VII. THERMAL CONDUCTIVITY OF SOME SOLIDS

CONTENTS

Additional Reference to Entire Chapter: NBS Circular 556

PREFACE to the THERMAL CONDUCTIVITY INTEGRALS of SOLIDS at LOW TEMPERATURES

The thermal conductivity integrals for metallic solids are presented in this section as a function of temperature for the range from 4 to 300°K. The thermal conductivity integral is defined from the Fourier equation for steady unidirectional conduction which is:

$$Q = \lambda \ A \frac{dT}{dL}$$

where:

Q = rate of heat conduction, negative in the direction of increasing length

λ = thermal conductivity

A = cross-sectional area of the heat conduction path, and normal to the direction of heat flow

$\frac{dT}{dL}$ = temperature gradient along the path at the section under consideration

T = temperature

L = length

For a constant cross-section area this may be reduced to:

$$Q \frac{L}{A} = \int_{T_1}^{T_2} \lambda \ dT$$

where T_1 and T_2 are the temperatures at any two points along the path of the heat flow.

The thermal conductivity integrals tabulated in this section are values of:

$$\int_{T_o}^{T_L} \lambda \ dT$$

where T_o and T_L are temperatures along a heat flow path communicating between heat reservoirs at $T_o = 4^oK$ and T_L at length L from T_o. The heat flow along a conductor of constant cross-section area A, through length L, may then be determined from the difference of the thermal conductivity integrals, i.e.,

(Continued on following page)

$$Q \frac{L}{A} = \int_{T_1}^{T_2} \lambda \, dT = \int_{T_o}^{T_2} \lambda \, dT - \int_{T_o}^{T_1} \lambda \, dT$$

(In calculating the values of the thermal conductivity integrals presented in this section, a linear interpolation was assumed between the temperature intervals tabulated on the data sheets.)

Of the metals included, four become superconducting above 4°K. These metals and their transition temperatures are:

Metals	Index	Transition Temperature*
Lead	13.142-3	7.22°K
Niobium	13.151	8.7 - 8.9°K
Tantalum	13.151	4.38°K
Vanadium	13.151	4.89°K

The values of the thermal conductivity for these metals below the superconducting transition temperatures are for the normal state rather than the superconducting state.

Several of the data sheets include extrapolated values, and are so noted on the individual data sheets. The extrapolations are based on the characteristics of the thermal conductivity curves of metals in the same series classification. The estimated deviation of the thermal conductivity integrals over the extrapolated range is not more than 10% from the probable values.

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*<u>American Institute of Physics Handbook</u>, McGraw-Hill Book Co., Inc., New York (1957) sec. 4, p. 49

THERMAL CONDUCTIVITY
of COPPERS

Source of Data:

(a) R. L. Powell, H. M. Roder and W. J. Hall, to be published

(b) R. L. Powell, H. M. Roder and W. M. Rogers, J. Appl. Phys. 28, 1282-1288 (1957)

(c) Same as (b).

(d) R. W. Powers, D. Schwartz and H. L. Johnston, TR 264-5, Cryogenics Laboratory, Ohio State University (1951) 11 pp.

(e) R. L. Powell and D. O. Coffin, Rev. Sci. Instr. 26, 516 (1955).

(f) Same as (b).

Comments:

(a) High Purity; 99.999% pure, annealed, (Am. Smelt Ref.)

(b) Coalesced; 99.98% pure, annealed, (Phelps Dodge)

(c) Electrolytic Tough Pitch; 99.95% pure, annealed

(d) O.F.H.C.; 99.95% pure, annealed

(e) (Pb) Cu; 1% Pb, annealed

(f) (Te) Cu; 0.6% Te, annealed

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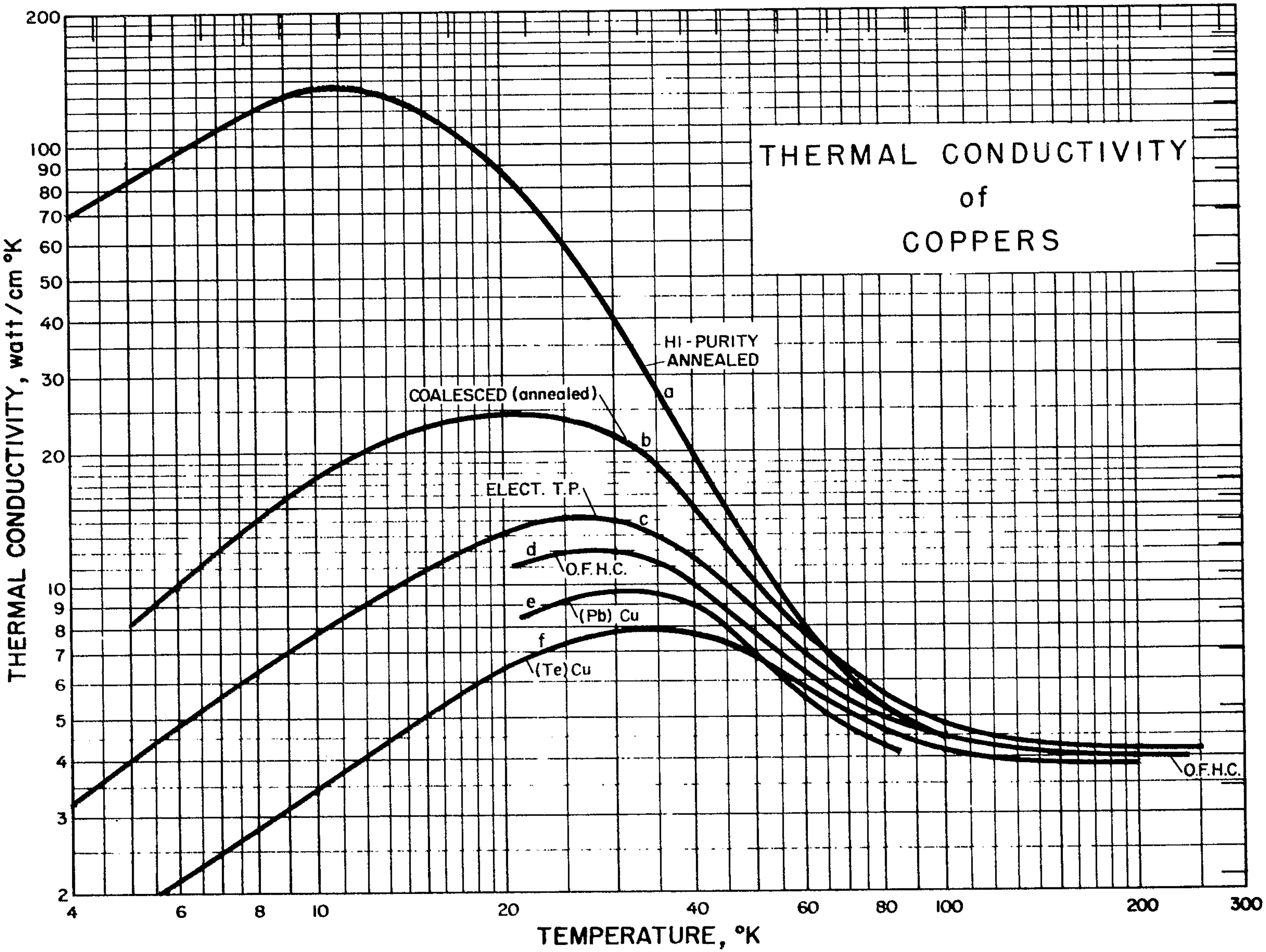
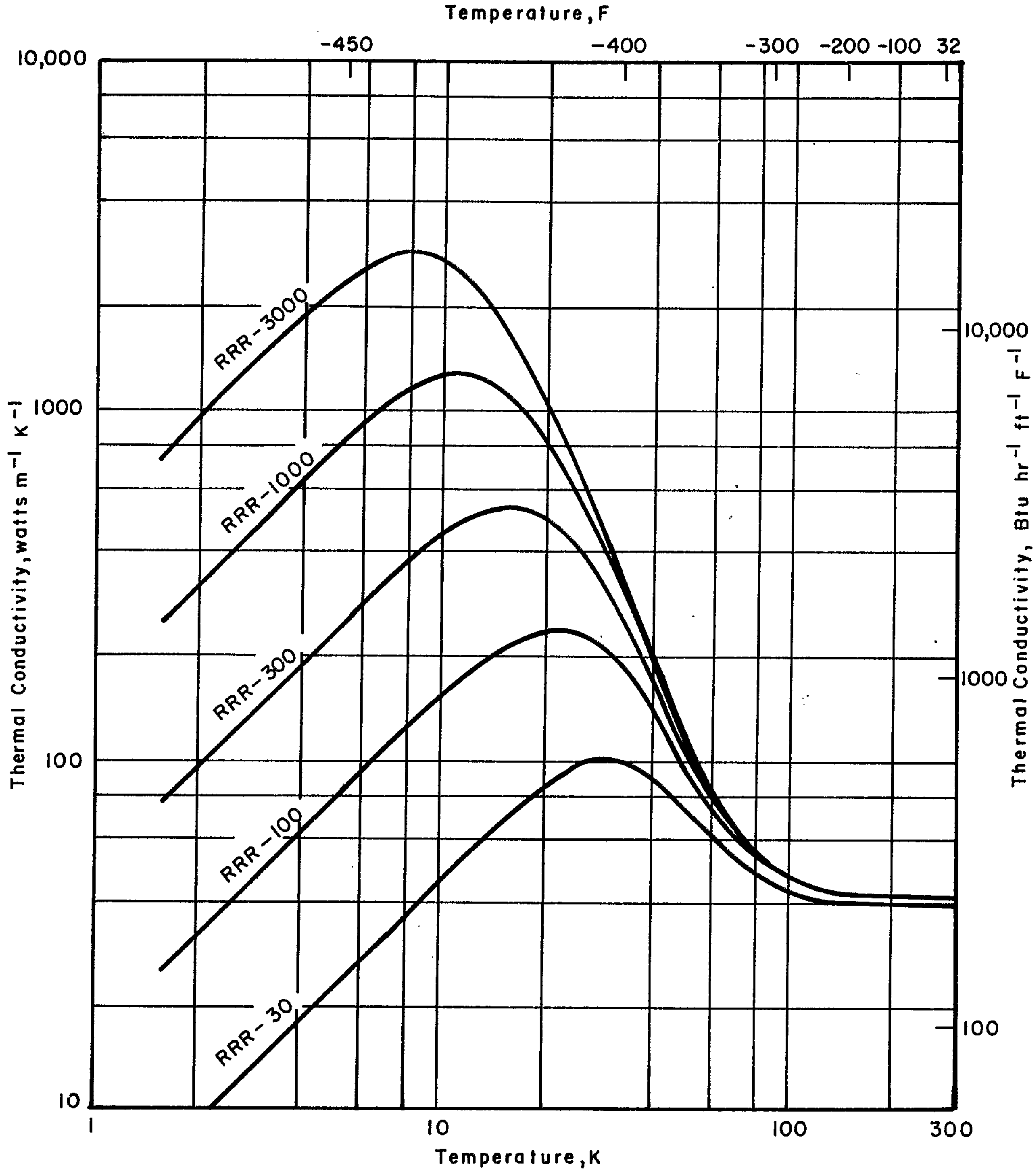

THERMAL CONDUCTIVITY
of
COPPERS
HI-PURITY
ANNEALED
a
COALESCED (annealed)
b
ELECT. T.P.
c
d
O.F.H.C.
e
(Pb) Cu
f
(Te) Cu
O.F.H.C.
THERMAL CONDUCTIVITY, watt/cm °K
200
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
TEMPERATURE, °K
4
6
8
10
20
40
60
80
100
200
300



THERMAL CONDUCTIVITY VERSUS TEMPERATURE FOR COPPER

THERMAL CONDUCTIVITY INTEGRALS

for COPPERS

Comments: The six curves were extrapolated to 300°K. The curve for O.F.H.C. was extrapolated to 4°K and the curve for (Pb)Cu was extrapolated to 6°K. It is estimated that the extrapolated values do not deviate more than 10% from the probable values.

$$Q = \frac{A}{L} \int_{T_o}^{T_L} \lambda \, dT; \qquad Q \frac{L}{A} = \int_{T_o}^{T_L} \lambda \, dT$$

Where:

Q = heat flow in watts
A = cross sectional area in cm^2
L = length in cm
λ = thermal conductivity in watts/cm-°K
T = temperature in °K
T_o = initial temperature (6°K for [Pb]Cu and [Te]Cu; 4°K for all other Coppers)

Thermal Conductivity Integrals are on following page.

Temp. °K	Thermal Conductivity watts/cm-°K					
	Hi-Purity Annealed	Coalesced	Elect. T.P.	O.F.H.C.	(Pb) Cu	(Te) Cu
4	70	6.2	3.2	2.4*		
6	96	10.	4.8	3.7*	2.7*	2.2
8	120	14.	6.3	4.7*	3.6*	2.8
10	134	17.5	7.8	6.0*	4.5*	3.4
15	120	23	11	8.5*	6.3*	5.0
20	88	24	13	11 *	8 *	6.5
25	60	23	14	12	9.2	7.3
30	40	22	14	12	9.6	7.8
35	28	18.5	13	11	9.5	7.9
40	20	15	11.5	10	9	7.7
50	12	10	8.8	7.7	6.9	6.8
60	8.0	7.8	7.0	6.2	5.5	5.8
70	6.2	6.5	5.9	5.5	4.7	5.2
76	5.7	6.0	5.5	5.2	4.5	4.9
80	5.2	5.7	5.2	4.9	4.3	4.6
90	4.7	5.1	4.7	4.7	4.0*	4.3
100	4.5	4.8	4.5	4.5	3.8*	4.2
120	4.3	4.5	4.3	4.3	3.7*	4.0
140	4.2	4.3	4.2	4.2	3.6*	3.8
160	4.1	4.2	4.1	4.1	3.6*	3.8
180	4.0	4.2	4.0	4.0	3.6*	3.8
200	4.0	4.2	4.0	4.0	3.6*	3.8
250	4.0	4.2*	4.0	4.0	3.6*	3.8*
300	4.0*	4.2*	4.0*	4.0*	3.6*	3.8*

* Extrapolated Values

THERMAL CONDUCTIVITY INTEGRALS

for COPPERS (cont.)

Temp. °K	$\int_{T_o}^{T_L} \lambda\, dT$ watts/cm					
	Hi-Purity Annealed	Coalesced	Elect. T.P.	O.F.H.C.	(Pb) Cu	(Te) Cu
6	166	16.2	8.00	6.1		
8	382	40.2	19.1	14.5	6.3	5
10	636	71.7	33.2	25.2	14.4	11.2
15	1270	173	80.2	61.4	41.4	32.2
20	1790	290	140	110	77.2	60.9
25	2160	408	208	168	120	95.4
30	2410	520	278	228	167	133
35	2580	622	345	285	215	172
40	2700	705	406	338	261	211
50	2860	830	508	426	341	284
60	2960	919	587	496	403	347
70	3030	991	651	554	454	402
76	3070	1030	686	586	481	432
80	3090	1050	707	606	499	451
90	3140	1100	756	654	540	496
100	3180	1160	802	700	579	538
120	3270	1250	891	788	654	620
140	3360	1340	976	874	727	698
160	3440	1420	1060	956	799	774
180	3520	1510	1140	1040	871	850
200	3600	1590	1220	1120	943	926
250	3800	1800	1420	1320	1120	1120
300	4000	2000	1620	1520	1300	1310

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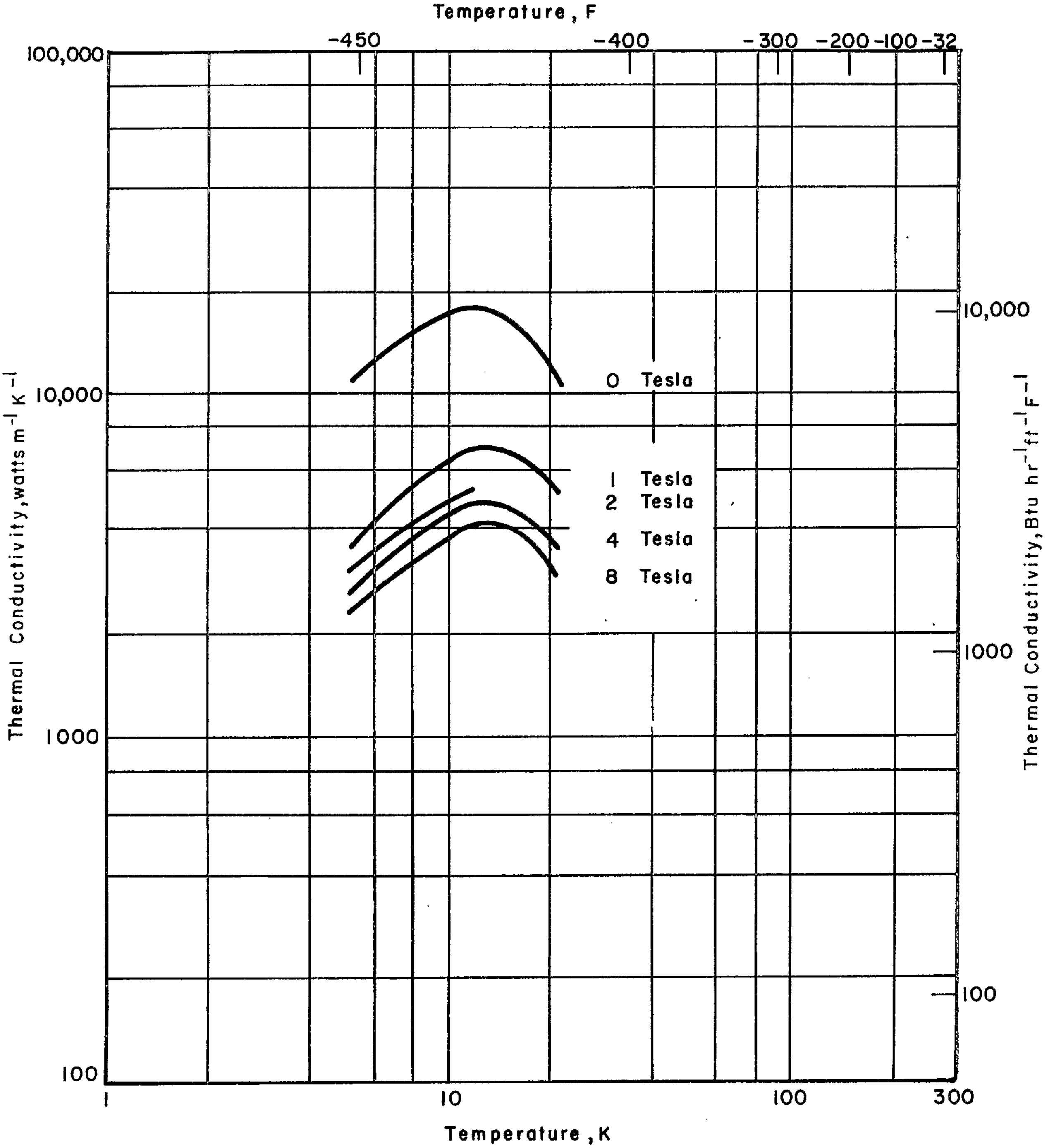

THERMAL CONDUCTIVITY VERSUS TEMPERATURE FOR COPPER AT SEVERAL MAGNETIC FIELD STRENGTHS (RRR-1520)

THERMAL CONDUCTIVITY
of SILVER and GOLD

Source of Data:
- (a) G. K. White, Proc. Phys. Soc. (London) A66, 844-845 (1953); C. H. Lees, Phil. Trans. Roy. Soc. (London) A208, 381-443 (1908)
- (b) G. K. White, Ibid. (a)
- (c) G. K. White, Proc. Phys. Soc. (London) A66, 559-564 (1953); W. Meissner, Ann. Physik 47, 1001-1058 (1915)
- (d) G. K. White, Ibid. (c)

Comments:
- (a) Silver 1; 99.999% pure, annealed, and 99.9% pure (Johnson, Matthey)
- (b) Silver 2; 99.999% pure, drawn (Johnson, Matthey)
- (c) Gold 1; 99.999% pure, annealed (Johnson, Matthey), 99.999% pure, annealed (Mylius)
- (d) Gold 2; 99.9% pure, drawn, (Garrett)

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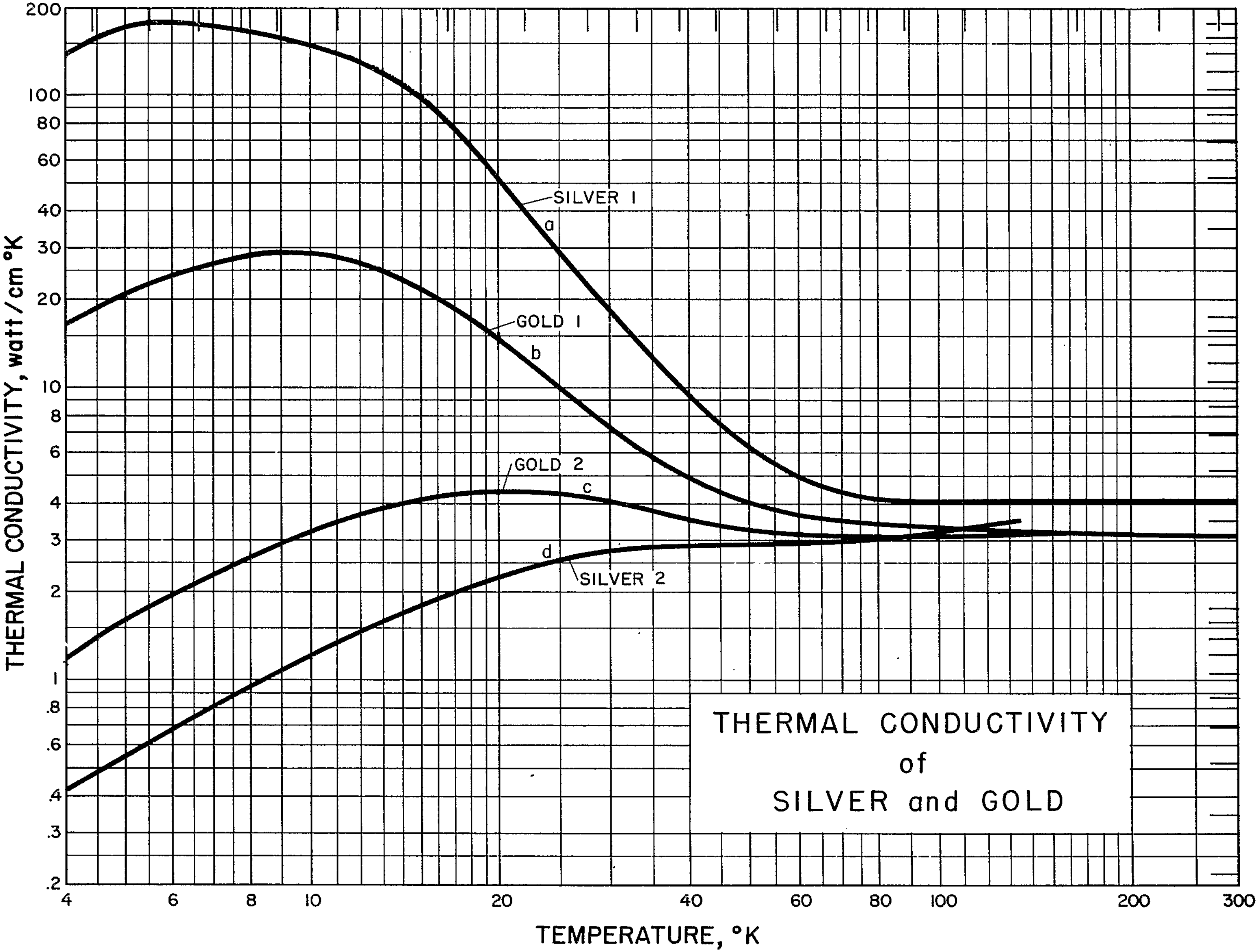

