition (%) [1]	Conductivity [1]	State [1]
	w/cm deg K	
56.57 Cu, 17.65 Zn, 13.24 Ni, 0.10 Fe, 2.23 Sn, 10.44 Pb.	.31 [2]	Sand-cast.
89.08 Cu, 4.98 Ni, 0.08 Fe, 5.11 Al, 0.74 Si	.45 [2]	Quenched.
89.08 Cu, 4.98 Ni, 0.08 Fe, 5.11 Al, 0.74 Si	.57 [2]	Reheated.
89.08 Cu, 4.98 Ni, 0.08 Fe, 5.11 Al, 0.74 Si	.66 [2]	Furnace-cooled.
56.13 Cu, 42.34 Zn, 1.02 Ni, 0.49 Fe	1.14 [2]	
89.38 Cu, 0.31 Ni, 0.52 Fe, .38 Sn, 9.41 Al	0.60 [2]	
75.79 Cu, 22.22 Zn, 0.01 Fe, 1.98 Al	1.00 [2]	
59.35 Cu, 38.36 Zn, 0.12 Mn, 1.06 Fe, 0.98 Sn, .13 Pb.	1.01 [2]	
99.654 Cu, 0.03 Fe, .32 Si	1.65 [2]	
95.61 Cu, 4.51 Mn, 0.11 Fe	0.46 [2]	
99.21 Cu, 0.01 Fe, .01 Si, .85 Cd	3.45 [2]	
98.41 Cu, 0.02 Fe, .59 Sn, .02 Si, 1.07 Cd	2.33 [2]	
72.49 Cu, 17.76 Zn, 3.34 Mn, 1.78 Fe, 4.44 Al	0.50 [2]	
94.00 Cu, 1.03 Mn, 0.08 Fe, 4.68 Si	0.25 [2]	Sand-cast.
95.69 Cu, 0.99 Mn, 0.16 Fe, 3.23 Si	0.33 [2]	
98.10 Cu, 0.30 Mn, 0.06 Fe, 1.50 Si	0.54 [2]	
81.55 Cu, 14.21 Zn, 0.20 Mn, 0.04 Fe, 4.00 Si	0.28 [2]	Chill-cast.
95.83 Cu, 1.12 Zn, 0.02 Fe, 3.11 Si	0.37 [2]	
78.30 Cu, 0.20 Ni, 8.04 Sn, 13.32 Pb, 0.1 P	0.42 [2]	Sand-cast.
87.86 Cu, 3.05 Zn, 0.03 Fe, 8.87 Sn	0.54 [2]	Sand-cast.
88.36 Cu, 1.90 Zn, 0.07 Fe, 9.55 Sn	0.50 [2]	Sand-cast.
60.54 Cu, 36.46 Zn, 0.21 Mn, 0.73 Fe, 1.48 Sn, 0.04 Al.	0.96 [2]	Sand-cast.
99.04 Cu, 0.07 Fe, .9 Cd	2.76 [2]	
50.75 Cu, 0.47 Mn, 48.69 Fe, 0.05 Si, .02 C	0.99 [2]	

[1] These values were determined by C. S. Smith (1935) at 20°C. Sometimes the composition percentages add up to more than 100.

[2] The miscellaneous alloys were extensively worked, annealed, and slowly cooled except where noted.

COPPER ALLOYS (Cont'd)

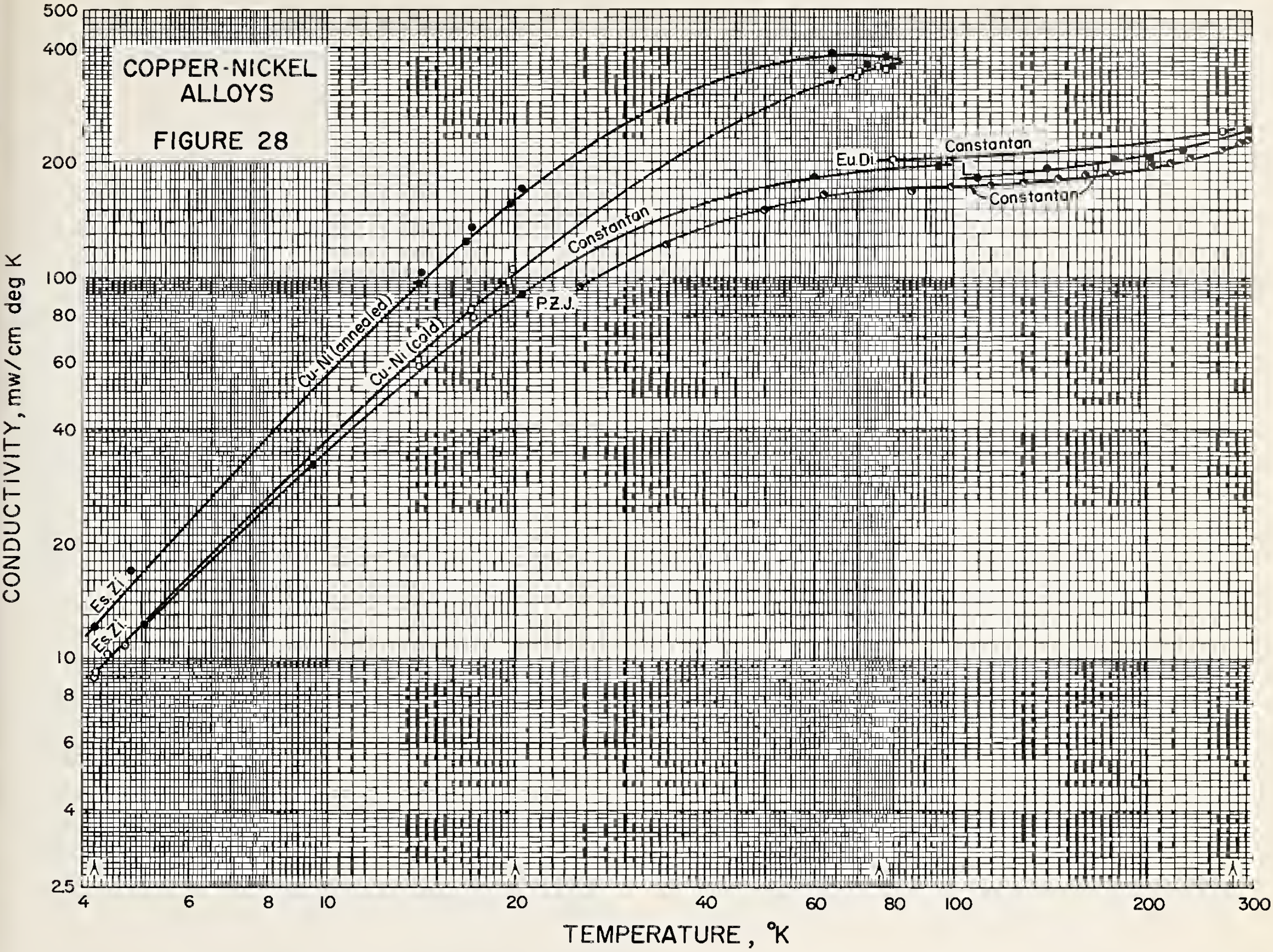
Curve	Composition (%)	Remarks	Reference
Fig. 27; Kr. S.-Ger. silv.	64 Cu, 20 Zn, 16 Ni	"Neusilber"	J. Karweil and K. Schäfer (1939).
Fig. 27; Kr. Sc.-bronze.	46 Cu, 41 Zn, 13 Ni	"Silberbronze"	Do.
Fig. 29a; Al. Mn.-Ger. silv.	45.9 Cu, 42.1 Zn, 9.8 Ni, 2.0 Pb, 0.15 Fe, 0.05 Mn.	"German silver"; data fits equation $k=5.3\times10^{-4}$ T^3.	J. F. Allen and E. Mendoza (1948).
Fig. 27, Fig. 29a; B.-Ger. silv.	47 Cu, 41 Zn, 9 Ni, 2 Pb.	Mean diameter of crystals was 0.02 mm.	R. Berman (1951b).

COPPER ALLOYS (Cont'd)
COMPANY AND TRADE MANUALS

Name	Nominal Composition (%)	Conductivity
		w/cm deg K
Coppers:		
Electrolytic Tough Pitch	99.92 Cu, 0.04 O_2	3.91
Deoxidized	99.94 Cu, 0.02 P	3.39
Oxygen-free high cond	99.92 Cu	3.93
Silver bearing	99.9 Cu, trace Ag	3.93
Arsenical phosphorized	99.45 Cu, 0.3 As, 0.03 P	1.76
Free cutting	99.4 Cu, 0.6 Te	3.55
Boron deoxidized	99.98 Cu, 0.02 B	3.88
Selenium copper	99.4 Cu, 0.6 Se	3.84
Leaded copper	99.0 Cu, 1.0 Pb	3.84
Chromium copper	99.05 Cu, 0.85 Cr	3.24
Cadmium copper	99.00 Cu, 1.00 Cd	3.44
Brasses:		
Gilding	95 Cu, 5 Zn	2.34
Commercial bronze	90 Cu, 10 Zn	1.88
Bearing bronze	90 Cu, 9.5 Zn, 0.5 Sn	1.73
Commercial bronze	87.5 Cu, 12.5 Zn	1.73
Red brass	85 Cu, 15 Zn	1.59
Low brass	80 Cu, 20 Zn	1.38
Cartridge brass	70 Cu, 30 Zn	1.21
Yellow brass	65 Cu, 35 Zn	1.17
Muntz metal	60 Cu, 40 Zn	1.21

