Thermal Conductivity of Ten Selected Binary Alloy Systems

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This work reviews and discusses the available data and information on the thermal conductivity of ten selected binary alloy systems and presents the recommended values resulting from critical evaluation, analysis, and synthesis of the available data. The ten binary alloy systems selected are the systems of aluminum-copper, aluminum-magnesium, copper-gold, copper-nickel, copper-palladium, copper-zinc, gold-palladium, gold-silver, iron-nickel, and silver-palladium. The recommended values given include values of the total thermal conductivity, electronic thermal conductivity, and lattice thermal conductivity. The uncertainty of the values is generally of the order of ±10%. The values for each of the alloy systems except two are given for 25 alloy compositions: 0.5, 1, 3, 5, 10(5)95, 97, 99, and 99.5%. For most of the alloy compositions, the values cover the temperature range from 4 K to the solidus temperature or 1200 K. In addition, reliable methods for the estimation of the electronic and lattice thermal conductivities of alloys have been developed in this study.

Key words: Alloys; conductivity; critical evaluation; data analysis; data compilation; data synthesis; electrical resistivity; metals; recommended values; thermal conductivity; thermoelectric power.

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TABLE 20. THERMAL CONDUCTIVITY OF GOLD + PALLADIUM ALLOYS -- SPECIMEN CHARACTERIZATION AND MEASUREMENT INFORMATION

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) Au	Pd	Composition (continued), Specifications, and Remarks
1	93	Schulze, F.A.	1911	E	298.2		50	50	Electrical conductivity 3.74 x 10^4 Ω^{-1} cm^{-1} at 25 C.
2	93	Schulze, F.A.	1911	E	298.2		60	40	Electrical conductivity 4.02 x 10^4 Ω^{-1} cm^{-1} at 25 C.
3	93	Schulze, F.A.	1911	E	298.2		70	30	Electrical conductivity 5.45 x 10^4 Ω^{-1} cm^{-1} at 25 C.
4	93	Schulze, F.A.	1911	E	298.2		80	20	Electrical conductivity 7.82 x 10^4 Ω^{-1} cm^{-1} at 25 C.
5	93	Schulze, F.A.	1911	E	298.2		90	10	Electrical conductivity 13.27 x 10^4 Ω^{-1} cm^{-1} at 25 C.
6	61	Grüneisen, E. and Reddemann, H.	1934	L	21-87	22	95	5	Calculated composition; heated at 800 C for 2 hr; electrical resistivity 3.479, 3.939, and 5.44 $\mu\Omega$ cm at 22, 83, and 273 K, respectively.
7	61	Grüneisen, E. and Reddemann, H.	1934	L	21-86	23	90	10	Calculated composition; heated at 800 C for 2 hr; electrical resistivity 7.175, 7.605, and 9.10 $\mu\Omega$ cm at 22, 83, and 273 K, respectively.
8	61	Grüneisen, E. and Reddemann, H.	1934	L	21-92	24	60.1	39.9	Calculated composition; heated at 800 C for 2 hr; electrical resistivity 23.66, 24.48, and 27.1 $\mu\Omega$ cm at 22, 83, and 273, K, respectively.
9	85	Laubitz, M.J. and Van der Meer, M.P.	1968	L	300-1203	Platinel 1503	65.05	34.95	~1.2 cm in diameter and 10 cm long; supplied by Engelhard Ind.; annealed at 800 to 900 K for 60 hr; electrical resistivity ratio $\rho(273K)/\rho(4K)$ = 1.133; electrical resistivity reported as 24.3, 25.1, 25.5, 25.9, 26.4, 26.9, 27.5, 28.2, 28.9, 29.5, 30.1, 30.8, 31.5, 31.9, 33.0 $\mu\Omega$ cm at 310, 420, 485, 551, 614, 688, 755, 821, 890, 953, 1012, 1072, 1140, 1198, and 1304 K, respectively; data extracted from smooth curve.

TABLE 21. THERMAL CONDUCTIVITY OF PALLADIUM + GOLD ALLOYS -- SPECIMEN CHARACTERIZATION AND MEASUREMENT INFORMATION

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) Pd	Au	Composition (continued), Specifications, and Remarks
1	93	Schulze, F.A.	1911	E	298.2		90	10	1 mm thick wire specimen obtained from Heracus Co.; electrical conductivity $6.65 \times 10^4\ \Omega^{-1}\ cm^{-1}$ at 25 C.
2	93	Schulze, F.A.	1911	E	298.2		80	20	1 mm thick wire specimen obtained from Heracus Co.; electrical conductivity $5.33 \times 10^4\ \Omega^{-1}\ cm^{-1}$ at 25 C.
3	93	Schulze, F.A.	1911	E	298.2		70	30	1 mm thick wire specimen obtained from Heracus Co.; electrical conductivity $4.72 \times 10^4\ \Omega^{-1}\ cm^{-1}$ at 25 C.
4	93	Schulze, F.A.	1911	E	298.2		60	40	1 mm thick wire specimen obtained from Heracus Co.; electrical conductivity $3.89 \times 10^4\ \Omega^{-1}\ cm^{-1}$ at 25 C.
5*	93	Schulze, F.A.	1911	E	298.2		50	50	1 mm thick wire specimen obtained from Heracus Co.; electrical conductivity $3.74 \times 10^4\ \Omega^{-1}\ cm^{-1}$ at 25 C.

* Not shown in figure.

4.8. Gold-Silver Alloy System

The gold-silver alloy system forms a continuous series of solid solutions over the entire range of compositions [104]. Possible existence of ordered structures due to the formation of AgAu, Ag_3Au, Ag_3Au_2 and $AgAu_3$ intermetallic compounds has been reported [183].

There are 39 sets of experimental data available for the thermal conductivity of this alloy system. Of the 22 data sets available for Au + Ag alloys listed in table 23 and shown in figure 51, nine sets cover only a narrow temperature range from 273 to 373 K, which is the highest temperature at which data exist. Of the 17 data sets for Ag + Au alloys listed in table 24 and shown in figure 52, four sets likewise cover only the narrow temperature range from 273 to 373 K, which is also the highest temperature at which data exist. This alloy system is one of those in which at first sight the recommendations seem to be merely extensive extrapolations from a few scattered experimental curves, but in fact the recommended values for the electronic component are calculated from an extensive body of electrical resistivity data and those for the lattice component are calculated from well tested semi-theoretical methods.

Thermal conductivities of this alloy system have been reported in five papers [61, 63, 94, 95, and 172]. The measurements by Grüneisen and Reddemann [61] (Au + Ag curves 1 and 2 and Ag + Au curves 1 and 2) appear to be the most reliable, though there is some uncertainty in the compositions of their gold-rich specimens. For most of their specimens, separation of the electronic component from the measured total thermal conductivities gives reasonable values for the lattice component, without much scatter when these k_g values are plotted against the composition. However, the data for their 0.7% Au specimen (Ag + Au curve 1) are questionable. The resistivities reported by Grüneisen and Reddemann for this specimen are as much as 15% higher than expected, while separation of the lattice component gives negative values in some cases. The lattice component for the 15.5% Ag specimen is 25% higher than the calculation from eq (35) at 83 K, but the reported resistivity of this specimen is about 5% higher than expected for an alloy of this composition; an error in the resistivity measurement of this magnitude would account for the disagreement with the result from eq (35). The separated lattice components for the 62.2 and 35.4% Ag specimens (Ag + Au curve 2 and Au + Ag curve 1) show good agreement with the k_g values obtained from eq (35) at 83 K.

The most recent measurements, by Crisp and Rungis [94] (Au + Ag curves 12-20 and Ag + Au curves 8-17), cover a wide range of composition below 300 K. Unfortunately, however, their measurements seem not to be accurate enough to give reasonable lattice thermal conductivities. Lattice conductivities of low accuracy were reported from 4 to 30 K for several alloys in the 0.5-5.0 atomic percent solute range. But separation of the electronic component from their measured total thermal conductivities results in negative values for the lattice component for most of their specimens at 83 and 273 K. In their paper it was mentioned that the separation failed for the most dilute and the most concentrated alloys; in the former case because the lattice component is only a very small portion of the total, and because the conductivity measurements were not sufficiently precise in the very concentrated alloys.

Early measurements by Sedström [63] (Au + Ag curves 3-11 and Ag + Au curves 3-7) in 1919 yield positive lattice thermal conductivities at 273 K, but the k_g values scatter and seem to be high.

Van Baarle et al. [95] have measured the thermal conductivities of 1.26 At.% and 2.92 At.% Au alloys between 2 and 30 K, but they have reported only the lattice thermal conductivity values. Because only lattice components were reported, the original measurements of Van Baarle et al. are not included in table 24 and figure 52. Below 10 K their lattice conductivities for the 1.26 At.% Au alloy conflict with the lattice conductivities reported by White et al. [188] for Ag-Sn alloys with 0.14 and 0.3 At.% Sn. The data reported by Van Baarle et al. in this range are as much as 15% higher than the lattice components of White et al., which in this report were assumed to be the values of the lattice component for "pure" Ag. In their separation of the lattice component, Van Baarle et al. did not consider deviations from Matthiessen's rule and its thermal analog. As a result, their reported lattice conductivities are too low at the higher temperatures. At the present time, it is difficult to judge the reliability of their results because total conductivities are not reported and because the low-temperature results of Crisp and Rungis [94] which might have been compared are highly uncertain.

Since the Au-Ag system is a non-transition solid-solution alloy system, for which the calculations from eqs (12) and (35) should be more reliable, and since the calculated results show reasonable agreement with the reliable experimental data of Gruneisen and Reddemann [61], the recommendations were almost entirely based on the calculated values. Recommended values for the electrical resistivity of Au-Ag alloys were obtained from ref. [7]. The experimental values of k_u for Au and Ag used in eq (35) were obtained from White et al. [188]. For the dilute alloys (0.5-5.0% solute) at temperatures between 40 and 100 K, the calculations were not followed exactly because calculations of the lattice component of the thermal conductivity in this range are expected to fall below the actual values. In this composition and temperature range, the k_g values were adjusted upward in such a way as to be consistent with the experimental data for the "pure" element, the experimental data of Van Baarle et al., and the calculations for the more concentrated alloys. The only other place in which calculations were not used directly was at low temperatures where the lattice conductivity data of Van Baarle et al. [95] made it possible to give provisional values for the 3.00 and 5.00% Au alloys. Although Van Baarle et al. reported data down to 4 K, the provisional values given in table 22 for the 3.00% Au alloy have not been extended below 20 K because of conflicts with the data for "pure" Ag from White et al. [188].

A graphical comparison of the recommended total thermal conductivities with some of the experimental data is given in figures 47 and 48. The smooth solid curves in these figures were obtained by interpolating the recommended values of table 22 in order to obtain thermal conductivities for the

desired alloy compositions. The recommended thermal conductivities show excellent agreement (within 3%) with the data of Grüneisen and Reddemann [61] for concentrated alloys (Au + Ag curves 1 and 2 and Ag + Au curve 2). For the dilute alloy of Grüneisen and Reddemann (Ag + Au curve 1) the agreement is good at 80 K but at lower temperatures the recommendations show an upward trend and pass above the experimental data by up to 25%. In this region, the electronic component constitutes 95% of the total, and it would require unreasonably large uncertainties in the electrical resistivity of the dilute alloys to account for a reduction in the total conductivity by 25%. Considering the difficulties with this specimen discussed earlier, it was concluded that the data were unreliable and no attempts were made to bring the recommendations into better agreement with the questionable experimental results.

The agreement of the recommended thermal conductivities with the work of other investigators is in general poor. As discussed above, the data of Crisp and Rungis [94] are unreliable. They routinely differ from the recommendations by 20% and in some cases differ from the recommendations and the data of Grüneisen and Reddemann by much more. For example, a comparison of the corresponding data of Grüneisen and Reddemann (Au + Ag curve 1 and Ag + Au curve 2) and of Crisp and Rungis (Au + Ag curve 12 and Ag + Au curve 8) for specimens of similar compositions show disagreements of up to 25 and 60%, respectively. Nevertheless, some of the data of Crisp and Rungis [94] (Au + Ag curves 14, 17, and 20 and Ag + Au curves 9–17) agree with the recommendations to within 15% or better and are shown in figures 47 and 48 for comparison. Similarly, the early measurements of Sedström [63] often differ from the recommendations by 15–20%, but some of the data (Au + Ag curves 7–11 and Ag + Au curves 3–7) show better agreement and appear in the comparison figures. Sedström's measurements often exhibit a more rapid increase with temperature than the recommendations.

The recommended values for k, k_e, and k_g are tabulated in table 22 for 25 alloy compositions mostly covering the temperature range from 40 K to the solidus temperatures. These values are for disordered alloys which have not been severely cold worked or quenched. For two alloys, with 3% and 5% Au, the tabulated values cover the range down to 20 K and 4 K, respectively. The k_e values are given from 4 K to the solidus temperatures for all 25 alloy compositions. The values for k are also presented in figures 49 and 50 except for those for 40% and 45% Ag alloys which are not shown in figure 49 for the sake of clarity. The recommended curve for 65% Au alloy is also shown in figure 50 in order to show more clearly the systematic variation of the thermal conductivity with alloy composition. The uncertainties of the k values are stated in a footnote to table 22, in which the values of residual electrical resistivity for the alloys are also given. The uncertainties of the k_e and k_g values are indicated by their being designated as recommended, provisional, or typical values. The ranges of uncertainties of recommended, provisional, and typical values are less than ±15%, between ±15 and ±30%, and greater than ±30%, respectively.

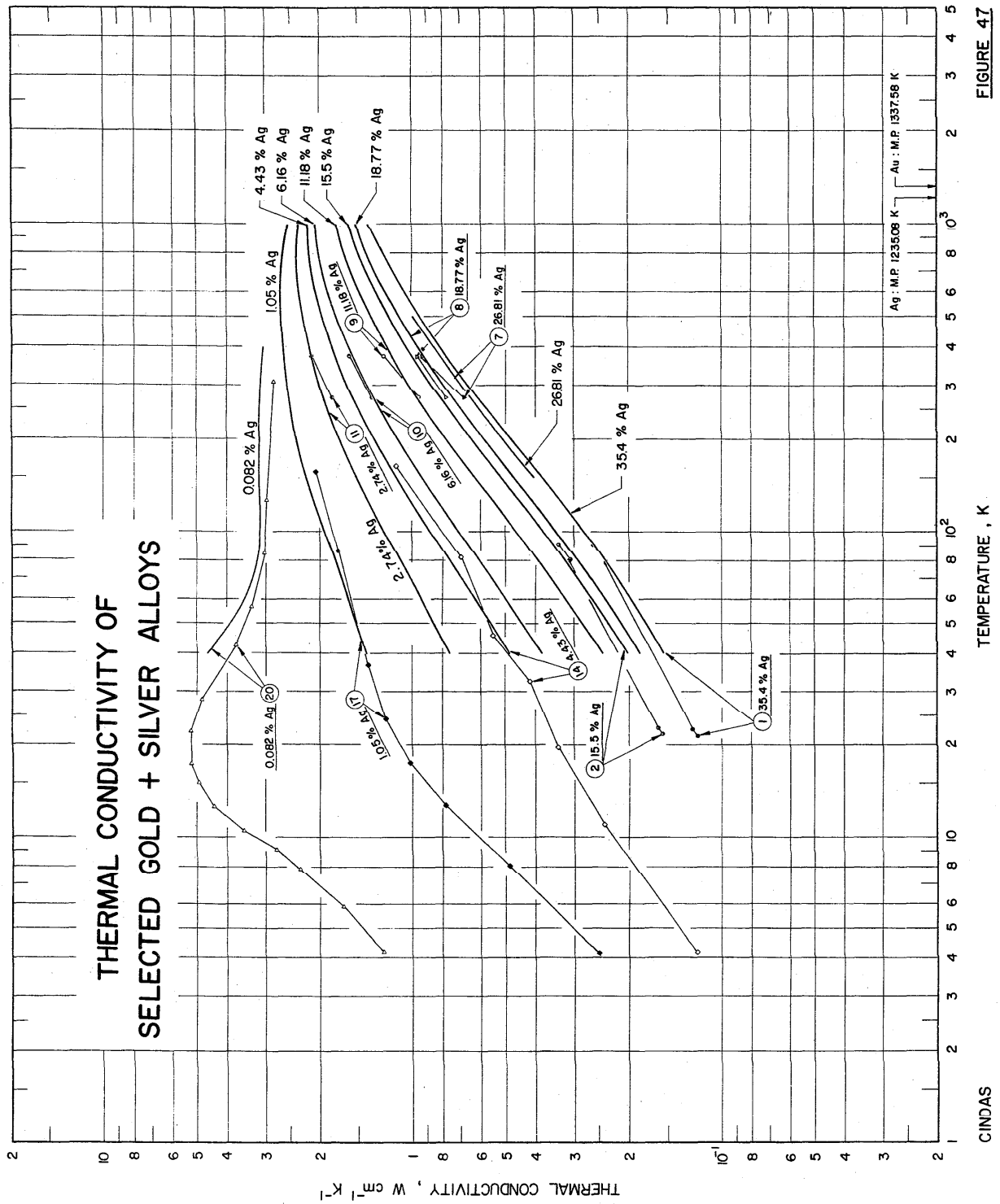
THERMAL CONDUCTIVITY OF
SELECTED GOLD + SILVER ALLOYS
Ag : M.P. 1235.08 K
Au : M.P. 1337.58 K
4.43 % Ag
6.16 % Ag
11.18 % Ag
15.5 % Ag
18.77 % Ag
1.05 % Ag
0.082 % Ag
26.81 % Ag
35.4 % Ag
2.74 % Ag
6.16 % Ag
11.18 % Ag
18.77 % Ag
0.082 % Ag
1.05 % Ag
2.74 % Ag
4.43 % Ag
15.5 % Ag
35.4 % Ag
THERMAL CONDUCTIVITY , W cm⁻¹ K⁻¹
TEMPERATURE , K
CINDAS

FIGURE 47

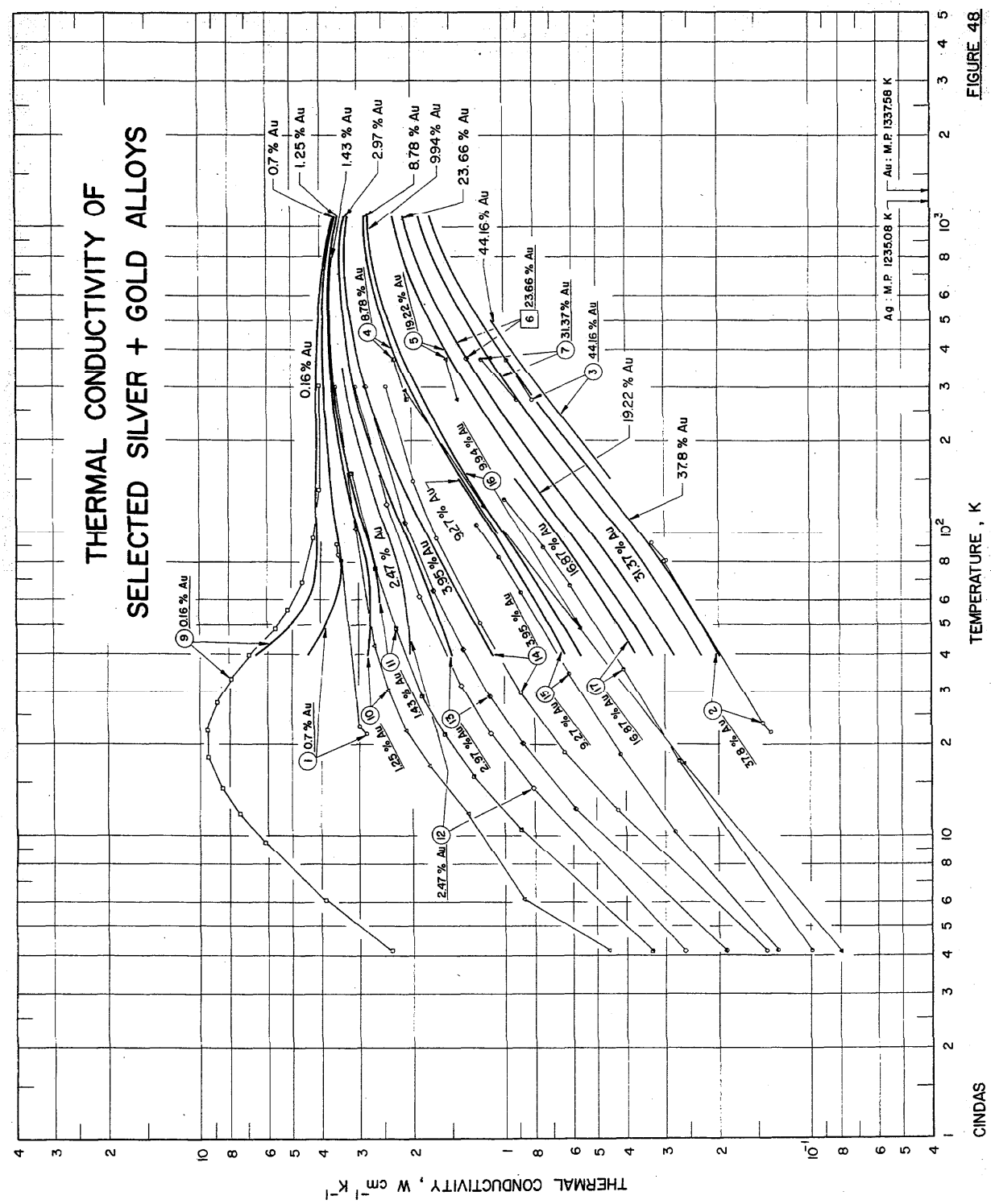
THERMAL CONDUCTIVITY OF
SELECTED SILVER + GOLD ALLOYS
0.7 % Au
1.25 % Au
1.43 % Au
2.97 % Au
8.78 % Au
9.94 % Au
23.66 % Au
44.16 % Au
0.16 % Au
19.22 % Au
31.37 % Au
37.8 % Au
Ag : M.P. 1235.08 K
Au : M.P. 1337.58 K
THERMAL CONDUCTIVITY , W cm⁻¹ K⁻¹
TEMPERATURE , K
CINDAS
CINDAS