THERMAL CONDUCTIVITY
of
SILVER and GOLD

THERMAL CONDUCTIVITY INTEGRALS
for SILVER and GOLD

Comments: The curve for Silver 2 was extrapolated to 300°K. It is estimated that the extrapolated values do not deviate more than 10% from the probable values.

$$Q = \frac{A}{L}\int_{T_o}^{T_L} \lambda \, dT; \qquad Q\,\frac{L}{A} = \int_{T_o}^{T_L} \lambda \, dT$$

Where:

Q = heat flow in watts
A = cross sectional area in cm^2.
L = length in cm
λ = thermal conductivity in watts/cm-°K
T = temperature in °K
T_o = initial temperature (4°K)

Temp. °K	Thermal Conductivity watts/cm-°K				$\int_{T_o}^{T_L} \lambda \, dT$ watts/cm			
	Ag 1	Au 1	Au 2	Ag 2	Ag 1	Au 1	Au 2	Ag 2
4	140	17	1.2	.42				
6	180	24	1.9	.68	320	41.0	3.1	1.1
8	170	28	2.6	.95	670	93.0	7.6	2.73
10	150	28	3.2	1.3	990	149	13.4	4.98
15	98	22	4.2	1.8	1610	274	31.9	12.7
20	52	14	4.4	2.3	1980	364	53.4	23.0
25	29	10	4.3	2.5	2190	424	75.2	35.0
30	18	7.3	4.0	2.8	2310	467	95.9	48.2
35	13	5.9	3.8	2.9	2380	500	115	62.5
40	9.5	5.0	3.6	2.9	2440	528	134	77.0
50	6.3	4.0	3.2	2.9	2520	573	168	106
60	5.0	3.8	3.1	2.9	2570	612	199	135
70	4.5	3.5	3.1	2.9	2620	648	230	164
76	4.3	3.4	3.1	3.0	2650	669	249	182
80	4.2	3.3	3.1	3.1	2670	682	261	194
90	4.1	3.3	3.1	3.1	2710	715	292	224
100	4.1	3.2	3.1	3.2	2750	748	323	256
120	4.1	3.2	3.1	3.3	2830	812	385	321
140	4.1	3.2	3.1	3.5*	2910	876	447	389
160	4.1	3.1	3.1	3.7*	2990	939	509	461
180	4.1	3.1	3.1	3.8*	3080	1000	571	536
200	4.1	3.1	3.1	3.8*	3160	1060	633	612
250	4.1	3.1	3.1	3.8*	3360	1220	788	802
300	4.1	3.1	3.1	3.8*	3570	1370	943	992

* Extrapolated Values

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THERMAL CONDUCTIVITY of BERYLLIUM and MAGNESIUM

Source of Data: (a) H.-D. Erfling and E. Gruneisen, Ann. Physik 41, 89-99 (1942).

(b) G.K. White and S.B. Woods, Can. J. Physics 33, 58-73 (1955).

(c) W.R.G. Kemp, A.K. Sreedhar and G.K. White, Proc. Phys. Soc. (London) A66, 1077-1078 (1953).

(d) Same as (c)

Comments: (a) Beryllium-1; "high Purity" single crystal, (Degussa)

(b) Beryllium-2; 2% magnesium, sintered rod, (Brush)

(c) Magnesium-1; 99.98% pure, annealed in vacum 3 hours at 350°C, (Johnson, Matthey)

(d) Magnesium-2; 99.98% pure, cold drawn, (Johnson, Matthey)

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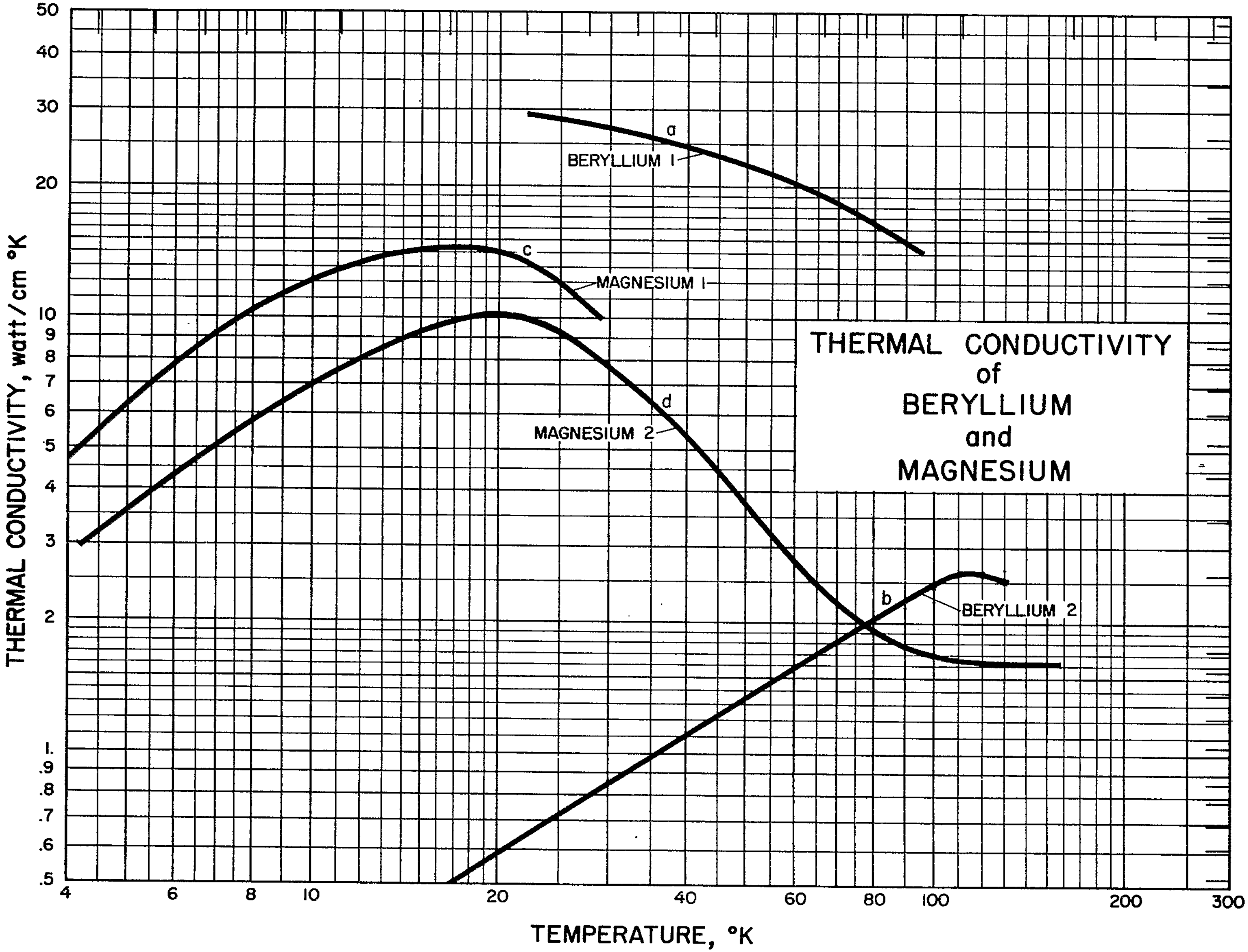

THERMAL CONDUCTIVITY of BERYLLIUM and MAGNESIUM

THERMAL CONDUCTIVITY INTEGRALS
for BERYLLIUM and MAGNESIUM

Comments: The four curves were extrapolated to 300°K and the curve for Beryllium 1 was also extrapolated to 4°K. It is estimated that the extrapolated values do not deviate more than 10% from the probable values.

$$Q = \frac{A}{L} \int_{T_o}^{T_L} \lambda \, dT; \qquad Q \frac{L}{A} = \int_{T_o}^{T_L} \lambda \, dT$$

Where:

Q = heat flow in watts
A = cross sectional area in cm^2
L = length in cm
λ = thermal conductivity in watts/cm-°K
T = temperature in °K
T_o = initial temperature (4°K for Beryllium 1, Magnesium 1 and Magnesium 2; 20°K for Beryllium 2)

Temp. °K	Thermal Conductivity watts/cm-°K				$\int_{T_o}^{T_L} \lambda \, dT$ watts/cm			
	Be 1	Mg 1	Mg 2	Be 2	Be 1	Mg 1	Mg 2	Be 2
4	10 *	4.7	2.8					
6	16 *	7.8	4.3		26	12.5	7.1	
8	22 *	10.4	5.8		64	30.7	17.2	
10	25 *	12	7.0		111	53.1	30	
15	28 *	14.2	9.3		244	119	70.7	
20	30 *	14	10	.59	388	189	119	
25	28	12	9.3	.72	534	254	167	3.28
30	27	9.5 *	7.8	.85	671	308	210	7.2
35	26	7.5 *	6.4	.98	804	350	246	11.8
40	25	6.3 *	5.3	1.1	931	385	275	17.0
50	23	4.5 *	3.8	1.35	1170	439	320	29.2
60	20	3.5 *	2.8	1.6	1390	479	353	44.0
70	18.4	2.8 *	2.3	1.8	1580	510	379	61.0
76	17.5	2.6 *	2.1	1.9	1680	527	392	72.1
80	16.5	2.5 *	1.9	2.0	1750	538	400	79.9
90	15.0	2.2 *	1.78	2.3	1910	560	418	101
100	13.5	1.9 *	1.70	2.5	2050	581	436	125
120	11.5*	1.7 *	1.63	2.6	2300	617	469	176
140	10.0*	1.63*	1.61	2.4 *	2520	650	501	226
160	8.5*	1.61*	1.61*	2.2 *	2700	682	534	272
180	7.5*	1.61*	1.61*	1.9 *	2860	715	566	313
200	6.5*	1.61*	1.61*	1.75*	3000	747	598	350
250	5.0*	1.61*	1.61*	1.4 *	3290	827	678	429
300	4.0*	1.61*	1.61*	1.15*	3520	908	759	492

* Extrapolated Values

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THERMAL CONDUCTIVITY of ALUMINUM, GALLIUM, INDIUM, and THALLIUM

Source of Data:

(a) R. A. Andrews, R. T. Webber and D. A. Spohr, Phys. Rev. 84, 994-996 (1951); R. W. Powers, D. Schwartz, and H. L. Johnston, TR 264-5, Cryogenic Laboratory, Ohio State University 11 pp (1951).

(b) R. L. Powell, W. J. Hall and H. M. Roder, to be published.

(c) H. M. Rosenberg, Phil. Trans. Roy. Soc. (London) A247, 441-497 (1955).

(d) Same as (c)

(e) Same as (c)

Comments:

(a) Aluminum-1; 99.996% pure, single crystal (Alcoa) and 99.99% pure, cold drawn (Alcoa)

(b) Aluminum-2; 99% commercial pure, (Alcoa) drawn

(c) Gallium; Single crystal

(d) Indium; 99.993% pure, (Johnson, Matthey)

(e) Thallium; 99.99% pure, (Johnson, Matthey)

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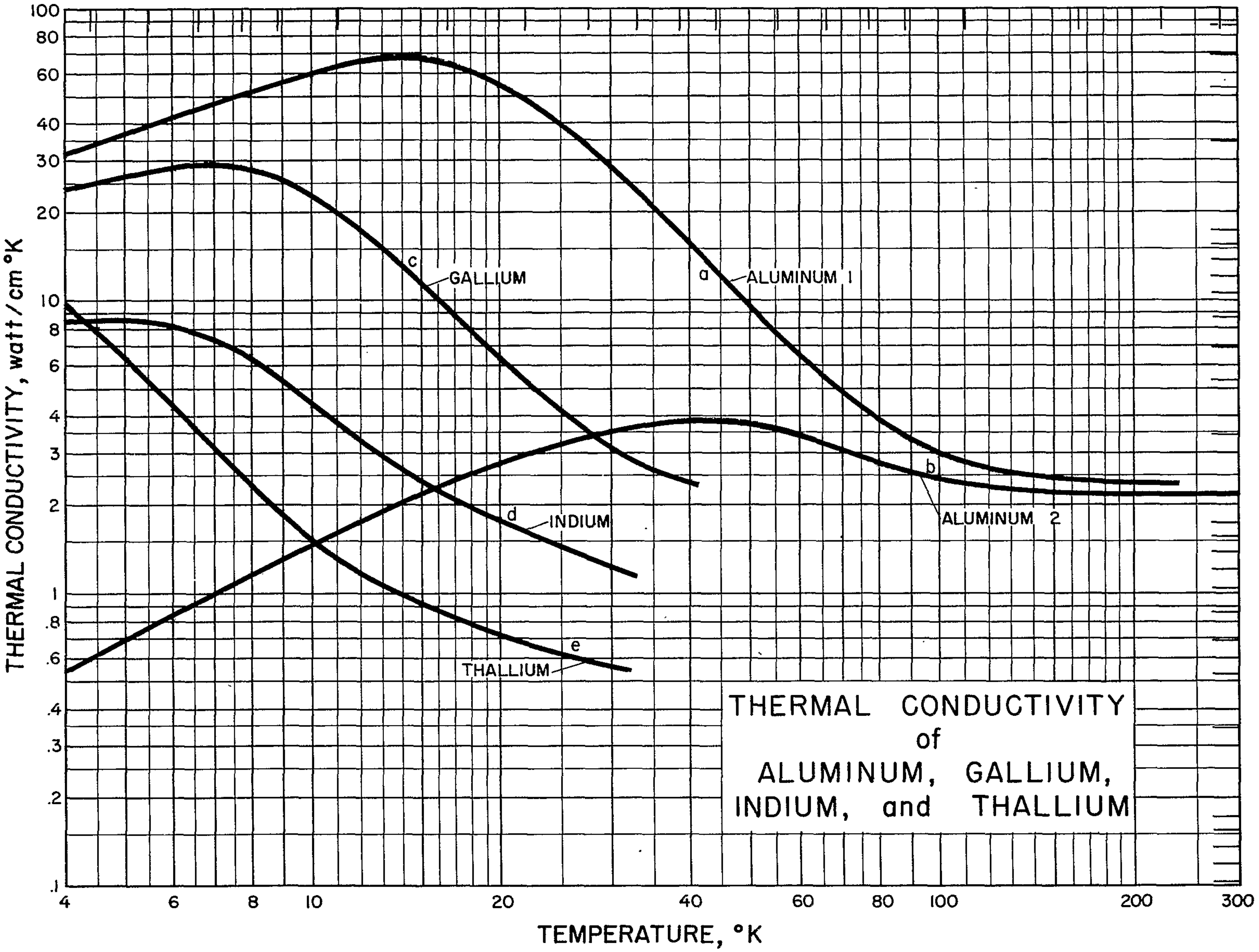

THERMAL CONDUCTIVITY of ALUMINUM, GALLIUM, INDIUM, and THALLIUM

THERMAL CONDUCTIVITY INTEGRALS
for ALUMINUM, GALLIUM, INDIUM and THALLIUM

Comments: The curves for Aluminum-1, Gallium, Indium and Thallium have been extrapolated to 300°K. It is estimated that the extrapolated values deviate no more than 10% from the probable values.

$$Q = \frac{A}{L} \int_{T_o}^{T_L} \lambda \, dT; \qquad Q \frac{L}{A} = \int_{T_o}^{T_L} \lambda \, dT$$

Where:

Q = heat flow in watts
A = cross sectional area in cm^2
L = length in cm
λ = thermal conductivity in watts/cm-°K
T = temperature in °K
T_o = initial temperature (4°K)

Thermal Conductivity Integrals are on following page.

Temp. °K	Thermal Conductivity watts/cm-°K				
	Aluminum-1	Aluminum-2	Gallium	Indium	Thallium
4	31.5	.54	24.0	8.4	9.8
6	42	.84	28.0	8.2	4.4
8	52	1.2	28.0	6.3	2.3
10	60	1.45	23	4.4	1.5
15	68	2.2	12	2.4	.92
20	55	2.75	6.3	1.8	.72
25	39	3.2	4.2	1.45	.62
30	28.5	3.5	3.2	1.2	.57
35	21	3.75	2.6	1.1 *	.52
40	16	3.8	2.35	1.0 *	.505*
50	9.5	3.75	2.1 *	.9 *	.47 *
60	6.6	3.4	1.85*	.84*	.46 *
70	4.95	3.1	1.8 *	.8 *	.44 *
76	4.3	2.9	1.75*	.79*	.42 *
80	3.9	2.8	1.7 *	.77*	.42 *
90	3.35	2.6	1.65*	.73*	.42 *
100	3.0	2.4	1.55*	.72*	.42 *
120	2.7	2.3	1.50*	.70*	.40 *
140	2.5	2.2	1.4 *	.69*	.39 *
160	2.4	2.2	1.4 *	.68*	.39 *
180	2.35	2.2	1.4 *	.67*	.38 *
200	2.35	2.2	1.4 *	.66*	.38 *
250	2.35*	2.2	1.4 *	.66*	.38 *
300	2.35*	2.2	1.4 *	.66*	.38 *

* Extrapolated Values

THERMAL CONDUCTIVITY INTEGRALS
for ALUMINUM, GALLIUM, INDIUM and THALLIUM (cont.)

Temp. °K	$\int_{T_o}^{T_L} \lambda \, dT$ watts/cm				
	Aluminum-1	Aluminum-2	Gallium	Indium	Thallium
6	73.5	1.38	52	16.6	14.2
8	168	3.42	108	31.1	20.9
10	280	6.07	159	41.8	24.7
15	600	15.2	246	58.8	30.8
20	907	27.6	292	69.3	34.8
25	1140	42.4	318	77.4	38.2
30	1310	59.2	337	84.0	41.2
35	1430	77.3	352	89.8	43.9
40	1530	96.2	364	95.0	46.5
50	1650	134	386	104	51.3
60	1740	170	406	113	56.0
70	1790	202	424	121	60.5
76	1820	220	435	126	63.1
80	1840	232	442	129	64.7
90	1870	258	458	137	68.9
100	1900	284	474	144	73.1
120	1960	330	505	158	81.3
140	2010	376	534	172	89.2
160	2060	420	562	186	97.0
180	2110	464	590	199	105
200	2160	508	618	213	112
250	2270	618	688	246	131
300	2390	728	758	279	150

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THERMAL CONDUCTIVITY
of TIN and LEAD

Source of Data: (a) H.M. Rosenberg, Phil.Trans. Roy. Soc. (London) A247, 441-497 (1955)

(b) Same as (a) and W. Meissner, Ann. Physik 47, 1001-1058 (1915)

Comments: (a) Tin; 99.995% pure, single crystal, (Johnson, Matthey)

(b) Lead; 99.998% pure, single crystal (Tadanac) and 99.998% pure, cold drawn, (Kahlbaum)

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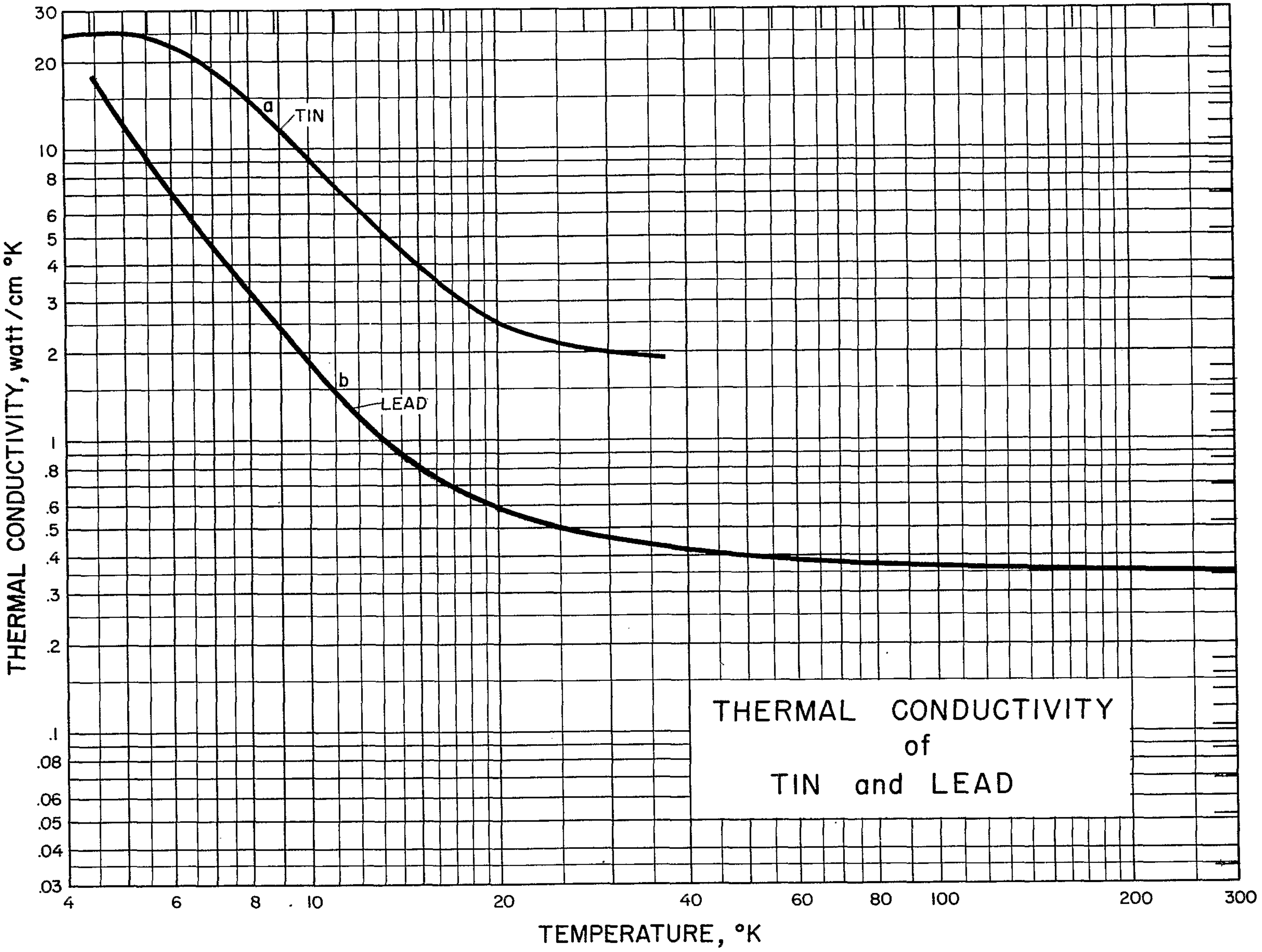

THERMAL CONDUCTIVITY of TIN and LEAD

THERMAL CONDUCTIVITY INTEGRALS
for TIN and LEAD†

Comments: The curve for Tin was extrapolated to 300°K; the curve for Lead was extrapolated to 4°K. It is estimated that the extrapolated values deviate no more than 10% from the probable values.

$$Q = \frac{A}{L} \int_{T_O}^{T_L} \lambda \, dT; \qquad Q \frac{L}{A} = \int_{T_O}^{T_L} \lambda \, dT$$

Where:

Q = heat flow in watts
A = cross sectional area in cm^2
L = length in cm
λ = thermal conductivity in watts/cm-°K
T = temperature in °K
T_O = initial temperature (4°K)

Temp. °K	Thermal Conductivity watts/cm-°K		$\int_{T_O}^{T_L} \lambda \, dT$ watts/cm	
	Tin	Lead	Tin	Lead
4	25	20*		
6	24	7.0	48.0	27.0
8	14.9	3.3	86.0	37.3
10	9.1	1.8	110	42.4
15	4.0	.82	143	49.0
20	2.5	.59	159	52.5
25	2.2	.5	171	55.2
30	2.0	.47	181	57.6
35	1.9	.44	191	59.9
40	1.9*	.42	201	63.3
50	1.9*	.40	220	69.9
60	1.9*	.38	239	73.8
70	1.9*	.38	258	77.6
76	1.9*	.37	269	79.9
80	1.9*	.37	277	81.3
90	1.8*	.37	295	85.0
100	1.8*	.36	313	88.7
120	1.8*	.36	349	95.9
140	1.8*	.36	385	103
160	1.8*	.36	421	110
180	1.8*	.36	457	117
200	1.8*	.35	493	125
250	1.8*	.35	583	142
300	1.8*	.35	673	160

* Extrapolated Values † See second page of the preface.