COPPER ALLOYS (Cont'd)
COMPANY AND TRADE MANUALS

Name	Nominal Composition (%)	Conductivity
		w/cm deg K
Leaded Brasses:		
Leaded commercial bronze	90 Cu, 9.5 Zn, 0.5 Pb	1.80
Leaded commercial bronze	89 Cu, 0.25 Zn, 1.75 Pb	1.80
Commercial bronze	90.25 Cu, 6.9 Zn, 1.75 Pb, 1 Ni.	1.40
Low leaded brass	64.5 Cu, 35 Zn, 0.5 Pb	1.17
Low leaded brass	67 Cu, 32.5 Zn, 0.5 Pb	1.16
Medium leaded brass	64.5 Cu, 34.5 Zn, 1.0 Pb	1.17
High leaded brass	62.5 Cu, 35.75 Zn, 1.75 Pb	1.17
High leaded brass	64 Cu, 34 Zn, 2.0 Pb	1.15
Extra high leaded brass	62.5 Cu, 35 Zn, 2.5 Pb	1.17
Free cutting brass	61.5 Cu, 35.5 Zn, 3 Pb	1.17
Leaded Muntz metal	60 Cu, 39.5 Zn, 0.5 Pb	1.21
Free cuting Muntz metal	60.5 Cu, 38.4 Zn, 1.1 Pb	1.17
Forging brass	60 Cu, 38 Zn, 2 Pb	1.17
Architectural bronze	57 Cu, 40 Zn, 3 Pb	1.21
Leaded naval brass	60 Cu, 37.5 Zn, 0.7 to 1.75 Pb, 0.75 Sn.	1.17
Leaded tin bearing bronze	87 Cu, 4 Zn, 8 Sn, 1 Pb	0.47
High leaded tin bronze (bushing)	80 Cu, 10 Sn, 10 Pb	0.47
Dairy bronze	64 Cu, 8 Zn, 20 Ni, 4 Pb, 4 Sn	0.23
Leaded nickel brass	60 Cu, 16 Zn, 16 Ni, 5 Pb, 3 Sn.	0.27
Special Brasses:		
Admiralty metal	71 Cu, 28 Zn, 1 Sn	1.09
Naval brass	60 Cu, 39.25 Zn, 0.75 Sn	1.17
Manganese bronze	58.5 Cu, 39 Zn, 1.4 Fe, 1 Sn, 0.1 Mn.	1.09
Aluminum brass	76 Cu, 22 Zn, 2 Al	1.00
"Ambronze-474"	94.97 Cu, 4.0 Zn, 1.0 Sn, 0.03 P.	1.64
"Ambronze-421"	88.00 Cu, 10.0 Zn, 2.0 Sn	1.19
Manganese red brass	85.0 Cu, 14.0 Zn, 1.0 Mn	0.99
Silicon red brass	82.0 Cu, 17.0 Zn, 1.0 Si	0.67
Trumpet brass	81.0 Cu, 18.0 Zn, 1.0 Sn	1.21
Arsenical admiralty	71.0 Cu, 28.0 Zn, 1.0 Sn, 0.04 As.	1.11
Manganese brass	70.0 Cu, 29.0 Zn, 1.0 Mn	0.74
Nickel silver 18%-B	55 Cu, 27 Zn, 18 Ni	0.29
Nickel silver 15%	66 Cu, 19 Zn, 15 Ni	0.35
Leaded nickel silver 12%	65 Cu, 20.7 Zn, 12 Ni, 2 Pb, 0.3 Mn.	0.40
Phosphor bronze 5%-A	95 Cu, 5 Sn, trace P	0.80
Phosphor bronze 8%-C	92 Cu, 8 Sn, trace P	0.63
Phosphor bronze 10%-D	90 Cu, 10 Sn, trace P	0.50
Phosphor bronze 1.25%-E	98.75 Cu, 1.25 Sn, trace P	2.05
Phosphor bronze	98.7 Cu, 1.25 Sn, 0.05 P	2.18
Do	98.24 Cu, 1.75 Sn, 0.01 P	1.47
Do	95.95 Cu, 4.0 Sn, 0.05 P	0.81
Do	95.75 Cu, 4.0 Sn, 0.25 P	0.81
Do	95.17 Cu, 4.0 Sn, 0.08 P, 0.5 Fe.	0.76
Do	94.75 Cu, 5.0 Sn, 0.25 P	0.81
Do	93.9 Cu, 5.0 Sn, 0.1 P, 1 Pb	0.83
Do	93.7 Cu, 6.0 Sn, 0.3 P	0.57
Do	91.75 Cu, 8.0 Sn, 0.25 P	0.62
Do	89.75 Cu, 10.0 Sn, 0.25 P	0.50
Do	87.90 Cu, 4.0 Sn, 4 Zn, 4 Pb, 0.1 P.	0.55
Special Bronzes:		
Silicon bronze A	96 Cu, 3 Si	0.38
Silicon bronze B	97 Cu, 1.5 Si	0.59
"Everdur-1010"	95.8 Cu, 3.1 Si, 1.1 Mn	0.33
"Everdur-1012"	95.6 Cu, 3.0 Si, 1.0 Mn, 0.4 Pb.	0.33
"Everdur-1015"	98.25 Cu, 1.5 Si, 0.25 Mn	0.54
"Everdur-1014"	90.75 Cu, 2.0 Si, 7.25 Al	0.45
5% Aluminum bronze	95 Cu, 5 Al	0.83
	92 Cu, 8 Al	0.71
10% Aluminum bronze	88 Cu, 10 Al	0.60
	82.5 Cu, 10 Al, 5 Ni, 2.5 Fe	0.38
Aluminum silicon bronze	91 Cu, 7 Al, 2 Si	0.38
"Calsun"	95.5 Cu, 2.5 Al, 2.0 Sn	0.87
Chromium copper	99.05 Cu, 0.85 Cr	3.20
"Hitenso-961"	99.0 Cu, 1.0 Cd	3.44
"Hitenso-965"	98.6 Cu, 0.8 Cd, 0.6 Sn	2.33
Aluminum bronze 89-1-10	89 Cu, 10 Al, 1 Fe	0.55
Aluminum bronze 86-4-10	86 Cu, 10 Al, 4 Fe	0.59
Aluminum bronze	87.5 Cu, 9 Al, 3.5 Fe	0.59



COPPER ALLOYS (Cont'd)
COMPANY AND TRADE MANUALS

Name	Nominal Composition (%)	Conductivity	State
		w/cm deg K	
Beryllium Coppers:			
Beryllium copper	97 Cu, 2 Be, 0.25 Co	0.84	Solution treated, quenched.
		1.05	As above plus chemically hardened.
		0.84	As above plus cold-rolled.
		0.75	Solution treated, chemically quenched, cold-rolled.
Beryllium alloy 25	2 Be, 0.3 Co, balance Cu	1.21	
Beryllium alloy 165	1.7 Be, 0.3 Co, balance Cu	1.21	
Beryllium alloy 10	0.5 Be, 2.4 Co, balance Cu	2.26	
Beryllium alloy 50	0.4 Be, 1.55 Co, 1.0 Ag, balance Cu.	2.22	
Beryllium alloy 20C	2.1 Be, 0.5 Co, balance Cu	1.05	
Beryllium alloy 275C	2.7 Be, 0.5 Co, balance Cu	0.96	
Beryllium alloy 10C	0.6 Be, 2.5 Co, balance Cu	2.13	

COPPER-NICKEL ALLOYS

See also the "COPPER ALLOY" graph and tables.

Curve	Composition (%)	Conductivity and remarks	Reference
		w/cm deg K	
....	About 62 Cu, 22 Zn, 15 Ni.	"Neusilber"; $k=0.29$ at 0°C.	L. Lorenz (1881).
....	60 Cu, 40 Ni	"Constantan"; $k=0.23$ at 18°C.	W. Jaeger and H. Diesselhorst (1900).
....	54 Cu, 46 Ni	$k=0.21$ at 18°C	E. Grüneisen (1900).
Fig. 27; L. Ger. silv.	62 Cu, 22 Zn, 15 Ni	"German silver"	C. H. Lees (1908).
L.-Plat	Approx. same as above.	"Platinoid"	Do.
....	60 Cu, 40 Ni	"Eureka" or constantan; $k=0.21$ at 17°C.	T. Barratt and R. M. Winter (1925).
Fig. 28; Eu. Di.-constantan.	60 Cu, 40 Ni	51 crystals per cm; also measured samples with other crystal size.	A. Eucken and K. Dittrich (1927).
....	1 Ni	$k=1.50$ at 83°K, 0.62 at 21°K.	E. Grüneisen and E. Goens (1927).
Fig. 27; Kr. Sc. Ger. silv.	64 Cu, 16 Ni, 20 Zn	"Neusilber"	J. Karweil and K. Schäfer (1939).