FIGURE 48

TABLE 22. RECOMMENDED THERMAL CONDUCTIVITY OF GOLD-SILVER ALLOY SYSTEM†

[Temperature, T, K; Thermal Conductivity, k, W cm^{-1} K^{-1}; Electronic Thermal Conductivity, k_e, W cm^{-1} K^{-1}; Lattice Thermal Conductivity, k_g, W cm^{-1} K^{-1}]

Au: 99.50% (99.09 At.%) Ag: 0.50% (0.91 At.%)				Au: 99.00% (98.19 At.%) Ag: 1.00% (1.81 At.%)				Au: 97.00% (94.66 At.%) Ag: 3.00% (5.34 At.%)				Au: 95.00% (91.23 At.%) Ag: 5.00% (8.77 At.%)			
ρ_o = 0.28 μΩ cm				ρ_o = 0.530 μΩ cm				ρ_o = 1.52 μΩ cm				ρ_o = 2.470 μΩ cm			
T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g
4		0.349		4		0.184		4		0.0643		4		0.0396	
6		0.524		6		0.277		6		0.0964		6		0.0593	
8		0.698		8		0.369		8		0.129		8		0.0791	
10		0.873		10		0.461		10		0.161		10		0.0989	
15		1.31		15		0.691		15		0.241		15		0.148	
20		1.75		20		0.922		20		0.321		20		0.198	
25		1.86		25		1.06		25		0.390		25		0.241	
30		2.01		30		1.19		30		0.454		30		0.284	
40	2.21	2.07	0.142‡	40	1.49	1.37	0.120‡	40	0.656	0.571	0.0850‡	40	0.436	0.363	0.0727‡
50	2.24	2.12	0.124‡	50	1.61	1.50	0.106‡	50	0.745	0.669	0.0763‡	50	0.502	0.437	0.0653‡
60	2.29	2.18	0.109‡	60	1.68	1.59	0.0945‡	60	0.836	0.767	0.0690‡	60	0.567	0.507	0.0596‡
70	2.34	2.24	0.0970‡	70	1.77	1.69	0.0848‡	70	0.917	0.853	0.0637‡	70	0.628	0.573	0.0550‡
80	2.36	2.27	0.0878‡	80	1.84	1.76	0.0770‡	80	0.989	0.930	0.0587‡	80	0.685	0.634	0.0512‡
90	2.42	2.34	0.0800‡	90	1.92	1.85	0.0710‡	90	1.06	1.01	0.0546‡	90	0.742	0.694	0.0479‡
100	2.48	2.41	0.0729‡	100	2.00	1.93	0.0657‡	100	1.13	1.08	0.0515‡	100	0.798	0.753	0.0450‡
150	2.70	2.65	0.0528‡	150	2.29	2.24	0.0489‡	150	1.43	1.39	0.0398‡	150	1.05*	1.01	0.0352‡
200	2.80	2.76	0.0412‡	200	2.44	2.41	0.0388‡	200	1.64*	1.61	0.0326‡	200	1.25*	1.22	0.0292‡
250	2.83	2.80	0.0337‡	250	2.53	2.50	0.0320‡	250	1.80*	1.77	0.0276‡	250	1.41*	1.38	0.0250‡
273	2.85	2.82	0.0311‡	273	2.56	2.53	0.0297‡	273	1.86*	1.83	0.0258‡	273	1.47	1.45	0.0235‡
300	2.86	2.83	0.0285‡	300	2.59	2.56	0.0273‡	300	1.92*	1.90	0.0240‡	300	1.54	1.52	0.0219‡
350	2.86*	2.84	0.0247‡	350	2.64*	2.61	0.0238‡	350	2.02*	2.00	0.0212‡	350	1.65	1.63	0.0196‡
400	2.88*	2.86	0.0218‡	400	2.67*	2.65	0.0211‡	400	2.10*	2.09	0.0190‡	400	1.75*	1.73	0.0177‡
500	2.85*	2.83	0.0176‡	500	2.70*	2.68	0.0171‡	500	2.22*	2.21	0.0158‡	500	1.90*	1.88	0.0149‡
600	2.83*	2.82	0.0147‡	600	2.70*	2.68	0.0145‡	600	2.30*	2.28	0.0135‡	600	2.00*	1.99	0.0128‡
700	2.80*	2.78	0.0127‡	700	2.69*	2.68	0.0125‡	700	2.34*	2.33	0.0118‡	700	2.07*	2.06	0.0133‡
800	2.75*	2.74	0.0111‡	800	2.66*	2.65	0.0110‡	800	2.36*	2.35	0.0105‡	800	2.12*	2.11	0.0101‡
900	2.69*	2.68	0.00994‡	900	2.61*	2.60	0.00982‡	900	2.35*	2.34	0.00944‡	900	2.15*	2.14	0.00913‡
1000	2.63*	2.62	0.00896‡	1000	2.56*	2.55	0.00888‡	1000	2.33*	2.32	0.00858‡	1000	2.15*	2.14	0.00834‡
1200	2.49*	2.49	0.00749‡	1200	2.44*	2.43	0.00744‡	1200	2.27*	2.27	0.00725‡	1200	2.14*	2.13	0.00710‡
1337	2.41*	2.40	0.00670‡	1337	2.37*	2.36	0.00668‡	1336	2.22*	2.21	0.00655‡	1335	2.12*	2.11	0.00645‡

† Uncertainties in the total thermal conductivity, k, are as follows:
99.50 Au - 0.50 Ag: ±10%.
99.00 Au - 1.00 Ag: ±10% below 273 K, ±7% between 273 and 500 K, and ±10% above 500 K.
97.00 Au - 3.00 Ag: ±10% below 273 K, ±7% between 273 and 500 K, and ±10% above 500 K.
95.00 Au - 5.00 Ag: ±10% below 273 K, ±7% between 273 and 500 K, and ±10% above 500 K.

‡ Provisional value.

* In temperature range where no experimental thermal conductivity data are available.

TABLE 22. RECOMMENDED THERMAL CONDUCTIVITY OF GOLD-SILVER ALLOY SYSTEM (continued) †

[Temperature, T, K; Thermal Conductivity, k, W cm^{-1} K^{-1}; Electronic Thermal Conductivity, k_e, W cm^{-1} K^{-1}; Lattice Thermal Conductivity, k_g, W cm^{-1} K^{-1}]

Au: 90.00% (83.13 At.%) Ag: 10.00% (16.87 At.%)				Au: 85.00% (75.63 At.%) Ag: 15.00% (24.37 At.%)				Au: 80.00% (68.66 At.%) Ag: 20.00% (31.34 At.%)				Au: 75.00% (62.16 At.%) Ag: 25.00% (37.84 At.%)			
ρ_o = 4.53 μΩ cm				ρ_o = 6.12 μΩ cm				ρ_o = 7.36 μΩ cm				ρ_o = 8.24 μΩ cm			
T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g
4		0.0216		4		0.0160		4		0.0133		4		0.0119	
6		0.0324		6		0.0240		6		0.0199		6		0.0178	
8		0.0431		8		0.0319		8		0.0266		8		0.0237	
10		0.0539		10		0.0399		10		0.0332		10		0.0296	
15		0.0809		15		0.0599		15		0.0498		15		0.0445	
20		0.108		20		0.0798		20		0.0664		20		0.0593	
25		0.132		25		0.0989		25		0.0823		25		0.0735	
30		0.157		30		0.118		30		0.0980		30		0.0877	
40	0.262	0.205	0.0576‡	40	0.208	0.155	0.0531‡	40	0.180*	0.129	0.0509‡	40	0.165*	0.116	0.0499‡
50	0.303	0.250	0.0527‡	50	0.238	0.190	0.0484‡	50	0.205*	0.159	0.0464‡	50	0.188*	0.143	0.0455‡
60	0.344	0.295	0.0487‡	60	0.269	0.224	0.0447‡	60	0.231*	0.188	0.0427‡	60	0.211*	0.169	0.0419‡
70	0.383	0.338	0.0453‡	70	0.300	0.258	0.0416‡	70	0.257*	0.217	0.0397‡	70	0.234*	0.195	0.0389‡
80	0.421	0.379	0.0424‡	80	0.330	0.291	0.0389‡	80	0.282*	0.245	0.0372‡	80	0.257*	0.220	0.0365‡
90	0.459	0.420	0.0399‡	90	0.360	0.323	0.0366‡	90	0.308*	0.273	0.0350‡	90	0.280*	0.246	0.0343‡
100	0.497	0.460	0.0377‡	100	0.390*	0.355	0.0346‡	100	0.334*	0.301	0.0331‡	100	0.304*	0.271	0.0325‡
150	0.676	0.646	0.0299‡	150	0.534*	0.506	0.0275‡	150	0.457*	0.431	0.0264‡	150	0.416*	0.390	0.0259‡
200	0.833*	0.808	0.0250‡	200	0.665*	0.641	0.0232‡	200	0.573*	0.550	0.0223‡	200	0.522*	0.501	0.0219‡
250	0.971*	0.949	0.0217‡	250	0.782*	0.762	0.0202‡	250	0.678*	0.658	0.0194‡	250	0.621*	0.602	0.0192‡
273	1.03	1.01	0.0205‡	273	0.833	0.814	0.0191‡	273	0.723	0.704	0.0184‡	273	0.664	0.646	0.0181‡
300	1.09	1.07	0.0192‡	300	0.889	0.872	0.0180‡	300	0.775	0.757	0.0173‡	300	0.712	0.695	0.0171‡
350	1.20	1.18	0.0173‡	350	0.986	0.970	0.0162‡	350	0.864	0.848	0.0157‡	350	0.797	0.781	0.0155‡
400	1.29*	1.28	0.0158‡	400	1.07*	1.06	0.0149‡	400	0.947*	0.932	0.0144‡	400	0.874*	0.860	0.0143‡
500	1.44*	1.43	0.0135‡	500	1.22*	1.21	0.0128‡	500	1.09*	1.08	0.0124‡	500	1.01*	1.00	0.0123‡
600	1.57*	1.56	0.0118‡	600	1.34*	1.33	0.0112‡	600	1.21*	1.20	0.0110‡	600	1.13*	1.12	0.0109‡
700	1.66*	1.65	0.0105‡	700	1.44*	1.43	0.0101‡	700	1.32*	1.31	0.00987‡	700	1.24*	1.23	0.00988‡
800	1.74*	1.73	0.00946‡	800	1.53*	1.52	0.00913‡	800	1.40*	1.39	0.00898‡	800	1.33*	1.32	0.00895‡
900	1.79*	1.79	0.00863‡	900	1.59*	1.58	0.00836‡	900	1.47*	1.46	0.00825‡	900	1.40*	1.39	0.00823‡
1000	1.83*	1.82	0.00794‡	1000	1.64*	1.63	0.00772‡	1000	1.52*	1.52	0.00763‡	1000	1.45*	1.45	0.00763‡
1200	1.89*	1.88	0.00684‡	1200	1.72*	1.71	0.00671‡	1200	1.61*	1.61	0.00666‡	1200	1.55*	1.54	0.00668‡
1331	1.92*	1.91	0.00630‡	1327	1.77*	1.76	0.00620‡	1322	1.67*	1.66	0.00615‡	1317	1.59*	1.58	0.00620‡

† Uncertainties in the total thermal conductivity, k, are as follows:
90.00 Au - 10.00 Ag: ±10% below 273 K, ±7% between 273 and 500 K, and ±10% above 500 K.
85.00 Au - 15.00 Ag: ±10% below 273 K, ±7% between 273 and 500 K, and ±10% above 500 K.
80.00 Au - 20.00 Ag: ±10% below 273 K, ±7% between 273 and 500 K, and ±10% above 500 K.
75.00 Au - 25.00 Ag: ±10% below 273 K, ±7% between 273 and 500 K, and ±10% above 500 K.

‡ Provisional value.

* In temperature range where no experimental thermal conductivity data are available.

TABLE 22. RECOMMENDED THERMAL CONDUCTIVITY OF GOLD-SILVER ALLOY SYSTEM (continued) †

[Temperature, T, K; Thermal Conductivity, k, W cm^{-1} K^{-1}; Electronic Thermal Conductivity, k_e, W cm^{-1} K^{-1}; Lattice Thermal Conductivity, k_g, W cm^{-1} K^{-1}]

Au: 70.00% (56.10 At.%) Ag: 30.00% (43.90 At.%)				Au: 65.00% (50.42 At.%) Ag: 35.00% (49.58 At.%)				Au: 60.00% (45.10 At.%) Ag: 40.00% (54.90 At.%)				Au: 55.00% (40.10 At.%) Ag: 45.00% (59.90 At.%)			
ρ_o = 8.77 μΩ cm				ρ_o = 9.0 μΩ cm				ρ_o = 8.93 μΩ cm				ρ_o = 8.66 μΩ cm			
T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g
4		0.0111		4		0.0109		4		0.0109		4		0.0113	
6		0.0167		6		0.0163		6		0.0164		6		0.0169	
8		0.0223		8		0.0217		8		0.0219		8		0.0226	
10		0.0279		10		0.0271		10		0.0274		10		0.0282	
15		0.0418		15		0.0407		15		0.0410		15		0.0423	
20		0.0557		20		0.0543		20		0.0547		20		0.0564	
25		0.0691		25		0.0673		25		0.0679		25		0.0701	
30		0.0825		30		0.0803		30		0.0811		30		0.0836	
40	0.159*	0.109	0.0497‡	40	0.156	0.106	0.0502‡	40	0.158*	0.107	0.0511‡	40	0.163*	0.110	0.0526‡
50	0.180*	0.134	0.0453‡	50	0.177	0.131	0.0457‡	50	0.179*	0.132	0.0466‡	50	0.184*	0.136	0.0479‡
60	0.201*	0.159	0.0417‡	60	0.197	0.155	0.0421‡	60	0.200*	0.157	0.0429‡	60	0.205*	0.161	0.0441‡
70	0.223*	0.184	0.0388‡	70	0.218	0.179	0.0392‡	70	0.221*	0.181	0.0399‡	70	0.227*	0.186	0.0410‡
80	0.244*	0.208	0.0363‡	80	0.240	0.203	0.0367‡	80	0.242*	0.205	0.0374‡	80	0.249*	0.211	0.0384‡
90	0.267*	0.232	0.0342‡	90	0.261	0.227	0.0345‡	90	0.264*	0.229	0.0352‡	90	0.271*	0.235	0.0362‡
100	0.288*	0.256	0.0324‡	100	0.282	0.250	0.0327‡	100	0.285*	0.252	0.0333‡	100	0.294*	0.259	0.0343‡
150	0.395*	0.370	0.0259‡	150	0.387	0.361	0.0262‡	150	0.391*	0.364	0.0267‡	150	0.402*	0.375	0.0275‡
200	0.497*	0.475	0.0219‡	200	0.486	0.464	0.0221‡	200	0.490*	0.468	0.0226‡	200	0.505*	0.481	0.0232‡
250	0.592*	0.571	0.0192‡	250	0.579	0.560	0.0194‡	250	0.584*	0.564	0.0198‡	250	0.601*	0.581	0.0203‡
273	0.632	0.614	0.0181‡	273	0.620	0.601	0.0184‡	273	0.624	0.606	0.0187‡	273	0.642	0.623	0.0193‡
300	0.679	0.661	0.0171‡	300	0.666	0.649	0.0173‡	300	0.671	0.653	0.0177‡	300	0.689	0.671	0.0182‡
350	0.760	0.744	0.0155‡	350	0.746	0.731	0.0157‡	350	0.752	0.736	0.0161‡	350	0.773	0.756	0.0165‡
400	0.836*	0.822	0.0143‡	400	0.822*	0.808	0.0145‡	400	0.828	0.813	0.0148‡	400	0.852	0.837	0.0152‡
500	0.969*	0.957	0.0124‡	500	0.956*	0.943	0.0125‡	500	0.964*	0.951	0.0128‡	500	0.992*	0.978	0.0132‡
600	1.09*	1.08	0.0110‡	600	1.07*	1.06	0.0111‡	600	1.08*	1.07	0.0114‡	600	1.12*	1.10	0.0117‡
700	1.19*	1.18	0.00988‡	700	1.18*	1.17	0.0100‡	700	1.19*	1.18	0.0102‡	700	1.22*	1.21	0.0105‡
800	1.28*	1.27	0.00901‡	800	1.26*	1.26	0.00915‡	800	1.28*	1.27	0.00936‡	800	1.31*	1.30	0.00963‡
900	1.35*	1.35	0.00830‡	900	1.34*	1.33	0.00843‡	900	1.35*	1.34	0.00863‡	900	1.39*	1.38	0.00888‡
1000	1.41*	1.41	0.00770‡	1000	1.40*	1.39	0.00783‡	1000	1.42*	1.41	0.00801‡	1000	1.45*	1.44	0.00825‡
1200	1.51*	1.50	0.00676‡	1200	1.50*	1.49	0.00687‡	1200	1.52*	1.51	0.00704‡	1100	1.51*	1.50	0.00771‡
1311	1.55*	1.54	0.00630‡	1306	1.54*	1.53	0.00650‡	1300	1.55*	1.54	0.00660‡	1295	1.59*	1.58	0.00685‡

† Uncertainties in the total thermal conductivity, k, are as follows:
70.00 Au - 30.00 Ag: ±10% below 273 K, ±7% between 273 and 500 K, and ±10% above 500 K.
65.00 Au - 35.00 Ag: ±10% below 273 K, ±7% between 273 and 500 K, and ±10% above 500 K.
60.00 Au - 40.00 Ag: ±10% below 273 K, ±7% between 273 and 500 K, and ±10% above 500 K.
55.00 Au - 45.00 Ag: ±10% below 273 K, ±7% between 273 and 500 K, and ±10% above 500 K.

‡ Provisional value.

* In temperature range where no experimental thermal conductivity data are available.

TABLE 22. RECOMMENDED THERMAL CONDUCTIVITY OF GOLD-SILVER ALLOY SYSTEM (continued) †

[Temperature, T, K; Thermal Conductivity, k, W cm^{-1} K^{-1}; Electronic Thermal Conductivity, k_e, W cm^{-1} K^{-1}; Lattice Thermal Conductivity, k_g, W cm^{-1} K^{-1}]

Au: 50.00% (35.39 At.%) Ag: 50.00% (64.61 At.%)				Au: 45.00% (30.94 At.%) Ag: 55.00% (69.06 At.%)				Au: 40.00% (26.75 At.%) Ag: 60.00% (73.25 At.%)				Au: 35.00% (22.77 At.%) Ag: 65.00% (77.23 At.%)			
ρ_o = 8.30 μΩ cm				ρ_o = 7.79 μΩ cm				ρ_o = 7.16 μΩ cm				ρ_o = 6.42 μΩ cm			
T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g
4		0.0118		4		0.0125		4		0.0136		4		0.0152	
6		0.0177		6		0.0188		6		0.0205		6		0.0228	
8		0.0235		8		0.0251		8		0.0273		8		0.0304	
10		0.0294		10		0.0314		10		0.0341		10		0.0381	
15		0.0442		15		0.0470		15		0.0512		15		0.0571	
20		0.0589		20		0.0627		20		0.0682		20		0.0761	
25		0.0732		25		0.0778		25		0.0849		25		0.0945	
30		0.0874		30		0.0929		30		0.101		30		0.113	
40	0.170*	0.115	0.0544‡	40	0.179*	0.122	0.0568‡	40	0.193	0.133	0.0598‡	40	0.212	0.148	0.0634‡
50	0.192*	0.142	0.0496‡	50	0.203*	0.151	0.0518‡	50	0.219	0.164	0.0545‡	50	0.240	0.182	0.0579‡
60	0.214*	0.169	0.0458‡	60	0.227*	0.179	0.0478‡	60	0.245	0.194	0.0503‡	60	0.269	0.216	0.0535‡
70	0.237*	0.194	0.0426‡	70	0.251*	0.206	0.0445‡	70	0.271	0.224	0.0469‡	70	0.298	0.248	0.0498‡
80	0.260*	0.220	0.0399‡	80	0.275*	0.234	0.0417‡	80	0.297	0.254	0.0439‡	80	0.327	0.280	0.0467‡
90	0.283*	0.246	0.0376‡	90	0.300*	0.261	0.0393‡	90	0.324	0.283	0.0414‡	90	0.356	0.313	0.0440‡
100	0.306*	0.271	0.0356‡	100	0.324*	0.287	0.0372‡	100	0.350*	0.311	0.0392‡	100	0.385*	0.344	0.0416‡
150	0.419*	0.391	0.0285‡	150	0.444*	0.414	0.0298‡	150	0.479*	0.448	0.0313‡	150	0.527*	0.493	0.0333‡
200	0.526*	0.502	0.0241‡	200	0.557*	0.532	0.0252‡	200	0.600*	0.573	0.0265‡	200	0.658*	0.630	0.0282‡
250	0.626*	0.605	0.0211‡	250	0.662*	0.640	0.0220‡	250	0.712*	0.689	0.0232‡	250	0.780*	0.756	0.0246‡
273	0.670	0.650	0.0200‡	273	0.708	0.687	0.0209‡	273	0.760*	0.738	0.0220‡	273	0.833*	0.810	0.0233‡
300	0.719	0.701	0.0189‡	300	0.760	0.740	0.0197‡	300	0.816*	0.795	0.0207‡	300	0.892*	0.870	0.0220‡
350	0.806	0.789	0.0171‡	350	0.851	0.833	0.0179‡	350	0.913*	0.894	0.0188‡	350	0.996*	0.976	0.0200‡
400	0.888*	0.872	0.0158‡	400	0.936*	0.920	0.0164‡	400	1.00*	0.987	0.0173‡	400	1.09*	1.07	0.0183‡
500	1.03*	1.02	0.0136‡	500	1.09*	1.07	0.0142‡	500	1.16*	1.15	0.0149‡	500	1.26*	1.24	0.0158‡
600	1.16*	1.15	0.0121‡	600	1.22*	1.21	0.0126‡	600	1.30*	1.29	0.0132‡	600	1.40*	1.39	0.0140‡
700	1.27*	1.26	0.0109‡	700	1.34*	1.32	0.0114‡	700	1.42*	1.41	0.0119‡	700	1.52*	1.51	0.0126‡
800	1.36*	1.35	0.00996‡	800	1.43*	1.42	0.0104‡	800	1.52*	1.51	0.0109‡	800	1.62*	1.61	0.0114‡
900	1.44*	1.43	0.00918‡	900	1.51*	1.50	0.00955‡	900	1.60*	1.59	0.00999‡	900	1.71*	1.70	0.0105‡
1000	1.51*	1.50	0.00853‡	1000	1.58*	1.57	0.00887‡	1000	1.67*	1.66	0.00927‡	1000	1.78*	1.77	0.00974‡
1100	1.56*	1.55	0.00797‡	1100	1.63*	1.62	0.00828‡	1100	1.73*	1.72	0.00865‡	1100	1.84*	1.83	0.00908‡
1289	1.65*	1.64	0.00710‡	1284	1.72*	1.71	0.00740‡	1278	1.82*	1.81	0.00775‡	1273	1.93*	1.92	0.00820‡

† Uncertainties in the total thermal conductivity, k, are as follows:
50.00 Au - 50.00 Ag: ±10% below 273 K, ±7% between 273 and 500 K, and ±10% above 500 K.
45.00 Au - 55.00 Ag: ±10% below 273 K, ±7% between 273 and 500 K, and ±10% above 500 K.
40.00 Au - 60.00 Ag: ±10% below 273 K, ±7% between 273 and 500 K, and ±10% above 500 K.
35.00 Au - 65.00 Ag: ±10% below 273 K, ±7% between 273 and 500 K, and ±10% above 500 K.