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THERMAL CONDUCTIVITY of VANADIUM, NIOBIUM, and TANTALUM

Source of Data: (a) G. K. White and S. B. Woods, Can. J. Physics 35, 892-900 (1957)

(b) Same as (a)

(c) H. M. Rosenberg, Phil. Trans. Roy. Soc. (London) A247, 441-497 (1955)

Comments: (a) Vanadium; 99.9% pure, (Electrometallurgical Co.)

(b) Niobium; 99.9% pure, annealed in vacuum, (Fansteel Metal)

(c) Tantalum; 99.98% pure, (Johnson, Matthey)

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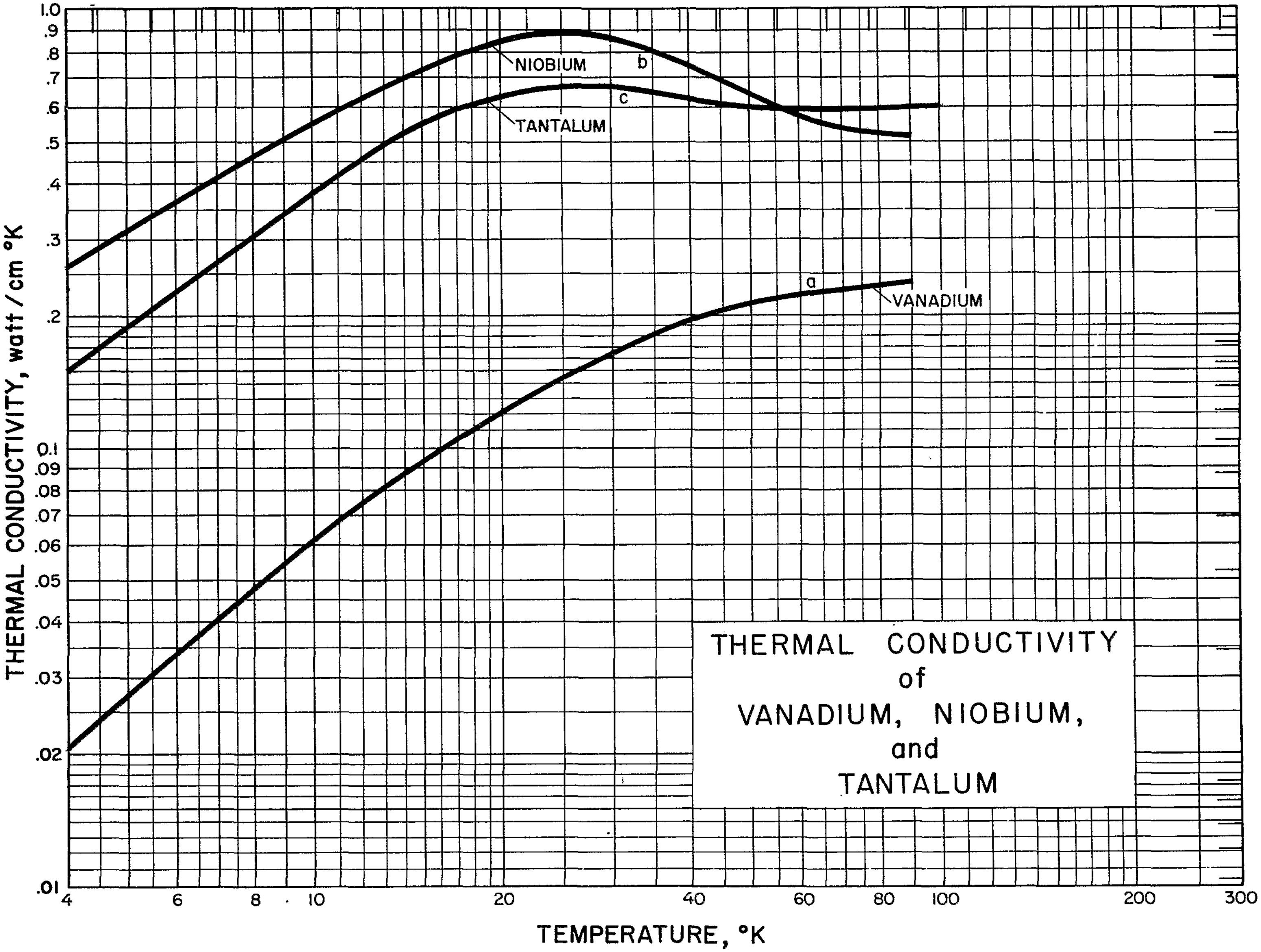
THERMAL CONDUCTIVITY of VANADIUM, NIOBIUM, and TANTALUM
NIOBIUM
b
c
TANTALUM
a
VANADIUM
THERMAL CONDUCTIVITY, watt / cm °K
1.0
.9
.8
.7
.6
.5
.4
.3
.2
0.1
.09
.08
.07
.06
.05
.04
.03
.02
.01
4
6
8
10
20
40
60
80
100
200
300
TEMPERATURE, °K

THERMAL CONDUCTIVITY INTEGRALS†
for VANADIUM, NIOBIUM and TANTALUM

Comments: The curves for Vanadium, Niobium and Tantalum have been extrapolated to 300°K. It is estimated that the extrapolated values deviate no more than 10% from the probable values.

$$Q = \frac{A}{L} \int_{T_o}^{T_L} \lambda \, dT; \qquad Q \frac{L}{A} = \int_{T_o}^{T_L} \lambda \, dT$$

Where:

Q = heat flow in watts
A = cross sectional area in cm^2
L = length in cm
λ = thermal conductivity in watts/cm-°K
T = temperature in °K
T_o = initial temperature (4°K)

Temp. °K	Thermal Conductivity watts/cm-°K			$\int_{T_o}^{T_L} \lambda \, dT$ watts/cm		
	Niobium	Tantalum	Vanadium	Niobium	Tantalum	Vanadium
4	.26	.15	.021			
6	.36	.23	.034	.620	.380	.055
8	.46	.30	.048	1.44	.910	.137
10	.55	.38	.062	2.45	1.59	.247
15	.72	.55	.093	5.62	3.92	.634
20	.84	.63	.120	9.52	6.86	1.17
25	.88	.68	.143	13.8	10.1	1.82
30	.87	.67	.164	18.2	13.5	2.59
35	.80	.65	.180	22.4	16.8	3.45
40	.74	.63	.196	26.2	20.0	4.39
50	.65	.60	.215	33.2	26.2	6.45
60	.58	.60	.225	39.3	32.2	8.65
70	.54	.60	.23	44.9	38.2	10.9
76	.53	.60	.235	48.1	41.8	12.3
80	.52	.60	.24	50.2	44.2	13.3
90	.51	.61	.245	55.4	50.2	15.7
100	.51*	.61	.245*	60.5	56.3	18.1
120	.50*	.61*	.245*	70.6	68.5	23.0
140	.50*	.62*	.245*	80.6	80.8	27.9
160	.50*	.63*	.25 *	90.6	93.3	32.9
180	.50*	.65*	.25 *	101	106	37.9
200	.50*	.66*	.25 *	110	119	42.9
250	.50*	.68*	.25 *	136	153	55.4
300	.50*	.69*	.25 *	160	187	67.9

* Extrapolated Values

† See second page of the preface.

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THERMAL CONDUCTIVITY OF CHROMIUM, MOLYBDENUM, and TUNGSTEN

Source of Data: (a) A.F.A. Harper, W.R.G. Kemp, P.G. Klemens, R.J. Tainsh, and G.K. White, Phil. Mag. 2, 577-583 (1957).

(b). H.M. Rosenberg, Phil. Trans. Roy. Soc. (London) A247, 441-497 (1955); W.G. Kannaluik, Proc. Roy. Soc. (London) A141, 159-168 (1933)

(c). W.J. deHaas and J. deNobel, Physica 5, 449-463 (1938)

Comments: (a) Chromium; 99.998% pure, recrystallized.

(b) Molybdenum; 99.95% pure and 99.8% pure

(c) Tungsten; Philips, single crystal

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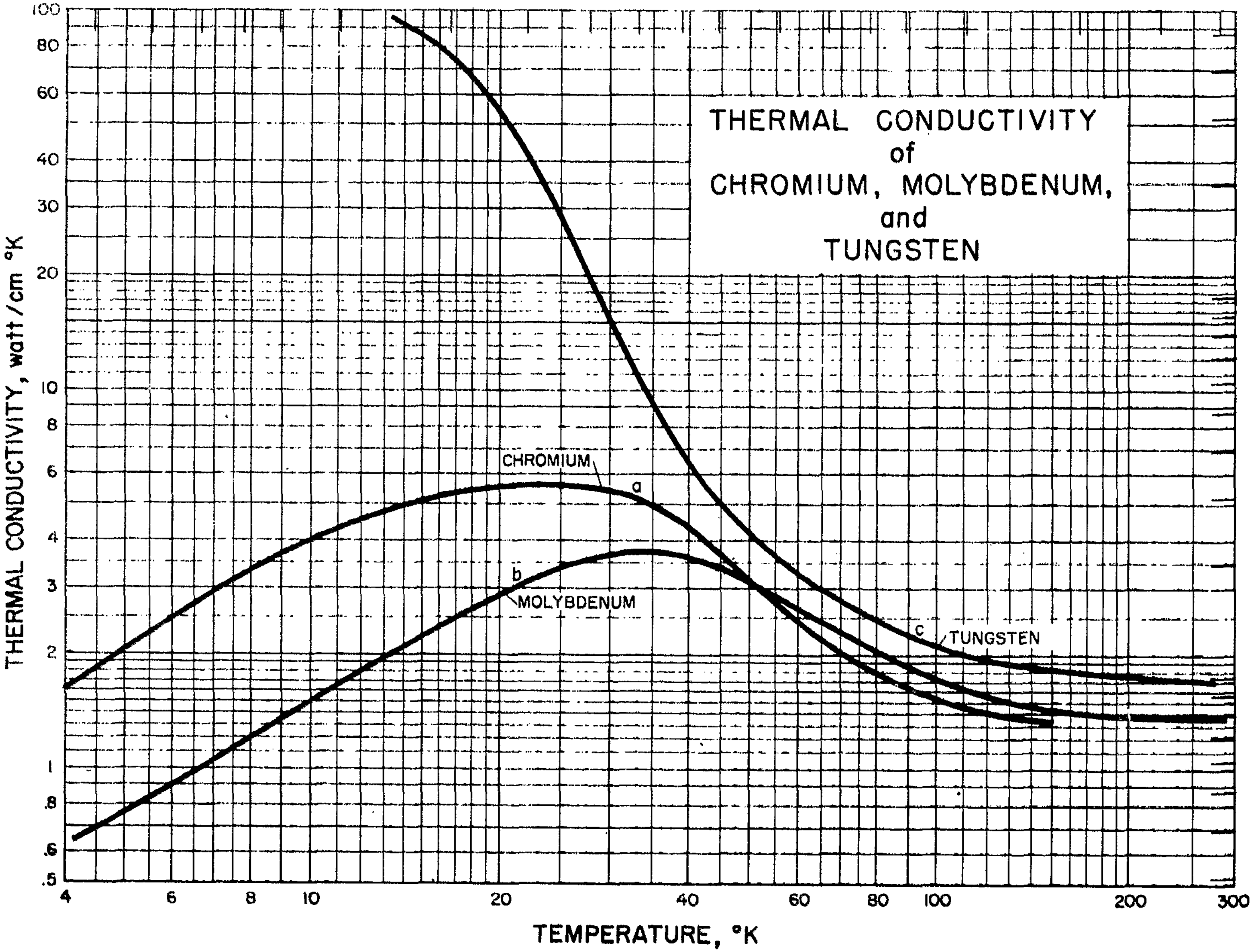
THERMAL CONDUCTIVITY
of
CHROMIUM, MOLYBDENUM,
and
TUNGSTEN
THERMAL CONDUCTIVITY, watt / cm °K
100
80
60
40
30
20
10
8
6
4
3
2
1
.8
.6
.5
TEMPERATURE, °K
4
6
8
10
20
40
60
80
100
200
300
CHROMIUM
a
b
MOLYBDENUM
c
TUNGSTEN

THERMAL CONDUCTIVITY INTEGRALS

for CHROMIUM, MOLYBDENUM and TUNGSTEN

Comments: The curve for Chromium was extrapolated to 300°K; the curve for Tungsten was extrapolated to 4°K. It is estimated that the extrapolated values do not deviate more than 10% from the probable values.

$$Q = \frac{A}{L} \int_{T_o}^{T_L} \lambda \, dT; \qquad Q \frac{L}{A} = \int_{T_o}^{T_L} \lambda \, dT$$

Where:

Q = heat flow in watts
A = cross sectional area in cm^2
L = length in cm
λ = thermal conductivity in watts/cm-°K
T = temperature in °K
T_o = initial temperature (4°K)

Temp. °K	Thermal Conductivity watts/cm-°K			$\int_{T_o}^{T_L} \lambda \, dT$ watts/cm		
	Cr	Mb	W	Cr	Mb	W
4	1.62	.62	46*			
6	2.5	.90	67*	4.12	1.52	119
8	3.3	1.20	83*	9.92	3.62	282
10	4.0	1.50	100*	17.2	6.32	472
15	5.1	2.25	86	40.0	15.7	937
20	5.6	2.9	54	66.7	28.6	1290
25	5.7	3.4	28	95.0	44.3	1500
30	5.4	3.7	15	123	62.1	1600
35	5.0	3.75	9.0	149	80.7	1660
40	4.2	3.6	6.5	172	99.1	1700
50	3.2	3.2	4.2	209	133	1760
60	2.4	2.7	3.3	238	163	1790
70	2.0	2.3	2.8	260	188	1820
76	1.9	2.2	2.6	272	201	1840
80	1.8	2.1	2.5	280	210	1850
90	1.65	1.86	2.3	297	229	1880
100	1.53	1.74	2.2	313	247	1900
120	1.40	1.57	1.93	342	281	1940
140	1.35	1.47	1.85	370	311	1980
160	1.32*	1.41	1.80	396	340	2010
180	1.30*	1.40	1.78	422	368	2050
200	1.30*	1.38	1.76	448	396	2080
250	1.25*	1.37	1.70	512	464	2170
300	1.25*	1.37	1.70	575	533	2260

* Extrapolated Values

Reprinted from WADD TECH. REPORT 60-56

THERMAL CONDUCTIVITY of IRON, COBALT, and NICKEL

Source of Data:

(a) H.M. Rosenberg, Phil. Trans. Roy. Soc. (London) A247, 441-497 (1955)
R.W. Powers, J.B. Ziegler and H.L. Johnston, TR 264-6, Cryogenics Laboratory, Ohio State University, 17 pp (1951)

(b) G.K. White and S.B. Woods, Can. J. Physics 35, 656-665 (1957)

(c) W.R.G. Kemp, P.G. Klemens, and G.K. White, Aust. J. Physics 9, 180-188 (1956)

(d) R.W. Powers, D. Schwartz and H.L. Johnston, TR 264-5, Cryogenic Laboratory, Ohio State University 11 pp (1951)

Comments:

(a) Iron; 99.99% pure, annealed, (Johnson, Matthey) and 99.99% pure, (Johnson, Matthey)

(b) Cobalt; 99.99% pure, annealed, Johnson, Matthey)

(c) Nickel-1; 99.99% pure, annealed, (Johnson, Matthey)

(d) Nickel-2; 99% pure (Int. Nickel)

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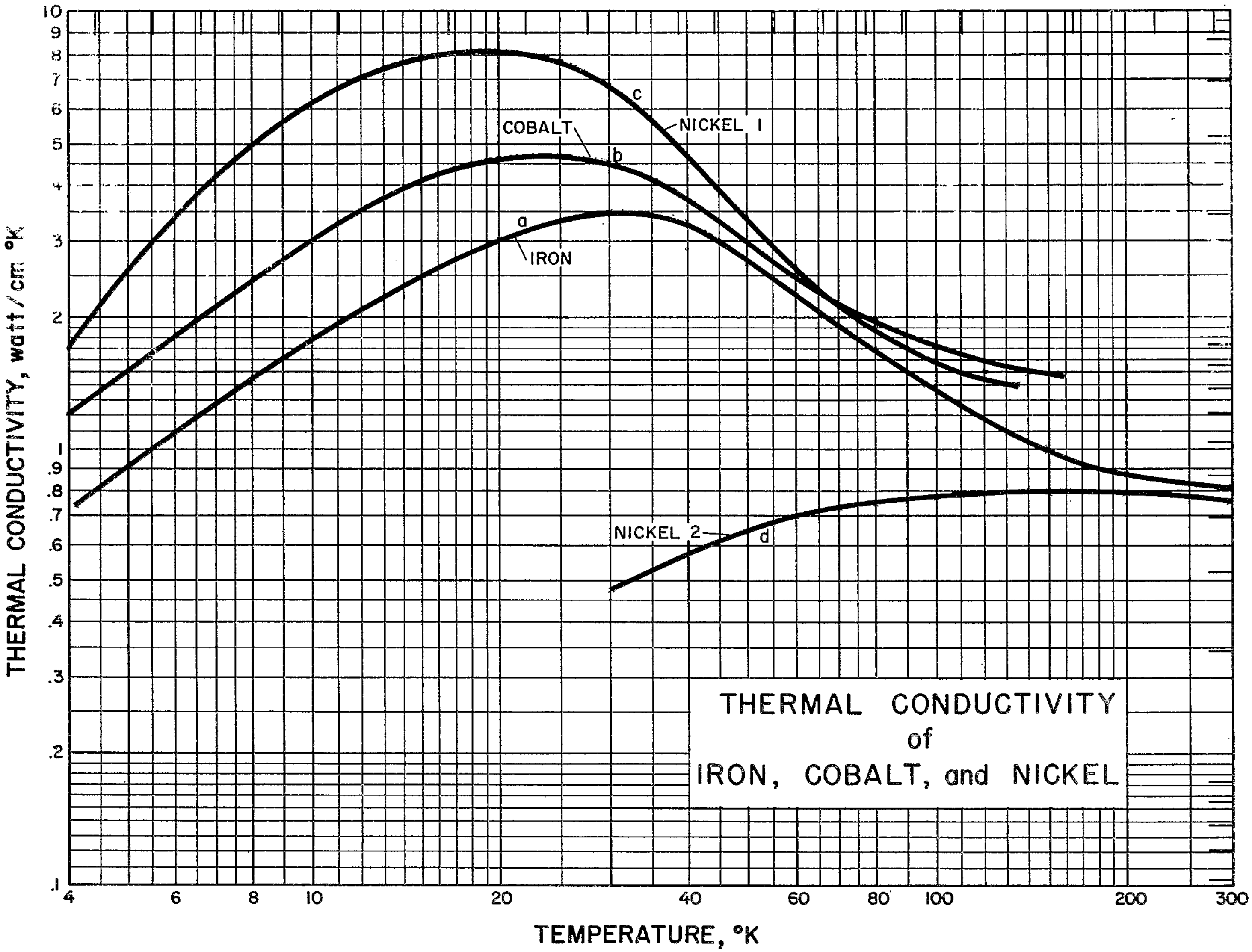
THERMAL CONDUCTIVITY of IRON, COBALT, and NICKEL
THERMAL CONDUCTIVITY, watt / cm °K
TEMPERATURE, °K
10
9
8
7
6
5
4
3
2
1
.9
.8
.7
.6
.5
.4
.3
.2
.1
4
6
8
10
20
40
60
80
100
200
300
c
NICKEL 1
COBALT
b
a
IRON
NICKEL 2
d

THERMAL CONDUCTIVITY INTEGRALS
for IRON, COBALT and NICKEL

Comments: The curves for Cobalt and Nickel 1 were extrapolated to 300°K; the curve for Nickel 2 was extrapolated to 6°K. It is estimated that the extrapolated values do not deviate more than 10% from the probable values.

$$Q = \frac{A}{L} \int_{T_o}^{T_L} \lambda \, dT; \qquad Q \frac{L}{A} = \int_{T_o}^{T_L} \lambda \, dT$$

Where:

Q = heat flow in watts
A = cross sectional area in cm^2
L = length in cm
λ = thermal conductivity in watts/cm-°K
T = temperature in °K
T_o = initial temperature (6°K for Nickel 2; 4°K for all others)

Temp. °K	Thermal Conductivity watts/cm-°K				$\int_{T_o}^{T_L} \lambda \, dT$ watts/cm			
	Ni 1	Co	Fe	Ni 2	Ni 1	Co	Fe	Ni 2
4	1.7	1.20	.72					
6	3.4	1.8	1.1	.1 *	5.10	3.00	1.82	
8	5.0	2.4	1.44	.14*	13.5	7.20	4.36	.240
10	6.2	3.0	1.8	.17*	24.7	12.6	7.60	.550
15	7.9	4.1	2.5	.27*	60.0	30.4	18.4	1.65
20	8.0	4.6	3.0	.35*	99.7	52.1	32.1	3.20
25	7.8	4.7	3.3	.42*	139	75.4	47.9	5.13
30	6.8	4.5	3.5	.48*	176	98.4	64.9	7.38
35	5.7	4.1	3.4	.53	207	120	82.1	9.90
40	4.7	3.7	3.3	.58	233	139	98.9	12.7
50	3.3	3.0	2.7	.65	273	173	129	18.8
60	2.6	2.5	2.3	.70	302	200	154	25.6
70	2.2	2.3	1.9	.73	326	224	175	32.7
76	2.0	2.1	1.8	.75	339	238	186	37.2
80	1.87	1.95	1.7	.76	347	246	193	40.2
90	1.70	1.81	1.5	.77	365	264	209	47.8
100	1.60	1.70	1.37	.78	381	282	223	55.6
120	1.45	1.60	1.19	.80	412	315	249	71.4
140	1.39	1.50	1.04	.80	440	346	271	87.4
160	1.33*	1.47	.95	.80	467	376	291	103
180	1.31*	1.42*	.90	.80	494	405	310	119
200	1.30*	1.40*	.88	.80	520	433	327	135
250	1.30*	1.37*	.83	.78	585	502	370	175
300	1.30*	1.35*	.81	.76	650	570	411	213

* Extrapolated Values

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THERMAL CONDUCTIVITY OF RHODIUM, PALLADIUM, IRIDIUM, AND PLATINUM

Source of Data:

(a) G.K. White and S.B. Woods, Can. J. Physics 35, 248-257 (1957); R.W. Powell and R.P. Tye, "Int. Conf. on Low Temp" Paris, Sept. 1955.