COPPER-NICKEL ALLOYS (Cont'd)

Curve	Composition (%)	Conductivity and remarks	Reference
		w/cm deg K	
Fig. 29a; Al, Mn.-Ger. silv.	45.9 Cu, 42.1 Zn, 9.8 Ni, 2.0 Pb, 0.15 Fe, 0.05 Mn.	"German silver"; data fits equation $k=5.3\times10^{-4}$ T^3.	J. F. Allen and E. Mendoza (1948).
....	63 Cu, 20 Ni, 17 Zn...	"Nickel-silver"; $k=25.5$ mw/cm deg at 10°K, 48.5 at 15°K, 71.1 at 20°K.	K. R. Wilkinson and J. Wilks (1949).
....	70 Cu, 30 Ni.........	"Cupro-nickel"; $k=20.9$ mw/cm deg at 10°K, 35.6 at 15°K, 50.2 at 20°K.	Do.
Fig. 28; P.Z.J.-constantan.	55 Cu, 45 Ni.........	....	R. W. Powers, J. B. Ziegler, and H. L. Johnston (1951c).
Fig. 29a; Hu.-Cu-20% Ni.	80 Cu, 20 Ni.........	Also obtained $k=127$ mw/cm deg at 21.9°K and 79.9 at 16.3°K.	J. K. Hulm (1951).
Fig. 28; B.-Constantan.	60 Cu, 40 Ni.........	....	R. Berman (1951b).
Figs. 27, 29a; B.-Ger. silv.	47 Cu, 41 Zn, 9 Ni, 2 Pb.	Mean diameter of crystals was 0.02 mm.	Do.
Fig. 27; Es. Zi.-Cu-10% Ni, annealed.	90 Cu, 10 Ni.........	Two samples which were annealed, one a single crystal.	I. Estermann and J. E. Zimmermann (1952).
Es. Zi.-Cu-10% Ni, cold.	.....do..............	Two samples which were cold-worked.	Do.

COPPER-NICKEL ALLOYS (Cont'd)

Composition (%)	Conductivity
	w/cm deg K
99.73 Cu, 0.28 Ni, .01 Fe, .03 Mg	3.22 [1, 2]
99.47 Cu, 0.54 Ni, .02 Fe, .04 Mg	2.92 [1, 2]
97.94 Cu, 1.97 Ni, 0.02 Fe, .04 Mg	1.72 [1, 2]
94.92 Cu, 5.09 Ni, 0.01 Fe, .03 Mg	1.00 [1, 2]
89.90 Cu, 10.07 Ni, 0.02 Fe, .03 Mg, .02 C	0.62 [1, 2]
84.85 Cu, 15.07 Ni, 0.05 Fe, .01 Mg, .03 Mn	0.47 [1, 2]
79.68 Cu, 19.79 Ni, 0.23 Fe, .30 Mg	0.36 [1, 2]
69.54 Cu, 30.23 Ni, 0.05 Fe, .05 Mg, .13 Mn	0.29 [1, 2]

Composition (%)	Conductivity	State
	w/cm deg K	
64.14 Cu, 18.38 Ni, 0.19 Fe, 17,06 Zn, 0.3 Mn, .02 C.	0.33 [1, 3]	
63.37 Cu, 19.89 Ni, 0.14 Fe, 8.22 Zn, 3.31 Sn, 5.4 Pb, 0.23 Mn.	0.28 [1, 3]	Sand-cast.
96,05 Cu, 3.01 Ni, 0.004 Fe, .88 Si	0.76 [1, 3]	Quenched.
96.05 Cu, 3.01 Ni, 0.04 Fe, .88 Si	1.58 [1, 3]	Reheated.
96.05 Cu, 3.01 Ni, 0.04 Fe, .88 Si	1.69 [1, 3]	Furnace-cooled.
74.07 Cu, 19.96 Ni, 0.09 Fe, 5.31 Zn	0.39 [1, 3]	
64.5 Cu, 29.44 Ni, 0.07 Fe, 5.69 Zn	0.28 [1, 3]	

[1] The values were determined by C. S. Smith, E. W. Palmer (1935) at 20°C. Sometimes the composition percentages add up to more than 100.

[2] The copper-nickel alloys were deoxidized with magnesium, cold-rolled, and annealed at 800°C.

[3] The Miscellaneous alloys were extensively worked, annealed, and slowly cooled except where noted.

COPPER-NICKEL ALLOYS (Cont'd)
COMPANY AND TRADE MANUALS

Name	Nominal composition (%)	Conductivity
		w/cm deg K
Cupro-nickel 30%...	70 Cu, 30 Ni	0.29
Cupro-nickel 10%...	88.5 Cu, 10 Ni, 1.5 Fe	0.47
Nickel silver 18%-A.	65 Cu, 18 Ni, 17 Zn	0.33
Nickel silver 18%-B.	55 Cu, 18 Ni, 27 Zn	0.25
Nickel silver 15%...	66 Cu, 15 Ni, 19 Zn	0.35
Constantan.........	55 Cu, 45 Ni	0.23
Dairy bronze.......	64 Cu, 20 Ni, 8 Zn, 4 Pb, 4 Sn	0.23
Leaded nickel brass..	60 Cu, 16 Ni, 16 Zn, 5 Pb, 3 Sn	0.27
Leaded nickel silver 12%.	65 Cu, 12 Ni, 20.7 Zn, 2 Pb, 0.3 Mn	0.40

SILVER ALLOYS

Curve	Composition (%)	Conductivity and remarks	Reference
		w/cm deg K	
....	90 Ag, 10 Pd........	$k=1.41$ at 25°C..........	F. A. Schulze (1911).
....	80 Ag, 20 Pd........	$k=0.84$ at 25°C..........	Do.
....	70 Ag, 30 Pd........	$k=0.57$ at 25°C..........	Do.
....	60 Ag, 40 Pd........	$k=0.45$ at 25°C..........	Do.
....	50 Ag, 50 Pd........	$k=0.32$ at 25°C..........	Do.
....	90 Ag, 10 Pt........	$k=0.98$ at 25°C..........	Do.
....	75 Ag, 25 Pt........	$k=0.38$ at 25°C..........	Do.
....	70 Ag, 30 Pt........	$k=0.31$ at 25°C..........	Do.
....	67 Ag, 33 Pt........	$k=0.30$ at 25°C..........	Do.
Fig. 26; G. Re.-Ag-0.4% Au.	99.63 Ag, 0.37 Au....	....	E. Grüneisen and H. Reddemann (1934).
G. Re-Ag-25% Au.	75 Ag, 25 Au........	Single crystal............	Do.
G. Re.-Au 50% Ag.	50 Ag, 50 Au........	Single crystal............	Do.
Po.-Ag Solder.	50 Ag, 15.5 Cu, 16.5 Zn, 18 Cd.	"Easy-flo"; flame annealed.	R. L. Powell (1953).

GOLD ALLOYS

....	90 Au, 10 Pd........	$k=0.98$ at 25°C..........	F. A. Schulze (1911).
....	80 Au, 20 Pd........	$k=0.59$ at 25°C..........	Do.
....	70 Au, 30 Pd........	$k=0.44$ at 25°C..........	Do.
....	60 Au, 40 Pd........	$k=0.40$ at 25°C..........	Do.
....	50 Au, 50 Pd........	$k=0.36$ at 25°C..........	Do.
....	90 Au, 10 Pt........	$k=0.76$ at 25°C..........	Do.
....	80 Au, 20 Pt........	$k=0.41$ at 25°C..........	Do.
....	70 Au, 30 Pt........	$k=0.30$ at 25°C..........	Do.
....	60 Au, 40 Pt........	$k=0.26$ at 25°C..........	Do.

GOLD ALLOYS (Cont'd)

Curve	Composition (%)	Conductivity and remarks	Reference
		w/cm deg K	
....	92 atomic % Au, 8 atomic % Pt.	k=0.80 at 18°C..........	C. H. Johansson and J. O. Linde (1930).
....	84 Au, 16 Pt.........	k=0.48 at 18°C..........	Do.
....	68 Au, 32 Pt.........	k=0.23 at 18°C..........	Do.
....	55 Au, 45 Pt.........	k=0.21 at 18°C..........	Do.
Fig. 26; G. Re.-Au-50% Ag.	50 Au, 50 Ag........	Single crystal............	E. Grüneisen and H. Reddemann (1934).
G. Re.-Au-25% Ag.	75 Au, 25 Ag........	Single crystal............	Do.
G. Re.-Au-26% Cu.	73.7 Au, 26.4 Cu.....	Polycrystalline...........	Do.
G. Re.-Au-9% Cu.	91 Au, 9 Cu.........	Polycrystalline...........	Do.
....	50.1 Au, 49.9 Cu.....	Quenched from 800°C; k=0.193 at 86°K.	Do.
....	.....do..............	Same as above except annealed 22 hr at 360°C; k=1.28 at 85°K.	Do.
....	.....do..............	Requenched from 800°C; k=0.23 at 83°K.	Do.
G. Re.-Au-50% Cu.	.....do..............	Annealed 30 hr at 320°C...	Do.
G. Re.-Au-9% Pd.	91.2 Au, 8.8 Pd......	Tempered at 800°C for 2 hr.	Do.
....	83 Au, 17 Pd........	Annealed 2 hr at 800°C; approx. same curve as "Ag-25% Au".	Do.
....	69 Au, 25 Ag, 6 Pt....	k=0.53 at room temperature.	Trade Manual.

INDIUM, THALLIUM ALLOYS

....	66 Tl, 34 Pb.........	For a sample with "large" crystals, k=0.22 at 273° K, 0.13 at 80°K; for a sample with "small" crystals, k=0.23 at 273° K, 0.14 at 80°K.	A. Eucken and K. Dittrich (1927).
....	67 Tl, 34 Pb by atomic percent.	Measured relative change of thermal conductivity when the alloy became superconductive.	W. J. de Haas and H. Bremmer (1932).
Fig. 29, 29a; Br. H.-In-9% Pb.	91.4 In, 8.6 Pb by atomic percent.	Became superconducting at 4.2°K.	H. Bremmer and W. J. de Haas (1936).
Br. H.-Pb-50% In.	50 In, 50 Pb by atomic percent.	Became superconducting at 6.54°K.	Do.
Fig. 29a; Hu-In-10% Tl.	90 In, 10 Tl by atomic percent.	Single crystal; measured both in the normal and superconducting state; transition temperature about 3.4°K.	J. K. Hulm (1952b).