‡ Provisional value.

* In temperature range where no experimental thermal conductivity data are available.

TABLE 22. RECOMMENDED THERMAL CONDUCTIVITY OF GOLD-SILVER ALLOY SYSTEM (continued) †

[Temperature, T, K; Thermal Conductivity, k, W cm^{-1} K^{-1}; Electronic Thermal Conductivity, k_e, W cm^{-1} K^{-1}; Lattice Thermal Conductivity, k_g, W cm^{-1} K^{-1}]

Au: 30.00% (19.01 At.%) Ag: 70.00% (80.99 At.%)				Au: 25.00% (15.44 At.%) Ag: 75.00% (84.56 At.%)				Au: 20.00% (12.04 At.%) Ag: 80.00% (87.96 At.%)				Au: 15.00% (8.81 At.%) Ag: 85.00% (91.19 At.%)			
ρ_o = 5.60 μΩ cm				ρ_o = 4.75 μΩ cm				m ρ_o = 3.86 μΩ cm				ρ_o = 2.94 μΩ cm			
T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g
4		0.0175		4		0.0206		4		0.0253		4		0.0332	
6		0.0262		6		0.0309		6		0.0380		6		0.0499	
8		0.0349		8		0.0411		8		0.0506		8		0.0665	
10		0.0436		10		0.0514		10		0.0633		10		0.0831	
15		0.0654		15		0.0771		15		0.0949		15		0.125	
20		0.0873		20		0.103		20		0.127		20		0.166	
25		0.108		25		0.127		25		0.157		25		0.206	
30		0.129		30		0.152		30		0.187		30		0.244	
40	0.237*	0.169	0.0679‡	40	0.272*	0.198	0.0736‡	40	0.326	0.245	0.0809‡	40	0.408	0.317	0.0909‡
50	0.270*	0.208	0.0621‡	50	0.311*	0.244	0.0674‡	50	0.373	0.299	0.0744‡	50	0.469	0.385	0.0839‡
60	0.305*	0.245	0.0574‡	60	0.348*	0.286	0.0624‡	60	0.418	0.349	0.0689‡	60	0.524	0.446	0.0779‡
70	0.335*	0.282	0.0535‡	70	0.387*	0.328	0.0582‡	70	0.464	0.400	0.0643‡	70	0.580	0.508	0.0728‡
80	0.368*	0.318	0.0502‡	80	0.424*	0.370	0.0546‡	80	0.509	0.448	0.0603‡	80	0.635	0.567	0.0683‡
90	0.401*	0.354	0.0473‡	90	0.462*	0.411	0.0514‡	90	0.553	0.496	0.0569‡	90	0.691	0.626	0.0644‡
100	0.434*	0.389	0.0447‡	100	0.500*	0.451	0.0487‡	100	0.597	0.543	0.0538‡	100	0.744	0.683	0.0609‡
150	0.592*	0.556	0.0358‡	150	0.678*	0.640	0.0389‡	150	0.805	0.762	0.0429‡	150	0.990	0.942	0.0484‡
200	0.737*	0.707	0.0302‡	200	0.841*	0.808	0.0328‡	200	0.987*	0.951	0.0361‡	200	1.20*	1.16	0.0406‡
250	0.871*	0.844	0.0263‡	250	0.988*	0.960	0.0285‡	250	1.15*	1.12	0.0313‡	250	1.38*	1.35	0.0351‡
273	0.928	0.903	0.0249‡	273	1.05*	1.02	0.0270‡	273	1.22	1.19	0.0296‡	273	1.46*	1.43	0.0331‡
300	0.993	0.969	0.0235‡	300	1.12*	1.09	0.0254‡	300	1.29	1.26	0.0278‡	300	1.54*	1.51	0.0311‡
350	1.10	1.08	0.0213‡	350	1.24	1.21	0.0230‡	350	1.42	1.39	0.0251‡	350	1.68*	1.65	0.0279‡
400	1.20*	1.18	0.0195‡	400	1.35*	1.33	0.0210‡	400	1.54*	1.51	0.0229‡	400	1.80*	1.78	0.0254‡
500	1.38*	1.36	0.0168‡	500	1.53*	1.51	0.0181‡	500	1.73*	1.71	0.0196‡	500	2.01*	1.99	0.0216‡
600	1.53*	1.51	0.0148‡	600	1.68*	1.67	0.0159‡	600	1.89*	1.87	0.0172‡	600	2.17*	2.15	0.0188‡
700	1.65*	1.64	0.0133‡	700	1.81*	1.80	0.0142‡	700	2.02*	2.00	0.0154‡	700	2.29*	2.27	0.0167‡
800	1.76*	1.74	0.0121‡	800	1.91*	1.90	0.0129‡	800	2.12*	2.10	0.0139‡	800	2.38*	2.36	0.0151‡
900	1.83*	1.82	0.0111‡	900	1.99*	1.98	0.0118‡	900	2.19*	2.18	0.0127‡	900	2.45*	2.44	0.0137‡
1000	1.91*	1.90	0.0103‡	1000	2.06*	2.05	0.0109‡	1000	2.26*	2.24	0.0117‡	1000	2.50*	2.49	0.0126‡
1100	1.97*	1.96	0.0958‡	1100	2.12*	2.11	0.0101‡	1100	2.31*	2.30	0.0108‡	1100	2.54*	2.53	0.0116‡
1267	2.06*	2.05	0.0860‡	1261	2.20*	2.19	0.00920‡	1256	2.38*	2.37	0.00980‡	1251	2.59*	2.58	0.0105‡

† Uncertainties in the total thermal conductivity, k, are as follows:
30.00 Au - 70.00 Ag: ±10% below 273 K, ±7% between 273 and 500 K, and ±10% above 500 K.
25.00 Au - 75.00 Ag: ±10% below 273 K, ±7% between 273 and 500 K, and ±10% above 500 K.
20.00 Au - 80.00 Ag: ±10% below 273 K, ±7% between 273 and 500 K, and ±10% above 500 K.
15.00 Au - 85.00 Ag: ±10% below 273 K, ±7% between 273 and 500 K, and ±10% above 500 K.

‡ Provisional value.

* In temperature range where no experimental thermal conductivity data are available.

TABLE 22. RECOMMENDED THERMAL CONDUCTIVITY OF GOLD-SILVER ALLOY SYSTEM (continued) †

[Temperature, T, K; Thermal Conductivity, k, W cm^{-1} K^{-1}; Electronic Thermal Conductivity, k_e, W cm^{-1} K^{-1}; Lattice Thermal Conductivity, k_g, W cm^{-1} K^{-1}]

Au: 10.00% (5.74 At.%) Ag: 90.00% (94.26 At.%)				Au: 5.00% (2.80 At.%) Ag: 95.00% (97.20 At.%)				Au: 3.00% (1.67 At.%) Ag: 97.00% (98.33 At.%)				Au: 1.00% (0.55 At.%) Ag: 99.00% (99.45 At.%)			
ρ_o = 1.97 μΩ cm				ρ_o = 0.99 μΩ cm				ρ_o = 0.59 μΩ cm				ρ_o = 0.190 μΩ cm			
T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g
4		0.0496		4	0.125‡	0.0987	0.0259‡	4		0.166		4		0.514	
6		0.0744		6	0.202‡	0.148	0.0539‡	6		0.248		6		0.771	
8		0.0992		8	0.275‡	0.197	0.0776‡	8		0.331		8		1.03	
10		0.124		10	0.344‡	0.247	0.0969‡	10		0.414		10		1.29	
15		0.186		15	0.498‡	0.370	0.128‡	15		0.621		15		1.93	
20		0.248		20	0.636‡	0.494	0.142‡	20	1.01	0.828	0.179‡	20		2.57	
25		0.305		25	0.743‡	0.598	0.145‡	25	1.18	1.00	0.180‡	25		2.90	
30		0.363		30	0.849‡	0.705	0.144‡	30	1.33	1.15	0.176‡	30		3.21	
40	0.571	0.465	0.106‡	40	1.01‡	0.873	0.137‡	40	1.52	1.36	0.163‡	40	3.51	3.28	0.225‡
50	0.655	0.557	0.0981‡	50	1.14‡	1.01	0.127‡	50	1.65	1.50	0.148‡	50	3.32	3.12	0.200‡
60	0.726	0.635	0.0914‡	60	1.23	1.11	0.118‡	60	1.73	1.59	0.137‡	60	3.11	2.93	0.179‡
70	0.801	0.715	0.0855‡	70	1.32	1.21	0.110‡	70	1.84	1.71	0.127‡	70	3.10	2.94	0.162‡
80	0.872	0.792	0.0803‡	80	1.42	1.32	0.104‡	80	1.95	1.83	0.118‡	80	3.11	2.96	0.148‡
90	0.944	0.869	0.0757‡	90	1.53	1.43	0.0968‡	90	2.05	1.94	0.111‡	90	3.18	3.04	0.137‡
100	1.01	0.940	0.0716‡	100	1.62	1.53	0.0908‡	100	2.14	2.04	0.105‡	100	3.26	3.13	0.128‡
150	1.32	1.26	0.0566‡	150	2.00	1.92	0.0706‡	150	2.53	2.45	0.0799‡	150	3.50	3.41	0.0941‡
200	1.56	1.51	0.0471‡	200	2.27	2.21	0.0577‡	200	2.79	2.73	0.0643‡	200	3.67	3.59	0.0737‡
250	1.76	1.72	0.0404‡	250	2.49	2.44	0.0488‡	250	2.98	2.93	0.0538‡	250	3.77	3.71	0.0605‡
273	1.84	1.80	0.0380‡	273	2.57	2.52	0.0456‡	273	3.05	3.00	0.0500‡	273	3.77	3.71	0.0558‡
300	1.93	1.90	0.0355‡	300	2.64	2.60	0.0423‡	300	3.11	3.06	0.0462‡	300	3.81	3.75	0.0512‡
350	2.08	2.05	0.0318‡	350	2.77	2.74	0.0374‡	350	3.21	3.17	0.0405‡	350	3.84*	3.79	0.0444‡
400	2.21*	2.18	0.0287‡	400	2.88*	2.85	0.0335‡	400	3.29*	3.26	0.0360‡	400	3.87*	3.83	0.0391‡
500	2.40*	2.38	0.0242‡	500	3.03*	3.00	0.0277‡	500	3.39*	3.36	0.0295‡	500	3.87*	3.84	0.0316‡
600	2.55*	2.53	0.0209‡	600	3.13*	3.11	0.0237‡	600	3.45*	3.43	0.0250‡	600	3.85*	3.82	0.0265‡
700	2.66*	2.64	0.0185‡	700	3.19*	3.17	0.0206‡	700	3.47*	3.45	0.0217‡	700	3.82*	3.80	0.0229‡
800	2.73*	2.72	0.0165‡	800	3.22*	3.20	0.0183‡	800	3.48*	3.46	0.0192‡	800	3.79*	3.77	0.0201‡
900	2.77*	2.76	0.0150‡	900	3.27*	3.21	0.0165‡	900	3.45*	3.44	0.0171‡	900	3.72*	3.70	0.0179‡
1000	2.80*	2.79	0.0137‡	1000	3.22*	3.20	0.0149‡	1000	3.41*	3.40	0.0155‡	1000	3.65*	3.64	0.0161‡
1100	2.83*	2.82	0.0126‡	1100	3.20*	3.19	0.0137‡	1100	3.38*	3.36	0.0142‡	1100	3.58*	3.56	0.0147‡
1245	2.87*	2.86	0.0114‡	1240	3.18*	3.17	0.0123‡	1238	3.32*	3.31	0.0126‡	1236	3.50*	3.49	0.0132‡

† Uncertainties in the total thermal conductivity, k, are as follows:
10.00 Au - 90.00 Ag: ±10% below 273 K, ±7% between 273 and 500 K, and ±10% above 500 K.
5.00 Au - 95.00 Ag: ±15% below 40 K, ±10% between 40 and 273 K, ±7% between 273 and 500 K, and ±10% above 500 K.
3.00 Au - 97.00 Ag: ±15% below 40 K, ±10% between 40 and 273 K, ±7% between 273 and 500 K, and ±10% above 500 K.
1.00 Au - 99.00 Ag: ±10% below 273 K, ±7% between 273 and 500 K, and ±10% above 500 K.

‡ Provisional value.

* In temperature range where no experimental thermal conductivity data are available.

TABLE 22. RECOMMENDED THERMAL CONDUCTIVITY OF GOLD-SILVER ALLOY SYSTEM (continued) †

[Temperature, T, K; Thermal Conductivity, k, W cm^{-1} K^{-1}; Electronic Thermal Conductivity, k_e, W cm^{-1} K^{-1}; Lattice Thermal Conductivity, k_g, W cm^{-1} K^{-1}]

Au: 0.50% (0.28 At.%) Ag: 99.50% (99.72 At.%)			
ρ_o = 0.0800 μΩ cm			
T	k	k_e	k_g
4		1.22	
6		1.83	
8		2.44	
10		3.05	
15		4.58	
20		6.11	
25		6.08	
30		6.20	
40	5.20	4.93	0.266‡
50	4.41	4.18	0.232‡
60	3.86	3.66	0.204‡
70	3.73	3.55	0.182‡
80	3.72	3.56	0.164‡
90	3.74	3.59	0.149‡
100	3.79	3.65	0.138‡
150	3.90	3.80	0.0989‡
200	3.95	3.88	0.0768‡
250	4.01	3.95	0.0625‡
273	4.01	3.96	0.0576‡
300	4.03	3.98	0.0527‡
350	4.03	3.99	0.0455‡
400	4.03*	3.99	0.0400‡
500	4.01*	3.98	0.0322‡
600	3.97*	3.95	0.0270‡
700	3.92*	3.90	0.0232‡
800	3.87*	3.85	0.0203‡
900	3.79*	3.77	0.0181‡
1000	3.71*	3.69	0.0163‡
1100	3.64*	3.62	0.0148‡
1236	3.55*	3.54	0.0133‡

† Uncertainties in the total thermal conductivity, k, are as follows:
0.50 Au - 99.50 Ag: ±10%.

‡ Provisional value.

* In temperature range where no experimental thermal conductivity data are available.

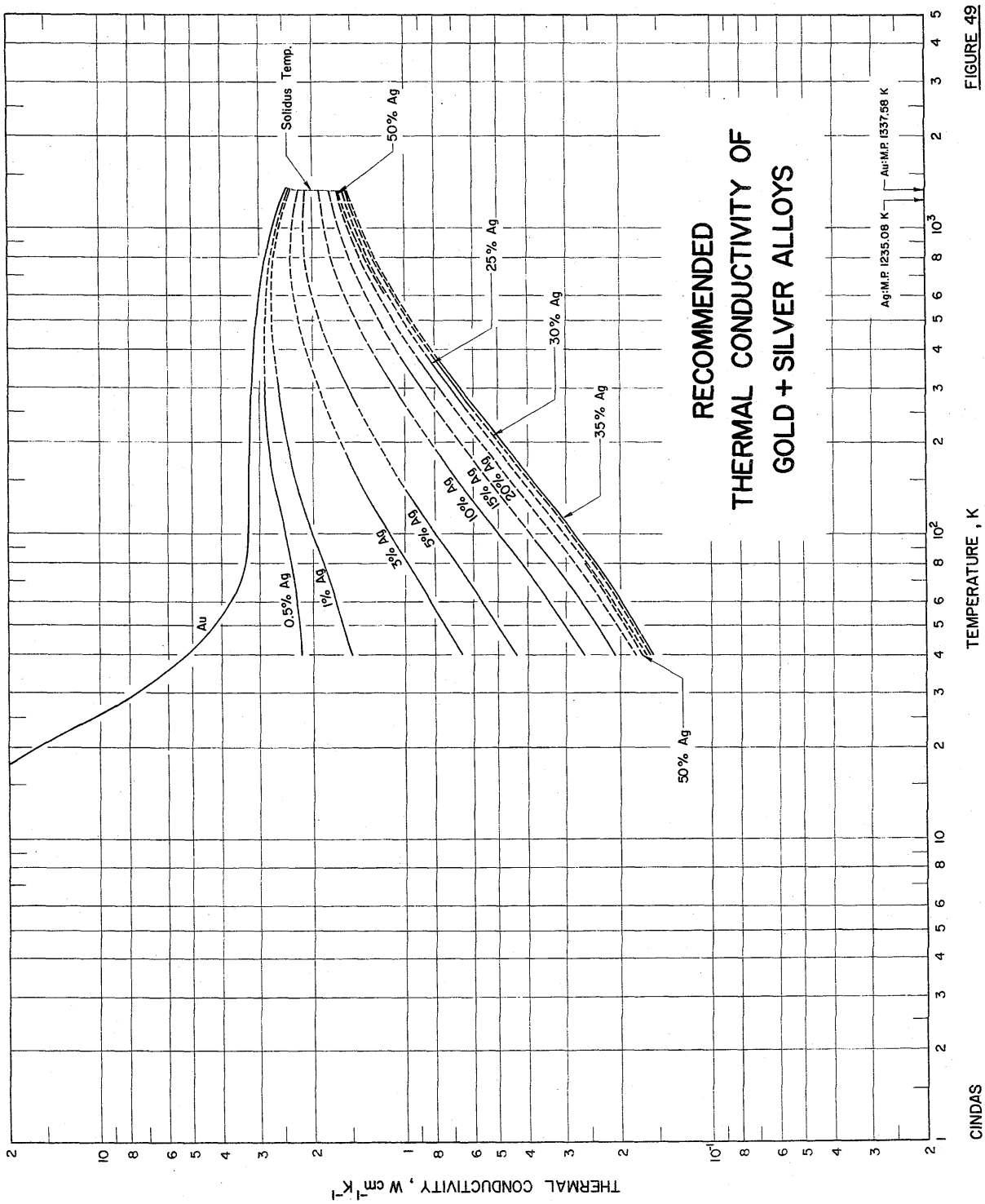
RECOMMENDED
THERMAL CONDUCTIVITY OF
GOLD + SILVER ALLOYS
Ag: M.P. 1235.08 K
Au: M.P. 1337.58 K
Solidus Temp.
50% Ag
25% Ag
30% Ag
35% Ag
20% Ag
15% Ag
10% Ag
5% Ag
3% Ag
1% Ag
0.5% Ag
Au
50% Ag
THERMAL CONDUCTIVITY , W cm⁻¹ K⁻¹
TEMPERATURE , K
CINDAS