(b) W.R.G. Kemp , P.G. Klemens, A.K. Sreedhar, and G.K. White, Phil. Mag. 46, 811-814 (1955).

(c) H.M. Rosenberg, Phil. Trans. Roy. Soc. (London) A247, 441-497 (1955); R.W. Powell and R.P. Tye, "Int. Conf. on Low Temp" Paris, Sept. 1955.

(d) H.M. Rosenberg, Phil. Trans. Roy. Soc. (London) A247, 441-497 (1955); W. Meissner, Ann. Physik 47, 1001-1058 (1915.

Comments:

(a) Rhodium; 99.99% pure, annealed, (Johnson, Matthey) and 99.9% pure, annealed, (Johnson, Matthey)

(b) Palladium; 99.99% pure, annealed, (Johnson, Matthey)

(c) Iridium; 99.995% pure, annealed, (Johnson, Matthey) and 99.9% pure, annealed, (Johnson, Matthey)

(d) Platinum; 99.999% pure, annealed, (Johnson, Matthey), and "very pure", annealed (Heraeus).

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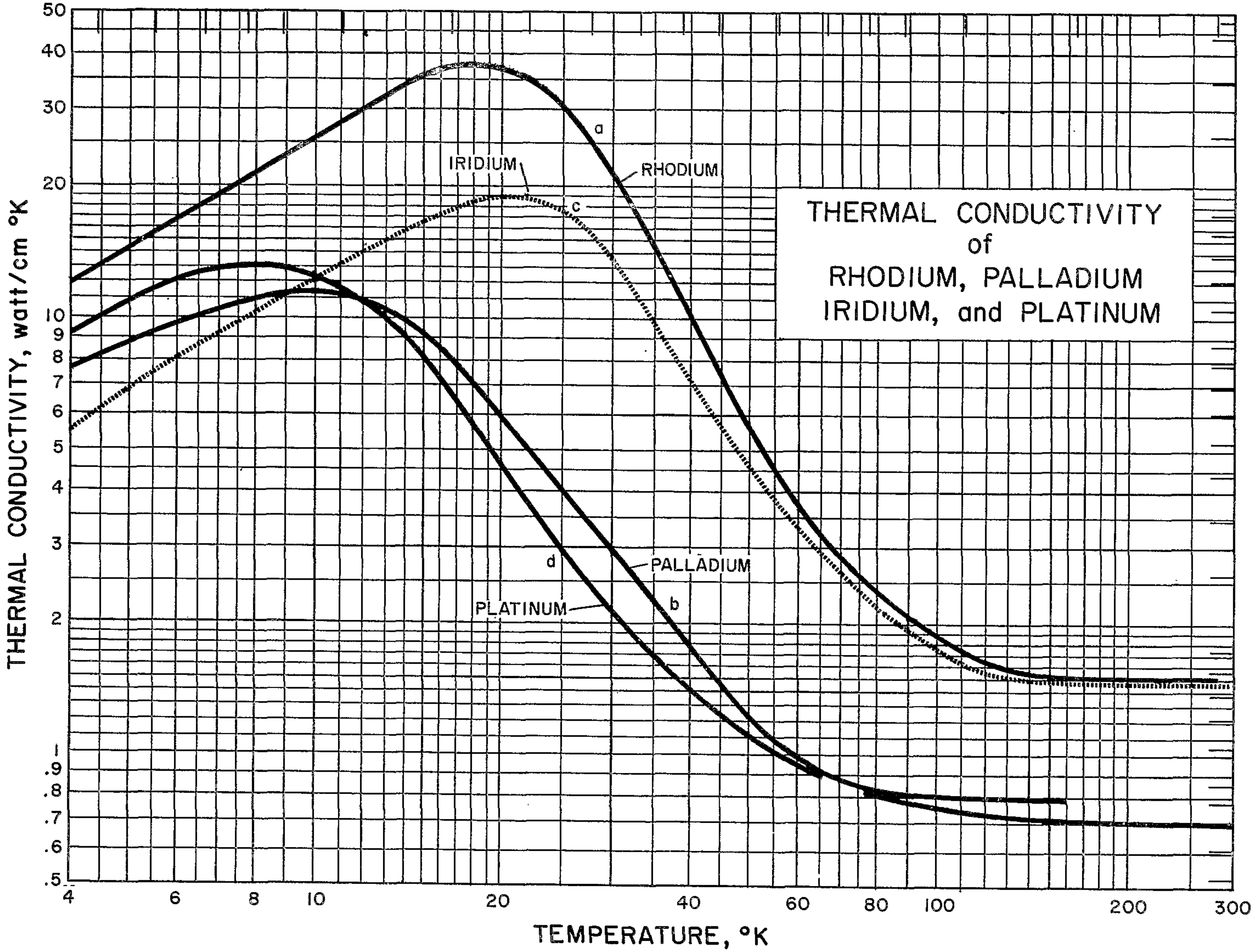
THERMAL CONDUCTIVITY
of
RHODIUM, PALLADIUM
IRIDIUM, and PLATINUM
THERMAL CONDUCTIVITY, watt/cm °K
TEMPERATURE, °K
RHODIUM
IRIDIUM
PALLADIUM
PLATINUM
a
b
c
d
50
40
30
20
10
9
8
7
6
5
4
3
2
1
.9
.8
.7
.6
.5
4
6
8
10
20
40
60
80
100
200
300

THERMAL CONDUCTIVITY INTEGRALS
for RHODIUM, PALLADIUM, IRIDIUM and PLATINUM

Comments: The thermal conductivity curve for Palladium has been extrapolated to 300°K. It is estimated that the extrapolated values deviate no more than 10% from the probable values.

$$Q = \frac{A}{L} \int_{T_o}^{T_L} \lambda \, dT; \qquad Q \frac{L}{A} = \int_{T_o}^{T_L} \lambda \, dT$$

Where:

Q = heat flow in watts
A = cross sectional area in cm^2
L = length in cm
λ = thermal conductivity in watts/cm-°K
T = temperature in °K
T_o = initial temperature (4°K)

Temp. °K	Thermal Conductivity watts/cm-°K				$\int_{T_o}^{T_L} \lambda \, dT$ watts/cm			
	Rh	Ir	Pd	Pt	Rh	Ir	Pd	Pt
4	12	5.5	7.7	9.2				
6	16.7	8.0	9.8	12	29.0	13.5	17.5	21.2
8	22	10.2	11.0	13	68.0	31.7	38.3	46.2
10	26	12.2	11.3	12.2	116	54.1	60.6	71.4
15	36	16.6	9.2	8	271	126	112	122
20	37	19	6	4.7	454	215	150	154
25	30	17.5	4	3	621	306	175	173
30	22	13.8	3	2.2	751	385	192	186
35	14.5	9.7	2.3	1.7	842	445	206	196
40	10	7.1	1.8	1.4	904	487	216	203
50	5.7	4.6	1.2	1.1	982	545	231	216
60	3.7	3.3	1.0	.95	1030	585	242	226
70	2.9	2.6	.88	.86	1060	614	251	235
76	2.6	2.4	.85	.83	1080	629	256	240
80	2.4	2.2	.83	.81	1090	639	260	244
90	2.1	1.95	.81	.78	1110	659	268	251
100	1.88	1.76	.80	.76	1130	677	276	259
120	1.65	1.55	.80	.73	1170	710	292	274
140	1.55	1.50	.80	.72	1200	741	308	288
160	1.51	1.48	.79	.71	1230	771	324	303
180	1.50	1.48	.79*	.70	1260	800	340	317
200	1.50	1.48	.79*	.70	1290	830	356	331
250	1.50	1.48	.79*	.70	1360	904	396	366
300	1.50	1.48	.79*	.70	1440	978	436	401

* Extrapolated Values

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THERMAL CONDUCTIVITY
of COPPER ALLOYS

Source of Data:
- (a) R. L. Powell, H. M. Roder, and W. M. Rogers, J. Appl. Phys. 28, 1282-1288 (1957).
- (b) Same as (a)
- (c) R. Berman, E. L. Foster, H. M. Rosenberg, Brit. J. Appl. Physics 6, 181-182 (1955).
- (d) R. Berman, Phil. Mag. 42, 642-650 (1951); C. H. Lees, Phil. Trans. Roy. Soc. (London) A208, 381-443 (1908).
- (e) C. H. Lees, Phil. Trans. Roy. Soc. (London) A208, 381-443 (1908).
- (f) Same as (a)

Comments:
- (a) Phos. Deox. Copper; 0.027% P, 99% Cu, Commercial hard temper.
- (b) (Pb) Brass; 35.7% Zn, 3.27% Pb, 1% Sn, 60% Cu, hard temper.
- (c) Beryllium Copper; 2% Be, 98% Cu, held at 300°C for two hours.
- (d) German Silver; 47% Cu, 41% Zn, 9% Ni, 2% Pb.; and 62% Cu, 22% Zn, 15% Ni.
- (e) Manganin; 84% Cu, 12% Mn, 4% Ni.
- (f) Silicon Bronze; 3.15% Si, 1.13% Mn, 1% Zn, 94% Cu, hard temper.

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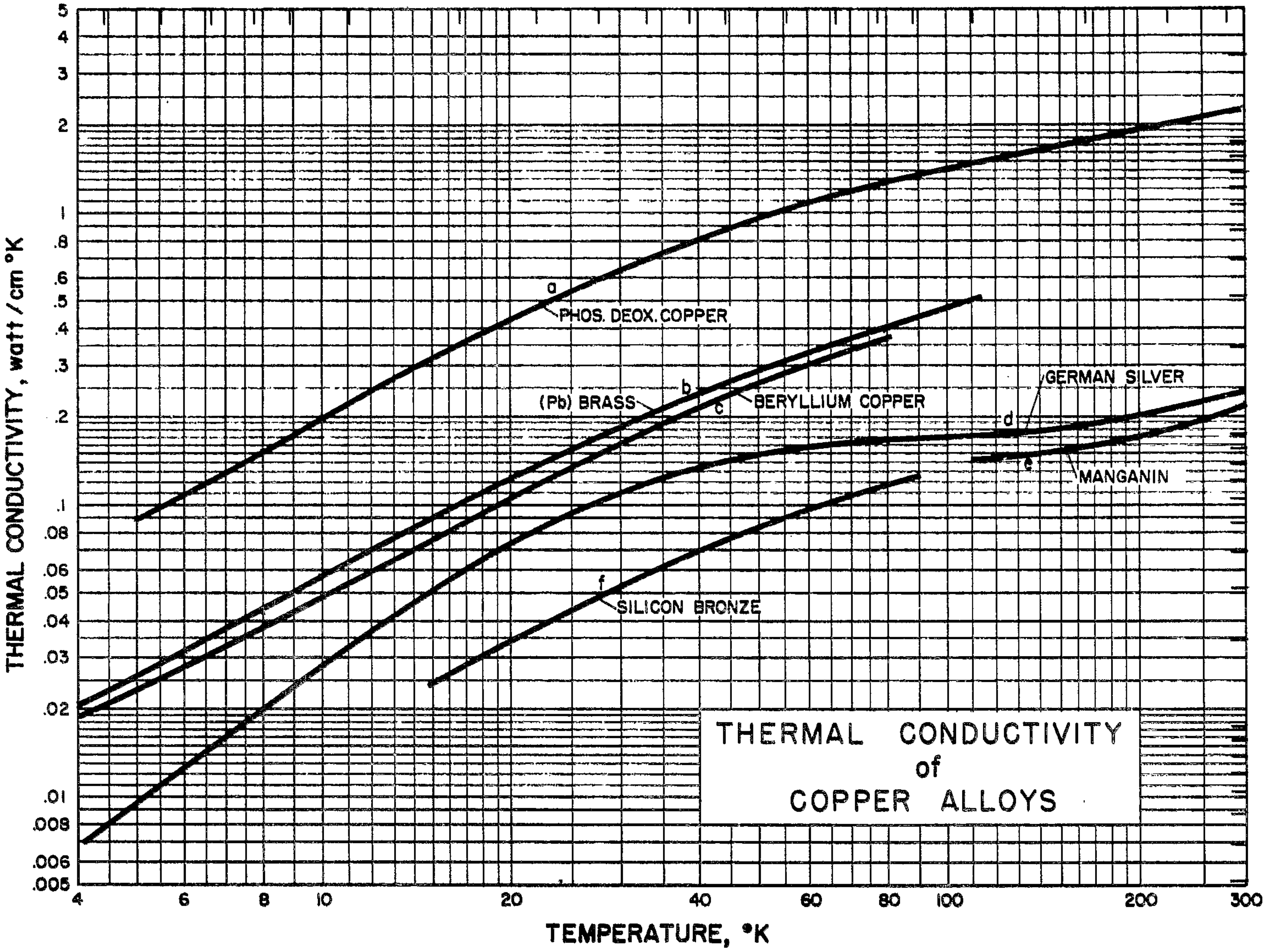

THERMAL CONDUCTIVITY
of
COPPER ALLOYS

THERMAL CONDUCTIVITY INTEGRALS
for COPPER ALLOYS

Comments: For the data tabulated below, the curves have been extrapolated as follows: Phos. Deox. Copper to 4°K; Silicon Bronze to 6°K and 300°K; Manganin to 20°K; (Pb) Brass and Beryllium Copper to 300°K. It is estimated that the extrapolated values deviate no more than 10% from the probable values.

$$Q = \frac{A}{L} \int_{T_o}^{T_L} \lambda \, dT; \qquad Q \frac{L}{A} = \int_{T_o}^{T_L} \lambda \, dT$$

Where:

Q = heat flow in watts
A = cross sectional area in cm^2
L = length in cm
λ = thermal conductivity in watts/cm-°K
T = temperature in °K
T_o = initial temperature (4°K for German Silver, Beryllium Copper, [Pb] Brass and Phos. Deox. Copper; 6°K for Silicon Bronze; 20°K for Manganin)

Thermal Conductivity Integrals are on following page.

Temp. °K	Thermal Conductivity watts/cm-°K					
	Phos. Deox Copper	Silicon Bronze	Manganin	(Pb) Brass	Beryllium Copper	German Silver
4	.067*			.021	.019	.0068
6	.109	.006*		.032	.028	.0128
8	.152	.01 *		.044	.038	.02
10	.196	.015*		.056	.048	.028
15	.32	.025		.09	.076	.052
20	.53	.034	.046*	.122	.106	.073
25	.63	.043	.064*	.153	.133	.092
30	.72	.052	.08 *	.183	.162	.11
35	.81	.061	.09 *	.21	.186	.122
40		.07	.10 *	.24	.21	.133
50	.96	.083	.11 *	.28	.26	.148
60	1.08	.096	.12 *	.33	.3	.158
70	1.18	.108	.13 *	.37	.34	.162
76	1.2	.112	.13 *	.38	.35	.165
80	1.27	.118	.13 *	.405	.37	.167
90	1.35	.126	.135*	.44	.4 *	.169
100	1.41	.136*	.14 *	.47	.42*	.17
120	1.52	.15 *	.143	.53*	.48*	.173
140	1.62	.16 *	.15	.6 *	.54*	.178
160	1.72	.17 *	.156	.65*	.58*	.185
180	1.83	.18 *	.162	.7 *	.62*	.192
200	1.92	.19 *	.17	.75*	.65*	.205
250	2.1	.20 *	.194	.85*	.7 *	.23
300	2.2	.22 *	.22	.9 *	.80*	.24

* Extrapolated Values

THERMAL CONDUCTIVITY INTEGRALS
for COPPER ALLOYS (cont.)

Temp. °K	$\int_{T_0}^{T_L} \lambda \, dT$ watts/cm					
	Phos. Deox. Copper	Silicon Bronze	Manganin	(Pb) Brass	Beryllium Copper	German Silver
6	.176			.053	.047	.0196
8	.437	.016		.129	.113	.0524
10	.785	.041		.229	.189	.100
15	2.08	.141		.594	.499	.300
20	3.95	.288		1.12	.954	.613
25	6.35	.481	.275	1.81	1.55	1.02
30	9.25	.718	.635	2.65	2.29	1.53
35	12.6	1.00	1.06	3.63	3.16	2.11
40	16.4	1.33	1.54	4.76	4.15	2.75
50	25.3	2.09	2.58	7.36	6.50	4.15
60	35.5	2.99	3.74	10.4	9.30	5.68
70	46.8	4.01	4.98	13.9	12.5	7.28
76	53.9	4.67	5.76	16.2	14.6	8.26
80	58.9	5.13	6.28	17.7	16.0	8.93
90	72.0	6.35	7.61	22.0	19.9	10.6
100	85.8	7.66	8.98	26.5	24.0	12.3
120	115	10.5	11.8	36.5	33.0	15.7
140	146	13.6	14.7	47.8	43.2	19.2
160	180	16.9	17.8	60.3	54.4	22.9
180	215	20.4	21.0	73.8	66.4	26.6
200	253	24.1	24.3	88.3	79.1	30.6
250	353	33.9	33.4	128	113	41.5
300	461	44.4	43.8	172	150	53.2

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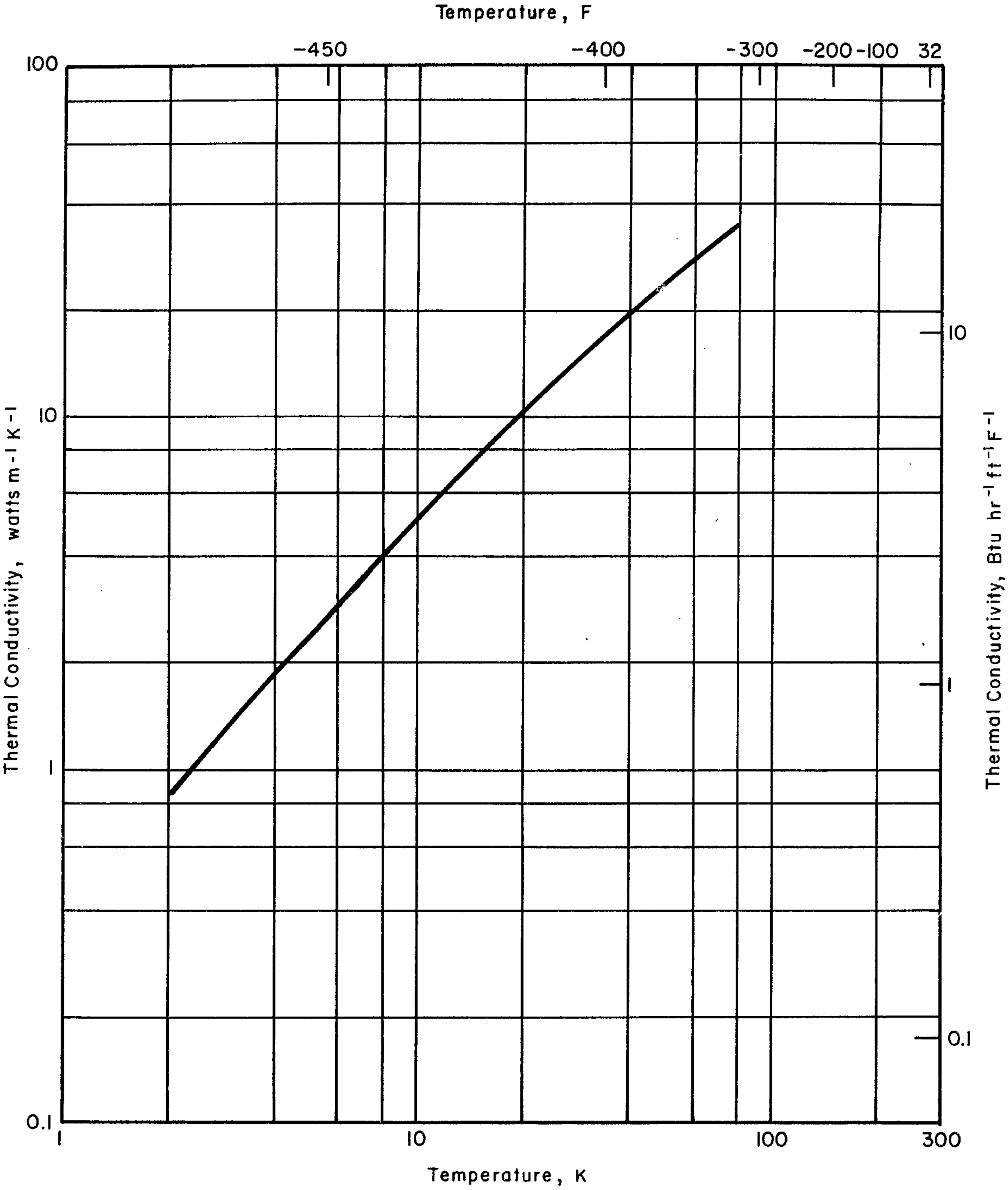

THERMAL CONDUCTIVITY VERSUS TEMPERATURE FOR COPPER ALLOY 98 CU-2 BE

THERMAL CONDUCTIVITY of COPPER-NICKEL and SILVER ALLOYS

Source of Data:	(a)	I. Estermann and J. E. Zimmerman, J. Appl. Phys. 23, 578-588 (1952)
	(b)	Same as (a).
	(c)	R. L. Powell, Unpublished (1953)
	(d)	R. Berman, Phil. Mag. 42, 642-650 (1951); R. W. Powers, J. B. Zeigler and H. L Johnston, TR 264-8, Ohio State Univ. (1951)

Comments:

(a) Cu-Ni (annealed; 90% Cu, 10% Ni; annealed

(b) Cu-Ni (cold); 90% Cu, 10% Ni; cold-worked

(c) Ag-Solder; 50% Ag, 15.5% Cu, 16.5% Zn, 18% Cd

(d) Constantan; 60% Cu, 40% Ni; and 55% Cu, 45% Ni.