ZINC ALLOYS

Trade Designation	Nominal composition (%)	Conductivity
		w/cm deg K
"Zamak-3".......	96 Zn, 4 Al, 0.04 Mg........................	1.13
"Zamak-5".......	95 Zn, 4 Al, 1 Cu, 0.04 Mg.................	1.09
"Zamak-2".......	93 Zn, 4 Al, 3 Cu, 0.03 Mg.................	1.05
Comm. rolled.....	99.8 Zn, 0.08 Pb...........................	1.09
Do..........	99.8 Zn, 0.06 Pb, 0.06 Cd..................	1.09
Rolled zinc alloy, "Zilloy-15".	98.7 Zn, 1 Cu, 0.01 Mg.....................	1.05

CADMIUM ALLOYS

Curve	Composition (%)	Remarks	Reference
Fig. 29; Eu. Ge.-Cd-33% Sb.	66.7 Cd, 33.3 Sb......	....	A. Eucken and G. Gehlhoff (1912).
Eu. Ge.-Cd-50% Sb.	50 Cd, 50 Sb.........	....	Do.

MERCURY ALLOYS

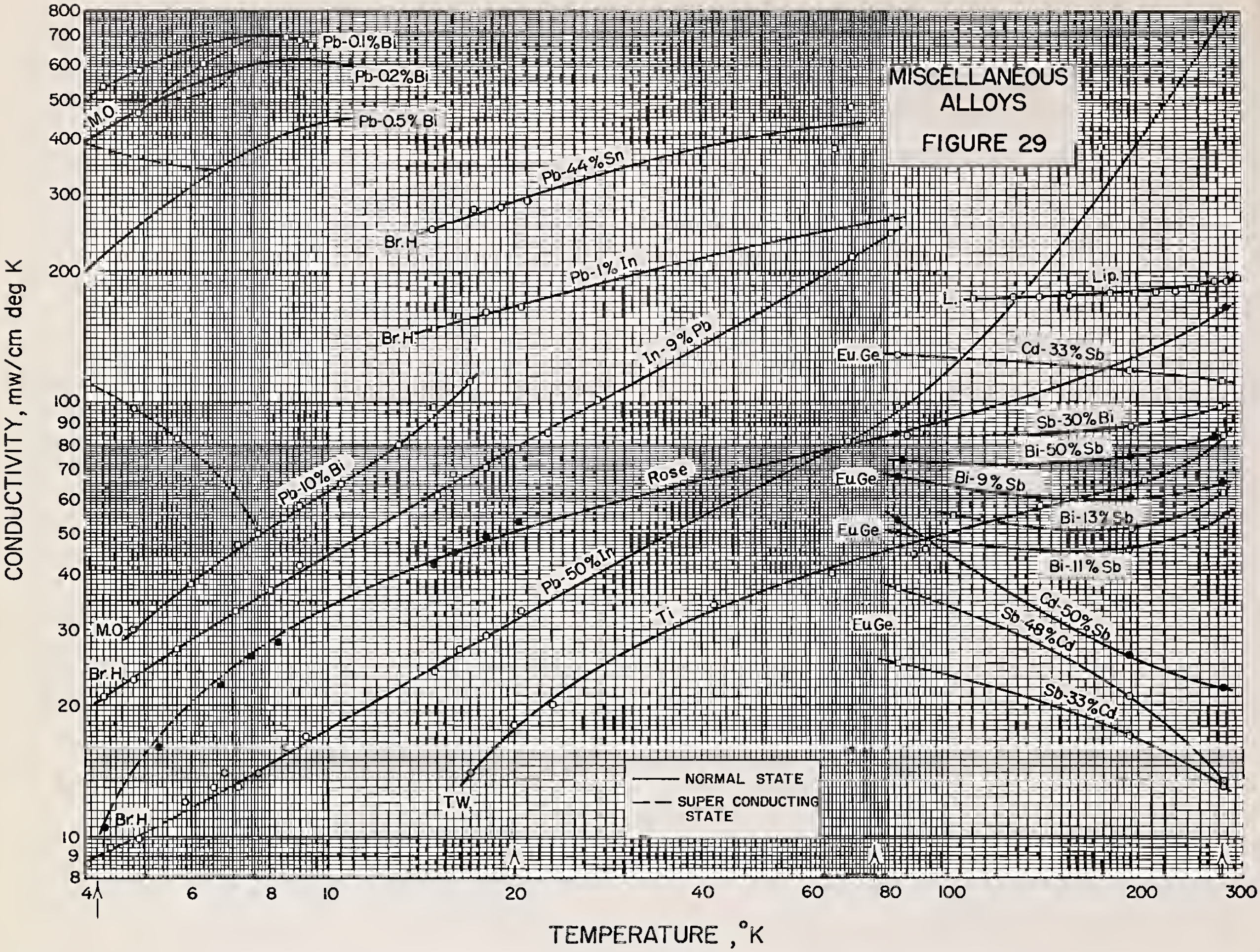
Composition (%)	Remarks	Reference
98.8 Hg, 1.19 In....	Measured ratio of conductivities in normal and superconducting states. See also the graph and table under "Metallic Elements".	J. K. Hulm (1950).

TIN ALLOYS

Curve	Composition	Remarks	Reference
Figs. 18a, b.	Up to 4% mercury...	See table under Figs. 18a, b, "Metallic Elements".	J. K. Hulm (1950).
Do.....	Up to 3% indium....	.....do..................	B. B. Goodman (1953).

TIN ALLOYS (Cont'd)
COMPANY AND TRADE MANUALS

Name	Nominal Composition (%)	Conductivity
		w/cm deg K
Eutectic soft solder..	63 Sn, 37 Pb............................	0.50
Tin foil............	92 Sn, 8 Zn.............................	0.59

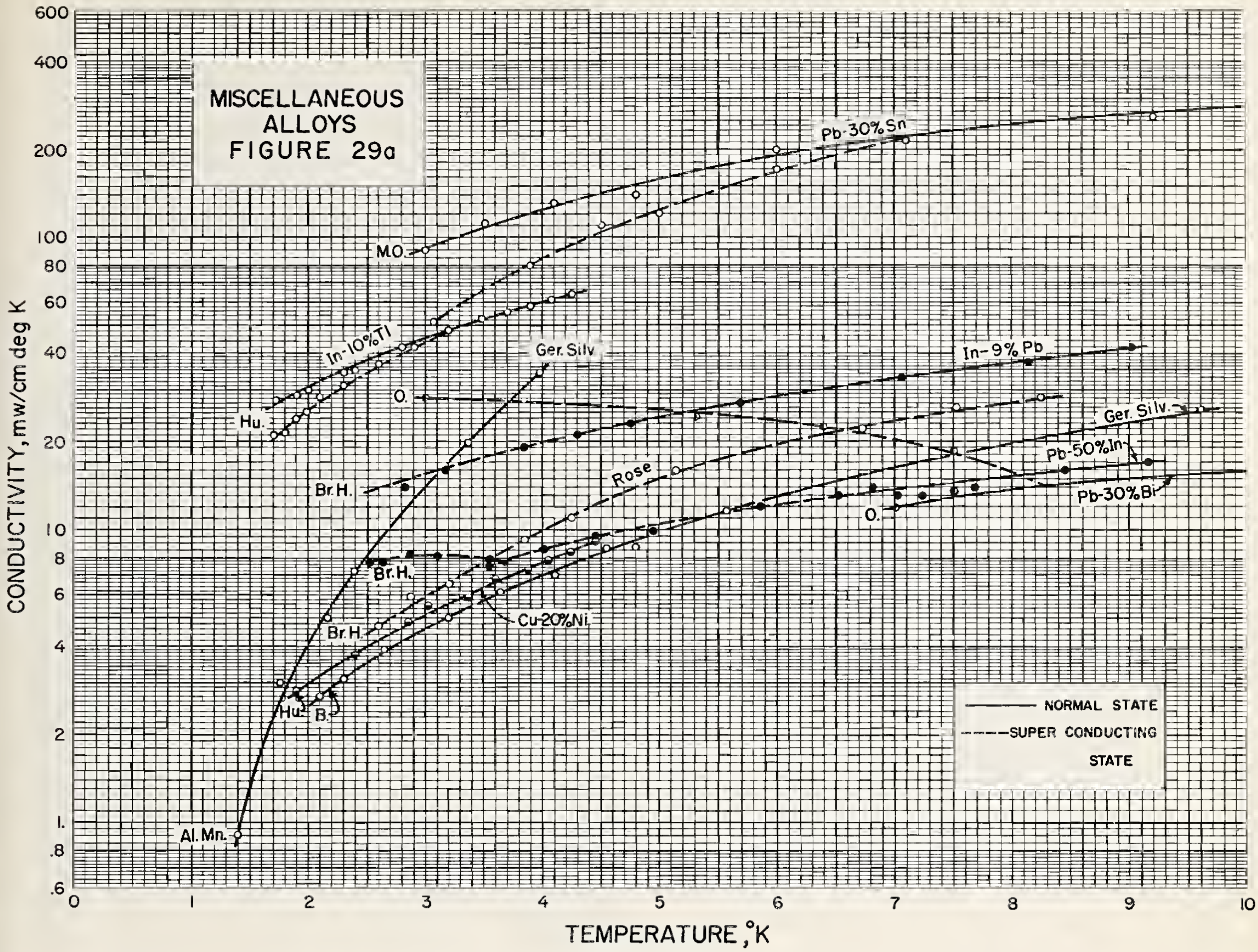


LEAD ALLOYS

Curve	Composition (%)	Remarks	Reference
Fig. 29; Br. H.-Pb-44% Sn.	56 Pb, 44 Sn	Not in solid solution	H. Bremmer and W. J. de Haas (1936).
....	90 Pb, 10 Bi	Measured conductivity in intermediate state and as a function of magnetic field.	K. Mendelssohn and R. B. Pontius (1937).
Fig. 29a; M. O.-Pb-30% Sn.	70 Pb, 30 Sn	Measured in normal and superconductive states.	K. Mendelssohn and J. L. Olsen (1950a).
Fig. 29; M. O.-Pb-0.1% Bi.	99.9 Pb, 0.1 Bi	....	Do.
M. O.-Pb-10% Bi.	90 Pb, 10 Bi	Note that the thermal conductivity in the superconductive state was higher than in the normal state.	Do.
M. O.-Pb-0.2% Bi.	99.8 Pb, 0.2 Bi	Measured in normal and superconductive states.	K. Mendelssohn and J. L. Olsen (1950c).
M. O.-Pb-0.5% Bi.	99.5 Pb, 0.5 Bi	.....do	Do.
Fig. 29a; O.-Pb-30% Bi.	70 Pb, 30 Bi	.....do	J. L. Olsen (1952).