FIGURE 49

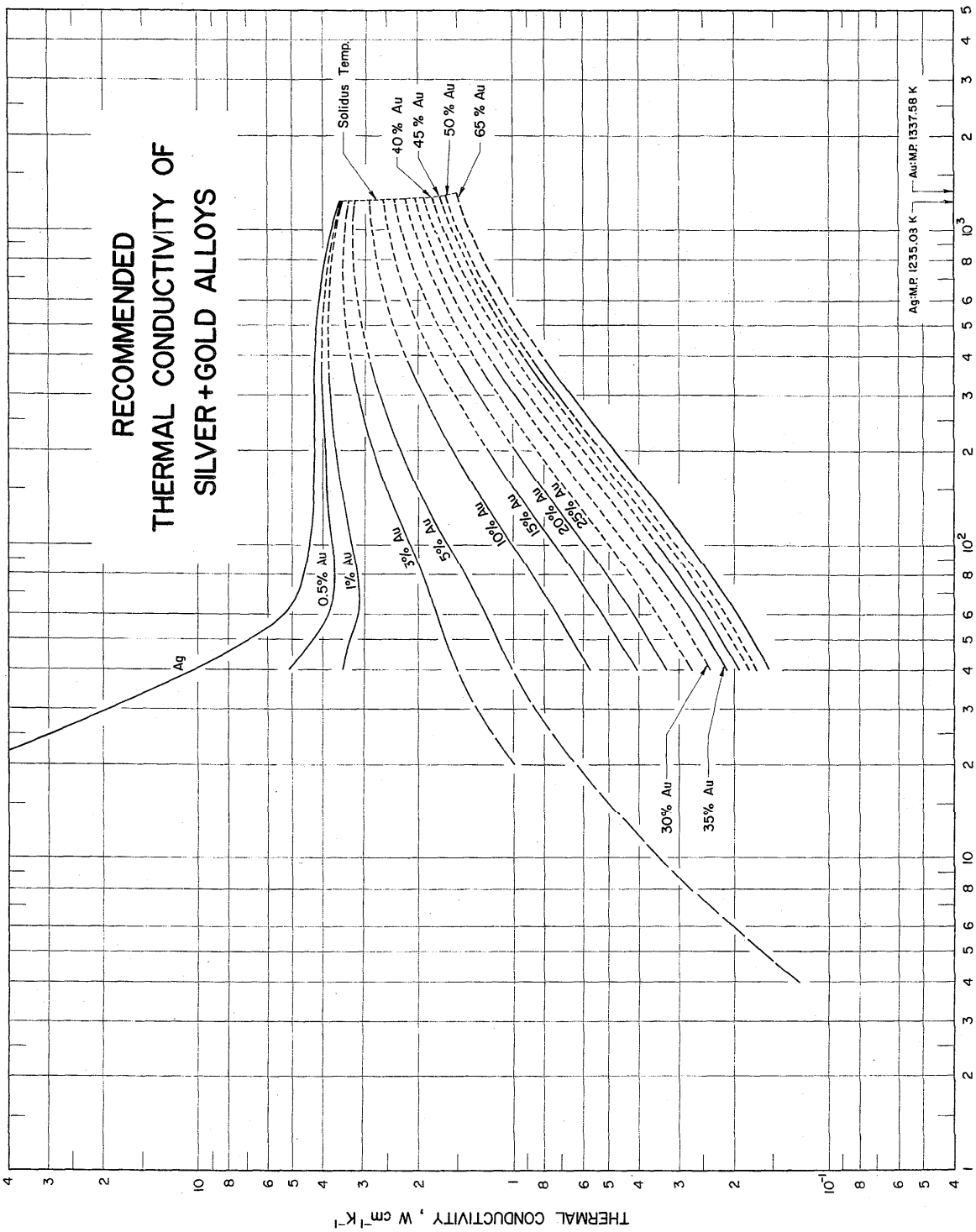
RECOMMENDED
THERMAL CONDUCTIVITY OF
SILVER+GOLD ALLOYS
Solidus Temp.
40 % Au
45 % Au
50 % Au
65 % Au
Ag:M.P. 1235.03 K
Au:M.P. 1337.58 K
Ag
0.5% Au
1% Au
3% Au
5% Au
10% Au
15% Au
20% Au
25% Au
30% Au
35% Au
THERMAL CONDUCTIVITY , W cm⁻¹ K⁻¹
TEMPERATURE , K
CINDAS

FIGURE 50

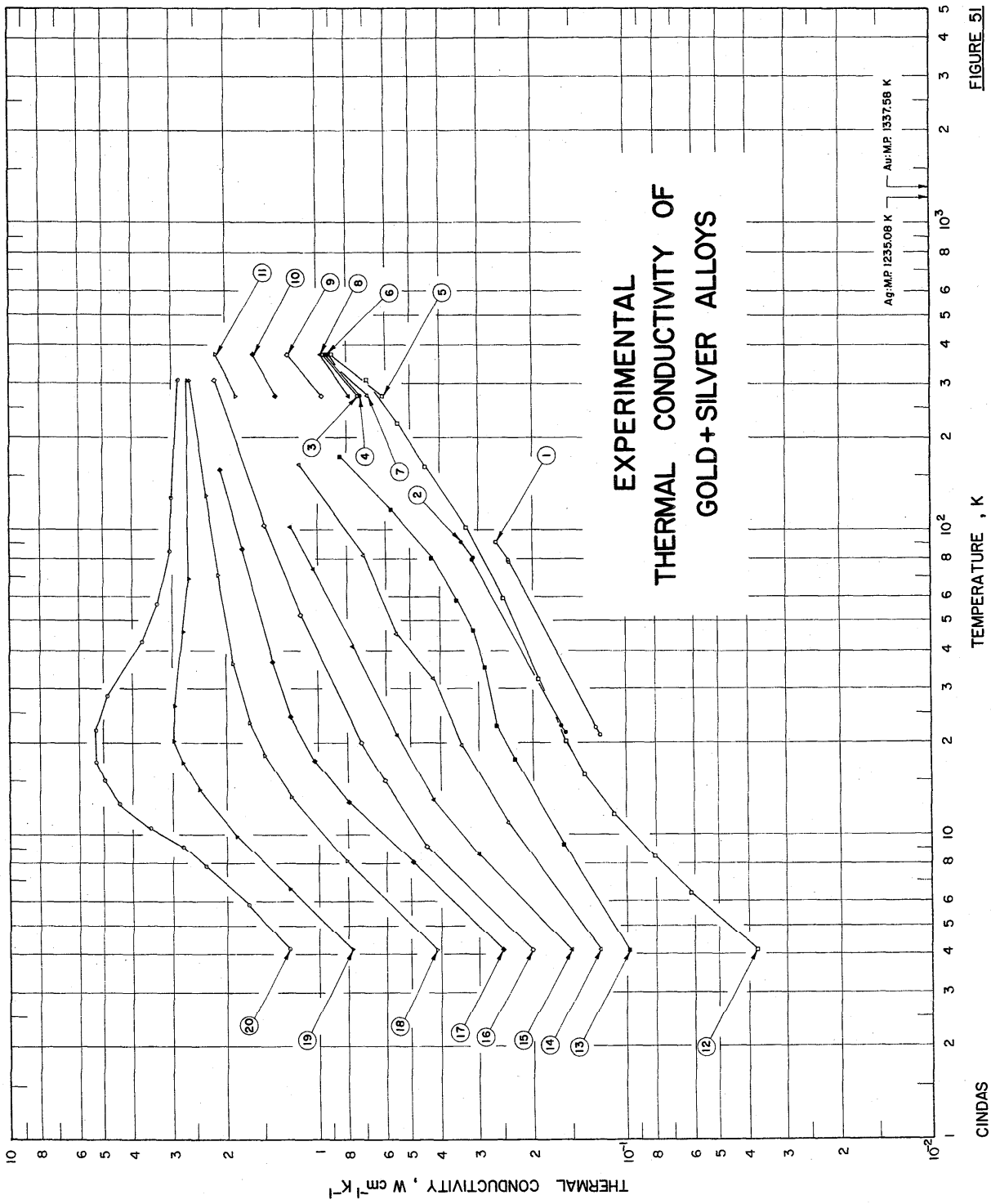
EXPERIMENTAL
THERMAL CONDUCTIVITY OF
GOLD+SILVER ALLOYS
Ag:M.P. 1235.08 K
Au:M.P. 1337.58 K
THERMAL CONDUCTIVITY , W cm⁻¹ K⁻¹
TEMPERATURE , K
CINDAS

FIGURE 51

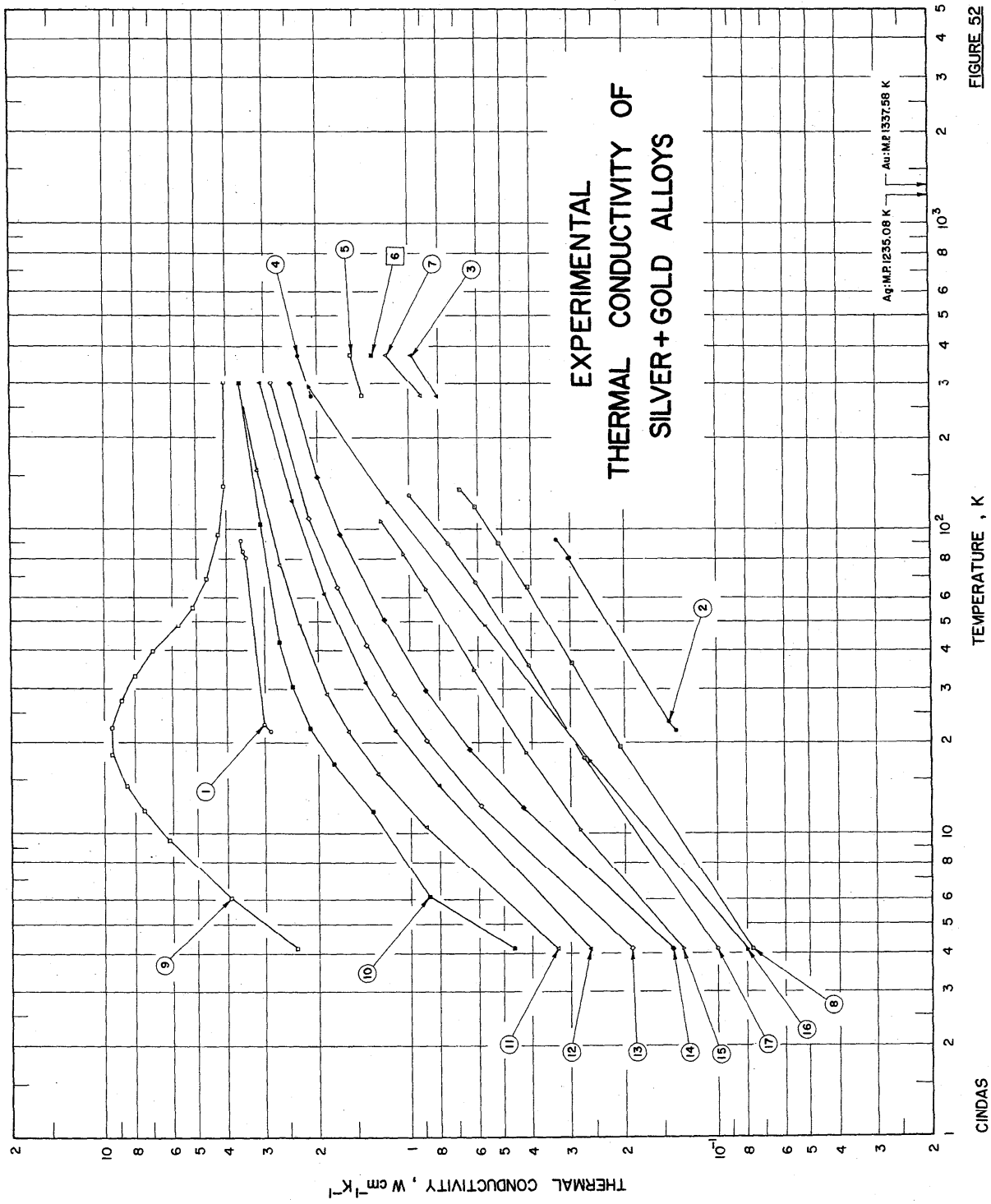
EXPERIMENTAL
THERMAL CONDUCTIVITY OF
SILVER+GOLD ALLOYS
Ag: M.P. 1235.08 K
Au: M.P. 1337.58 K
THERMAL CONDUCTIVITY , W cm⁻¹K⁻¹
TEMPERATURE , K
CINDAS

FIGURE 52

TABLE 23. THERMAL CONDUCTIVITY OF GOLD + SILVER ALLOYS -- SPECIMEN CHARACTERIZATION AND MEASUREMENT INFORMATION

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) Au	Ag	Composition (continued), Specifications, and Remarks
1	61	Grüneisen, E. and Reddemann, H.	1934	L	21-91	6	64.6	35.4	Calculated composition; single crystal; electrical resistivity 8.85, 9.32, and 10.8 $\mu\Omega$ cm at 22, 83, and 273 K, respectively.
2	61	Grüneisen, E. and Reddemann, H.	1934	L	22-92	7	84.5	15.5	Calculated composition; single crystal; electrical resistivity 6.69, 7.16, and 8.69 $\mu\Omega$ cm at 22, 83, and 273 K, respectively.
3	63	Sedström, E.	1919	T	273,373		54.62	45.38	Calculated composition; specimen rolled and drawn to 1 mm thick; heated 0.5 hr at temperature near the melting point; electrical conductivity 9.1 and 8.4 x 10^4 Ω^{-1} cm^{-1} at 0 and 100 C, respectively.
4	63	Sedström, E.	1919	T	273,373		60.32	39.68	Similar to the above specimen except electrical conductivity 9.1 and 8.5 x 10^4 Ω^{-1} cm^{-1} at 0 and 100 C, respectively.
5	63	Sedström, E.	1919	T	273,373		65.46	34.54	Similar to the above specimen except electrical conductivity 7.2 and 7.2 x 10^4 Ω^{-1} cm^{-1} at 0 and 100 C, respectively.
6	63	Sedström, E.	1919	T	273,373		69.17	30.83	Similar to the above specimen except electrical conductivity 8.9 and 8.4 x 10^4 Ω^{-1} cm^{-1} at 0 and 100 C, respectively.
7	63	Sedström, E.	1919	T	273,373		73.19	26.81	Similar to the above specimen except electrical conductivity 9.1 and 8.5 x 10^4 Ω^{-1} cm^{-1} at 0 and 100 C, respectively.
8	63	Sedström, E.	1919	T	273,373		81.23	18.77	Similar to the above specimen except electrical conductivity 10.2 and 9.6 x 10^4 Ω^{-1} cm^{-1} at 0 and 100 C, respectively.
9	63	Sedström, E.	1919	T	273,373		88.82	11.18	Similar to the above specimen except electrical conductivity 13.2 and 12.4 x 10^4 Ω^{-1} cm^{-1} at 0 and 100 C, respectively.
10	63	Sedström, E.	1919	T	273,373		93.84	6.16	Similar to the above specimen except electrical conductivity 18.1 and 15.9 x 10^4 Ω^{-1} cm^{-1} at 0 and 100 C, respectively.
11	63	Sedström, E.	1919	T	273,373		97.26	2.74	Similar to the above specimen except electrical conductivity 25.1 and 22.0 x 10^4 Ω^{-1} cm^{-1} at 0 and 100 C, respectively.
12	94	Crisp, R.S. and Rungis, J.	1970	L	4.1-307			35.39	Calculated composition from atomic percent; specimen purchased in three batches from Cambridge Metals Research Ltd., England, prepared from 99.999 and 99.9999 Au and 99.9999 Ag; about 0.5 to 1 mm in diameter and about 1 to 5 cm long; drawn down, etched, washed in distilled water and alcohol, dried and sealed into quartz capsules with 1/3 atmosphere of oxygen and then annealed for 72 hr at 900 C.
13	94	Crisp, R.S. and Rungis, J.	1970	L	4.1-173			12.7	Similar to the above specimen except the electrical resistivity reported as 6.038 and 8.107 $\mu\Omega$ cm at 0 and 273 K, respectively.
14	94	Crisp, R.S. and Rungis, J.	1970	L	4.1-165			4.43	Similar to the above specimen except the electrical resistivity reported as 2.603 and 4.695 $\mu\Omega$ cm at 0 and 273 K, respectively.
15	94	Crisp, R.S. and Rungis, J.	1970	L	4.1-100			2.29	Similar to the above specimen except the electrical resistivity reported as 1.404 and 3.517 $\mu\Omega$ cm at 0 and 273 K, respectively.
16	94	Crisp, R.S. and Rungis, J.	1970	L	4.1-307			1.33	Similar to the above specimen except the electrical resistivity reported as 0.855 and 2.991 $\mu\Omega$ cm at 0 and 273 K, respectively.
17	94	Crisp, R.S. and Rungis, J.	1970	L	4.1-156			1.05	Similar to the above specimen except the residual electrical resistivity reported as 0.670 $\mu\Omega$ cm.
18	94	Crisp, R.S. and Rungis, J.	1970	L	4.1-307			0.47	Similar to the above specimen except the electrical resistivity reported as 0.370 and 2.421 $\mu\Omega$ cm at 0 and 273 K, respectively.

TABLE 23. THERMAL CONDUCTIVITY OF GOLD + SILVER ALLOYS -- SPECIMEN CHARACTERIZATION AND MEASUREMENT INFORMATION (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) Au	Ag	Composition (continued), Specifications, and Remarks
19	94	Crisp, R.S. and Rungis, J.	1970	L	4.1-307			0.203	Similar to the above specimen except the electrical resistivity reported as 0.135 and 2.209 $\mu\Omega$ cm at 0 and 273 K, respectively.
20	94	Crisp, R.S. and Rungis, J.	1970	L	4.2-307			0.082	Similar to the above specimen except the electrical resistivity reported as 0.053 and 2.128 $\mu\Omega$ cm at 0 and 273 K, respectively.
21*	172	Kapoor, A., Rowlands, J.A., and Woods, S.B.	1974	L	0.65-4.0		94.26	5.74	Calculated composition (10 a/o Ag); 4 mm^2 in cross section and 10 cm long; prepared by induction melting 99.999 pure metals in argon, resulted ingot rolled to size; cold-worked; residual electrical resistivity 2.90 $\mu\Omega$ cm.
22*	172	Kapoor, A., et al.	1974	L	0.69-4.0				The above specimen annealed in vacuum at 1000 K for 12 hr; residual electrical resistivity 2.71 $\mu\Omega$ cm.

* Not shown in figure.

TABLE 24. THERMAL CONDUCTIVITY OF SILVER + GOLD ALLOYS -- SPECIMEN CHARACTERIZATION AND MEASUREMENT INFORMATION

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) Ag	Au	Composition (continued), Specifications, and Remarks
1	61	Grüneisen, E. and Reddemann, H.	1934	L	22-92	4	99.3	0.7	Calculated composition; wire specimen; electrical resistivity 0.163, 0.473, and 1.63 $\mu\Omega$ cm at 22, 83, and 273 K, respectively.
2	61	Grüneisen, E. and Reddeman, H.	1934	L	22-92	5	62.2	37.8	Calculated composition; single crystal; wire specimen; electrical resistivity 6.87, 7.25, and 8.57 $\mu\Omega$ cm at 22, 83, and 273 K, respectively.
3	63	Sedström, E.	1919	T	273,373		55.84	44.16	Calculated composition: wire specimen 1 mm in diameter; rolled and drawn; annealed at close to melting point for 0.5 hr; electrical conductivity 10.3 and 9.7 x 10^4 Ω^{-1} cm^{-1} at 0 and 100 C, respectively.
4	63	Sedström, E.	1919	T	273,373		91.22	8.78	Similar to the above specimen; electrical conductivity 29.3 and 24.2 x 10^4 Ω^{-1} cm^{-1} at 0 and 100 C, respectively.
5	63	Sedström, E.	1919	T	273,373		80.74	19.26	Similar to the above specimen except electrical conductivity 19.5 and 16.0 x 10^4 Ω^{-1} cm^{-1} at 0 and 100 C, respectively.
6	63	Sedström, E.	1919	T	273.2		76.34	23.66	Similar to the above specimen except electrical conductivity 14.7 and 13.5 x 10^4 Ω^{-1} cm^{-1} at 0 and 100 C, respectively.
7	63	Sedström, E.	1919	T	273,373		68.63	31.37	Similar to the above specimen except electrical conductivity 12.5 and 11.5 x 10^4 Ω^{-1} cm^{-1} at 0 and 100 C, respectively.
8	94	Crisp, R.S. and Rungis, J.	1970	L	4.2-136			40.31	Calculated composition from atomic percent; specimen purchased in three batches from Cambridge Metals Research Ltd., England; prepared from 99.9999 Ag and 99.999 and 99.9999 Au; about 0.5 to 1 mm in diameter and about 1 to 5 cm long; drawn down, etched, washed in distilled water and alcohol, dried and sealed into quartz capsules with 1/3 atmosphere of oxygen and then annealed for 72 hr at 900 C; electrical resistivity reported as 7.084 and 8.874 $\mu\Omega$ cm at 0 and 273 K, respectively.
9	94	Crisp, R.S. and Rungis, J.	1970	L	4.1-136			0.164	Similar to the above specimen except the electrical resistivity reported as 0.033 and 1.532 $\mu\Omega$ cm at 0 and 273 K, respectively.
10	94	Crisp, R.S. and Rungis, J.	1970	L	4.1-300			1.25	Similar to the above specimen except the electrical resistivity reported as 0.249 and 1.758 $\mu\Omega$ cm at 0 and 273 K, respectively.
11	94	Crisp, R.S. and Rungis, J.	1970	L	4.1-300			1.43	Similar to the above specimen except the electrical resistivity reported as 0.285 and 1.788 $\mu\Omega$ cm at 0 and 273 K, respectively.
12	94	Crisp, R.S. and Rungis, J.	1970	L	4.1-300			2.47	Similar to the above specimen except the electrical resistivity reported as 0.493 and 2.052 $\mu\Omega$ cm at 0 and 273 K, respectively.
13	94	Crisp, R.S. and Rungis, J.	1970	L	4.1-300			2.97	Similar to the above specimen except the electrical resistivity reported as 0.593 and 2.126 $\mu\Omega$ cm at 0 and 273 K, respectively.
14	94	Crisp, R.S. and Rungis, J.	1970	L	4.1-300			3.95	Similar to the above specimen except the electrical resistivity reported as 0.768 and 2.507 $\mu\Omega$ cm at 0 and 273 K, respectively.
15	94	Crisp, R.S. and Rungis, J.	1970	L	4.2-106			9.27	Similar to the above specimen except the electrical resistivity reported as 1.813 and 3.408 $\mu\Omega$ cm at 0 and 273 K, respectively.
16	94	Crisp, R.S. and Rungis, J.	1970	L	4.2-294			9.94	Similar to the above specimen except the electrical resistivity reported as 1.923 and 3.581 $\mu\Omega$ cm at 0 and 273 K, respectively.
17	94	Crisp, R.S. and Rungis, J.	1970	L	4.1-129			16.87	Similar to the above specimen except the electrical resistivity reported as 3.303 and 4.958 $\mu\Omega$ cm at 0 and 273 K, respectively.