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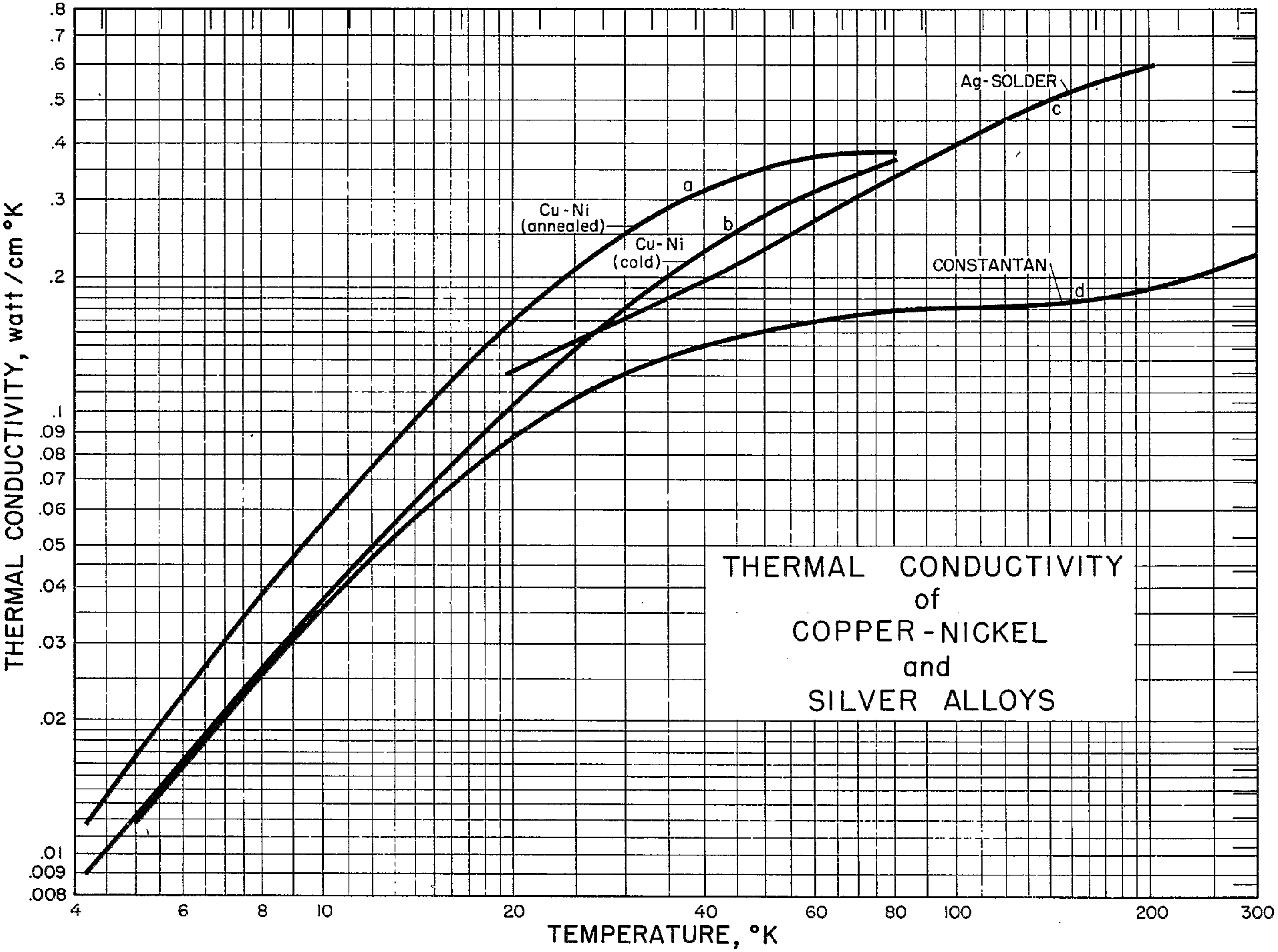

THERMAL CONDUCTIVITY of COPPER-NICKEL and SILVER ALLOYS

THERMAL CONDUCTIVITY INTEGRALS
for COPPER-NICKEL and SILVER ALLOYS

Comments: The curves for Cu-Ni (annealed), Cu-Ni (cold) and Ag-Solder were extrapolated to 300°K. The curve for Ag-Solder was also extrapolated to 4°K. It is estimated that the extrapolated values do not deviate more than 10% from the probable value.

$$Q = \frac{A}{L}\int_{T_0}^{T_L} \lambda \, dT; \qquad Q\,\frac{L}{A} = \int_{T_0}^{T_L} \lambda \, dT$$

Where:
Q = heat flow in watts
A = cross sectional area in cm^2
L = length in cm
λ = thermal conductivity in watts/cm-°K
T = temperature in °K
T_0 = initial temperature (4°K)

Temp. °K	Thermal Conductivity watts/cm-°K				$\int_{T_0}^{T_L} \lambda \, dT$ watts/cm			
	Ag Solder	Cu-Ni Anneal.	Cu-Ni Cold	Con-stantan	Ag Solder	Cu-Ni Anneal.	Cu-Ni Cold	Con-stantan
4	.022*	.011	.0083	.0080				
6	.037*	.023	.016	.0158	.059	.034	.024	.024
8	.052*	.038	.027	.026	.148	.095	.067	.066
10	.068*	.057	.037	.036	.268	.190	.131	.128
15	.10 *	.106	.07	.063	.688	.353	.399	.375
20	.124	.16	.103	.088	1.25	1.02	.831	.753
25	.142	.21	.137	.108	1.92	1.94	1.43	1.24
30	.16	.25	.17	.12	2.67	3.09	2.20	1.81
35	.18	.28	.20	.132	3.52	4.42	3.12	2.44
40	.20	.32	.23	.14	4.47	1.92	4.20	3.12
50	.23	.35	.28	.15	6.62	9.27	6.75	4.57
60	.27	.37	.32	.16	9.12	12.9	9.75	6.12
70	.30	.38	.34	.165	12.0	16.6	13.0	7.75
76	.33	.38	.36	.169	13.9	18.9	15.1	8.75
80	.34	.38	.37	.170	15.2	20.4	16.6	9.43
90	.37	.38*	.38*	.170	18.7	24.2	20.4	11.1
100	.40	.38*	.40*	.170	22.6	28.0	24.3	12.8
120	.45	.39*	.42*	.171	31.1	35.7	32.5	16.2
140	.50	.39*	.42*	.174	40.6	43.5	40.9	19.7
160	.54	.39*	.42*	.180	51.0	51.3	49.3	23.2
180	.58	.39*	.42*	.183	62.2	59.1	57.7	26.9
200	.60	.40*	.42*	.19	74.0	67.0	66.1	30.6
250	.65*	.40*	.42*	.21	105	87.0	87.1	40.6
300	.68*	.40*	.42*	.23	138	107.0	108.	51.6

* Extrapolated Values

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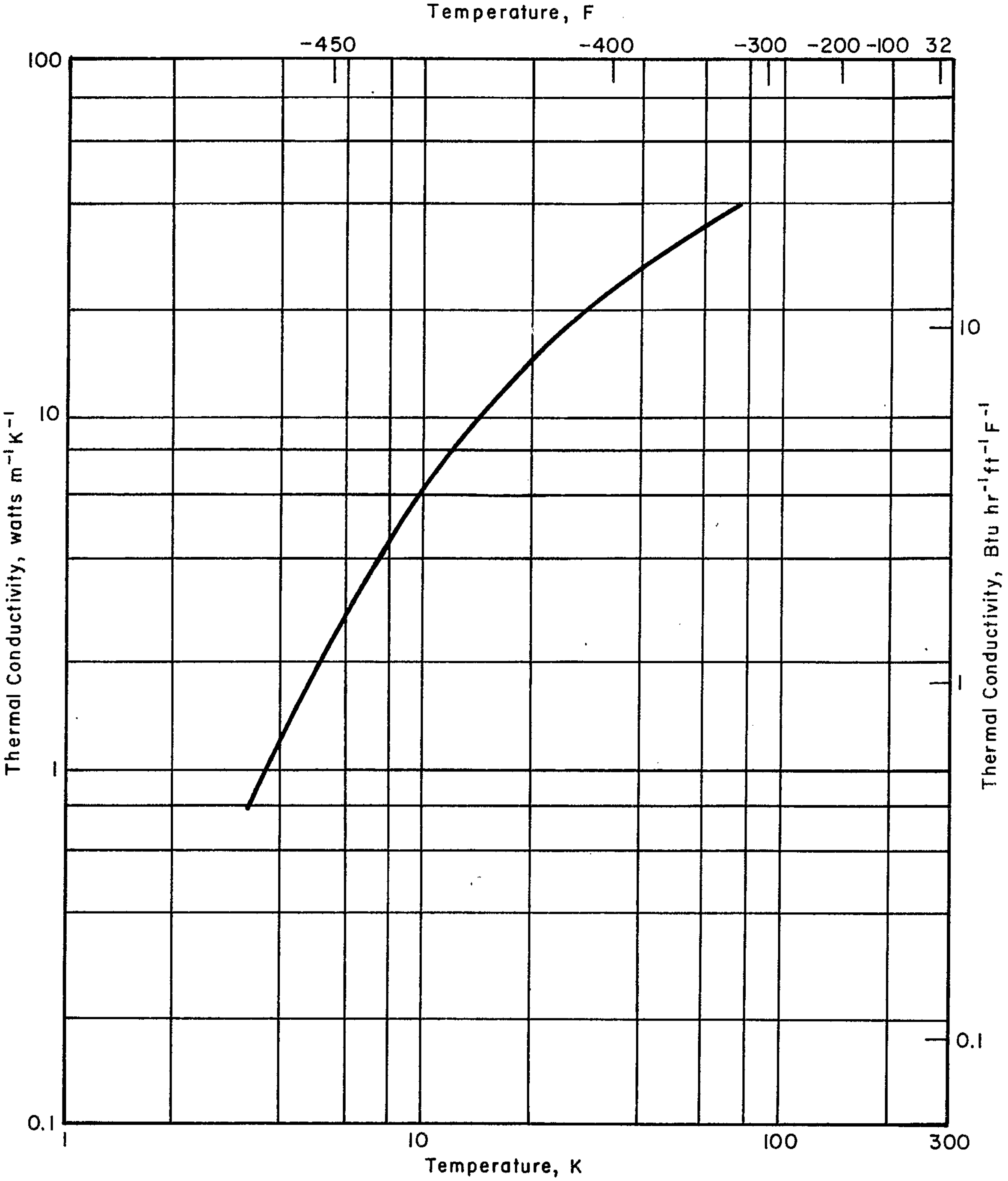

THERMAL CONDUCTIVITY VERSUS TEMPERATURE FOR COPPER ALLOY 90 CU- 10 NI

THERMAL CONDUCTIVITY of ALUMINUM ALLOYS

Source of Data:
(a) R. L. Powell, W. J. Hall, and H. M. Roder, to be published (1958)
(b) Same as (a)
(c) Same as (a)
(d) R. W. Powers, J. B. Ziegler, and H. L. Johnston, TR 264-7, Cryogenics Laboratory, Ohio State University 10 pp. (1951)
(e) Same as (a)
(f) Same as (a)
(g) Same as (d)
(h) Same as (a)

Comments:
(a) 1100-F; Alcoa, 99% Al, as fabricated.
(b) 6063-T5; Alcoa, 0.4% Si, 0.7% Mg, 98.5% Al, as fabricated.
(c) 3003-F; Alcoa, 1.2% Mn, 98.5% Al, as fabricated.
(d) 4 S; 0.16% Cu, 1.02% Mg, 1.20% Mn, 0.52% Fe, 0.13% Si, 0.02% Cr, 0.02% Ti.
(e) 5052-0; 0.25% Cr, 2.5% Mg, 97% Al, annealed.
(f) 5154-0; 0.25% Cr, 3.5% Mg, 96% Al, annealed.
(g) 75-S; 1.5% Cu, 5.5% Zn, 2.5% Mg, 0.2% Mn, 0.3% Cr.
(h) 2024-T4; 0.6% Mn, 1.5% Mg, 4.5% Cu, 93% Al, solution heat treated.

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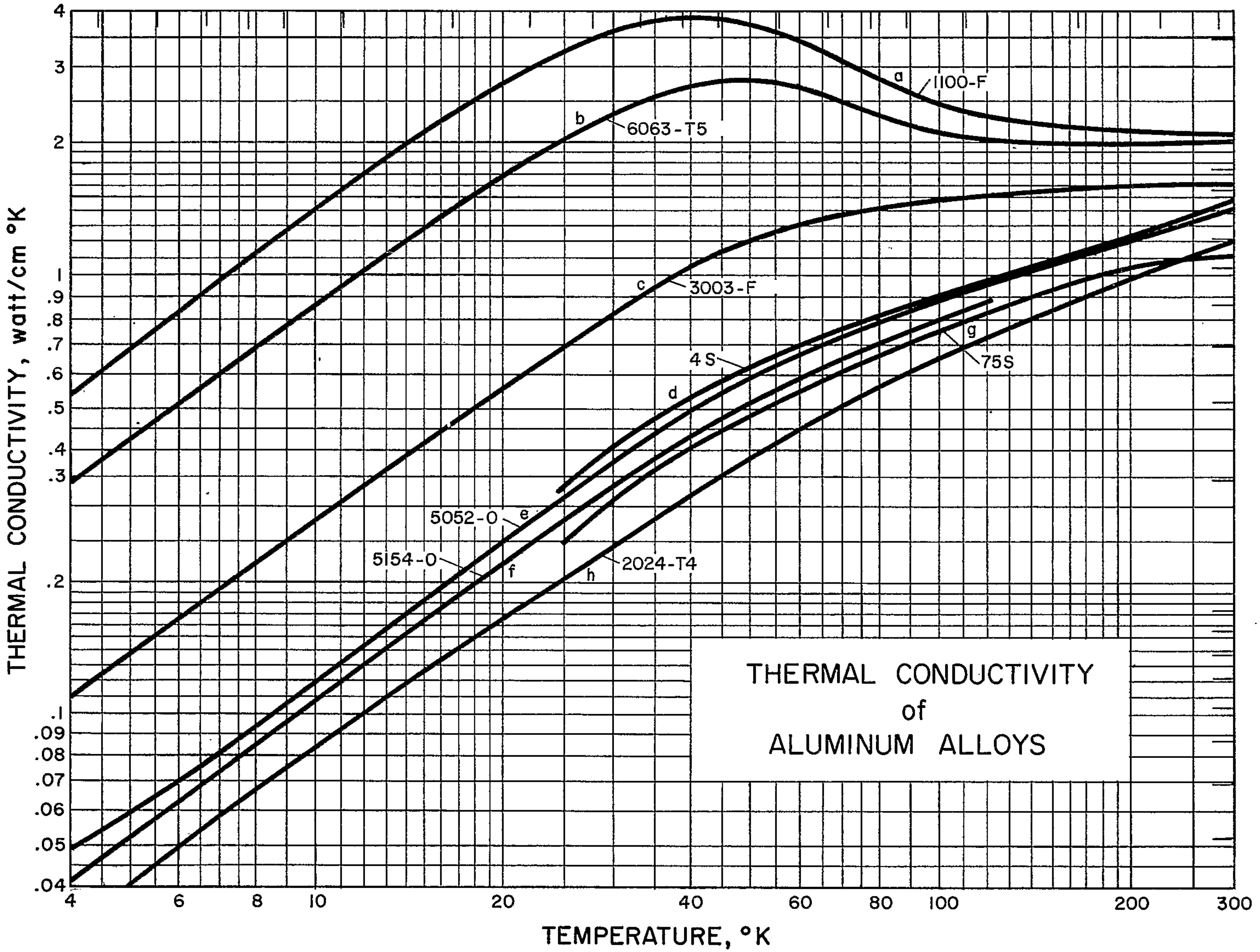

THERMAL CONDUCTIVITY of ALUMINUM ALLOYS

THERMAL CONDUCTIVITY INTEGRALS
for ALUMINUM ALLOYS

Comments: The Thermal Conductivity curves for 4 S, 75 S and 2024-T4 have been extrapolated to 4°K. The curve for 5154-0 has been extrapolated to 300°K. It is estimated that the extrapolated values deviate no more than 10% from the probable values.

$$Q = \frac{A}{L} \int_{T_0}^{T_L} \lambda \, dT; \qquad Q \frac{L}{A} = \int_{T_0}^{T_L} \lambda \, dT$$

Where:
Q = heat flow in watts
A = cross sectional area in cm^2
L = length in cm
λ = thermal conductivity in watts/cm-°K
T = temperature in °K
T_0 = initial temperature (4°K)

The Thermal Conductivity Integrals are on the following page.

Temp. °K	Thermal Conductivity watts/cm-°K							
	1100-F	6063-T5	3003-F	4 S	5052-0	5154-0	75 S	2024-T4
4	.55	.34	.11	.053*	.049	.041	.037*	.03*
6	.83	.51	.165	.078*	.07	.062	.057*	.05
8	1.12	.69	.23	.105*	.093	.085	.078*	.067
10	1.4	.86	.27	.13 *	.12	.108	.10 *	.083
15	2.2	1.3	.42	.20 *	.19	.163	.15 *	.127
20	2.8	1.7	.56	.27 *	.25	.23	.20 *	.165
25	3.3	2.0	.70	.34	.32	.28	.25	.20
30	3.6	2.3	.82	.41	.38	.33	.31	.24
35	3.8	2.6	.95	.48	.44	.38	.36	.28
40	3.9	2.7	1.05	.54	.50	.43	.40	.32
50	3.7	2.8	1.20	.62	.59	.51	.48	.38
60	3.4	2.7	1.30	.70	.68	.59	.55	.45
70	3.1	2.5	1.38	.77	.73	.66	.61	.51
76	2.9	2.4	1.40	.80	.77	.68	.64	.54
80	2.8	2.3	1.41	.81	.79	.70	.66	.56
90	2.6	2.2	1.45	.87	.84	.75	.70	.61
100	2.5	2.1	1.50	.90	.89	.80	.75	.65
120	2.3	2.05	1.51	.98	.96	.88*	.83	.73
140	2.25	2.0	1.54	1.06	1.04	.96*	.90	.80
160	2.20	2.0	1.58	1.11	1.08	1.01*	.96	.87
180	2.20	2.0	1.60	1.18	1.16	1.10*	1.00	.93
200	2.10	2.0	1.60	1.24	1.20	1.14*	1.05	.98
250	2.10	2.0	1.60	1.37	1.33	1.27*	1.10	1.10
300	2.10	2.0	1.60	1.48	1.42	1.38*	1.10	1.20

* Extrapolated Values

THERMAL CONDUCTIVITY INTEGRALS for ALUMINUM ALLOYS (cont.)

Temp. °K	$\int_{T_o}^{T_L} \lambda \, dT$ watts/cm							
	1100-F	6063-T5	3003-F	4 S	5052-0	5154-0	75-S	2024-T4
6	1.38	.850	.275	.131	.119	.103	.094	.080
8	3.33	2.05	.670	.314	.282	.250	.229	.197
10	5.85	3.60	1.17	.549	.495	.443	.407	.347
15	14.9	9.00	2.90	1.37	1.27	1.12	1.03	.872
20	27.4	16.5	5.34	2.55	2.37	2.10	1.91	1.60
25	42.6	25.8	8.50	4.07	3.80	3.38	3.03	2.51
30	59.9	36.5	12.3	5.95	5.55	4.90	4.43	3.61
35	78.4	48.8	16.7	8.17	7.60	6.68	6.11	4.91
40	97.6	62.0	21.7	10.7	9.95	7.70	8.01	6.41
50	136	89.5	33.0	16.5	15.4	12.4	12.4	9.91
60	171	117	45.5	23.1	21.7	17.9	17.6	14.1
70	204	143	58.9	30.5	28.8	24.2	23.6	18.9
76	222	158	67.2	35.2	33.3	28.2	27.1	22.0
80	233	167	72.8	38.4	36.4	30.9	29.7	24.2
90	260	190	87.1	46.8	44.6	38.2	36.5	30.1
100	286	211	102	55.7	53.2	45.9	43.8	36.3
120	334	253	132	74.5	71.7	62.7	59.6	50.1
140	379	293	162	94.9	91.7	81.1	76.9	65.4
160	424	333	194	117	113	101	95.5	82.1
180	468	373	225	139	135	122	115	100
200	511	413	257	164	159	144	136	119
250	616	513	337	229	222	205	189	171
300	721	613	417	300	291	271	244	229

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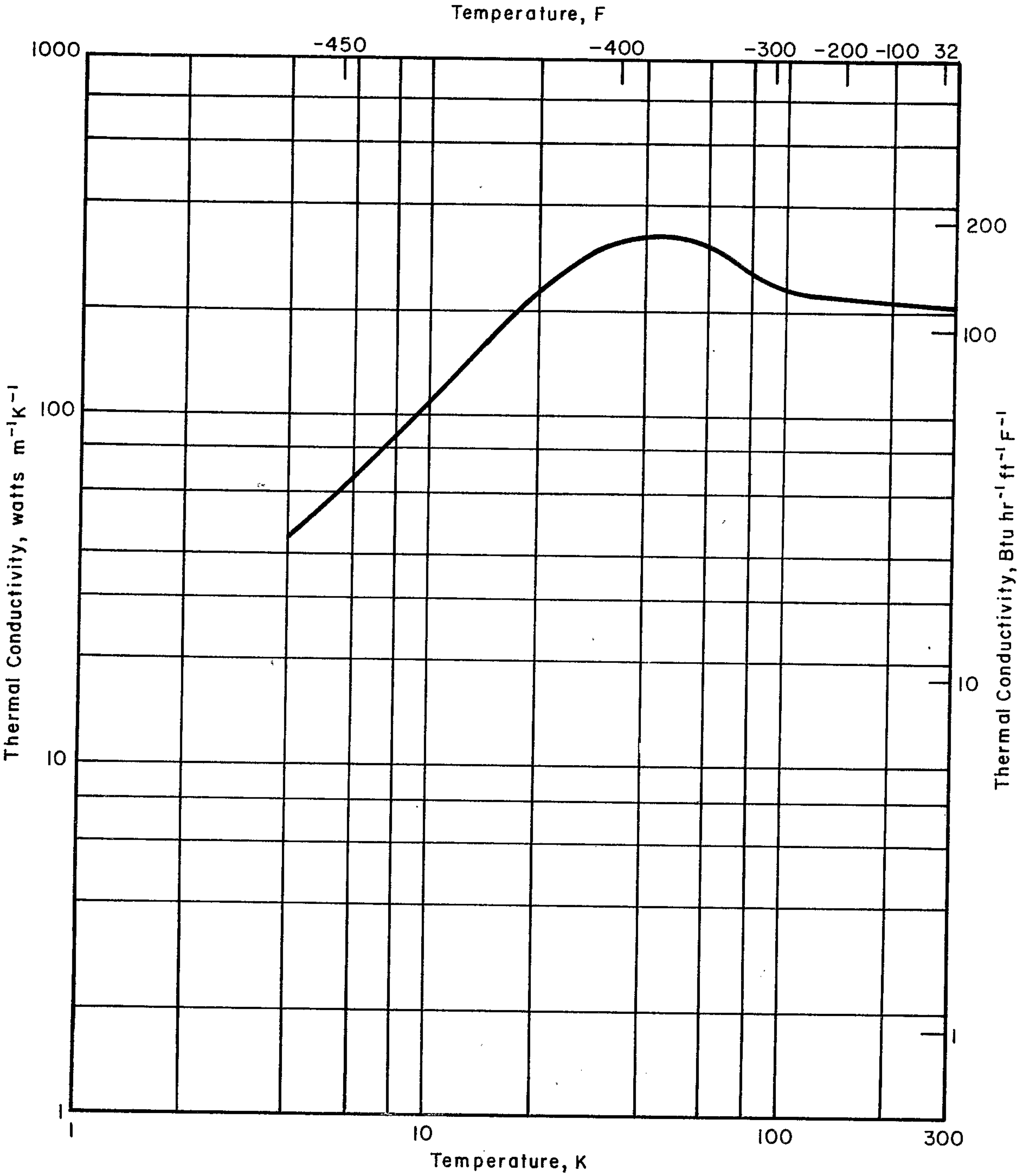

THERMAL CONDUCTIVITY VERSUS TEMPERATURE FOR ALUMINUM ALLOY 1100-0

THERMAL CONDUCTIVITY
of NICKEL ALLOYS

Source of Data:

(a) I. Estermann and J.E. Zimmerman, J. Appl. Phys. 23, 578-588 (1952); R.W. Powers, J.B. Ziegler, and H.L. Johnston, TR 264-8, Cryogenics Laboratory, Ohio State University (1951) 11 pp.