LEAD ALLOYS (Cont'd)

Name	Nominal composition (%)	Conductivity
		w/cm deg K
Corroding lead	99.73 Pb	0.35
1% antimonial lead	99 Pb, 1 Sb	0.33
Hard lead	96 Pb, 4 Sb	0.31
Do	94 Pb, 6 Sb	0.29
8% antimonial lead	92 Pb, 8 Sb	0.27
Grid metal	91 Pb, 9 Sb	0.27
5-95 soft solder	95 Pb, 5 Sn	0.36
20-80 soft solder	80 Pb, 20 Sn	0.37
50-50 soft solder	50 Pb, 50 Sn	0.46
Lead base babbitt	80 Pb, 15 Sb, 5 Sn	0.24
Do	75 Pb, 15 Sb, 10 Sn	0.24



BISMUTH ALLOYS

Curve	Composition (%)	Remarks	Reference
Fig. 29; L.-Lip.	50 Bi, 25 Pb, 14 Sn, 11 Cd.	"Lipowitz alloy"........	C. H. Lees (1908).
Ge. Ne.-Bi-50% Sb.	50, Bi, 50 Sb........	....	G. Gehlhoff and F. Neumeier (1913).
Ge. Ne.-Bi-20% Sb.	80 Bi, 20 Sb........	....	Do.
Ge. Ne.-Bi-13% Sb.	87 Bi, 13 Sb........	....	Do.
Ge. Ne.-Bi-11% Sb.	89 Bi, 11 Sb........	....	Do.
Ge. Ne.-Bi-9% Sb.	91 Bi, 9 Sb........	....	Do.
Fig. 29, 29a; Br. H.-Rose.	50 Bi, 25 Pb, 25 Sn....	"Rose's metal"..........	H. Bremmer and W. J. de Haas (1936).

ANTIMONY ALLOYS

Curve	Composition (%)	Remarks	Re erence
Fig. 29; Eu. Ge.-Cd-50% Sb.	50 Sb, 50 Cd........	....	A. Eucken and G. Gehlhoff (1912).
Eu. Ge.-Sb-48% Cd.	51.7 Sb, 48.3 Cd......	....	Do.
Eu. Ge.-Sb-33% Cd.	66.7 Sb, 33.3 Cd......	"Very hard"............	Do.
Ge. Ne.-Sb-30% Bi.	70 Sb, 30 Bi........	....	G. Gehlhoff and F. Neumeier (1913a).
Ge. Ne.-Bi-50% Sb.	50 Sb, 50 Bi........	....	Do.

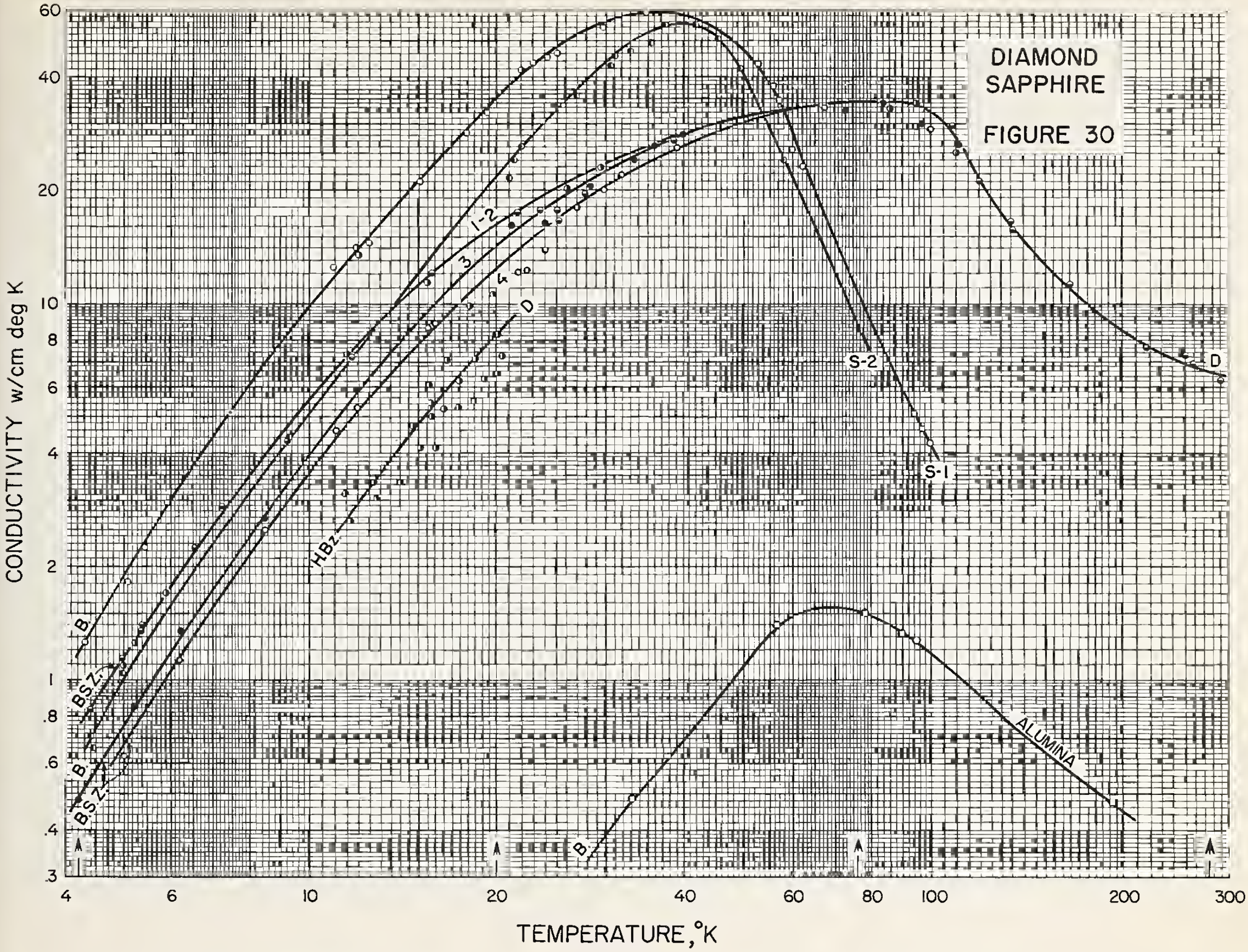
2.4. Dielectric Crystals

This section is not comprehensive but is representative of the dielectrics. There have been few measurements on the conductivity of dielectrics at low temperatures. However, three series of experiments especially worth noting in this short summary are A. Eucken and G. Kuhn (1928), W. J. de Haas and T. Biermasz (in late 1930's), and R. Berman and others of the Clarendon Laboratory at Oxford (1950's).

The following miscellaneous dielectrics were measured by A. Eucken and G. Kuhn (1928) (all percentages are mole percent):

Name	Remarks	Conductivity mw/cm deg K	
		83° K	273° K
Marble	Small crystals, 99.9% $CaCO_3$	42	33
Do	99.99% $CaCO_3$	54	38
Do	Large crystals	50	33
Calcite	Main crystal axis perpendicular to rod axis.	180	46
Do	Main crystal axis parallel to rod axis.	293	54
Sylvite	Natural crystal	159	75
KCl	Pressed at 8,000 atm	314	88
KCl	From a melt	402	92
NaCl	do	343	92
NaCl	Pressed at 8,000 atm	251	71
Rock salt	do	180	63
Sylvite	do	343	84
KCl	Pressed at 1,250 atm	243	75
KCl	Pressed at 2,500 atm	368	92
KCl	Pressed at 8,900 atm	402	96
KBr	Pressed at 8,000 atm	92	38
NaBr	do	50	25
KI	do	121	29
KF	do	234	71
NaF	do	519	105
RbI	do	59	33
RbCl	do	29	21
90% KBr, 10% KCl.	do	50	29
75% KBr, 25% KCl.	do	29	21
50% KBr, 50% KCl.	do	25	25

Name	Remarks	Conductivity mw/cm deg K	
		83° K	273° K
25% KBr, 75% KCl.	Pressed at 8,000 atm	46	33
10% KBr, 90% KCl.	do	80	50
50% KCl, 50% NaCl.	do	188	71
KNO_3	do	17	21
Mercuric chloride.	do	17	13
NH_4Cl	do	109	25
NH_4Br	do	67	25
$Ba(NO_3)_2$	do	33	13
Copper Sulfate.		29	21
Magnesium sulfate.		25	25
$K_4(FeCN_6)$		17	17
Chrom alum		13	21
Potassium alum.		13	21
Potassium bichromate.	Main crystal axis perpendicular to rod axis.	17	21
Do	Main crystal axis parallel to rod axis.	17	17
Topaz	Mineral		234
Zincblend	do	63	264
Beryll	do	88	84
Tourmaline	do	38	46