4.9. Iron-Nickel Alloy System

The iron-nickel alloy system does not form a continuous series of solid solutions at low temperatures. There is an α phase bounded on the right by a line extending from 0% Ni at about 1183 K passing through 9% Ni at 473 K and a γ phase bounded on the left by a line extending from 0% Ni at about 1183 K passing through 74% Ni near 473 K. In addition, there is a martensitic transformation in alloys containing up to 27 At.% Ni quenched from above about 770 K, resulting in a metastable α_2 phase. The phase diagram is further complicated by magnetic transitions: at about 1030 K in the α phase, at about 673 K in the $\alpha+\gamma$ phase mixture, and on a curve reaching a maximum of 895 K at about 65% Ni in the γ phase. Finally, there is an order-disorder transformation based on $FeNi_3$ covering a wide range of composition, about 50 to 80% Ni, which has a maximum transition temperature of about 776 K.

There are 99 sets of experimental data available for the thermal conductivity of this alloy system. However, of the 64 data sets available for Fe + Ni alloys listed in table 26 and shown in figure 57, 34 sets are merely single data points, and of the 35 data sets for Ni + Fe alloys listed in table 27 and shown in figure 58, five sets are single data points and 21 sets are for temperatures below 4.5 K. Few of these data sets are on binary alloys and those for the low Ni alloys are presumably not for the equilibrium phase. Since much of the data for the Fe-rich region is for low alloy steels containing other impurities which affect the resistivity as well as the thermal conductivity, essentially it is ϱ_0 that specifies the composition and the thermal conductivity. In this connection, the provisional values for Fe-3% Ni are from 12% to 15% below the values for an Fe-3.15% Ni specimen [191] (Fe + Ni curve 64), measured after this analysis was completed, over the temperature range from 90 K to 400 K. The resistivity of this specimen at 90 K is 6.98 $\mu\Omega$ cm while the residual resistivity cited for the provisional values is 7.20 $\mu\Omega$ cm corresponding to a resistivity of 8.67 $\mu\Omega$ cm at 90 K, a value 20% greater than that for the Fe-3.15% Ni specimen. Accordingly, the tabulated values should be used with caution taking account of the resistivity of the material.

For Fe + Ni alloys, no specimen containing less than 3% Ni was measured below 100 K. The conductivity-composition curve for 300 K was constructed based on the data of Powell and Hickman [96] (Fe + Ni curves 3 and 4), of Kohlhaas and Kierspe [97] (Fe + Ni curves 30, 31, and 63), and of Ingersoll et al. [98] (Fe + Ni curves 7-16). The specimens reported in [96] and [97] were well annealed, and the electrical resistivity measurements were consistent with the thermal conductivity results. No heat treatments were mentioned about the specimens of Ingersoll et al., but their results are the only systematic measurements made on a number of alloys covering a wide range of composition. The data of Ingersoll et al. thus provided important information on the variation of thermal conductivity with composition. The electronic thermal conductivities calculated from eq (12) were found to be unreliable for some temperatures and compositions: those alloys containing more than 20% Ni at temperatures above 300 K. Both the total k values and the calculated values of k_e at 300 K were plotted on a conductivity-composition graph and the differences between k and k_e were taken as k_g. The k_g values at lower and higher temperatures were obtained by extrapolation according to the appropriate theoretical temperature dependence. Except for those alloys containing more than 20% Ni at temperatures above 300 K, the total conductivity was obtained by adding the extrapolated k_g to the calculated k_e. For those alloys containing more than 20% Ni at temperatures above 300 K, the extrapolated k_e values were subtracted from the values of the total conductivity derived from the experimental data to obtain the values of k_e. In the process of calculating the electronic thermal conductivity, the correction due to the thermoelectric power was not made at this time because anomalous variation of thermoelectric power with composition at 260 °C was reported by Wang et al. [103] which requires further study. Since the corrections would be small, no more than 0.2% for all compositions except for the 30% Ni alloy, for which it comes to nearly 1% at 260 °C, the total thermal conductivity should not be in too large an error without this correction.

For Ni+Fe alloys, the conductivity-composition curve for k_g at 300 K was extrapolated from the Fe+Ni part to the Ni+Fe portion using the k value of Moore et al. [187] (Ni+Fe curve 36) for an alloy with 75.93% Ni as a reference point. That is, the sum of the extrapolated k_g value at 75% Ni and the k_e value calculated from the selected electrical resistivity for this composition was required to approximate the Moore et al. value. The k_e values for all compositions from 4 to 1100 K were calculated from the selected electrical resistivities, and the k_g values at 300 K were extrapolated to higher temperatures following the temperature dependence of eq (35). At low temperatures, all data [81,100,105,106] indicate that k_g is proportional to T, and the k_g values were extrapolated to higher temperature to join the k_g values extrapolated from 300 K to lower temperatures. The total thermal conductivity for each composition was then obtained by adding k_g to k_e, except below 60 K for alloys containing 5% iron or less. The respective ϱ_0 values were obtained based solely on the experimental data of ref. [81]. The correction due to the thermoelectric power, which would be no more than 2% of the total thermal conductivity for any composition at any temperature, was not made at this time for the same reason as for the Fe+Ni alloys. The recommended values are for totally disordered alloys only; there may be an order-disorder transformation in Ni+Fe alloys over a wide range of compositions.

A graphical comparison of the recommended total thermal conductivity values with selected experimental data is given in figures 53 and 54. The smooth solid curves in these figures were obtained by interpolating the recommended values of table 25 in order to obtain thermal conductivity values for the desired alloy compositions. For iron-rich alloys shown in figure 53, the recommended values are in agreement with the data of Chari and de Nobel [99] (Fe+Ni curve 1), of de Nobel [100] (Fe+Ni curve 35), and of Kohlhass and Kierspe [97] (Fe+Ni curves 30 and 31) at low temperatures to within 10%, and with the data of Powell and Hickman [96] (Fe+Ni curves 3 and 4), of Bäcklund [101] (Fe+Ni curves 24 and 25), and of Watson and Robinson [102] (Fe+Ni curves 19, 26, 28,

29, and 62) at higher temperatures to within 12%. For nickel-rich alloys shown in figure 54, the recommended values agree with the data of Berger and Rivier [107] (Ni+Fe curve 7), of Farrell and Greig [81] (Ni+Fe curves 12-14), and of de Nobel [100] (Ni+Fe curve 35) at low temperatures to within 5%, and with the data of Shelton and Swanger [108] (Ni+Fe curves 3-5), and of Moore et al. [187] (Ni+Fe curve 36) at higher temperatures to within 10%.

The recommended values for k, k_e, and k_g are tabulated in table 25 for 25 alloy compositions, for most of which the temperature range covered is from 4 to 1100 K. These values are for disordered alloys which have not been severely cold worked or quenched. The values for k are also presented in figures 55 and 56. The recommended curves for Fe-rich alloys containing 35 to 45% Ni are also shown in figure 56 in order to show more clearly the systematic variation of the thermal conductivity with alloy composition and to clarify the confusion in figure 55 due to crossover of curves. No values are given at temperatures above 1100 K at this time since there is a phase transformation in iron at 1183 K and it is as yet not known what effect such a transformation has on the lattice thermal conductivity of these alloys. It is noted that at high temperatures the differences between the k values of 5% and 10% nickel alloys are rather large. This is caused by the discontinuity of the Curie temperature at 5.5% nickel, where it drops from 1038 K to 677 K as nickel content increases [104]. The values of residual electrical resistivity for the alloys are also given in table 25. The uncertainties of the k values are stated in a footnote to table 25, while the uncertainties of the k_e and k_g values are indicated by their being designated as recommended, provisional, or typical values. The ranges of uncertainties of recommended, provisional, and typical values are less than ±15%, between ±15 and ±30%, and greater than ±30%, respectively.

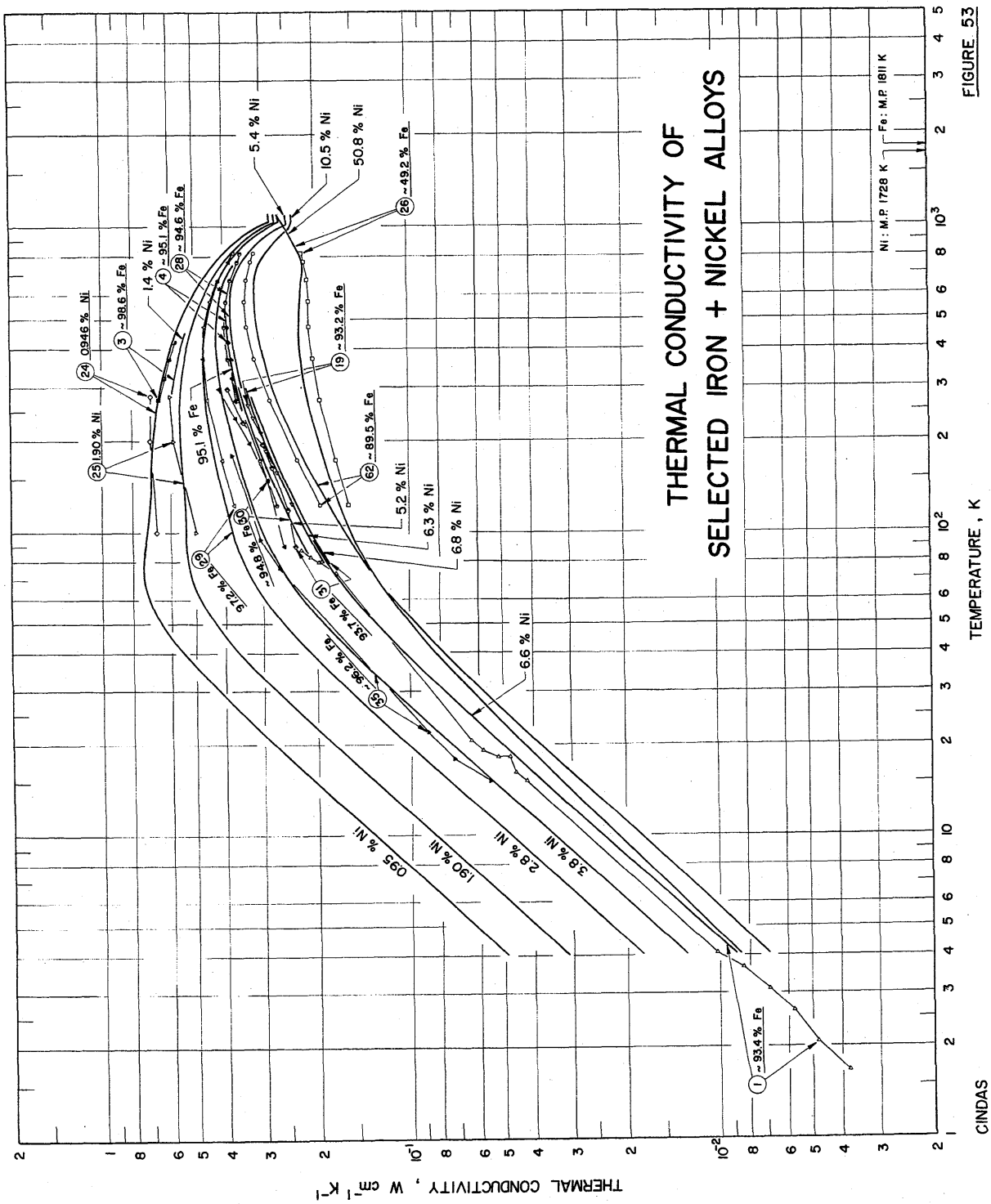
THERMAL CONDUCTIVITY OF
SELECTED IRON + NICKEL ALLOYS
Ni : M.P. 1728 K
Fe : M.P. 1811 K
5.4 % Ni
10.5 % Ni
50.8 % Ni
~49.2 % Fe
~95.1 % Fe
~94.6 % Fe
1.4 % Ni
~98.6 % Fe
0.946 % Ni
1.90 % Ni
95.1 % Fe
~93.2 % Fe
~89.5 % Fe
5.2 % Ni
6.3 % Ni
6.8 % Ni
~94.8 % Fe
97.2 % Fe
93.7 % Fe
~98.2 % Fe
6.6 % Ni
0.95 % Ni
1.90 % Ni
2.8 % Ni
3.8 % Ni
~93.4 % Fe
THERMAL CONDUCTIVITY , W cm⁻¹ K⁻¹
TEMPERATURE , K
CINDAS

FIGURE 53

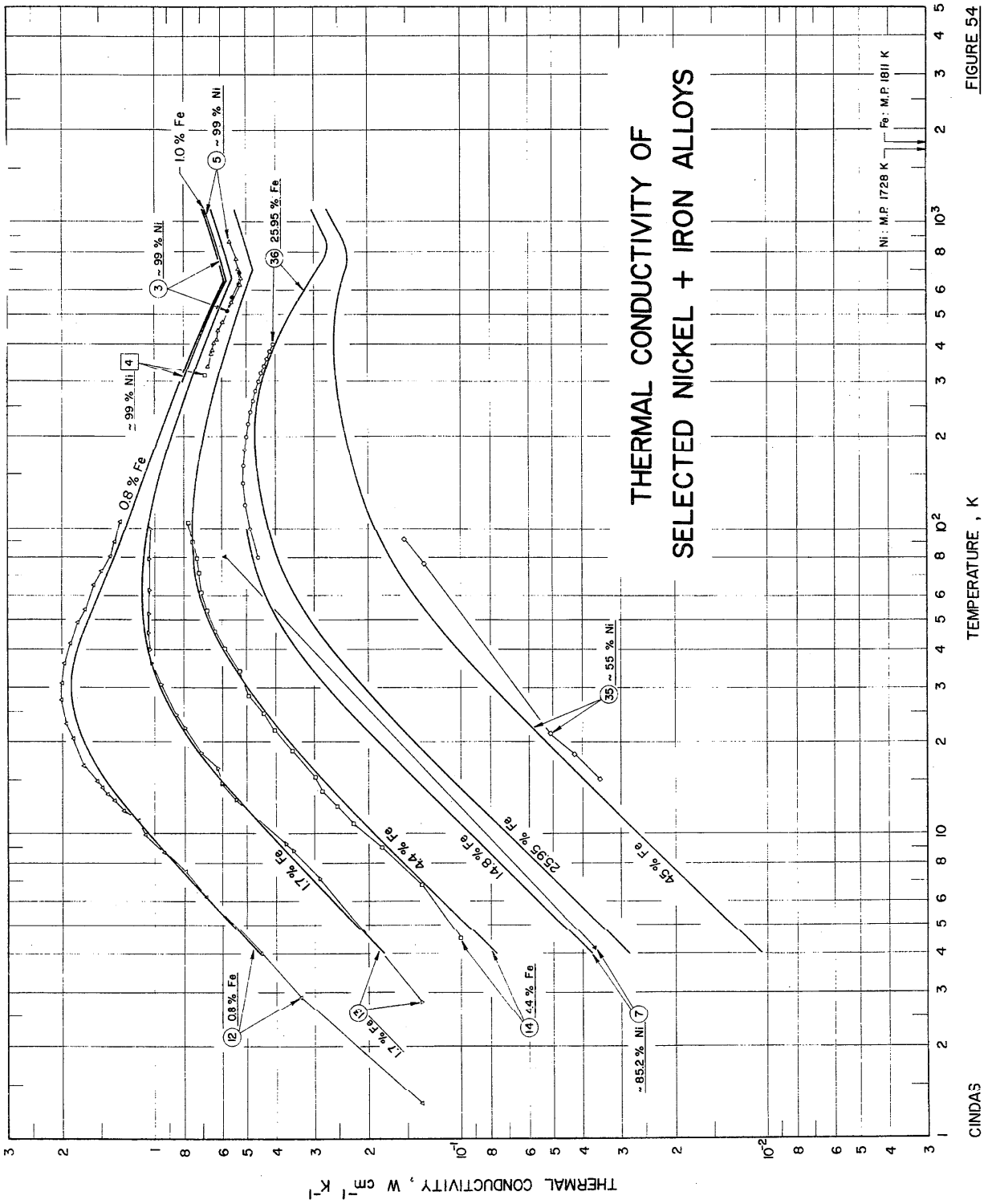
THERMAL CONDUCTIVITY OF
SELECTED NICKEL + IRON ALLOYS
Ni : M.P. 1728 K
Fe : M.P. 1811 K
~ 99 % Ni 4
0.8 % Fe
1.0 % Fe
5 ~ 99 % Ni
3 ~ 99 % Ni
36 25.95 % Fe
35 ~ 55 % Ni
45 % Fe
25.95 % Fe
14.8 % Fe
4.4 % Fe
1.7 % Fe
12 0.8 % Fe
13 1.7 % Fe
14 4.4 % Fe
~ 85.2 % Ni 7
THERMAL CONDUCTIVITY , W cm⁻¹ K⁻¹
TEMPERATURE , K
CINDAS

FIGURE 54

TABLE 25. RECOMMENDED THERMAL CONDUCTIVITY OF IRON-NICKEL ALLOY SYSTEM†

[Temperature, T, K; Thermal Conductivity, k, W cm^{-1} K^{-1}; Electronic Thermal Conductivity, k_e, W cm^{-1} K^{-1}; Lattice Thermal Conductivity, k_g, W cm^{-1} K^{-1}]

Fe: 99.50% (99.52 At.%) Ni: 0.50% (0.48 At.%)				Fe: 99.00% (99.05 At.%) Ni: 1.00% (0.95 At.%)				Fe: 97.00% (97.14 At.%) Ni: 3.00% (2.86 At.%)				Fe: 95.00% (95.23 At.%) Ni: 5.00% (4.77 At.%)			
ρ_o = 1.20 μΩ cm				ρ_o = 2.40 μΩ cm				ρ_o = 7.20 μΩ cm				ρ_o = 10.8 μΩ cm			
T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g
4	0.0868*‡			4	0.0445*‡			4	0.0148*‡	0.0136‡	0.00125‡	4	0.00978‡	0.00905‡	0.000732‡
6	0.133*‡			6	0.0688*‡			6	0.0229*‡	0.0204‡	0.00250‡	6	0.0151‡	0.0136‡	0.00147‡
8	0.180*‡			8	0.0924*‡			8	0.0312*‡	0.0271‡	0.00408‡	8	0.0205‡	0.0181‡	0.00239‡
10	0.229*‡			10	0.120*‡			10	0.0398*‡	0.0339‡	0.00592‡	10	0.0261‡	0.0226‡	0.00347‡
15	0.351*‡			15	0.187*‡			15	0.0623‡	0.0508‡	0.0115‡	15	0.0407‡	0.0339‡	0.00678‡
20	0.471*‡			20	0.255*‡			20	0.0852‡	0.0672‡	0.0180‡	20	0.0559‡	0.0452‡	0.0107‡
25	0.586*‡			25	0.320*‡			25	0.108‡	0.0835‡	0.0250‡	25	0.0712‡	0.0562‡	0.0150‡
30	0.697*‡			30	0.386*‡			30	0.132‡	0.0991‡	0.0325‡	30	0.0866‡	0.0670‡	0.0196‡
40	0.879*‡			40	0.508*‡			40	0.178‡	0.130‡	0.0481‡	40	0.116‡	0.0867‡	0.0294‡
50	0.998*‡			50	0.602*‡			50	0.220‡	0.157‡	0.0632‡	50	0.143‡	0.104‡	0.0391‡
60	1.04*‡	0.774‡	0.265‡	60	0.667*‡	0.465‡	0.202‡	60	0.256‡	0.179‡	0.0770‡	60	0.168‡	0.120‡	0.0485‡
70	1.02*‡	0.737‡	0.288‡	70	0.701*‡	0.478‡	0.223‡	70	0.287‡	0.198‡	0.0889‡	70	0.190‡	0.133‡	0.0568‡
80	0.984*‡	0.684‡	0.300‡	80	0.709*‡	0.474‡	0.235‡	80	0.310‡	0.212‡	0.0979‡	80	0.208‡	0.144‡	0.0638‡
90	0.938*‡	0.635‡	0.303‡	90	0.704*‡	0.464‡	0.240‡	90	0.328‡	0.224‡	0.104‡	90	0.223‡	0.154‡	0.0688‡
100	0.899‡	0.599‡	0.300‡	100	0.697‡	0.457‡	0.240‡	100	0.342‡	0.234‡	0.108‡	100	0.236‡	0.164‡	0.0724‡
150	0.816‡	0.555‡	0.261‡	150	0.678‡	0.465‡	0.213‡	150	0.387‡	0.282‡	0.105‡	150	0.282‡	0.208‡	0.0742‡
200	0.783‡	0.566‡	0.217‡	200	0.673‡	0.494‡	0.179‡	200	0.417‡	0.325‡	0.0923‡	200	0.315‡	0.248‡	0.0671‡
250	0.746‡	0.564‡	0.182‡	250	0.654‡	0.503‡	0.151‡	250	0.434‡	0.354‡	0.0800‡	250	0.341‡	0.282‡	0.0589‡
273	0.733‡	0.564‡	0.169‡	273	0.650‡	0.509‡	0.141‡	273	0.444‡	0.369‡	0.0750‡	273	0.349‡	0.294‡	0.0553‡
300	0.711‡	0.555‡	0.156‡	300	0.637‡	0.507‡	0.130‡	300	0.446‡	0.377‡	0.0695‡	300	0.358‡	0.306‡	0.0519‡
350	0.673‡	0.537‡	0.136‡	350	0.612‡	0.499‡	0.113‡	350	0.451‡	0.390‡	0.0613‡	350	0.368‡	0.322‡	0.0458‡
400	0.637‡	0.517‡	0.120‡	400	0.586‡	0.486‡	0.100‡	400	0.450‡	0.395‡	0.0545‡	400	0.376‡	0.335‡	0.0408‡
500	0.575*‡	0.478‡	0.0972‡	500	0.541‡	0.460‡	0.0814‡	500	0.442‡	0.397‡	0.0446‡	500	0.385‡	0.352‡	0.0335‡
600	0.522*‡	0.440‡	0.0817‡	600	0.497‡	0.429‡	0.0685‡	600	0.428‡	0.390‡	0.0376‡	600	0.386‡	0.358‡	0.0284‡
700	0.471*‡	0.401‡	0.0702‡	700	0.452‡	0.393‡	0.0591‡	700	0.400‡	0.367‡	0.0325‡	700	0.370‡	0.346‡	0.0245‡
800	0.417*	0.355	0.0616‡	800	0.403	0.351	0.0518‡	800	0.362	0.333	0.0286‡	800	0.338		
900	0.367*	0.312	0.0548‡	900	0.355*	0.309	0.0462‡	900	0.321	0.295	0.0255‡	900	0.305		
1000	0.319*	0.269	0.0494‡	1000	0.309*	0.267	0.0416‡	1000	0.281	0.258	0.0230‡	1000	0.263		
1100	0.289*	0.244	0.0451‡	1100	0.281*	0.243	0.0379‡	1100	0.261			1100	0.250		

† Uncertainties in the total thermal conductivity, k, are as follows:
99.50 Fe - 0.50 Ni: ± 15% up to 700 K and ± 10% above 700 K.
99.00 Fe - 1.00 Ni: ± 15% up to 700 K and ± 10% above 700 K.
97.00 Fe - 3.00 Ni: ± 15% up to 700 K and ± 10% above 700 K.
95.00 Fe - 5.00 Ni: ± 15% up to 700 K and ± 10% above 700 K.