(b) Same as (a).

(c) Same as (a).

(d) I. Estermann and J.E. Zimmerman, J. Appl, Phys. 23, 578-588 (1952).

(e) J. Karweil and K. Schafer, Ann. Physik 36, 567-577 (1939); R.W. Powers, J.B. Ziegler, and H.L. Johnston, TR 264-8, Cryogenics Laboratory, Ohio State University (1951) 11 pp.

Comments:

(a) Monel; annealed; and 67%Ni, 30% Cu, 1.4% Fe, 1.0%Mn, 0.15% C, 0.1% Si, 0.01% S, hot-rolled

(b) Monel; Hard-drawn; and 67% Ni, 30% Cu, 1.4% Fe, 1.0% Mn, 0.15% C. 0.1% Si, 0.01% S, Cold-rolled

(c) Inconel; Annealed; and 80% Ni, 14% Cr, 6% Fe.

(d) Inconel; Hard-drawn

(e) Contracid; 60% Ni, 15% Cr, 16% Fe, 7% Mo; and 60.05% Ni, 14.74% Cr, 15.82% Fe, 7.2% Mo, 2.14% Mn, 0.05% C.

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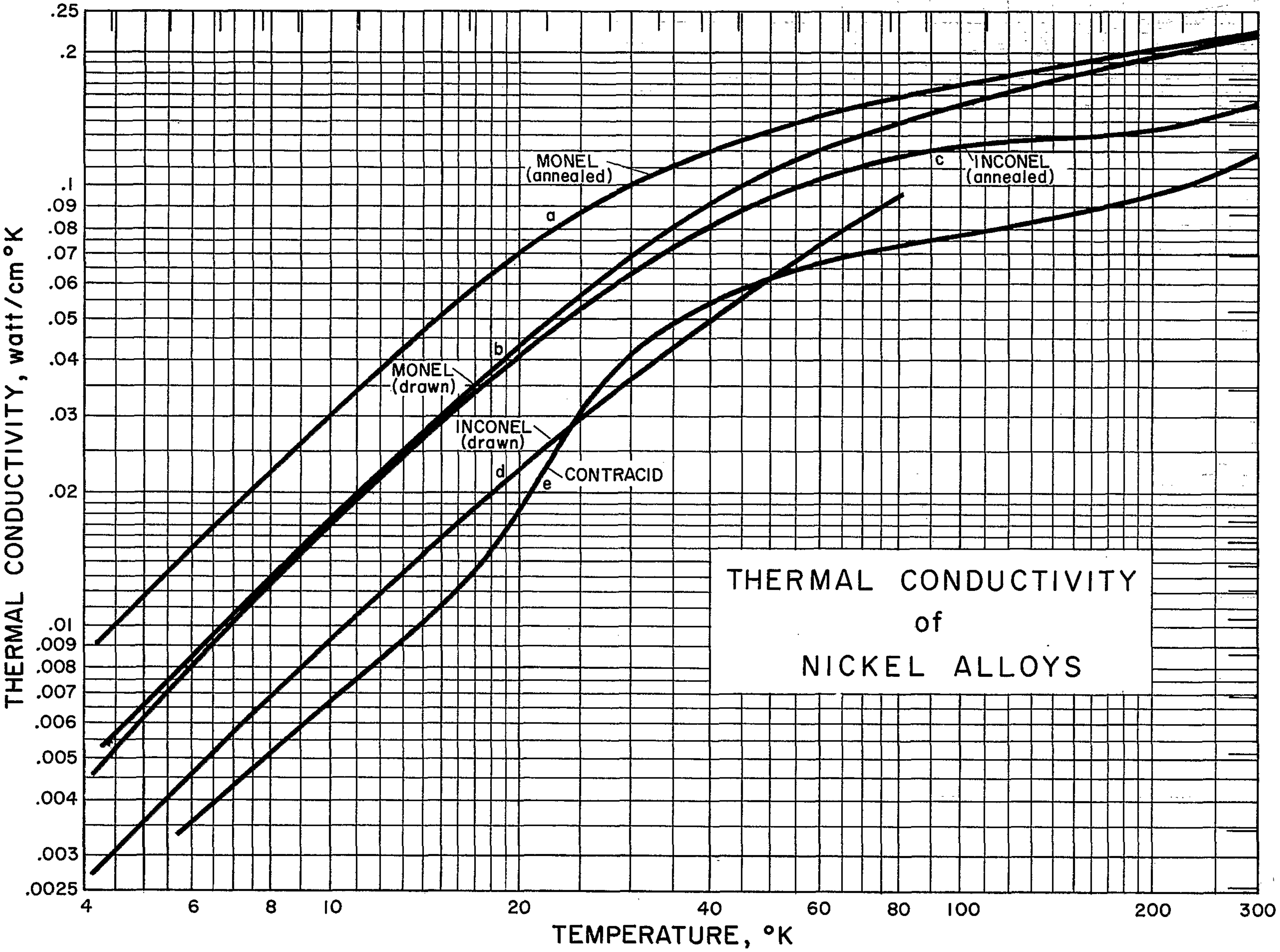

THERMAL CONDUCTIVITY of NICKEL ALLOYS

THERMAL CONDUCTIVITY INTEGRALS

for NICKEL ALLOYS

Comments: The curve for Inconel (annealed) has been extrapolated to 300°K. It is estimated that the extrapolated values deviate no more than 10% from the probable values.

$$Q = \frac{A}{L} \int_{T_o}^{T_L} \lambda \, dT; \qquad Q \frac{L}{A} = \int_{T_o}^{T_L} \lambda \, dT$$

Where:

Q = heat flow in watts
A = cross sectional area in cm^2
L = length in cm
λ = thermal conductivity in watts/cm-°K
T = temperature in °K
T_o = initial temperature (6°K for Contracid; 4°K for all other Nickel Alloys)

Thermal Conductivity Integrals are on following page.

Temp. °K	Thermal Conductivity watts/cm-°K				
	Monel (Annealed)	Monel (Drawn)	Inconel (Annealed)	Inconel (Drawn)	Contracid
4	.0085	.0043	.0048	.00252	
6	.0150	.0080	.0085	.0046	.0036
8	.022	.0126	.0130	.0068	.0052
10	.030	.0174	.0175	.0092	.0067
15	.051	.030	.029	.016	.011
20	.070	.043	.041	.023	.0185
25	.088	.057	.053	.029	.031
30	.100	.069	.063	.036	.041
35	.110	.080	.072	.043	.049
40	.120	.090	.080	.050	.055
50	.133	.110	.094	.062	.062
60	.143	.120	.103	.073	.067
70	.150	.130	.110	.085	.070
76	.155	.135	.115	.090	.072
80	.160	.140	.118	.095	.073
90	.165	.147	.120	.105*	.075
100	.170	.152	.123	.113*	.078
120	.180	.163	.127	.127*	.081
140	.186	.173	.129	.137*	.084
160	.191	.182	.130	.146*	.089
180	.200	.190	.132	.152*	.092
200	.210	.198	.135	.160*	.096
250	.220	.210	.145	.170*	.108
300	.230	.220	.152	.180*	.118

* Extrapolated Values

THERMAL CONDUCTIVITY INTEGRALS
for NICKEL ALLOYS (cont.)

Temp. °K	$\int_{T_0}^{T_L} \lambda \, dT$ watts/cm				
	Monel (Annealed)	Monel (Drawn)	Inconel (Annealed)	Inconel (Drawn)	Contracid
6	.0235	.0123	.0133	.00712	
8	.0605	.0329	.0348	.0185	.00880
10	.112	.0629	.0653	.0345	.0207
15	.315	.181	.182	.0975	.0650
20	.618	.364	.356	.195	.139
25	1.01	.614	.592	.325	.262
30	1.48	.929	.882	.488	.442
35	2.01	1.30	1.22	.685	.667
40	2.58	1.73	1.60	.918	.927
50	3.85	2.73	2.47	1.48	1.51
60	5.23	3.88	3.45	2.15	2.16
70	6.69	5.13	4.52	2.94	2.84
76	7.61	5.92	5.19	3.47	3.29
80	8.24	6.47	5.66	3.84	3.56
90	9.86	7.91	6.85	4.84	4.30
100	11.5	9.40	8.06	5.93	5.06
120	15.0	12.6	10.6	8.33	6.65
140	18.7	15.9	13.1	11.0	8.30
160	22.5	19.5	15.7	13.8	10.0
180	26.4	23.2	18.3	16.8	11.8
200	30.5	27.1	21.0	19.9	13.7
250	41.2	37.3	28.0	28.1	18.8
300	52.5	48.0	35.4	36.9	24.5

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THERMAL CONDUCTIVITY of MISCELLANEOUS ALLOYS

Source of Data:
(a) R. Berman, E. L. Foster, and H. M. Rosenberg
Brit. J. Appl. Physics 6, 181-182 (1955)
(b) H. Bremmer and W. J. deHaas,
Physica 3, 692-704 (1936).
(c) Same as (a)
(d) Same as (b)
(e) Same as (b)
(f) W. W. Tyler and A. C. Wilson
Knolls Atomic Power Laboratory Report 803,
41 pp. (1952)

Comments:
(a) Soft Solder; 60% Sn, 40% Pb
(b) Lead - 44% Tin; 56% Pb, 44% Sn
(c) Wood's Metal; 48% Pb, 13% Sn, 13% Cd
(d) Rose's Metal; 50% Bi, 25% Pb, 25% Sn
(e) Lead - 50% Indium; 50% In, 50% Pb
(f) Titanium; Rem - Cru, RC130-B, 4.7% Mn, 3.99% Al, 0.14% C.

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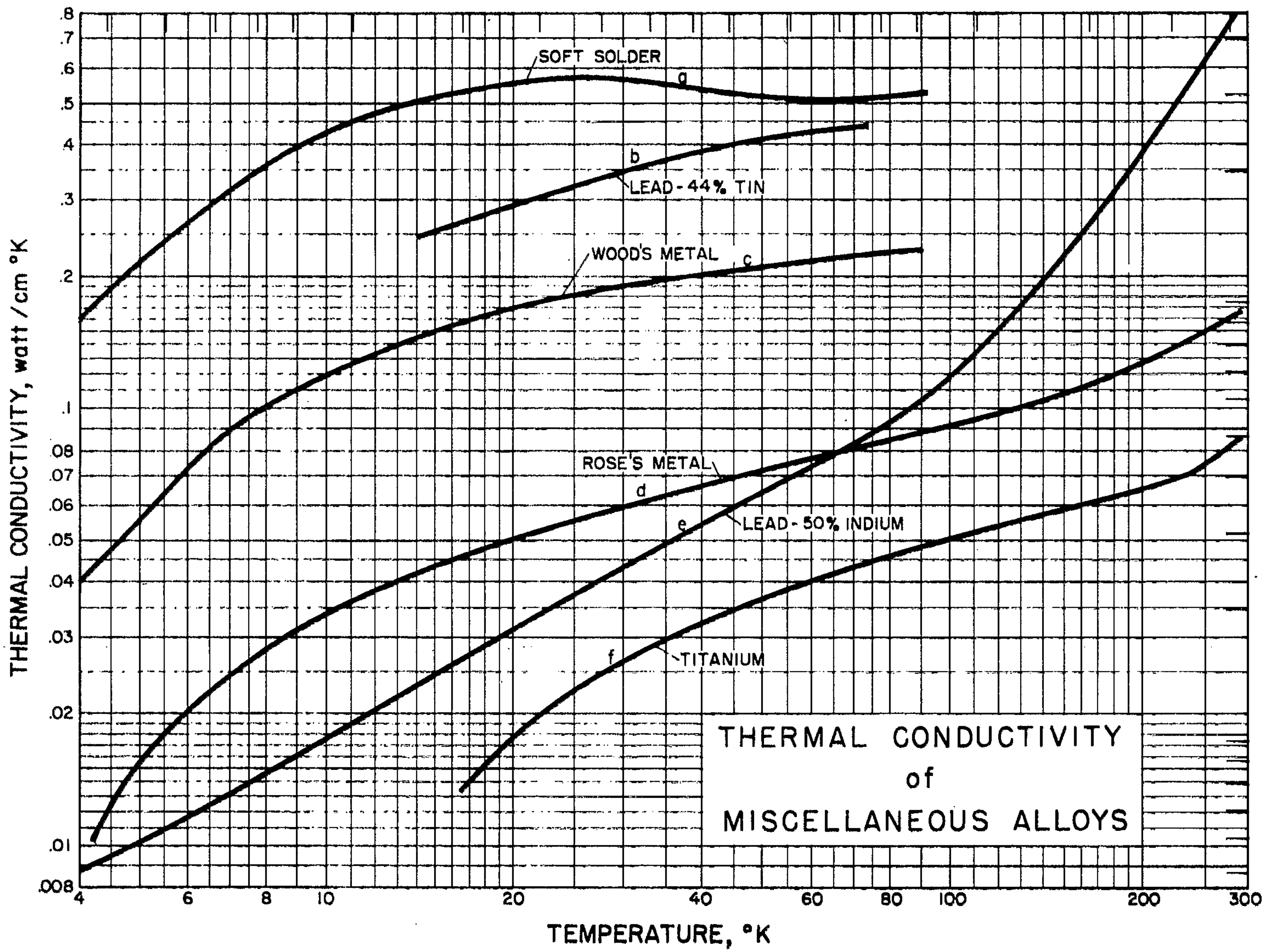

THERMAL CONDUCTIVITY of MISCELLANEOUS ALLOYS

THERMAL CONDUCTIVITY INTEGRALS
for MISCELLANEOUS ALLOYS

Comments: The curves for Miscellaneous Alloys have been extrapolated to 300°K. The curves for Lead - 44% Tin and Roses's Metal have been extrapolated to 4°K, while the curve for Titanium has been extrapolated to 15°K. It is estimated that the extrapolated values deviate no more than 10% from the probable values.

$$Q = \frac{A}{L} \int_{T_O}^{T_L} \lambda \, dT; \qquad Q \frac{L}{A} = \int_{T_O}^{T_L} \lambda \, dT$$

Where:

Q = heat flow in watts
A = cross sectional area in cm^2
L = length in cm
λ = thermal conductivity in watts/cm-°K
T = temperature in °K
T_O = initial temperature (15°K for Titanium, 4°K for all other Miscellaneous Alloys)

Thermal Conductivity Integrals are on the following page.

Temp. °K	Thermal Conductivity watts/cm-°K					
	Lead-44% Tin	Rose's Metal	Titanium	Lead-50% Indium	Wood's Metal	Soft Solder
4	.08 *	.0092*		.0088	.04	.16
6	.123*	.02		.0116	.072	.265
8	.16 *	.028		.0146	.10	.36
10	.19 *	.0335		.0175	.118	.42
15	.255	.0435	.0112*	.0245	.15	.52
20	.29	.0505	.0177	.032	.17	.55
25	.32	.056	.023	.037	.18	.57
30	.34	.059	.027	.043	.188	.57
35	.37	.063	.0295	.049	.196	.56
40	.38	.066	.032	.054	.20	.54
50	.42	.0715	.037	.064	.21	.52
60	.425	.077	.04	.073	.22	.51
70	.44	.081	.043	.082	.22	.51
76	.44	.083	.045	.089	.225	.52
80	.445*	.085	.046	.093	.225	.525
90	.46 *	.088	.048	.104	.23	.53
100	.465*	.091	.051	.118	.235	.54*
120	.47 *	.097	.054	.152	.235*	.55*
140	.47 *	.104	.057	.195	.235*	.56*
160	.47 *	.111	.06	.25	.235*	.56*
180	.47 *	.12	.063	.32	.24*	.56*
200	.48 *	.128	.065	.38	.24*	.56*
250	.48 *	.15	.074	.62	.24*	.57*
300	.48 *	.17*	.088*	.9*	.24*	.57*

* Extrapolated Values

THERMAL CONDUCTIVITY INTEGRALS
for MISCELLANEOUS ALLOYS (cont.)

Temp. °K	$\int_{T_o}^{T_L} \lambda \, dT$ watts/cm					
	Lead-44% Tin	Rose's Metal	Titanium	Lead 50% Indium	Wood's Metal	Soft Solder
6	.203	.0292		.0204	.112	.425
8	.486	.0772		.0466	.284	1.05
10	.836	.139		.0787	.502	1.83
15	1.95	.331		.184	1.17	4.18
20	3.31	.566	.0722	.325	1.97	6.86
25	4.84	.832	.174	.497	2.85	9.66
30	6.49	1.12	.299	.697	3.77	12.5
35	8.26	1.42	.440	.927	4.73	15.3
40	10.1	1.75	.594	1.18	5.72	18.1
50	14.1	2.43	.939	1.77	7.77	23.4
60	18.4	3.18	1.32	2.46	9.92	28.5
70	22.7	3.97	1.74	3.23	12.1	33.6
76	25.3	4.46	2.00	3.75	13.4	36.7
80	27.1	4.80	2.18	4.11	14.4	38.8
90	31.6	5.66	2.66	5.10	16.6	44.1
100	36.2	6.56	3.15	6.21	19.0	49.4
120	45.6	8.44	4.20	8.91	23.6	60.3
140	55.0	10.4	5.31	12.4	28.4	71.4
160	64.4	12.6	6.48	16.8	33.0	82.6
180	73.8	14.9	7.71	22.5	37.8	93.8
200	83.3	17.4	8.99	29.5	42.6	105
250	107	24.3	12.5	54.5	54.6	133
300	131	32.3	16.5	92.5	66.6	162

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THERMAL CONDUCTIVITY OF GLASSES and PLASTICS

Source of Data:
- (a) R. L. Powell and W. A. Blanpied, NBS Circular 556, 68 (1954)
- (b) R. L. Powell, W. M. Rogers, and D. O. Coffin J. Research NBS, 59, 349-355 (1957)
- (c) R. Berman, E. L. Foster and H. M. Rosenberg Brit. J. Appl. Physics 6, 181-182 (1955)
- (d) R. Berman Proc. Roy. Soc. (London) A208, 90-108 (1951)

Comments:
- (a) Glass; average value of quartz, Pyrex, and borosilicate glasses.
- (b) Teflon; extruded
- (c) Nylon; Imperial Chem. Ind.; drawn monofilament.
- (d) Perspex; An English organic glass thermo-plastic similar to Lucite or Plexiglass.

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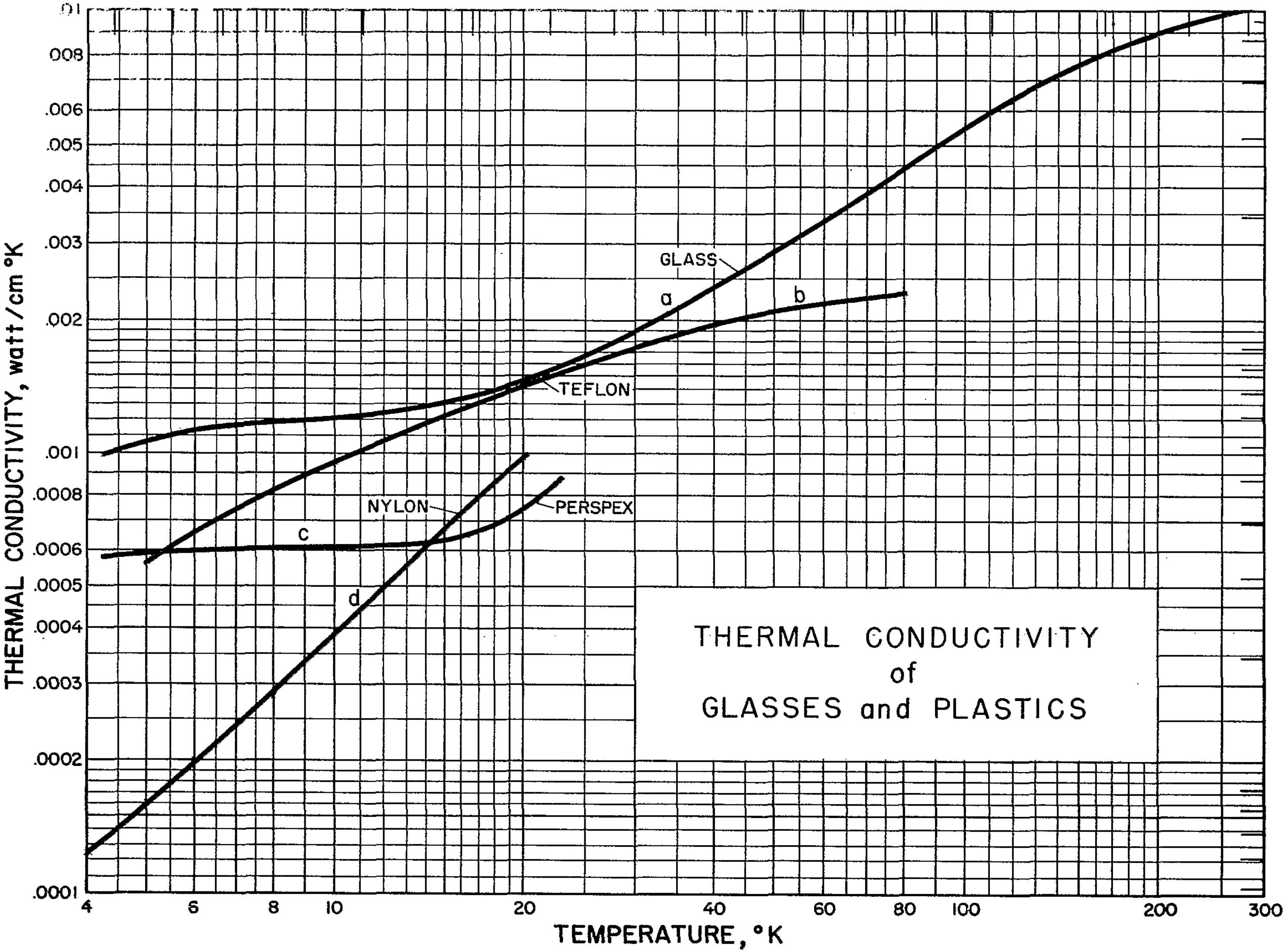

THERMAL CONDUCTIVITY of GLASSES and PLASTICS

THERMAL CONDUCTIVITY INTEGRALS
for GLASSES and PLASTICS

Comments: The curves for Teflon, Nylon, and Perspex were extrapolated to 300°K. It is estimated that the extrapolated values do not deviate more than 10% from the probable value.