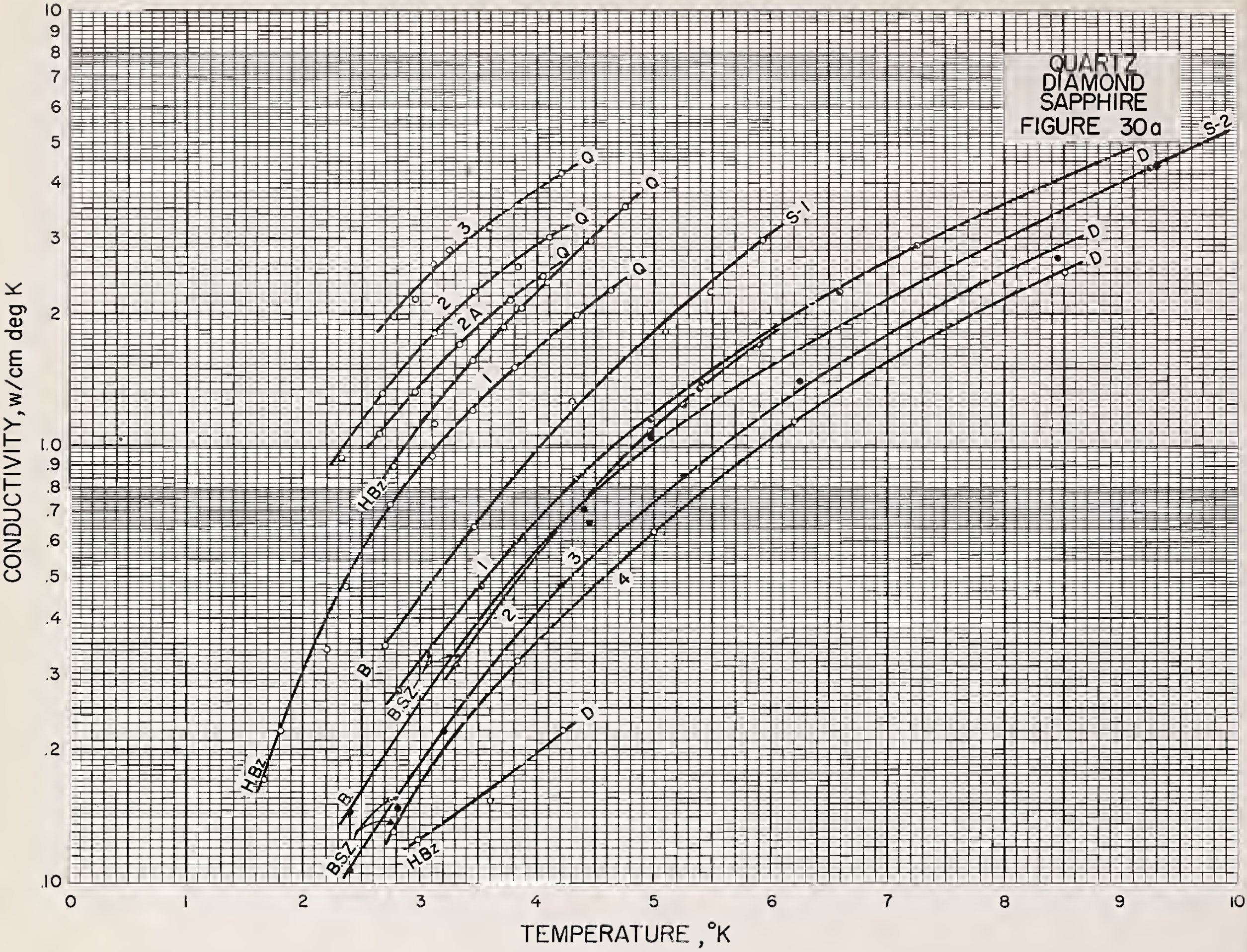


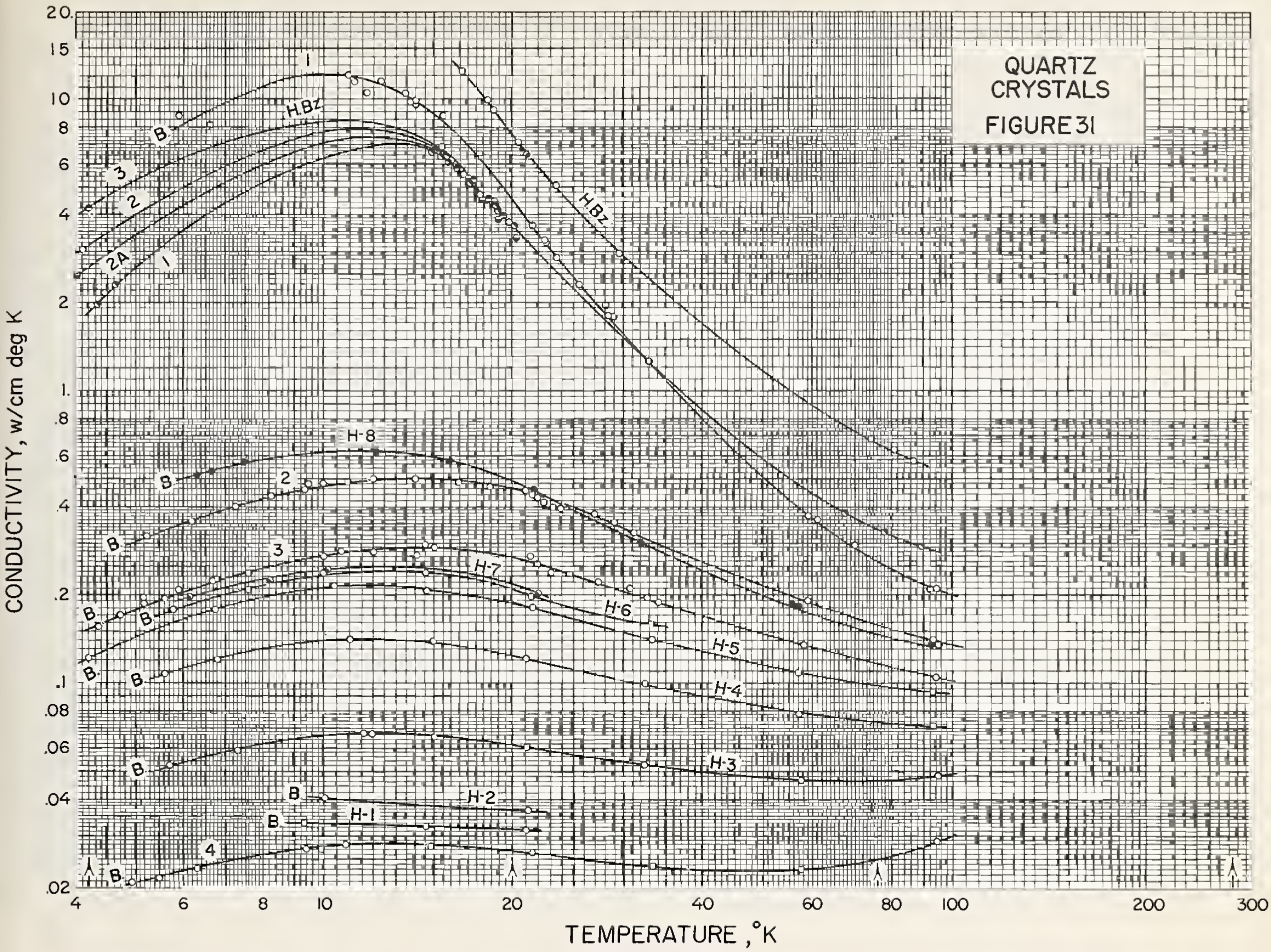
DIAMOND

Curve	Remarks	Reference
Fig. 30 and 30a; H.Bz.-D.	In addition to the two curves, they obtained $k=14.3$ at 89° K.	W. J. de Haas and T. Biermasz (1938).
B. S. Z.- D.-1.	Measured the "size effect" in diamond crystals of square cross-section. #1 was 3.9 mm wide, #2 was 3.1 mm wide, #3 was 1.7 mm wide, #4 was 1.1 mm wide. They used a type I stone. All were several centimeters long.	R. Berman, F. E. Simon, and J. M. Ziman (1953).