‡ Provisional value.

‡ Typical value.

* In temperature range where no experimental thermal conductivity data are available.

TABLE 25. RECOMMENDED THERMAL CONDUCTIVITY OF IRON-NICKEL ALLOY SYSTEM (continued) †

[Temperature, T, K; Thermal Conductivity, k, W cm^{-1} K^{-1}; Electronic Thermal Conductivity, k_e, W cm^{-1} K^{-1}; Lattice Thermal Conductivity, k_g, W cm^{-1} K^{-1}]

Fe: 90.00% (90.44 At.%) Ni: 10.00% (9.56 At.%)				Fe: 85.00% (85.63 At.%) Ni: 15.00% (14.37 At.%)				Fe: 80.00% (80.79 At.%) Ni: 20.00% (19.21 At.%)				Fe: 75.00% (75.93 At.%) Ni: 25.00% (24.07 At.%)			
ρ_o = 14.8 μΩ cm				ρ_o = 17.1 μΩ cm				ρ_o = 19.4 μΩ cm				ρ_o = 22.6 μΩ cm			
T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g
4	0.00697‡	0.00661‡	0.000364‡	4	0.00598‡	0.00571‡	0.000267‡	4	0.00525‡			4	0.00450‡		
6	0.0107‡	0.00990‡	0.000752‡	6	0.00911‡	0.00857‡	0.000538‡	6	0.00800‡			6	0.00684‡		
8	0.0144‡	0.0132‡	0.00120‡	8	0.0123‡	0.0114‡	0.000881‡	8	0.0108‡			8	0.00923‡		
10	0.0183‡	0.0165‡	0.00176‡	10	0.0156‡	0.0143‡	0.00129‡	10	0.0137‡			10	0.0117‡		
15	0.0284‡	0.0248‡	0.00345‡	15	0.0240‡	0.0215‡	0.00253‡	15	0.0210‡			15	0.0179‡		
20	0.0385‡	0.0330‡	0.00548‡	20	0.0326‡	0.0286‡	0.00405‡	20	0.0284‡			20	0.0243‡		
25	0.0489‡	0.0412‡	0.00775‡	25	0.0412‡	0.0355‡	0.00575‡	25	0.0359‡			25	0.0308‡		
30	0.0593‡	0.0491‡	0.0102‡	30	0.0499‡	0.0423‡	0.00760‡	30	0.0435‡			30	0.0372‡		
40	0.0790‡	0.0636‡	0.0154‡	40	0.0669‡	0.0553‡	0.0116‡	40	0.0583‡			40	0.0498‡		
50	0.0977‡	0.0770‡	0.0207‡	50	0.0830‡	0.0673‡	0.0157‡	50	0.0721‡			50	0.0619‡		
60	0.115‡	0.0889‡	0.0260‡	60	0.0978‡	0.0780‡	0.0198‡	60	0.0848‡			60	0.0733‡		
70	0.130‡	0.0993‡	0.0309‡	70	0.111‡	0.0872‡	0.0236‡	70	0.0967‡			70	0.0839‡		
80	0.143‡	0.108‡	0.0354‡	80	0.122*‡	0.0954‡	0.0271‡	80	0.107*‡			80	0.0933‡		
90	0.154‡	0.115‡	0.0391‡	90	0.133*‡	0.103‡	0.0304‡	90	0.117*‡			90	0.102‡		
100	0.163‡	0.121‡	0.0421‡	100	0.143*‡			100	0.126*‡			100	0.110‡		
150	0.208‡	0.161‡	0.0468‡	150	0.182*‡			150	0.161*‡			150	0.142‡		
200	0.239‡	0.195‡	0.0437‡	200	0.210*‡			200	0.188*‡			200	0.164‡		
250	0.263‡	0.224‡	0.0390‡	250	0.233*‡			250	0.208*‡			250	0.182‡		
273	0.272‡	0.235‡	0.0370‡	273	0.240‡			273	0.216‡			273	0.188‡		
300	0.281‡	0.246‡	0.0349‡	300	0.248‡			300	0.224‡			300	0.195‡		
350	0.293*‡	0.262‡	0.0311‡	350	0.259*‡			350	0.235‡			350	0.205‡		
400	0.303*‡	0.275‡	0.0279‡	400	0.267*‡			400	0.244‡			400	0.213‡		
500	0.313*‡			500	0.278*‡			500	0.255‡			500	0.222‡		
600	0.319*‡			600	0.286*‡			600	0.263‡			600	0.237‡		
700	0.316*‡			700	0.284*‡			700	0.264‡			700	0.241‡		
800	0.297*			800	0.274*			800	0.255			800	0.233		
900	0.270*			900	0.254*	0.243	0.0114‡	900	0.238*	0.228	0.0101‡	900	0.220*	0.211	0.00920‡
1000	0.240*	0.228	0.0121‡	1000	0.237*	0.227	0.0103‡	1000	0.228*	0.219	0.00911‡	1000	0.218*	0.210	0.00838‡
1100	0.238*	0.227	0.0110‡	1100	0.233*	0.224	0.00939‡	1100	0.219*	0.211	0.00837‡	1100	0.224*	0.216	0.00771‡

† Uncertainties in the total thermal conductivity, k, are as follows:
90.00 Fe - 10.00 Ni: ±15% up to 700 K and ±10% above 700 K.
85.00 Fe - 15.00 Ni: ±15% up to 700 K and ±10% above 700 K.
80.00 Fe - 20.00 Ni: ±15% up to 700 K and ±10% above 700 K.
75.00 Fe - 25.00 Ni: ±15% up to 700 K and ±10% above 700 K.

‡ Provisional value.

‡ Typical value.

* In temperature range where no experimental thermal conductivity data are available.

TABLE 25. RECOMMENDED THERMAL CONDUCTIVITY OF IRON-NICKEL ALLOY SYSTEM (continued)†

[Temperature, T, K; Thermal Conductivity, k, W cm^{-1} K^{-1}; Electronic Thermal Conductivity, k_e, W cm^{-1} K^{-1}; Lattice Thermal Conductivity, k_g, W cm^{-1} K^{-1}]

Fe: 70.00% (71.04 At.%) Ni: 30.00% (28.96 At.%)				Fe: 65.00% (66.13 At.%) Ni: 35.00% (33.87 At.%)				Fe: 60.00% (61.19 At.%) Ni: 40.00% (38.81 At.%)				Fe: 55.00% (56.23 At.%) Ni: 45.00% (43.77 At.%)			
ρ_o = 32.7 μΩ cm				ρ_o = 59.1 μΩ cm				ρ_o = 36.1 μΩ cm				ρ_o = 22.0 μΩ cm			
T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g
4	0.00315‡			4	0.00180‡			4	0.00442‡			4	0.00610*‡		
6	0.00480‡			6	0.00277‡			6	0.00666‡			6	0.00917*‡		
8	0.00650‡			8	0.00378‡			8	0.00887‡			8	0.0122*‡		
10	0.00824‡			10	0.00482‡			10	0.0111‡			10	0.0153*‡		
15	0.0127‡			15	0.00757‡			15	0.0166‡			15	0.0228*‡		
20	0.0174‡			20	0.0105‡			20	0.0222‡			20	0.0305*‡		
25	0.0220‡			25	0.0135‡			25	0.0276‡			25	0.0379*‡		
30	0.0267‡			30	0.0166‡			30	0.0328‡			30	0.0451*‡		
40	0.0361‡			40	0.0227‡			40	0.0431‡			40	0.0588*‡		
50	0.0452‡			50	0.0289‡			50	0.0526‡			50	0.0713*‡		
60	0.0538‡			60	0.0350‡			60	0.0613‡			60	0.0819*‡		
70	0.0617‡			70	0.0407‡			70	0.0689‡			70	0.0921*‡		
80	0.0691‡			80	0.0460‡			80	0.0757‡			80	0.100*‡		
90	0.0757‡			90	0.0510‡			90	0.0815‡			90	0.108*‡		
100	0.0820‡			100	0.0554‡			100	0.0862‡			100	0.114*‡		
150	0.106‡			150	0.0721‡			150	0.102			150	0.135		
200	0.123‡			200	0.0825			200	0.112			200	0.149		
250	0.136‡			250	0.0905			250	0.119			250	0.158		
273	0.141‡			273	0.0938			273	0.121			273	0.161		
300	0.146			300	0.0973			300	0.124			300	0.164		
350	0.154			350	0.104			350	0.129			350	0.168		
400	0.161			400	0.110			400	0.133			400	0.172		
500	0.175			500	0.124			500	0.141			500	0.177		
600	0.189			600	0.139			600	0.151			600	0.182		
700	0.197			700	0.155			700	0.166			700	0.190	0.180	0.00988‡
800	0.197	0.187	0.00950‡	800	0.170	0.161	0.00913‡	800	0.182	0.173	0.00893‡	800	0.204	0.195	0.00882‡
900	0.200*	0.191	0.00849‡	900	0.184*	0.176	0.00818‡	900	0.198*	0.190	0.00807‡	900	0.219	0.211	0.00795‡
1000	0.208*	0.200	0.00771‡	1000	0.199*	0.192	0.00740‡	1000	0.212*	0.204	0.00736‡	1000	0.233	0.226	0.00725‡
1100	0.216*	0.209	0.00704‡	1100	0.210*	0.203	0.00676‡	1100	0.223*	0.216	0.00679‡	1100	0.245	0.238	0.00668‡

† Uncertainties in the total thermal conductivity, k, are as follows:
70.00 Fe - 30.00 Ni: ±20% below 300 K and ±12% above 300 K.
65.00 Fe - 35.00 Ni: ±20% below 200 K and ±12% above 200 K.
60.00 Fe - 40.00 Ni: ±20% below 150 K, ±10% between 150 and 500 K, and ±12% above 500 K.
55.00 Fe - 45.00 Ni: ±20% below 150 K, ±8% between 150 and 500 K, and ±10% above 500 K.

‡ Provisional value.

‡ Typical value.

* In temperature range where no experimental thermal conductivity data are available.

TABLE 25. RECOMMENDED THERMAL CONDUCTIVITY OF IRON-NICKEL ALLOY SYSTEM (continued)†

[Temperature, T, K; Thermal Conductivity, k, W cm^{-1} K^{-1}; Electronic Thermal Conductivity, k_e, W cm^{-1} K^{-1}; Lattice Thermal Conductivity, k_g, W cm^{-1} K^{-1}]

Fe: 50.00% (51.25 At.%) Ni: 50.00% (48.75 At.%)				Fe: 45.00% (46.24 At.%) Ni: 55.00% (53.76 At.%)				Fe: 40.00% (41.21 At.%) Ni: 60.00% (58.79 At.%)				Fe: 35.00% (36.15 At.%) Ni: 65.00% (63.85 At.%)			
ρ_o = 14.8 μΩ cm				ρ_o = 10.9 μΩ cm				ρ_o = 7.95 μΩ cm				ρ_o = 5.97 μΩ cm			
T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g
4	0.00819*‡			4	0.0105			4	0.0139*			4	0.0181*		
6	0.0123*‡			6	0.0158			6	0.0210*			6	0.0272*		
8	0.0164*‡			8	0.0211			8	0.0279*			8	0.0362*		
10	0.0205*‡			10	0.0264			10	0.0349*			10	0.0453*		
15	0.0308‡			15	0.0399			15	0.0524*			15	0.0680*		
20	0.0410‡			20	0.0529			20	0.0698*			20	0.0906*		
25	0.0511‡			25	0.0657			25	0.0864*			25	0.112*		
30	0.0609‡			30	0.0781			30	0.103*			30	0.133*		
40	0.0794‡			40	0.102			40	0.134*			40	0.173*		
50	0.0956‡			50	0.123			50	0.161*			50	0.207*		
60	0.110‡			60	0.142			60	0.184*			60	0.236*		
70	0.122‡			70	0.157			70	0.202*			70	0.259*		
80	0.132‡			80	0.170			80	0.217*			80	0.278*		
90	0.142‡			90	0.181			90	0.229*			90	0.293*		
100	0.149‡			100	0.190			100	0.239*			100	0.305*		
150	0.174			150	0.220			150	0.270*			150	0.342*		
200	0.190			200	0.237			200	0.289*			200	0.359*		
250	0.202			250	0.247			250	0.299*‡			250	0.361*‡		
273	0.206			273	0.251			273	0.301*‡			273	0.358*‡		
300	0.210			300	0.254			300	0.302*‡			300	0.353*‡		
350	0.216			350	0.257			350	0.301*‡			350	0.346*‡		
400	0.218			400	0.257			400	0.295*‡			400	0.334*‡		
500	0.219			500	0.254			500	0.281*‡			500	0.309*‡		
600	0.220			600	0.247‡	0.236	0.0109‡	600	0.269*‡	0.258	0.0111‡	600	0.288*‡	0.276	0.0115‡
700	0.216	0.206	0.00962‡	700	0.236‡	0.226	0.00958‡	700	0.250*‡	0.240	0.00974‡	700	0.262*‡	0.252	0.0100‡
800	0.221	0.213	0.00858‡	800	0.234‡	0.225	0.00854‡	800	0.244*‡	0.235	0.00868‡	800	0.251*‡	0.242	0.00893‡
900	0.236	0.228	0.00774‡	900	0.245‡	0.237	0.00771‡	900	0.252*‡	0.244	0.00783‡	900	0.258*‡	0.250	0.00807‡
1000	0.250	0.243	0.00706‡	1000	0.259‡	0.252	0.00701‡	1000	0.266*‡	0.259	0.00714‡	1000	0.272*‡	0.265	0.00736‡
1100	0.261	0.254	0.00650‡	1100	0.271‡	0.265	0.00648‡	1100	0.278*‡	0.271	0.00659‡	1100	0.284*‡	0.277	0.00679‡

† Uncertainties in the total thermal conductivity, k, are as follows:
50.00 Fe ~ 50.00 Ni: ±15% below 150 K, ±8% between 150 and 500 K, and ±14% above 500 K.
45.00 Fe ~ 55.00 Ni: ±12% below 100 K, ±10% between 100 and 500 K, and ±20% above 500 K.
40.00 Fe ~ 60.00 Ni: ±12% below 200 K and ±20% above 200 K.
35.00 Fe ~ 65.00 Ni: ±12% below 200 K and ±20% above 200 K.

‡ Provisional value.

‡ Typical value.

* In temperature range where no experimental thermal conductivity data are available.

TABLE 25. RECOMMENDED THERMAL CONDUCTIVITY OF IRON-NICKEL ALLOY SYSTEM (continued)†

[Temperature, T, K; Thermal Conductivity, k, W cm^{-1} K^{-1}; Electronic Thermal Conductivity, k_e, W cm^{-1} K^{-1}; Lattice Thermal Conductivity, k_g, W cm^{-1} K^{-1}]

Fe: 30.00% (31.06 At.%) Ni: 70.00% (68.94 At.%)				Fe: 25.00% (25.95 At.%) Ni: 75.00% (74.05 At.%)				Fe: 20.00% (20.81 At.%) Ni: 80.00% (79.19 At.%)				Fe: 15.00% (15.65 At.%) Ni: 85.00% (84.35 At.%)			
ρ_o = 4.72 μΩ cm				ρ_o = 3.83 μΩ cm				ρ_o = 3.32 μΩ cm				ρ_o = 2.84 μΩ cm			
T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g
4	0.0225			4	0.0275			4	0.0317			4	0.0371‡		
6	0.0338*			6	0.0412*			6	0.0476*			6	0.0556‡		
8	0.0451*			8	0.0550*			8	0.0634*			8	0.0742‡		
10	0.0563*			10	0.0688*			10	0.0793*			10	0.0928‡		
15	0.0845*			15	0.103*			15	0.119*			15	0.139‡		
20	0.113*			20	0.138*			20	0.159*			20	0.184‡		
25	0.139*			25	0.170*			25	0.195*			25	0.228‡		
30	0.164*			30	0.201*			30	0.230*			30	0.269‡		
40	0.214*			40	0.256*			40	0.294*			40	0.338‡		
50	0.257*			50	0.301*			50	0.343*			50	0.392‡		
60	0.294*			60	0.339*			60	0.383*			60	0.432‡		
70	0.323*			70	0.367*			70	0.413*			70	0.458‡		
80	0.345*			80	0.388*			80	0.433*			80	0.476‡		
90	0.362*			90	0.404*			90	0.447*			90	0.488*‡		
100	0.374*			100	0.417*			100	0.457*			100	0.498*		
150	0.405*			150	0.453*			150	0.485*			150	0.515*		
200	0.416*			200	0.465*			200	0.494*			200	0.516*		
250	0.410*‡			250	0.458*			250	0.482*			250	0.500*		
273	0.407*‡			273	0.449*			273	0.473*			273	0.494*		
300	0.400*‡			300	0.438			300	0.464			300	0.481*		
350	0.385*‡			350	0.419			350	0.441			350	0.458*	0.435	0.0234‡
400	0.368*‡			400	0.399*			400	0.420*			400	0.439*	0.418	0.0210‡
500	0.333*‡			500	0.356*	0.342	0.0146‡	500	0.373*	0.357	0.0158‡	500	0.395*	0.378	0.0175‡
600	0.304*‡	0.292	0.0118‡	600	0.320*‡	0.308	0.0125‡	600	0.337*‡	0.323	0.0136‡	600	0.360*‡	0.345	0.0150‡
700	0.274*‡	0.264	0.0103‡	700	0.288*‡	0.277	0.0109‡	700	0.309*‡	0.297	0.0119‡	700	0.333*‡	0.320	0.0131‡
800	0.258*‡	0.249	0.00918‡	800	0.270*‡	0.260	0.00971‡	800	0.287*‡	0.276	0.0106‡	800	0.316*‡	0.304	0.0117‡
900	0.264*‡	0.256	0.00828‡	900	0.273*‡	0.264	0.00876‡	900	0.289*‡	0.280	0.00949‡	900	0.325*‡	0.315	0.0105‡
1000	0.279*‡	0.271	0.00754‡	1000	0.288*‡	0.280	0.00798‡	1000	0.305*‡	0.297	0.00863‡	1000	0.339*‡	0.330	0.00950‡
1100	0.291*‡	0.284	0.00695‡	1100	0.301*‡	0.294	0.00734‡	1100	0.319*‡	0.311	0.00796‡	1100	0.352*‡	0.343	0.00876‡

† Uncertainties in the total thermal conductivity, k, are as follows:
30.00 Fe - 70.00 Ni: ±12% below 200 K and ±20% above 200 K.
25.00 Fe - 75.00 Ni: ±10% below 100 K, ±6% between 100 and 500 K, and ±15% above 500 K.
20.00 Fe - 80.00 Ni: ±12% below 100 K, ±6% between 100 and 500 K, and ±15% above 500 K.
15.00 Fe - 85.00 Ni: ±15% below 100 K, ±8% between 100 and 500 K, and ±15% above 500 K.

‡ Provisional value.

‡ Typical value.

* In temperature range where no experimental thermal conductivity data are available.