$$Q = \frac{A}{L} \int_{T_O}^{T_L} \lambda dT; \qquad Q \frac{L}{A} = \int_{T_O}^{T_L} \lambda dT$$

Where:

Q = heat flow in milliwatts
A = cross sectional area in cm^2
L = length in cm
λ = thermal conductivity in milliwatts/cm-°K
T = temperature in °K
T_O = initial temperature (4°K)

Temp. °K	Thermal Conductivity milliwatts/cm-°K				$\int_{T_O}^{T_L} \lambda dT$ milliwatts/cm			
	glass	teflon	perspex	nylon	glass	teflon	perspex	nylon
4	.97	.46	.58	.125				
6	1.14	.67	.60	.196	2.11	1.13	1.18	.321
8	1.19	.82	.60	.29	4.43	2.62	2.38	.807
10	1.20	.96	.61	.38	6.81	4.4	3.59	1.48
15	1.3	1.22	.63	.67	13.1	9.85	6.69	4.10
20	1.46	1.41	.75	.98	20.0	16.4	10.1	8.23
25	1.68	1.60	.97	1.28*	27.9	23.9	14.4	13.9
30	1.9	1.74	1.18*	1.5 *	36.8	32.3	19.6	20.8
35	2.2	1.86	1.35*	1.78*	47.1	41.3	25.9	29.0
40	2.4	1.95	1.50*	1.99*	58.6	50.8	33.0	38.5
50	2.9	2.1	1.80*	2.4 *	84.6	71.6	49.5	60.4
60	3.4	2.2	1.95*	2.7 *	115	93.6	68.3	85.9
70	3.9	2.3	2.10*	2.8 *	151	116	88.5	113
76	4.2	2.3	2.15*	2.9 *	175	130	101.	131
80	4.4	2.35	2.20*	3.0 *	194	139	110.	142
90	5.0	2.4 *	2.25*	3.1 *	240	163	132.	173
100	5.5	2.45*	2.25*	3.2 *	292	187	155.	204
120	6.4	2.45*	2.30*	3.3 *	408	237	200.	269
140	7.3	2.5 *	2.35*	3.4 *	542	287	247.	336
160	7.9	2.55*	2.40*	3.5 *	694	338	294.	405
180	8.5	2.60*	2.40*	3.5 *	858	390	342.	475
200	9.0	2.60*	2.40*	3.5 *	1030	442	390.	545
250	9.8	2.60*	2.40*	3.5 *	1500	572	510.	720
300	10.2	2.60*	2.40*	3.5 *	1990	702	630.	895

* Extrapolated Values

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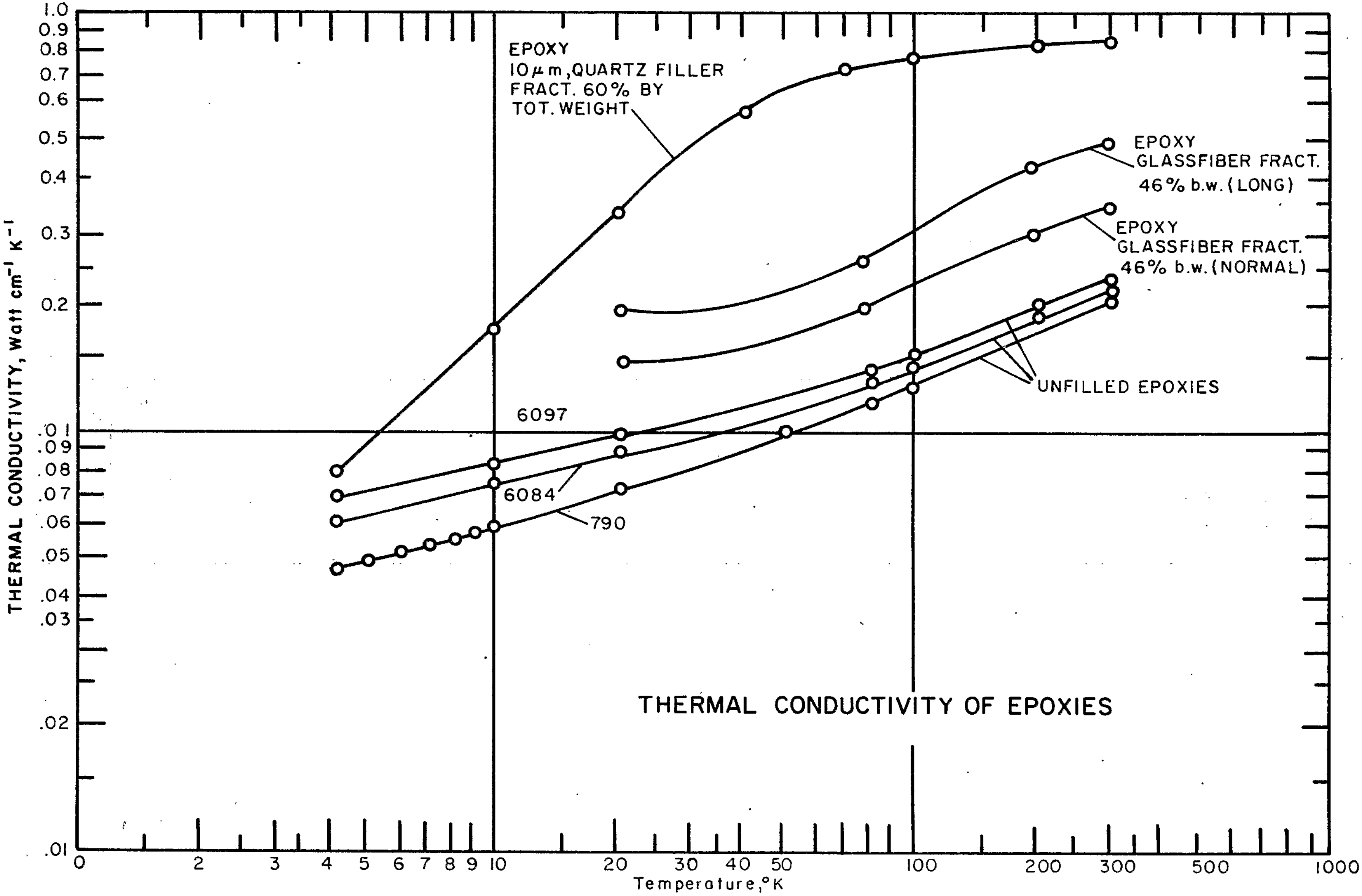

THERMAL CONDUCTIVITY OF EPOXIES

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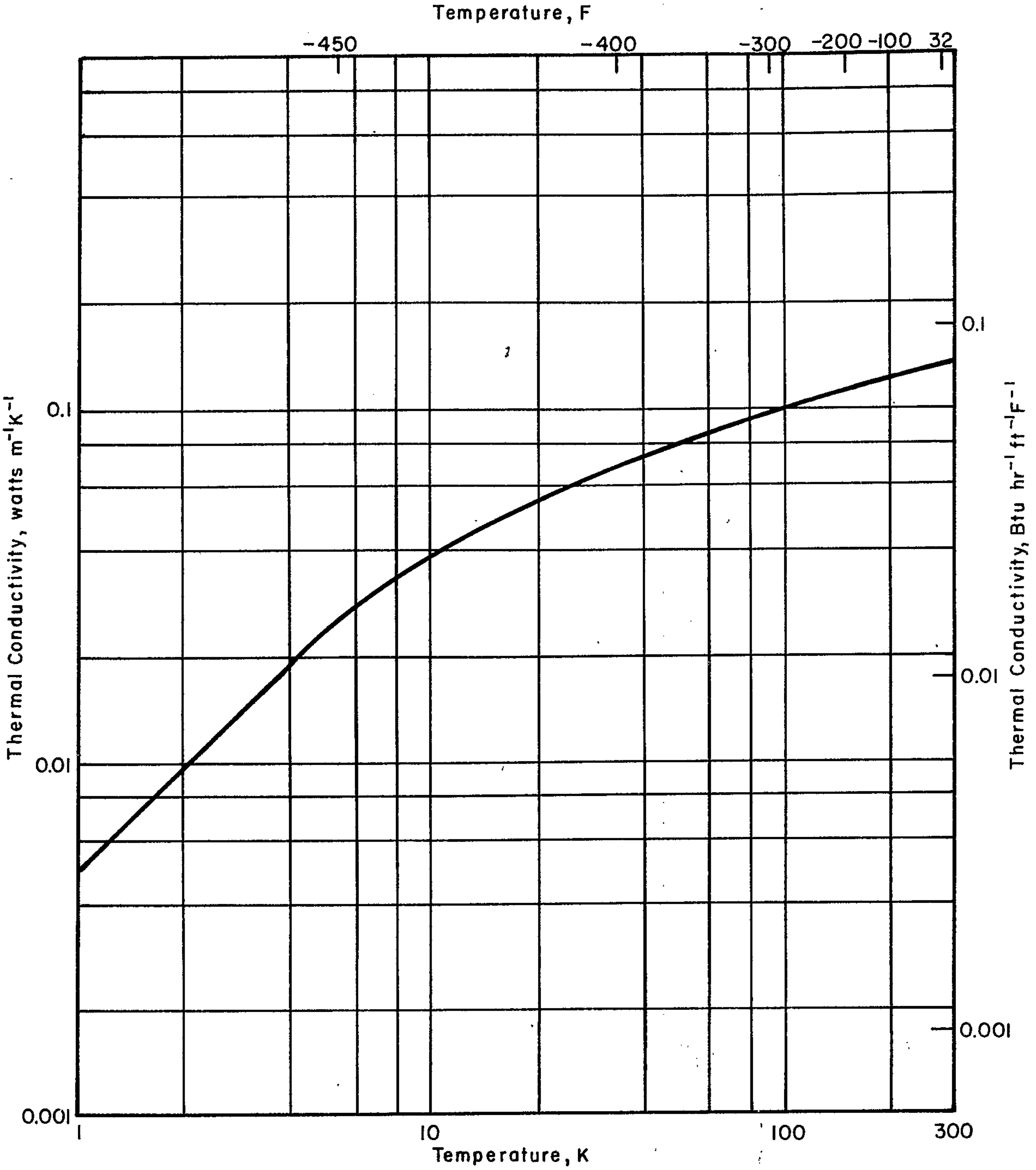

THERMAL CONDUCTIVITY VERSUS TEMPERATURE FOR POLYCHLOROTRIFLUORDETHYLENE (KEL-F)

THERMAL CONDUCTIVITY OF CARBON AND STAINLESS STEELS

Source of Data: R.L. Powell and W.A. Blanpied, N.B.S. Circular 556, 43 (1954)

References:

(a) (P.Z.J.) R.W. Powers, J.B. Ziegler, and H.L. Johnston, The Thermal Conductivity of Metals and Alloys at Low Temperatures II, TR 264-6, Cryogenics Laboratory, Ohio State University (1951a), 17 pp.

(b) (Kr.Sc.) J. Karweil, K. Schäfer, Die Warmeleitfahigkeit einger Schlecht Leitender Legierungen zwischen 3 und 30° K, Ann. Physik 36, 567-577 (1939)

(c.) C.H. Lees, The Effects of temperature and pressure on thermal conductivity of Solids. Part 2, Phil. Trars. Roy. Soc. (London) A208, 381-443 (1908).

(d) (T.W.) W.W. Tyler, A.C. Wilson, Jr., Thermal conductivity, electrical resistivity, and thermoelectric power of Titanium alloy RC-130-B, Knolls Atomic Power Laboratory Report 803 (1952) 41 p.p.

(e) (B) R. Berman, The Thermal Conductivity of Some Alloys at Low Temperatures, Phil Mag. 42, 642-650 (1951b)

(f) ($E_s \cdot Z_i$) I. Estermann, J.E. Zimmerman, Heat Conduction in Alloys at Low Temperatures, J. Appl. Phys. 23, 578-588 (1952)

January 20, 1967

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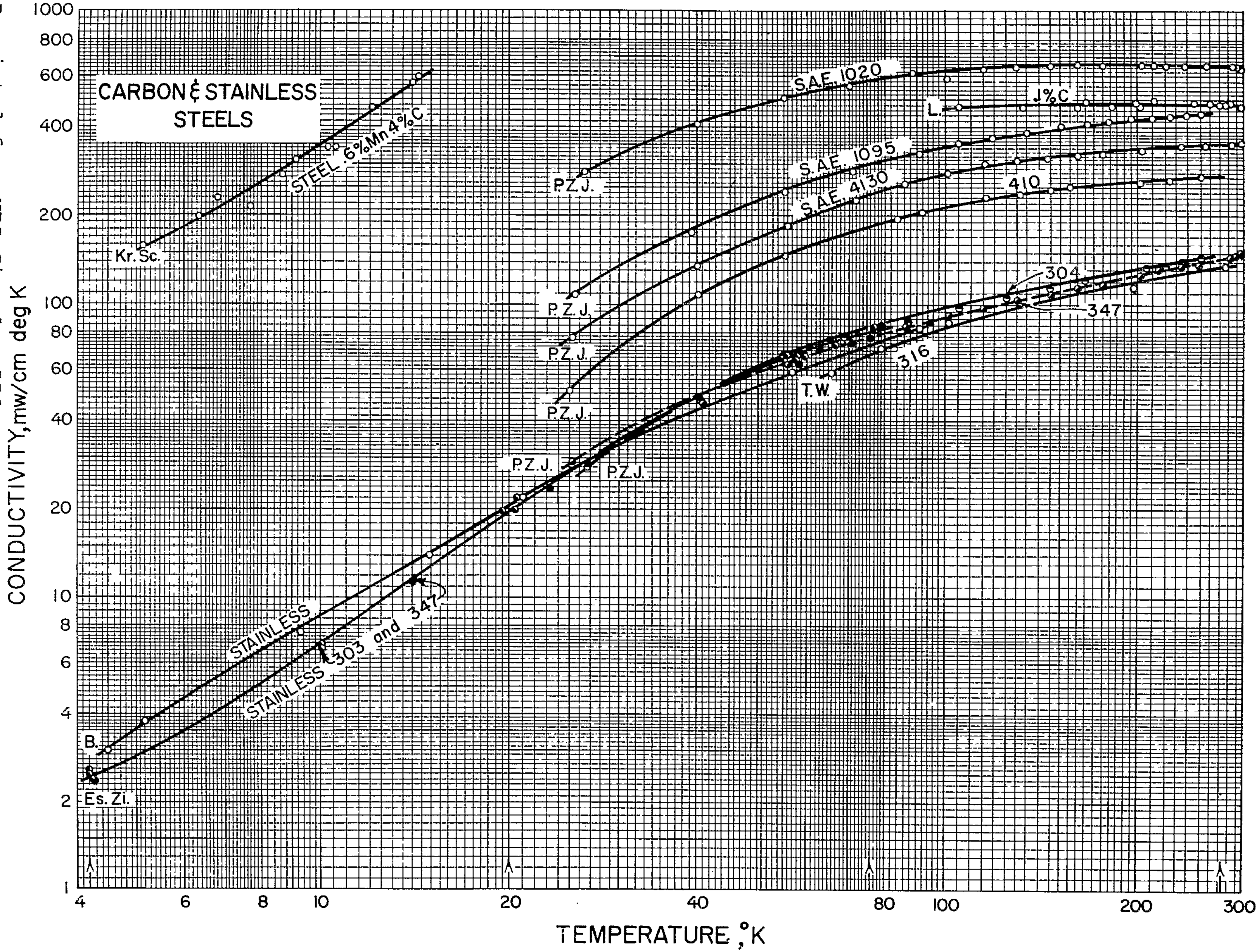
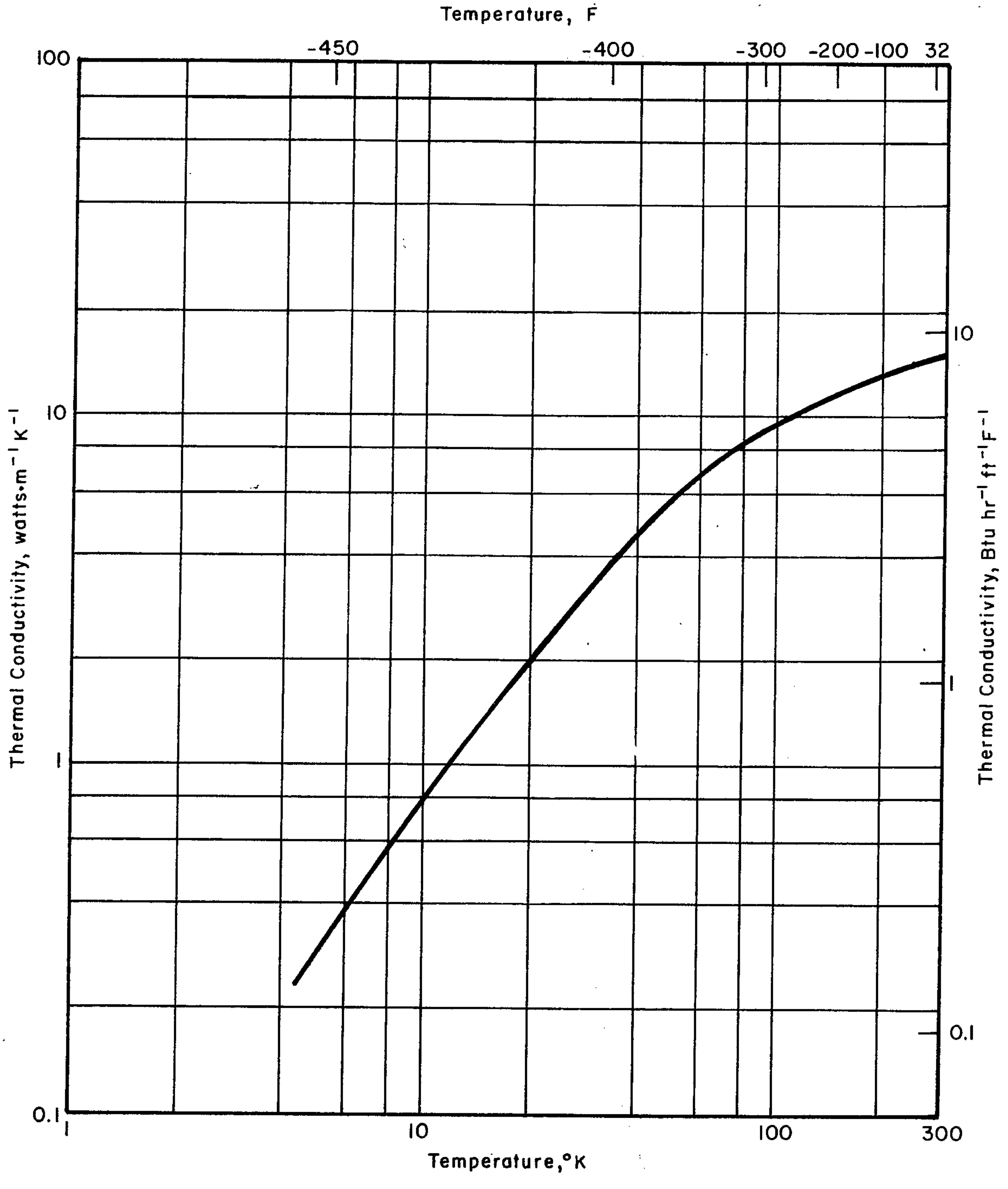
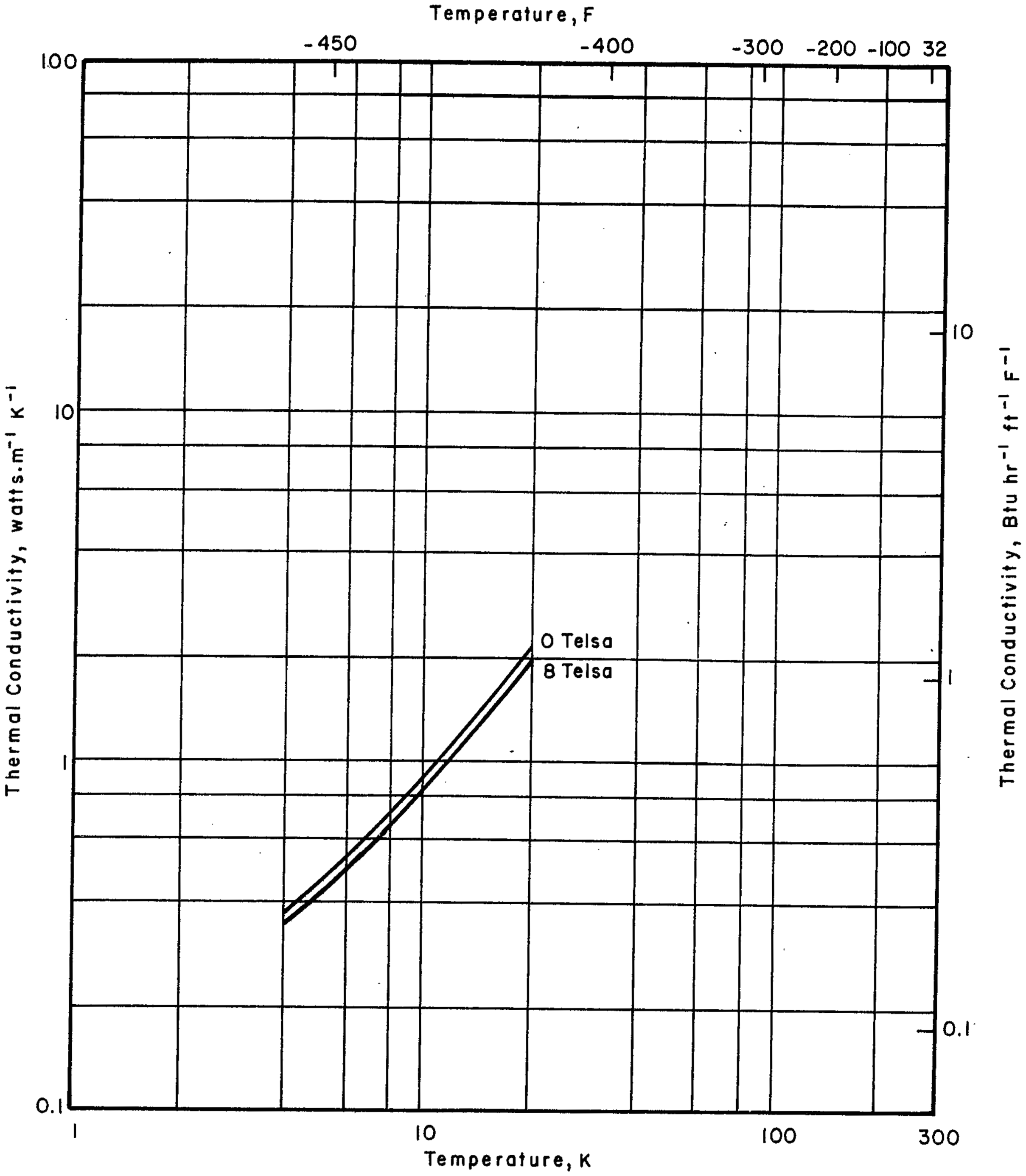
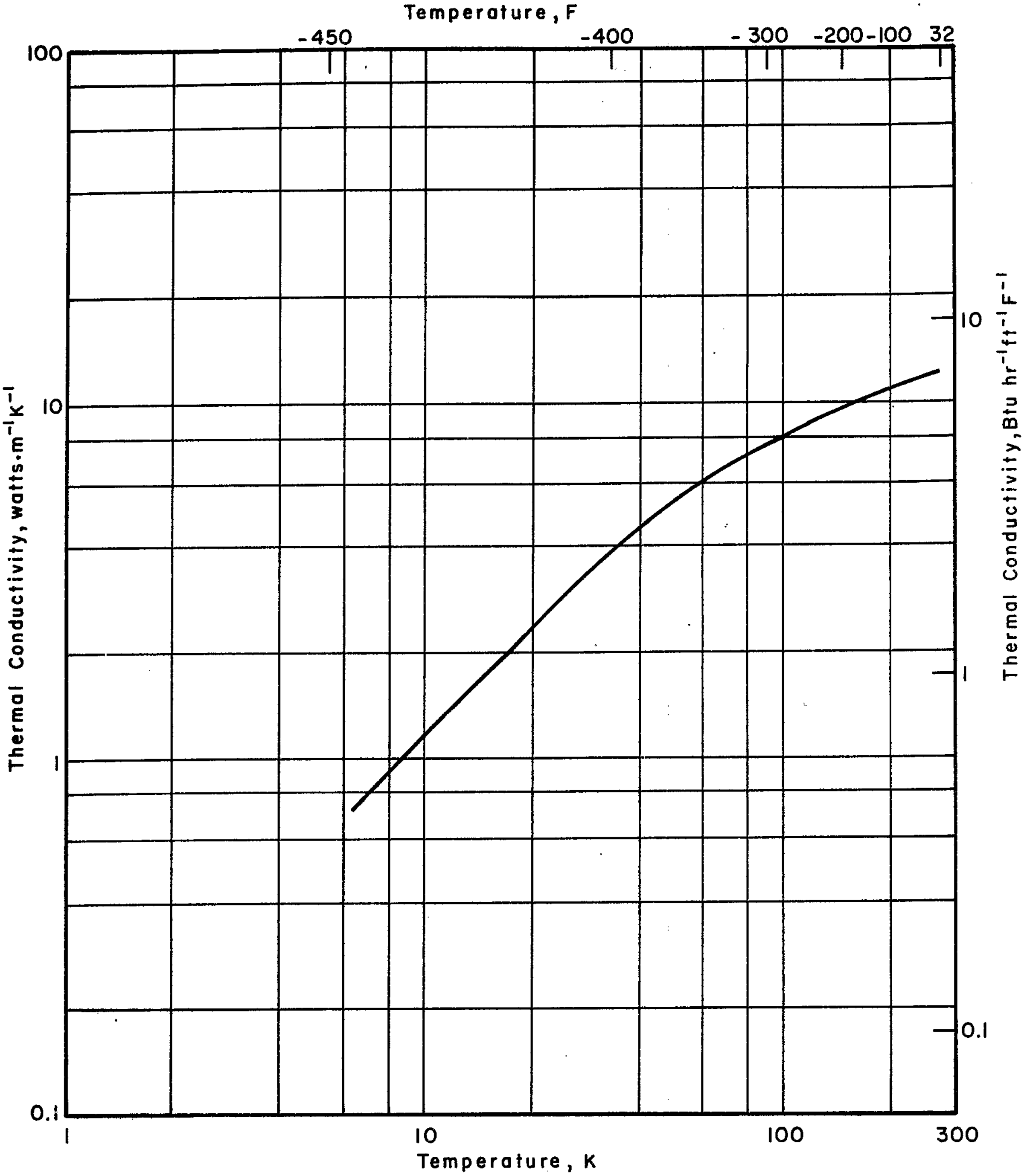