SAPPHIRE

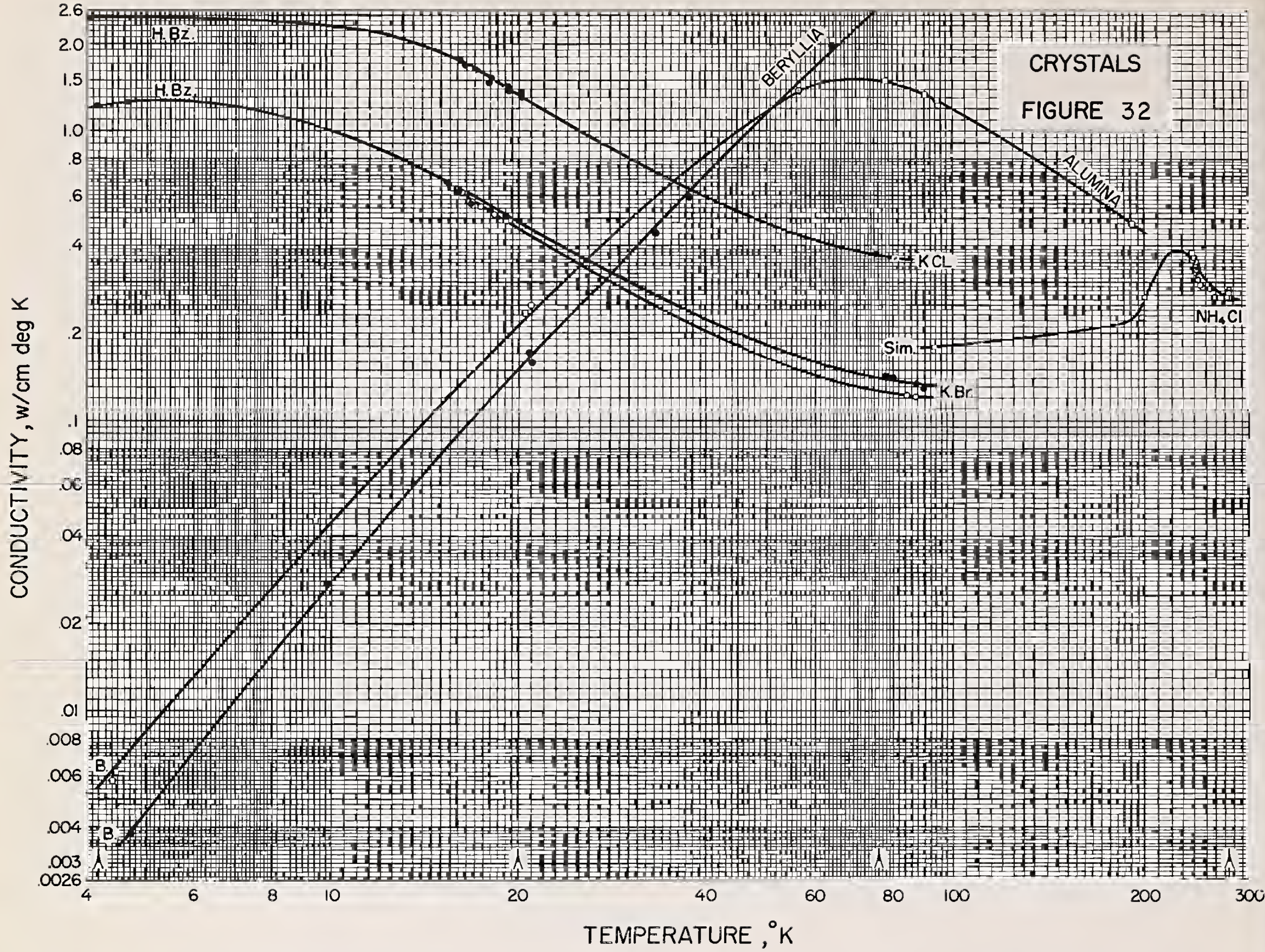
Curve	Remarks	Reference
Figs. 30, 30a; B.- S-1.	Curve S-1; artificial single crystal sapphire (corundum); 6 mm long, diameter of 3 mm; at lowest temperature, $k=2.7\text{x}10^{-2}\ T^3$; main crystal axis inclined 36° to rod axis.	R. Berman (1951).
Figs. 30, 30a; B.- S-2.	Same crystal as above except 1.5 mm diameter.	R. Berman (1952).
Figs. 30, 32; "Alumina".	Sintered alumina; density 3.70 g/cm³ (95% of single crystal); grain sizes about 5 to 30 microns.	Do.


QUARTZ
DIAMOND
SAPPHIRE
FIGURE 30a
CONDUCTIVITY, w/cm deg K
TEMPERATURE , °K
Q
3
2
2A
1
HBz
B
BSZ
S-1
S-2
D
4



QUARTZ

Curve	Remarks	Reference
Figs. 31, 30a; H. Bz.	A single crystal with principal axis parallel to rod axis; 5 cm long, 0.3 cm diameter.	W. J. de Haas and T. Biermasz (1935).
H. B.z-1	A single crystal with rod axis perpendicular to principal crystal axis and parallel to bisector of two binary axes; diameter 0.216 cm.	W. J. de Haas and T. Biermasz (1937).
H. Bz.-2	Same as above, except diameter 0.454 cm.	W. J. de Haas and T. Biermasz (1938a)
H. Bz.-2A	Same rod as 2, except diameter ground down to 0.359 cm.	W. J. de Haas and T. Biermasz (1938b).
Fig 31; B.-1, 2, 3, 4; H 1, 2, 3, 4, 5, 6, 7, 8.	Single crystal 5 cm long; square cross-section, 5 mm on a side; rod length perpendicular to principal axis; #1 was without neutron irradiation; #2 was with 1 unit irradiation; #3, second additional irradiation of 1.4 units; #4, third additional irradiation of 16.5 units. The "H" curves were after heating as follows: #1, 300°C for 8 hrs.; #2, 400°C for 6 hrs.; #3, 500°C for 6 hrs.; #4, 565°C for 6 hrs.; #5, 540°C for 60 hrs.; #6, 540°C for 677 hrs.; #7, 600°C for 1 hr.; #8, 700°C for 6 hrs.	R. Berman (1951).