TABLE 25. RECOMMENDED THERMAL CONDUCTIVITY OF IRON-NICKEL ALLOY SYSTEM (continued) †

[Temperature, T, K; Thermal Conductivity, k, W cm^{-1} K^{-1}; Electronic Thermal Conductivity, k_e, W cm^{-1} K^{-1}; Lattice Thermal Conductivity, k_g, W cm^{-1} K^{-1}]

Fe: 10.00% (10.46 At.%) Ni: 90.00% (89.54 At.%)				Fe: 5.00% (5.24 At.%) Ni: 95.00% (94.76 At.%)				Fe: 3.00% (3.15 At.%) Ni: 97.00% (96.85 At.%)				Fe: 1.00% (1.05 At.%) Ni: 99.00% (98.95 At.%)			
ρ_o = 2.38 μΩ cm				ρ_o = 1.62 μΩ cm				ρ_o = 1.04 μΩ cm				ρ_o = 0.364 μΩ cm			
T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g
4	0.0447‡			4	0.0683‡			4	0.0963‡			4	0.276‡		
6	0.0670‡			6	0.103‡			6	0.146‡			6	0.405‡		
8	0.0894‡			8	0.137‡			8	0.195‡			8	0.530‡		
10	0.112‡			10	0.170‡			10	0.243‡			10	0.655‡		
15	0.167‡			15	0.247‡			15	0.352‡			15	0.943‡		
20	0.220‡			20	0.320‡			20	0.449‡			20	1.17‡		
25	0.271‡			25	0.387‡			25	0.538‡			25	1.31‡		
30	0.317‡			30	0.446‡			30	0.612‡			30	1.39‡		
40	0.399‡			40	0.544‡			40	0.725‡			40	1.45‡		
50	0.454‡			50	0.611‡			50	0.798‡			50	1.43‡		
60	0.495‡			60	0.657‡			60	0.838‡			60	1.39‡		
70	0.521‡			70	0.684‡			70	0.857‡			70	1.34‡		
80	0.537‡			80	0.697‡			80	0.864‡			80	1.29‡		
90	0.545*‡			90	0.702‡			90	0.865‡			90	1.24‡		
100	0.550*			100	0.703			100	0.861‡			100	1.20		
150	0.561*			150	0.680*			150	0.816*			150	1.04*		
200	0.555*			200	0.659*			200	0.760*			200	0.937*		
250	0.538*			250	0.628*			250	0.714*			250	0.862*		
273	0.529*			273	0.619*			273	0.695*			273	0.835*		
300	0.517*			300	0.602*			300	0.675*			300	0.808*		
350	0.492*	0.464	0.0282‡	350	0.573*	0.528	0.0448‡	350	0.646*	0.586	0.0596‡	350	0.759*	0.668	0.0913‡
400	0.469*	0.444	0.0253‡	400	0.548*	0.508	0.0400‡	400	0.616*	0.563	0.0531‡	400	0.718*	0.638	0.0802‡
500	0.430*	0.409	0.0210‡	500	0.504*	0.471	0.0328‡	500	0.571*	0.527	0.0435‡	500	0.652*	0.586	0.0656‡
600	0.398*‡	0.383	0.0180‡	600	0.482*	0.454	0.0278‡	600	0.534*	0.497	0.0367‡	600	0.598*	0.544	0.0543‡
700	0.377*‡	0.367	0.0157‡	700	0.459*	0.435	0.0240‡	700	0.513*	0.481	0.0318‡	700	0.592*	0.545	0.0468‡
800	0.370*‡	0.364	0.0139‡	800	0.479*	0.458	0.0211‡	800	0.534*	0.506	0.0280‡	800	0.615*	0.574	0.0410‡
900	0.385*‡	0.378	0.0126‡	900	0.495*	0.476	0.0189‡	900	0.552*	0.527	0.0249‡	900	0.638*	0.602	0.0364‡
1000	0.399*‡	0.388	0.0114‡	1000	0.510*	0.493	0.0170‡	1000	0.572*	0.550	0.0225‡	1000	0.660*	0.627	0.0328‡
1100	0.413*‡	0.402	0.0105‡	1100	0.523*	0.508	0.0155‡	1100	0.590*	0.570	0.0205‡	1100	0.681*	0.651	0.0299‡

† Uncertainties in the total thermal conductivity, k, are as follows:
10.00 Fe - 90.00 Ni: ±15% below 100 K, ±8% between 100 and 500 K, and ±15% above 500 K.
5.00 Fe - 95.00 Ni: ±15% below 100 K, ±6% between 100 and 500 K, and ±10% above 500 K.
3.00 Fe - 97.00 Ni: ±15% below 150 K, ±6% between 150 and 500 K, and ±8% above 500 K.
1.00 Fe - 99.00 Ni: ±15% below 100 K, ±10% between 100 and 250 K, and ±6% above 250 K.

‡ Provisional value.

‡ Typical value.

* In temperature range where no experimental thermal conductivity data are available.

TABLE 25. RECOMMENDED THERMAL CONDUCTIVITY OF IRON-NICKEL ALLOY SYSTEM (continued)†

[Temperature, T, K; Thermal Conductivity, k, W cm^{-1} K^{-1}; Electronic Thermal Conductivity, k_e, W cm^{-1} K^{-1}; Lattice Thermal Conductivity, k_g, W cm^{-1} K^{-1}]

Fe: 0.50% (0.53 At.%) Ni: 99.50% (99.47 At.%)			
ρ_o = 0.182 μΩ cm			
T k k_e k_g			
4 0.545‡			
6 0.796‡			
8 1.04‡			
10 1.29‡			
15 1.85‡			
20 2.10‡			
25 2.33‡			
30 2.32‡			
40 2.19‡			
50 2.01‡			
60 1.84‡			
70 1.69‡			
80 1.57‡			
90 1.47‡			
100 1.38			
150 1.13*			
200 0.994*			
250 0.914*			
273 0.884*			
300 0.852*			
350 0.801 0.695 0.106‡			
400 0.758 0.665 0.0932‡			
500 0.686 0.611 0.0752‡			
600 0.625 0.562 0.0630‡			
700 0.621 0.567 0.0542‡			
800 0.643 0.596 0.0474‡			
900 0.667* 0.625 0.0422‡			
1000 0.689* 0.651 0.0380‡			
1100 0.708* 0.673 0.0346‡			

† Uncertainties in the total thermal conductivity, k, are as follows:
0.50 Fe - 99.50 Ni: ±20% below 100 K, ±10% between 100 and 250 K, and ±6% above 250 K.

‡ Provisional value.

‡ Typical value.

* In temperature range where no experimental thermal conductivity data are available.

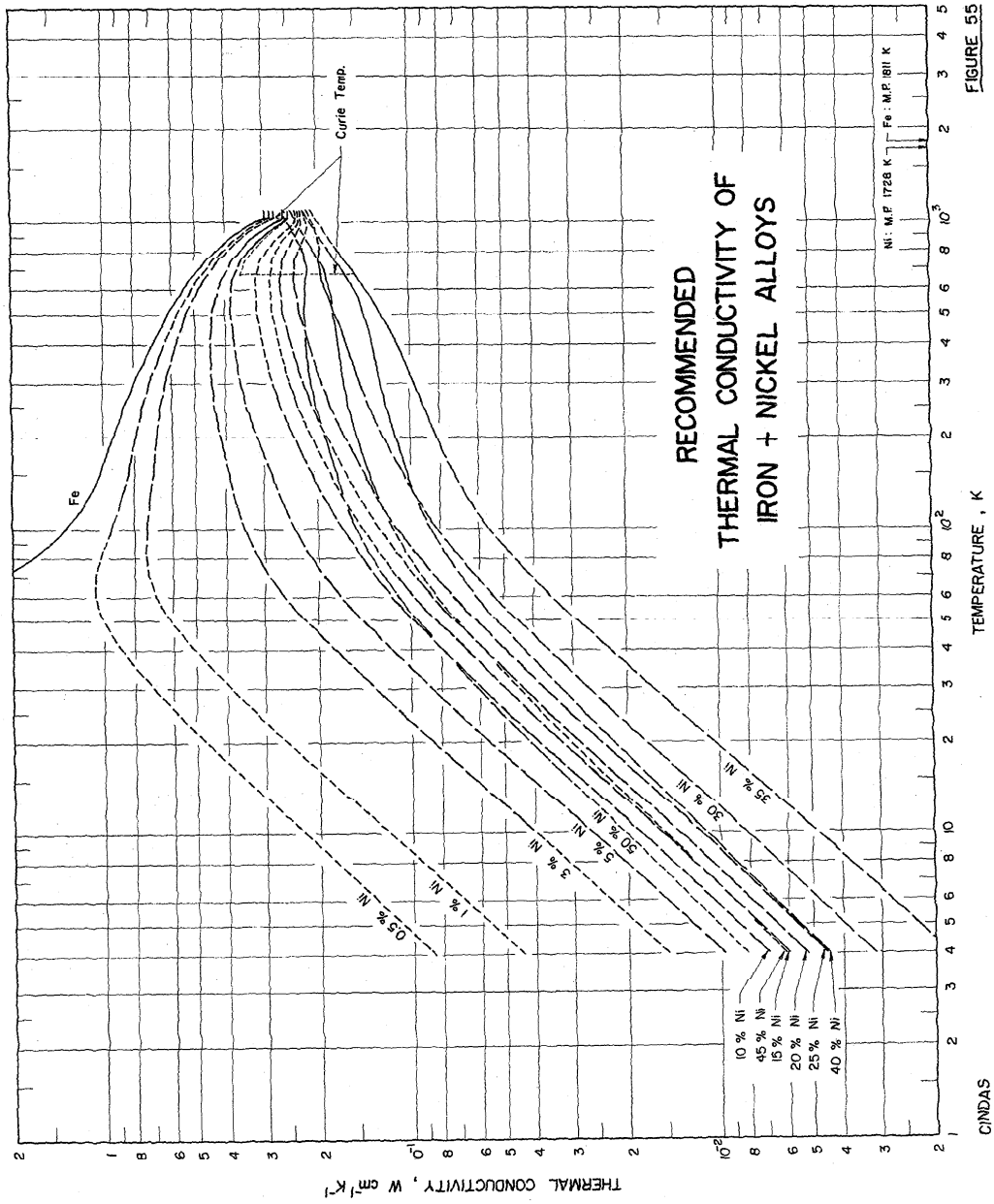
RECOMMENDED
THERMAL CONDUCTIVITY OF
IRON + NICKEL ALLOYS
Curie Temp.
Fe
Ni: M.P. 1728 K
Fe: M.P. 1811 K
0.5% Ni
1% Ni
3% Ni
5% Ni
30% Ni
35% Ni
10 % Ni
45 % Ni
15 % Ni
20 % Ni
25 % Ni
40 % Ni
THERMAL CONDUCTIVITY, W cm⁻¹ K⁻¹
TEMPERATURE, K
CINDAS

FIGURE 55

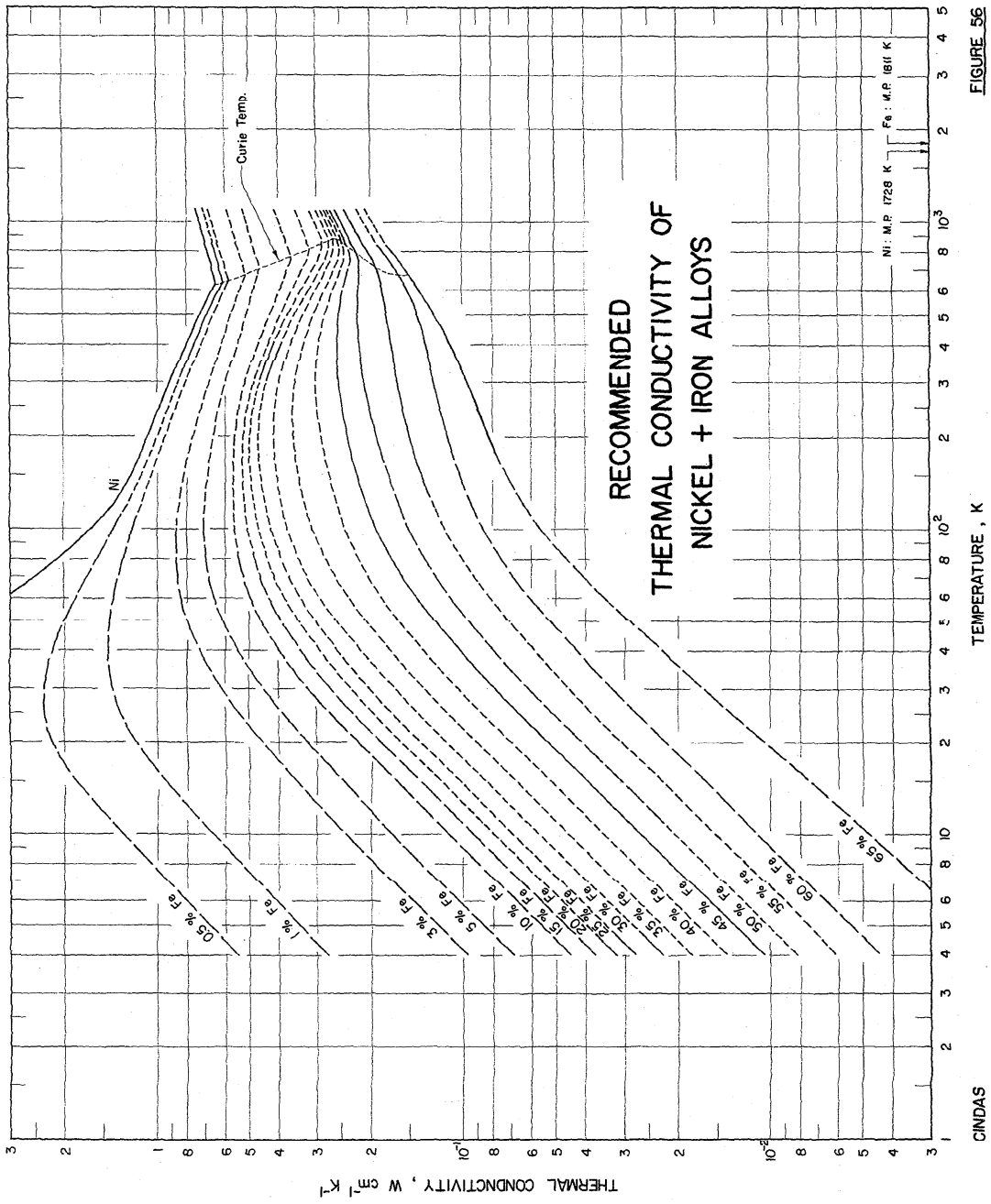
RECOMMENDED
THERMAL CONDUCTIVITY OF
NICKEL + IRON ALLOYS
Curie Temp.
Ni
Ni : M.P. 1728 K
Fe : M.P. 1811 K
0.5 % Fe
1 % Fe
3 % Fe
5 % Fe
10 % Fe
15 % Fe
20 % Fe
25 % Fe
30 % Fe
35 % Fe
40 % Fe
45 % Fe
50 % Fe
55 % Fe
60 % Fe
65 % Fe
THERMAL CONDUCTIVITY , W cm⁻¹ K⁻¹
TEMPERATURE , K
CINDAS

FIGURE 56

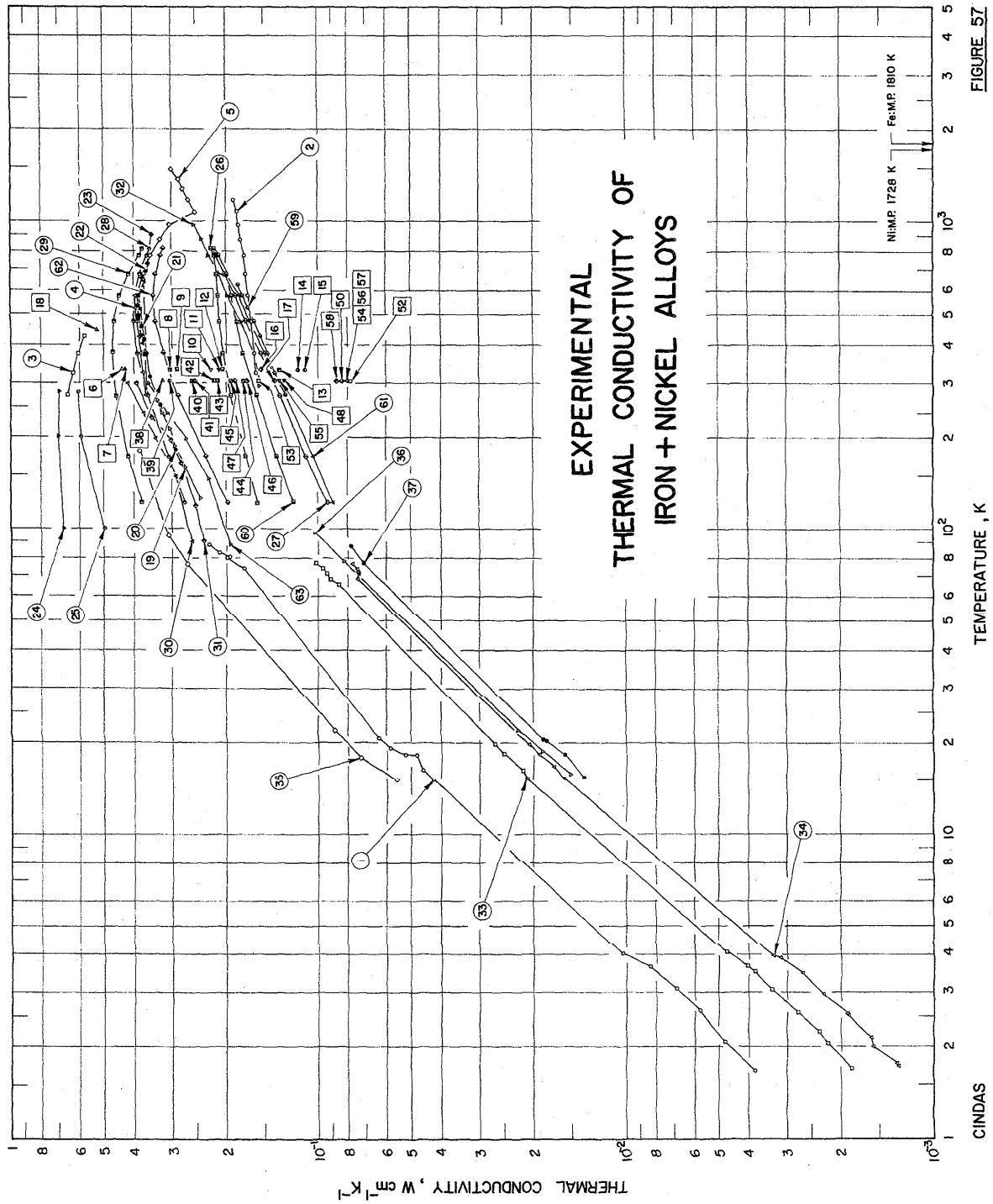
EXPERIMENTAL
THERMAL CONDUCTIVITY OF
IRON + NICKEL ALLOYS
Ni:M.P. 1728 K
Fe:M.P. 1810 K
THERMAL CONDUCTIVITY , W cm⁻¹ K⁻¹
TEMPERATURE , K
CINDAS

FIGURE 57

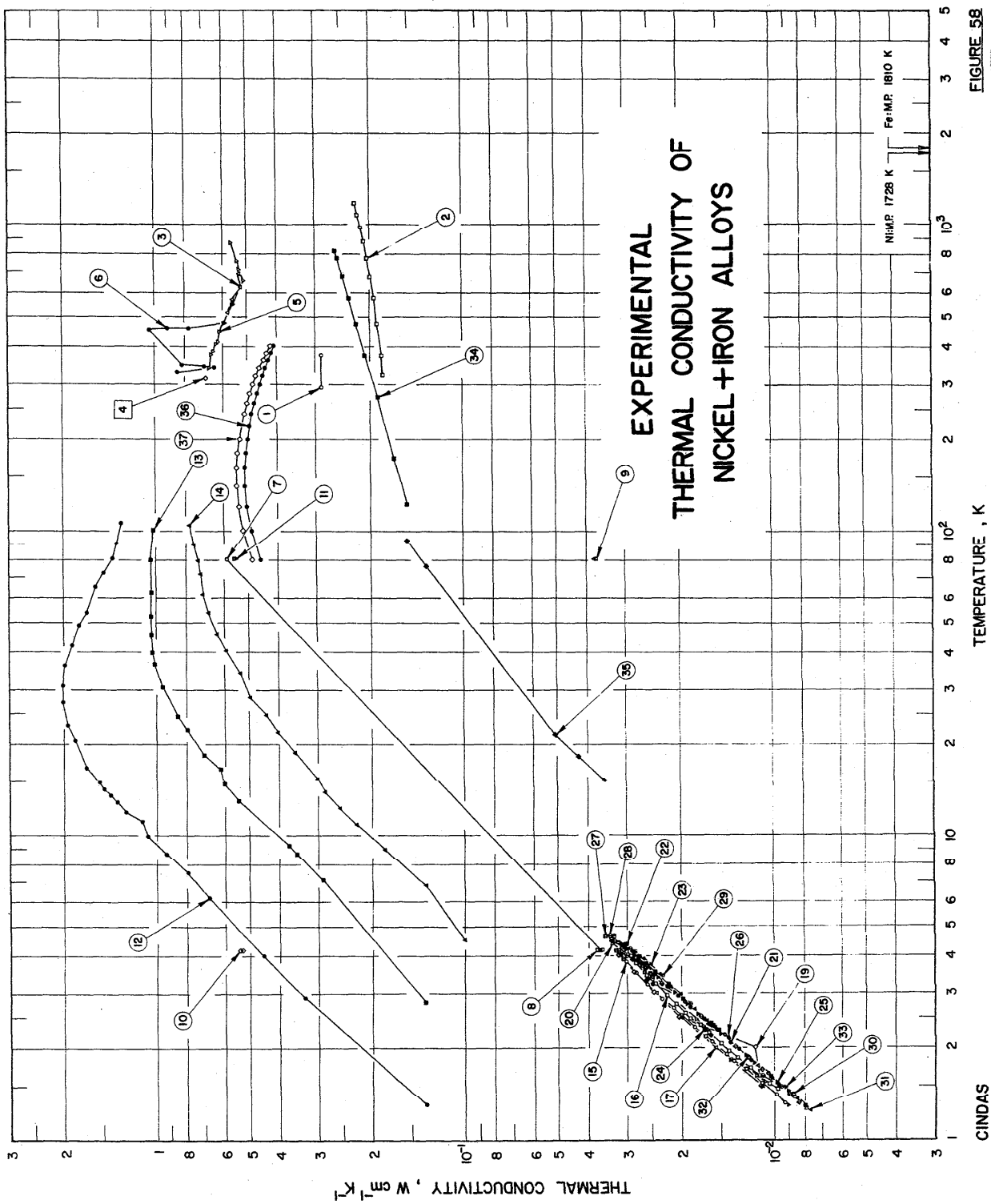
EXPERIMENTAL
THERMAL CONDUCTIVITY OF
NICKEL+IRON ALLOYS
Ni:M.P. 1728 K
Fe:M.P. 1810 K
THERMAL CONDUCTIVITY , W cm⁻¹ K⁻¹
TEMPERATURE , K
CINDAS