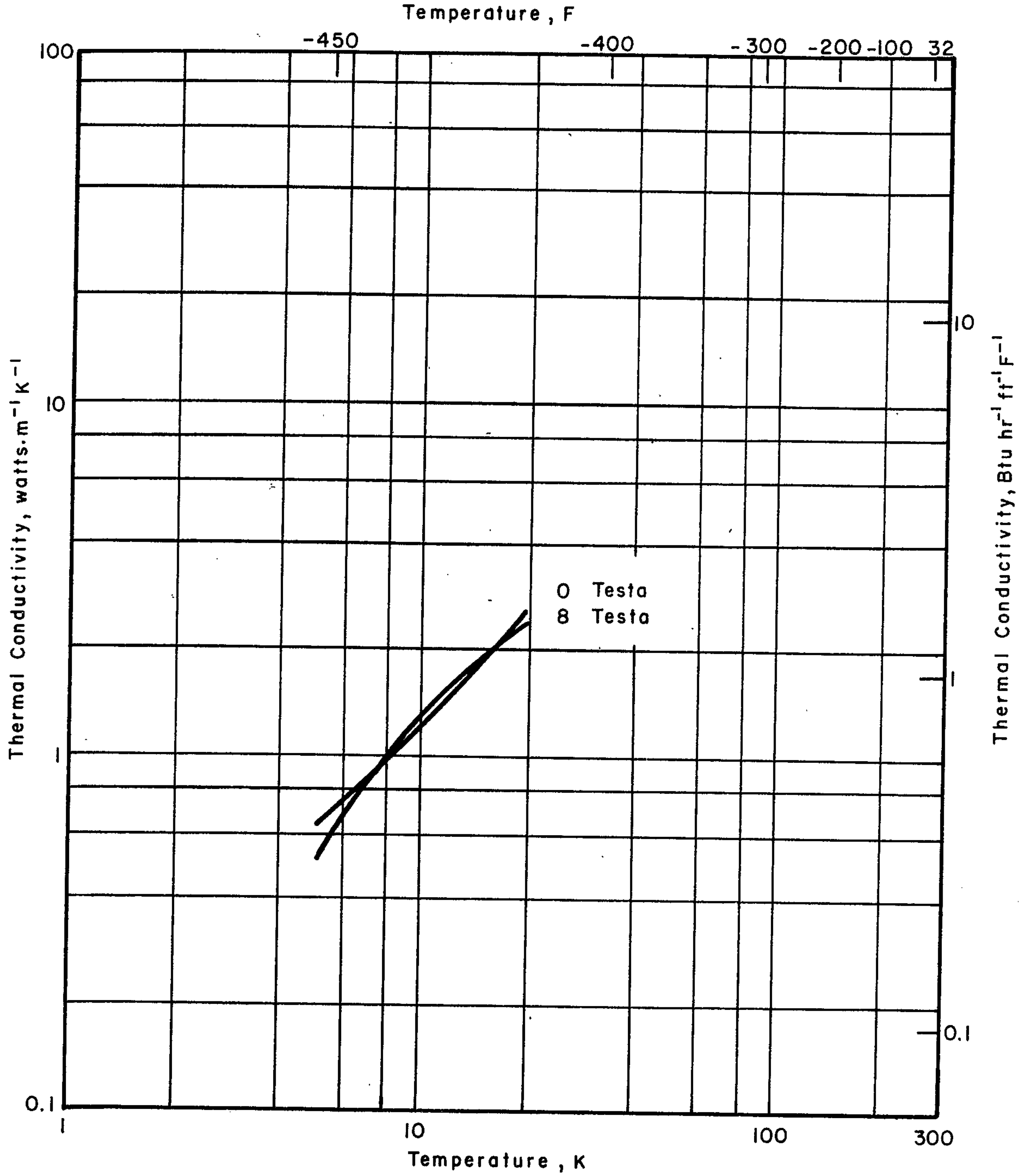
THERMAL CONDUCTIVITY VERSUS TEMPERATURE FOR TYPE 304 STAINLESS STEEL



THERMAL CONDUCTIVITY VERSUS TEMPERATURE FOR
TYPE 304 STAINLESS STEEL AT DIFFERENT MAGNETIC FIELD STRENGTHS



THERMAL CONDUCTIVITY VERSUS TEMPERATURE FOR TYPE 310 STAINLESS STEEL



THERMAL CONDUCTIVITY VERSUS TEMPERATURE FOR 310 STAINLESS STEEL AT TWO MAGNETIC FIELD STRENGTHS

THERMAL CONDUCTIVITY OF STAINLESS STEEL 304 A

T, K	k, Watt cm^{-1} K^{-1}	T, K	k, Watt cm^{-1} K^{-1}
0	0	450	0.177
0.1	0.000017*	500	0.184
1	0.00039*	600	0.198
5	0.0034*	700	0.212
10	0.0085*	800	0.225
25	0.027	900	0.239
50	0.058	1000	0.253*
75	0.080	1100	0.267*
100	0.095	1200	0.281*
150	0.115	1300	0.295*
200	0.130	1400	0.309*
250	0.142	1500	0.323*
273	0.147	1600	0.337*
300	0.152	(s) 1665	0.347*
350	0.162	(l) 1800	0.22**
400	0.170		

Data Source and Remarks

Nine sets of experimental data are available. Selected values from 27 to 250 K are taken from the data of Powers, Ziegler, and Johnston (1951) [32] and values from 373 to 923 K from the data of Ewing, Grand, and Miller (1952) [79] and Deverall (1959) [80]. There is no measurement on the liquid and the value is estimated.

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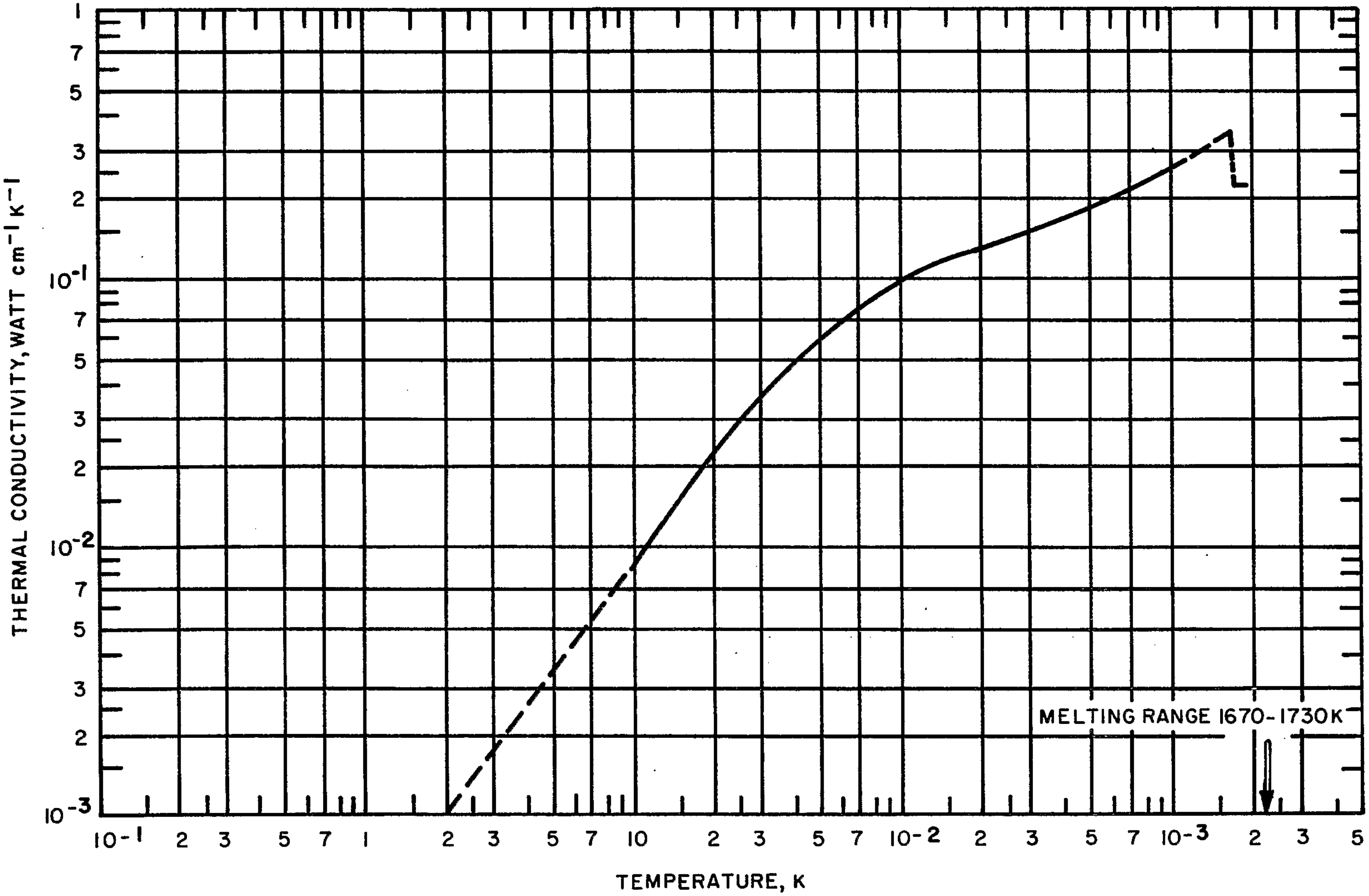
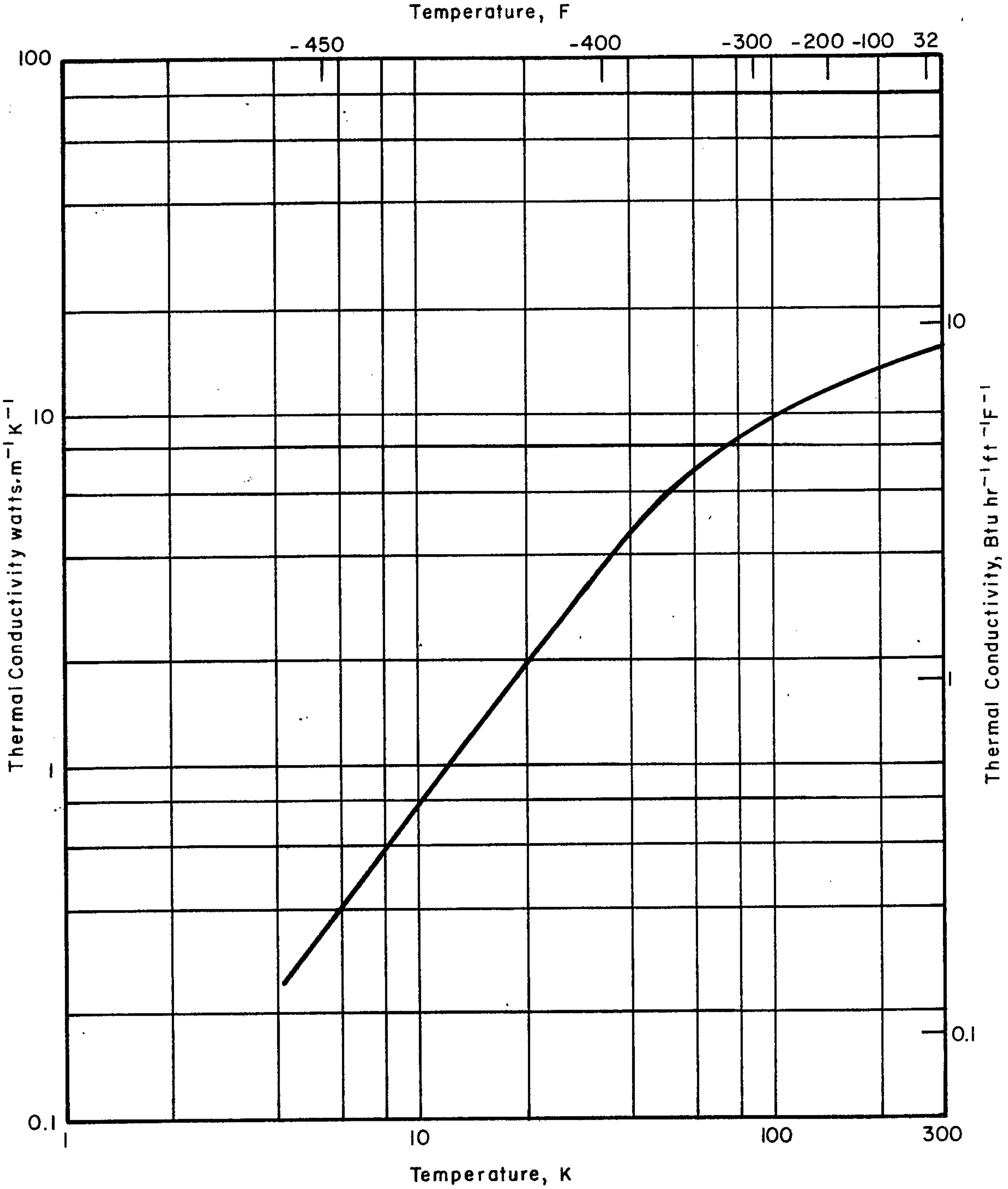
* Extrapolated.

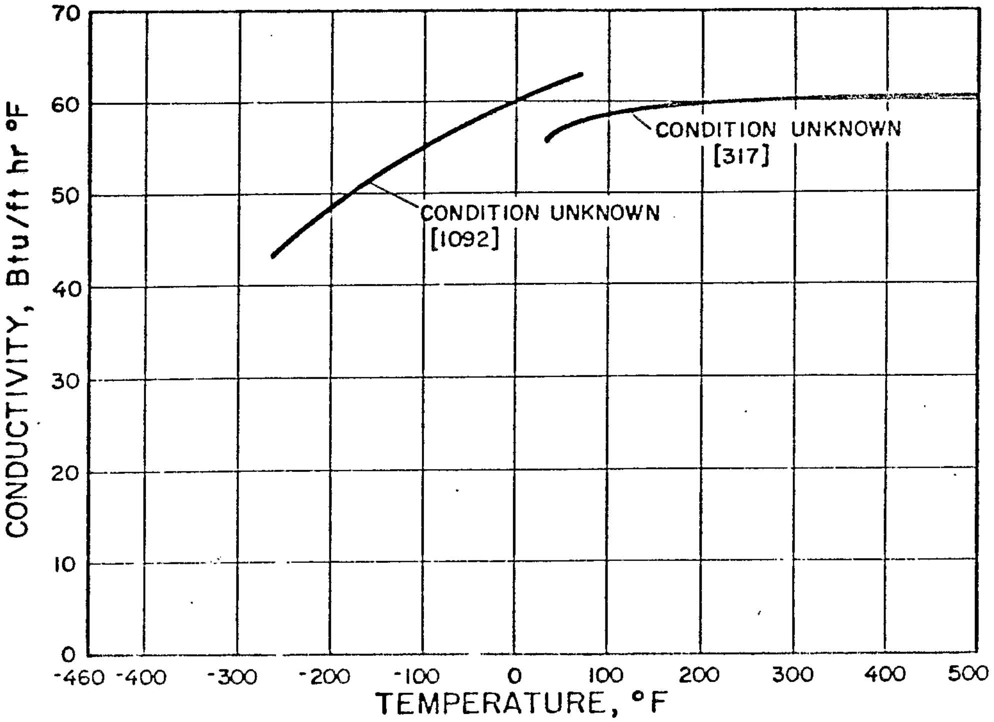
** Estimated



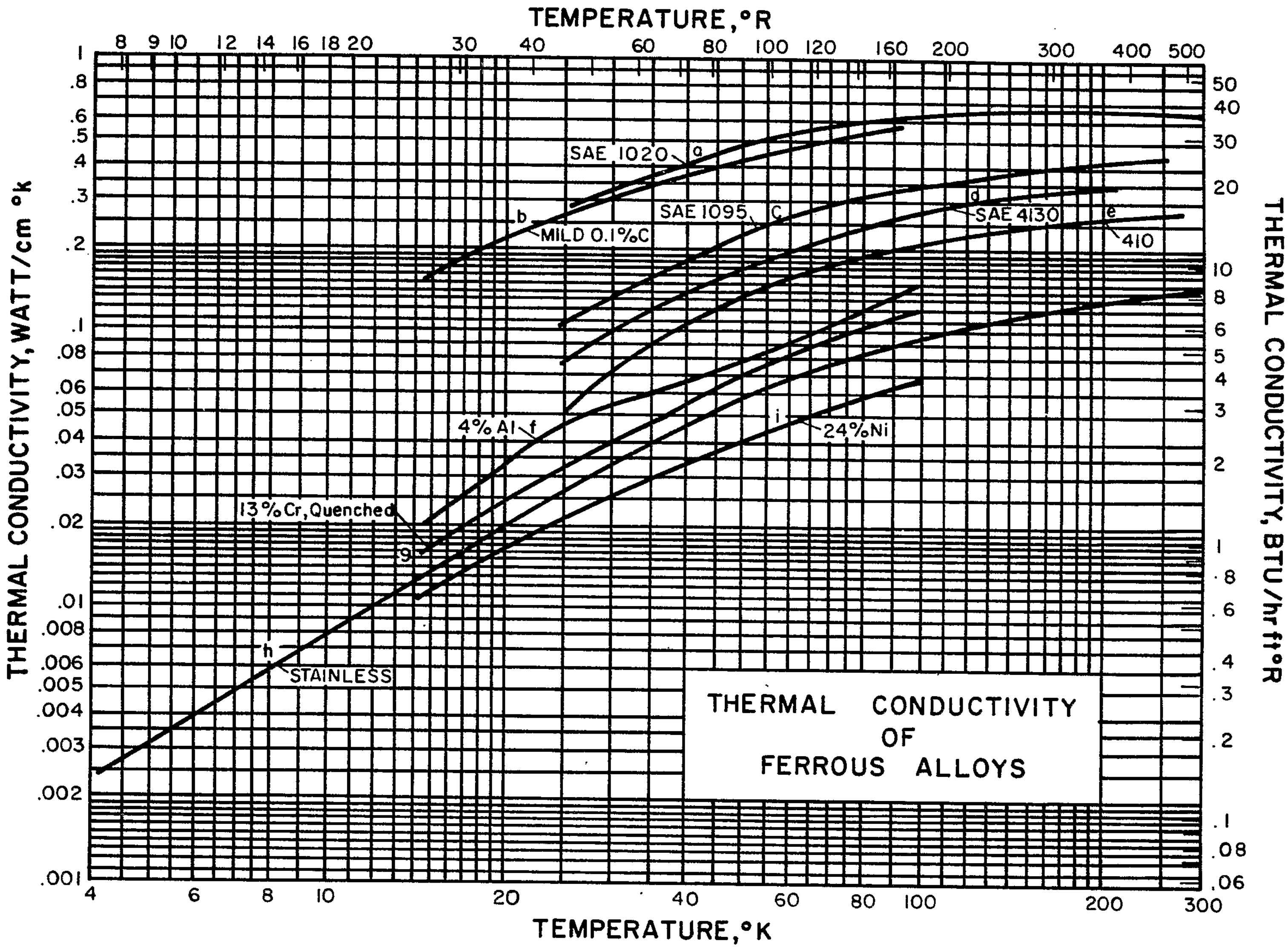
THERMAL CONDUCTIVITY OF STAINLESS STEEL 304A



THERMAL CONDUCTIVITY VERSUS TEMPERATURE FOR TYPE 316 STAINLESS STEEL



THERMAL CONDUCTIVITY OF 70 / 30 BRASS



THERMAL CONDUCTIVITY OF FERROUS ALLOYS