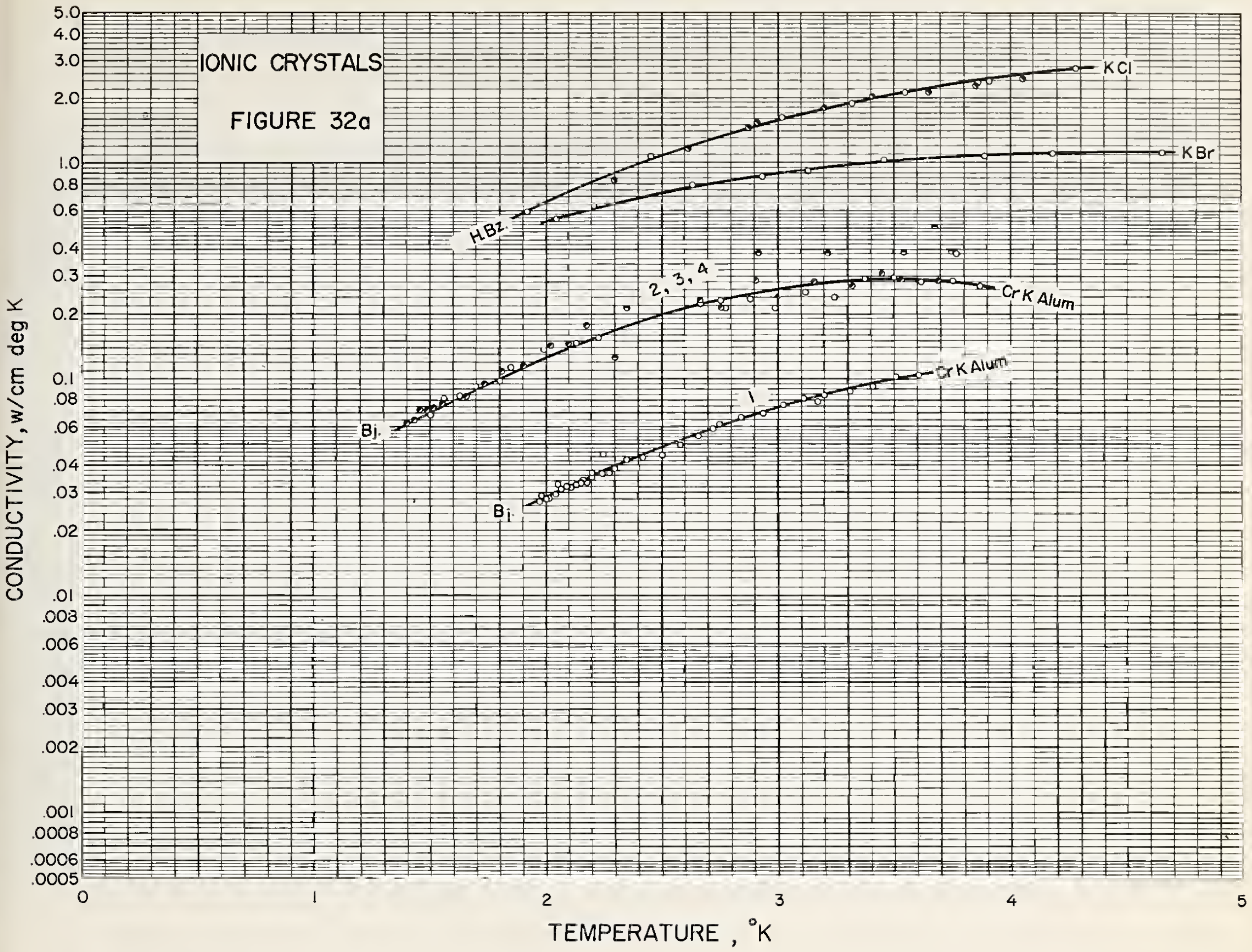


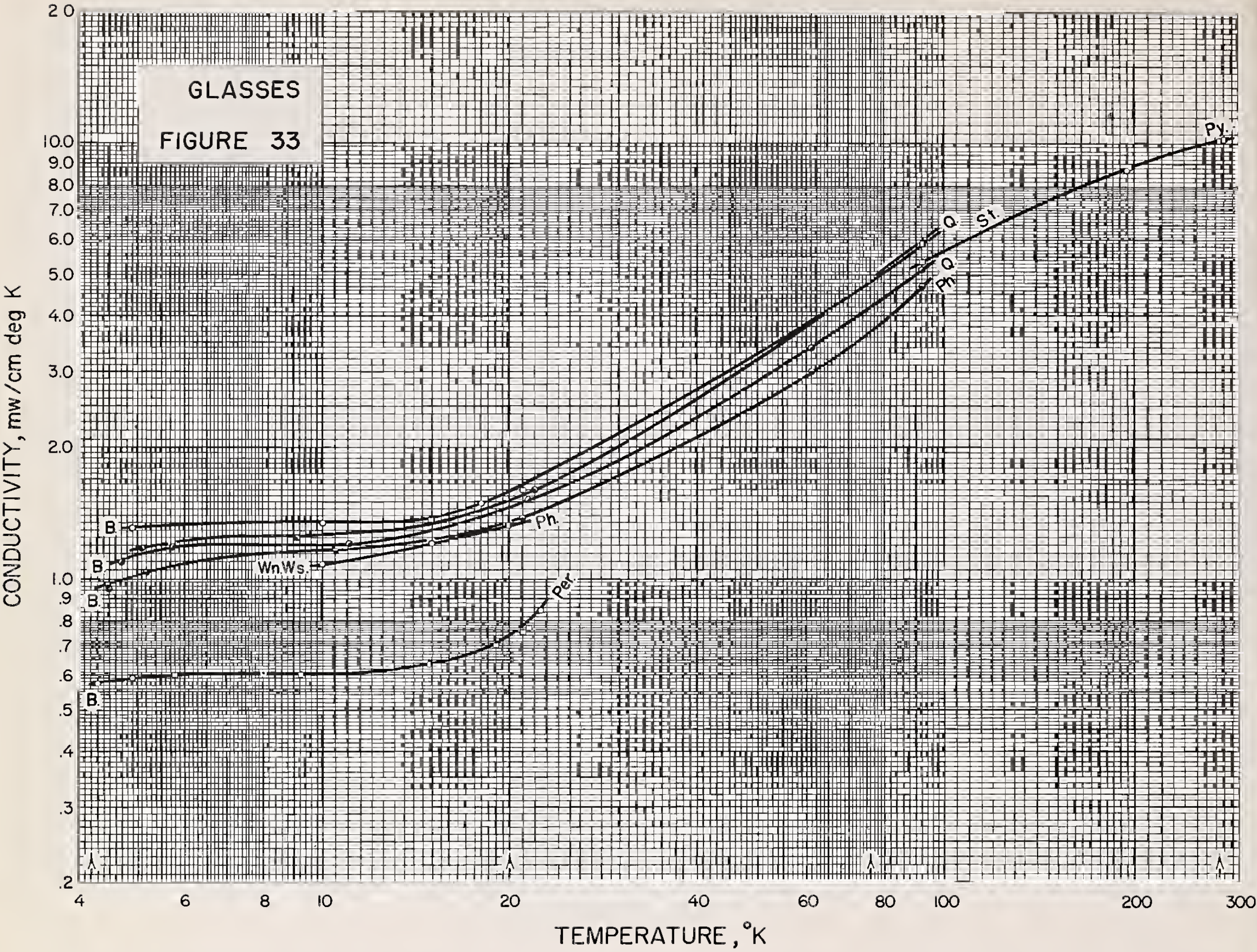
IONIC CRYSTALS

Curve	Remarks	Reference
Fig. 32; H. Bz.-KBr.	Measured a long potassium bromide crystal of approx. 3 cm diameter; the lower branch of the curve near 80°K is for a sample with soldered contacts; the upper, amalgam contacts.	W. J. de Haas and T. Biermasz (1937).
H. Bz.-KCl...	Measured along potassium chloride crystal of square cross-section with a side of 0.252 cm.	Do.
....	Measured the change in conductivity with change in crystal cross-section for several KCl crystals.	W. J. de Haas and T. Biermasz (1938a).
Fig. 32a; Bj.-CrK Alum.	Measured the conductivity of chromium potassium alum used in magnetic thermometry. Found that the conductivity depended on the rate of cooling of the alum. Curve 1 was for the sample cooled most rapidly.	D. Bijl (1949).
Fig. 32; Si.-NH_4Cl.	....	C. V. Simson (1951).

BERYLLIA

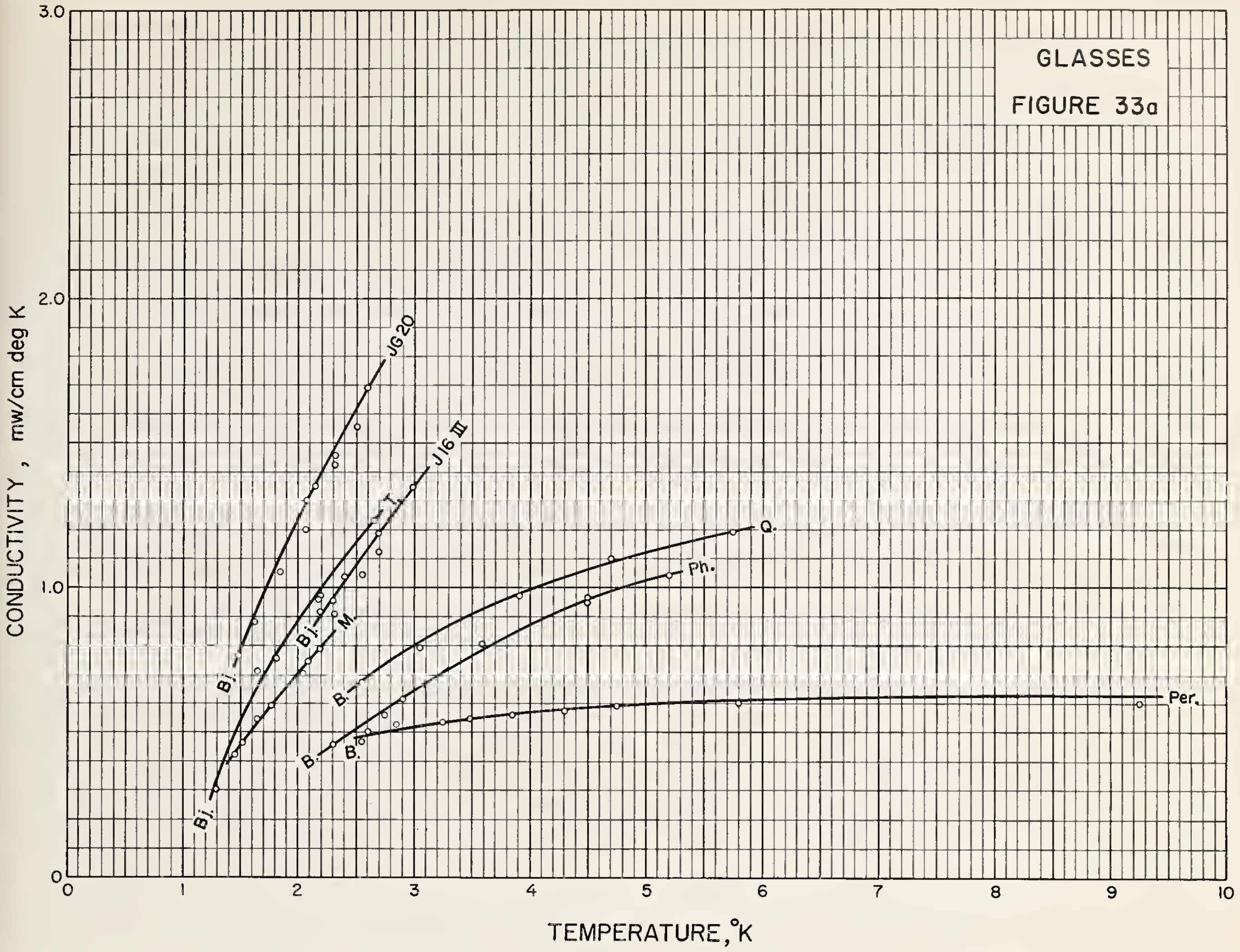
Curve	Remarks	Reference
Fig. 32-B. "Beryllia".	Sintered; density 2.94 g/cm³ (97% of single crystal); crystallites with dimensions between 10 and 40 microns; k=3.8 at 90°K.	R. Berman (1952).


IONIC CRYSTALS
FIGURE 32a
KCl
KBr
H.Bz.
2, 3, 4
Cr K Alum
1
Cr K Alum
Bj.
Bi
CONDUCTIVITY, w/cm deg K
TEMPERATURE , °K
5.0
4.0
3.0
2.0
1.0
0.8
0.6
0.4
0.3
0.2
0.1
.08
.06
.04
.03
.02
.01
.008
.006
.004
.003
.002
.001
.0008
.0006
.0005
0
1
2
3
4
5



DISORDERED DIELECTRICS

Curve	Composition	Reference
Fig. 33; St.-Py.	Pyrex glass	R. W. B. Stephens (1932).
Fig. 33; Wn.Ws.-Ph.	"Phoenix"; boro-silicate glass	K. R. Wilkinson and J. Wilks (1948).
Fig. 33a; Bj.-J.G. 20.	Jena Gerate 20 glass	D. Bijl (1949).
Bj.-T.	Thuringian glass	Do.
Bj.-J16 III	Jena 16 III glass	Do.
Bj.-M.	Monax glass	Do.
Figs. 33, 33a; B.-Ph.	"Phoenix" glass	R. Berman (1951).
B.-Q.	Quartz glass; upper curve is for a sample rod with approx. 7.5 mm diameter; lower curve, 6 mm diameter.	Do.
B.-Per.	Perspex plastic	Do.


GLASSES
FIGURE 33a
CONDUCTIVITY , mw/cm deg K
TEMPERATURE, °K
3.0
2.0
1.0
0
0
1
2
3
4
5
6
7
8
9
10
JG20
J16 III
T.
Bj.
Bj.
M.
Bj.
Q.
Ph.
B.
B.
B.
Per.

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