FIGURE 58

TABLE 26. THERMAL CONDUCTIVITY OF IRON + NICKEL ALLOYS -- SPECIMEN CHARACTERIZATION AND MEASUREMENT INFORMATION

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) Fe	Ni	Composition (continued), Specifications, and Remarks
1	99	Chari, M.S.R. and de Nobel, J.	1959	L	1.6-88	3703	Bal.	5.10	0.34 Mn, 0.16 Si, 0.11 C, 0.04 S, and 0.041 P; 7.5 mm diameter rod specimen; heated to 800 C and cooled in furnace.
2	132	Silverman, L.	1953	C	323-1173	42% Ni-iron	56.8	43.91	0.22 Mn, 0.050 C, and 0.003 S; annealed at 950 C; Advance used as comparative material.
3	96	Powell, R.W. and Hickman, M.J.	1939	C	273-423	Carbon steel; 1	Bal.	0.55	0.38 Mn, 0.08 Cu, 0.06 C, 0.039 As, 0.035 S, 0.03 Mo, 0.022 Cr, 0.017 P, 0.01 Si, and 0.001 Al; 1 in. diameter and 8 in. long; annealed at 930 C; density 7.871 g cm^{-3}; electrical resistivity 11.9, 14.6, 17.8, 21.1, and 24.9 $\mu\Omega$ cm at 0, 50, 100, 150, and 200 C, respectively.
4	96	Powell, R.W. and Hickman, M.J.	1939	C	273-573	Alloy steel; 9	Bal.	3.47	0.55 Mn, 0.325 C, 0.18 Si, 0.17 Cr, 0.086 Cu, 0.034 S, 0.032 P, 0.023 As, 0.04 Mo, 0.01 V, and 0.006 Al; annealed at 860 C; density 7.855 g cm^{-3}; electrical resistivity 25.5, 28.4, 31.5, 34.9, 38.5, 42.5, and 46.8 $\mu\Omega$ cm at 0, 50, 100, 150, 200, 250, and 300 C, respectively.
5	162	Powell, R.W.	1946	→	273-1473				The above specimen; thermal conductivity values calculated from measured electrical resistivity by the Wiedemann-Franz relation using extrapolated values of Lorenz function obtained from the previous thermal conductivity measurements.
6	98	Ingersoll, L.R., Mussehl, O.F., Swartz, D.L., Smith, H.F., Thompson, C.G., Mahre, M.A., Frederickson, J.F. and Hubbard, D.R.	1920	L	330	144E	Bal.	1.07	<0.1 C; electrolytic.
7	98	Ingersoll, L.R., et al.	1920	L	330	144F	Bal.	1.93	<0.1 C; electrolytic.
8	98	Ingersoll, L.R., et al.	1920	L	330	144J	Bal.	7.05	<0.1 C; electrolytic.
9	98	Ingersoll, L.R., et al.	1920	L	330	157D	Bal.	10.20	<0.1 C; electrolytic.
10	98	Ingersoll, L.R., et al.	1920	L	330	144M	Bal.	13.11	<0.1 C; electrolytic.
11	98	Ingersoll, L.R., et al.	1920	L	330	144P	Bal.	19.21	<0.1 C; electrolytic.
12	98	Ingersoll, L.R., et al.	1920	L	330	166G	Bal.	22.11	<0.1 C; electrolytic; electrical resistivity reported as 38.7, 45.4, 53.4, 62.7, 72.5, 82.1, 108.3, and 111.6 $\mu\Omega$ cm at 273.2, 373.2, 473.2, 573.2, 673.2, 773.2, 873.2, and 973.2 K, respectively.
13	98	Ingersoll, L.R., et al.	1920	L	330	154S	Bal.	25.20	<0.1 C; electrolytic.
14	98	Ingersoll, L.R., et al.	1920	L	330	166C	Bal.	28.42	<0.1 C; electrolytic.
15	98	Ingersoll, L.R., et al.	1920	L	330	166L	Bal.	35.09	<0.1 C; electrolytic; electrical resistivity reported as 90.3, 100.0, 108.1, 115.2, 119.4, 123.2, 125.9, and 129.3 $\mu\Omega$ cm at 273.2, 373.2, 473.2, 573.2, 673.2, 773.2, 873.2, and 973.2 K, respectively.
16	98	Ingersoll, L.R., et al.	1920	L	330	166O	Bal.	47.08	<0.1 C; electrolytic; electrical resistivity reported as 44.2, 60.0, 75.6, 92.1, 103.3, 109.3, 112.3, and 114.0 $\mu\Omega$ cm at 273.2, 373.2, 473.2, 573.2, 673.2, 773.2, 873.2, and 973.2 K, respectively.
17	131	Ellis, W.C., Morgan, F.L. and Sager, G.F.	1928	P	305	Climax	Bal.	30.0	2.5 mm diameter and 25 mm long; density 8.01 g cm^{-3}; electrical conductivity 1.052 x 10^4 Ω^{-1} cm^{-1} at 32 C; thermal conductivity value calculated from measured thermal diffusivity and specific heat capacity.

TABLE 26. THERMAL CONDUCTIVITY OF IRON + NICKEL ALLOYS -- SPECIMEN CHARACTERIZATION AND MEASUREMENT INFORMATION (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) Fe	Ni	Composition (continued), Specifications, and Remarks
18	163	Marue, H.	1925	C	446	Nickel steel	Bal.	3.41	0.45 C; steel used as comparative material.
19	102	Watson, T.W. and Robinson, H.E.	1961	L	125-263	AISI 2515	94.076	4.91	0.52 Mn, 0.33 Si, and 0.14 C; specimen about 2.54 cm in diameter and about 37 cm long; furnished by International Nickel Co.; normalized at 1144.3 K, tempered at 866.5 K.
20	102	Watson, T.W. and Robinson, H.E.	1961	L	183-483	AISI 2515			The above specimen, run 2.
21	102	Watson, T.W. and Robinson, H.E.	1961	L	372-573	AISI 2515			The above specimen, run 3.
22	102	Watson, T.W. and Robinson, H.E.	1961	L	400-696	AISI 2515			The above specimen, run 4.
23	102	Watson, T.W. and Robinson, H.E.	1961	L	423-908	AISI 2515			The above specimen, run 5.
24	101	Bäcklund, N.G.	1961	L	100-280	3		0.946	Original material supplied by Heracus, Inc.; re-melted and rolled into bars with a cross-section of about 15 mm^2 and a length of 100 mm; after a short rolling, annealed at 1373 K for 2 hr in evacuated silica tubes, then rolled to final form and annealed at about 773 K for 10 hr; electrical resistivity 3.4, 7.9, and 12.9 $\mu\Omega$ cm at 90, 193, and 290 K, respectively.
25	101	Bäcklund, N.G.	1961	L	100-280	5		1.90	Similar to the above specimen; electrical resistivity 5.3, 9.5, and 15.1 $\mu\Omega$ cm at 90, 193, and 290 K, respectively.
26	102	Watson, T.W. and Robinson, H.E.	1961	L	123-813	High-perm-49	49.503	49.15	0.44 Mn, 0.54 Si, 0.09 Cr, and 0.035 C; specimen 2.54 cm in diameter and 37 cm long; supplied by International Nickel Co.; packed in powder and annealed in hydrogen 5 hr at 922.1 K, 5 hr at 1450 K; furnace cooled to 700 K; data presented as a smooth curve.
27	102	Watson, T.W. and Robinson, H.E.	1961	L	123-813	Invar	63.97	35.41	0.13 Si, 0.06 C, and 0.04 Cr; specimen 2.54 cm in diameter and 37 cm long; supplied by International Nickel Co.; annealed 30 min at 1102.6 K, water-quenched, air-cooled at 588.7 K for 1 hr and at 369.3 K for 48 hr; data presented as a smooth curve.
28	102	Watson, T.W. and Robinson, H.E.	1961	L	123-813	AISI 2315	95.483	3.46	0.54 Mn, 0.32 Si, and 0.16 C; specimen 2.54 cm in diameter and 37 cm long; supplied by International Nickel Co.; normalized at 1172.5 K and tempered at 866.5 K; data presented as a smooth curve.
29	102	Watson, T.W. and Robinson, H.E.	1961	L	123-813	1% Ni	97.984	1.04	0.56 Mn, 0.27 Si, and 0.126 C; specimen 2.54 cm in diameter and 37 cm long; supplied by International Nickel Co.; normalized at 1200 K, tempered at 866.5 K; presented as a smooth curve.
30	97, 181	Kohlhaas, R. and Kierspe, W.	1965	L	90-298	10 Ni 14		3.75	0.45 Mn, 0.32 Si, and 0.06 C; heat-treated in air at 850 C for 0.5 hr and at 600 C for 2 hr; electrical resistivity 16.78, 21.80, 22.89, 24.31, 25.82, 27.08, 28.36, 29.50, and 30.70 $\mu\Omega$ cm at -190, -70, -50, -25, 0, 20, 40, 60, and 80 C, respectively.
31	97, 181	Kohlhaas, R. and Kierspe, W.	1965	L	90-298	12 Ni 19		4.75	0.40 Mn, 0.35 Si, and 0.086 C; same heat-treatment as above; electrical resistivity 18.26, 23.43, 24.51, 25.96, 27.81, 28.78, 29.98, 31.19, and 32.43 $\mu\Omega$ cm at -190, -70, -50, -25, 0, 20, 40, 60, and 80 C, respectively.
32	164	Bungardt, K. and Spyra, W.	1965	L	293-973	Ni 36	Bal.	36.91	0.32 Mn, 0.012 P, 0.08 Al, 0.05 Si, 0.06 Mo, 0.05 Co, 0.02 C, and 0.008 S; cylindrical specimen; heat-treated in water at 1000 C for 24 hr; electrical resistivity 78.1, 86.8, 96.3, 101.7, 105.7, 109.0, 112.2, 115.0, 117.5, 119.7, 121.8, and 123.7 $\mu\Omega$ cm at 20, 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, and 1100 C, respectively; smoothed values reported.

TABLE 26. THERMAL CONDUCTIVITY OF IRON + NICKEL ALLOYS -- SPECIMEN CHARACTERIZATION AND MEASUREMENT INFORMATION (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) Fe	Ni	Composition (continued), Specifications, and Remarks
33	99	Chari, M.S.R. and de Nobel, J.	1959	L	1.7-76	1287 I		11.39	0.93 Mn, 0.22 Si, and 0.18 C; 5.5 mm diameter rod specimen; heated to 800 C and cooled in furnace.
34	99	Chari, M.S.R. and de Nobel, J.	1959	L	1.7-76	1798 H		19.64	1.09 Mn and 0.43 C; 7.5 mm diameter rod specimen; same heat-treatment as the above specimen.
35	100	de Nobel, J.	1951	L	15-180	1287 D		1.92	0.72 Mn, 0.21 Si, and 0.14 C; 0.5 cm diameter and 4 cm long; heated to 800 C and cooled in furnace.
36	100	de Nobel, J.	1951	L	15-96	1449 A		31.4	0.82 Mn and 0.70 C; 0.5 cm diameter and 4 cm long; heated to 800 C and cooled in furnace.
37	100	de Nobel, J.	1951	L	15-87	3450-3		36.17	0.92 Mn, 0.09 S, and 0.16 C; 0.5 cm diameter and 4 cm long; heated to 1050 C and quenched in water.
38	165	Honda, K.	1918	E	303	2a		4.6	0.48 Cu, 0.31 Mn, 0.11 Si, 0.10 C, 0.028 P, 0.026 S, and 0.012 Co (calculated composition); 5 mm diameter and 20 cm long; prepared by melting together iron and nickel in a porcelain crucible, resulting alloy polished, forged, annealed, and filed to size; annealed at 900 C; electrical conductivity 3.62 x 10^4 Ω^{-1} cm^{-1} at 30 C.
39	165	Honda, K.	1918	E	303	2b			Same composition, dimensions, and fabrication method as the above specimen; cooled once to -190 C in liquid air; electrical conductivity 3.64 x 10^4 Ω^{-1} cm^{-1} at 30 C.
40	165	Honda, K.	1918	E	303	3a		9.2	0.67 Cu, 0.32 Mn, 0.11 C, 0.11 Si, 0.027 P, 0.025 S, and 0.024 Co (calculated composition); same dimensions and fabrication method as the above specimen; annealed at 900 C; electrical conductivity 2.81 x 10^4 Ω^{-1} cm^{-1} at 30 C.
41	165	Honda, K.	1918	E	303	3b			Same composition, dimensions, and fabrication method as the above specimen; cooled once to -190 C in liquid air; electrical conductivity 2.76 x 10^4 Ω^{-1} cm^{-1} at 30 C.
42	165	Honda, K.	1918	E	303	4a		13.8	0.87 Cu, 0.32 Mn, 0.12 C, 0.12 Si, 0.035 Co, 0.025 P, and 0.025 S (calculated composition); same dimensions and fabrication method as the above specimen; annealed at 900 C; electrical conductivity 2.65 x 10^4 Ω^{-1} cm^{-1} at 30 C.
43	165	Honda, K.	1918	E	303	4b			Same composition, dimensions, and fabrication method as the above specimen; cooled once to -190 C in liquid air; electrical conductivity 2.56 x 10^4 Ω^{-1} cm^{-1} at 30 C.
44	165	Honda, K.	1918	E	303	5a		18.5	1.06 Cu, 0.32 Mn, 0.13 C, 0.12 Si, 0.048 Co, 0.024 P, and 0.024 S (calculated composition); same dimensions and fabrication method as the above specimen; annealed at 900 C; electrical conductivity 2.22 x 10^4 Ω^{-1} cm^{-1} at 30 C.
45	165	Honda, K.	1918	E	303	5b			Same composition, dimensions, and fabrication method as the above specimen; cooled once to -190 C in liquid air; electrical conductivity 2.42 x 10^4 Ω^{-1} cm^{-1} at 30 C.
46	165	Honda, K.	1918	E	303	6a		21.2	1.17 Cu, 0.32 Mn, 0.135 C, 0.12 Si, 0.05 Co, 0.023 P, and 0.024 S (calculated composition); same dimensions and fabrication method as the above specimen; annealed at 900 C; electrical conductivity 2.01 x 10^4 Ω^{-1} cm^{-1} at 30 C.

TABLE 26. THERMAL CONDUCTIVITY OF IRON + NICKEL ALLOYS -- SPECIMEN CHARACTERIZATION AND MEASUREMENT INFORMATION (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) Fe	Ni	Composition (continued), Specifications, and Remarks
47	165	Honda, K.	1918	E	303	6b			Same composition, dimensions, and fabrication method as the above specimen; annealed at 900 C; electrical conductivity 2.20 x 10^4 Ω^{-1} cm^{-1} 30 C.
48	165	Honda, K.	1918	E	303	7a		23.6	1.27 Cu, 0.32 Mn, 0.14 C, 0.12 Si, 0.061 Co, 0.024 S, and 0.022 P (calculated composition); same dimensions and fabrication method as the above specimen; annealed at 900 C; electrical conductivity 1.82 x 10^4 Ω^{-1} cm^{-1} at 30 C.
49*	165	Honda, K.	1918	E	303	7b			Same composition, dimensions, and fabrication method as the above specimen; cooled once to -190 C in liquid air; electrical conductivity 2.33 x 10^4 Ω^{-1} cm^{-1} at 30 C.
50	165	Honda, K.	1918	E	303	9a		27.7	1.44 Cu, 0.32 Mn, 0.15 C, 0.12 Si, 0.071 Co, 0.023 S, and 0.021 P (calculated composition); same dimensions and fabrication method as the above specimen; annealed at 900 C; electrical conductivity 1.07 x 10^4 Ω^{-1} cm^{-1} at 30 C.
51*	165	Honda, K.	1918	E	303	9b			Same composition, dimensions, and fabrication method as the above specimen; cooled once to -190 C in liquid air; electrical conductivity 2.40 x 10^4 Ω^{-1} cm^{-1} at 30 C.
52	165	Honda, K.	1918	E	303	10a		29.1	1.51 Cu, 0.32 Mn, 0.15 C, 0.12 Si, 0.075 Co, 0.023 S, and 0.021 P (calculated composition); same dimensions and fabrication method as the above specimen; annealed at 900 C; electrical conductivity 1.02 x 10^4 Ω^{-1} cm^{-1} at 30 C.
53	165	Honda, K.	1918	E	303	10b			Same composition, dimensions, and fabrication method as the above specimen; cooled once to -190 C in liquid air; electrical conductivity 2.35 x 10^4 Ω^{-1} cm^{-1} at 30 C.
54	165	Honda, K.	1918	E	303	11a		30.5	1.56 Cu, 0.32 Mn, 0.155 C, 0.12 Si, 0.078 Co, 0.023 S, and 0.020 P (calculated composition); same dimensions and fabrication method as the above specimen; annealed at 900 C; electrical conductivity 1.08 x 10^4 Ω^{-1} cm^{-1} at 30 C.
55	165	Honda, K.	1918	E	303	11b			Same composition, dimensions, and fabrication method as the above specimen; cooled once to -190 C in liquid air; electrical conductivity 1.95 x 10^4 Ω^{-1} cm^{-1} at 30 C.
56	165	Honda, K.	1918	E	303	12a		32.8	1.65 Cu, 0.33 Mn, 0.15 C, 0.12 Si, 0.084 Co, 0.023 S, and 0.019 P (calculated composition); same dimensions and fabrication method as the above specimen; annealed at 900 C; electrical conductivity 1.01 x 10^4 Ω^{-1} cm^{-1} at 30 C.
57	165	Honda, K.	1918	E	303	12b			Similar to the above specimen except cooled once to -190 C in liquid air instead of annealing.
58	165	Honda, K.	1918	E	303	13a		36.9	1.83 Cu, 0.32 Mn, 0.17 C, 0.13 Si, 0.095 Co, 0.022 S, and 0.018 P (calculated composition); same dimensions and fabrication method as the above specimen; annealed at 900 C; electrical conductivity 1.25 x 10^4 Ω^{-1} cm^{-1} at 30 C.
59	96	Powell, R.W. and Hickman, M.J.	1939	C	273-623	High-Ni steel; 14		28.37	0.89 Mn, 0.28 C, 0.15 Si, 0.030 Cu, 0.027 As, 0.012 Al, 0.009 P, 0.003 S, and trace Cr; 1 in. diameter and 8 in. long; heated to 950 C and cooled in water; electrical resistivity 84.0, 86.8, 89.9, 92.9, 95.9, 98.9, 102.0, and 104.8 $\mu\Omega$ cm at 0, 50, 100, 150, 200, 250, 300, and 350 C, respectively; iron used as comparative material.

* Not shown in figure.

TABLE 26. THERMAL CONDUCTIVITY OF IRON + NICKEL ALLOYS -- SPECIMEN CHARACTERIZATION AND MEASUREMENT INFORMATION (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) Fe	Ni	Composition (continued), Specifications, and Remarks
60	102	Watson, T.W. and Robinson, H.E.	1961	L	123-813	Low-exp-42	56.303	42.11	0.97 Mn, 0.16 Si, 0.09 Cr, and 0.085 C; specimen 2.54 cm in diameter and 37 cm long; supplied by International Nickel Co.; annealed for 30 min at 1088.7 K, furnace cooled; data presented as a smooth curve.
61	102	Watson, T.W. and Robinson, H.E.	1961	L	123-813	free cut Invar	62.233	35.84	0.81 Mn, 0.34 Si, 0.12 Cr, and 0.08 C; specimen 2.54 cm in diameter and 37 cm long; supplied by International Nickel Co.; annealed for 30 min at 1102.6 K, water quenched, and air cooled 1 hr at 588.7 K, then 48 hr at 369.3 K; data presented as a smooth curve.
62	102	Watson, T.W. and Robinson, H.E.	1961	L	123-813	9% Ni	90.29	8.56	0.77 Mn, 0.28 Si, and 0.10 C; specimen 2.54 cm in diameter and 37 cm long; supplied by International Nickel Co.; normalized at (1650 + 1450 F) (1172 + 1061 K), tempered at 838.7 K; data presented as a smooth curve.
63	97, 181	Kohlhaas, R. and Kierspe, W.	1965	L	88-297	X8 Ni9		8.35	0.74 Mn, 0.28 Si, 0.051 C, 0.016 P, and 0.009 N; heat-treated in air at 790 C for 0.5 hr and at 570 C for 3.5 hr; electrical resistivity 22.66, 28.20, 29.34, 30.90, 32.56, 33.96, 35.21, 36.48, and 37.70 $\mu\Omega$ cm at -190, -70, -50, -25, 0, 20, 40, 60, and 80 C, respectively.
64*	191	Holder, T.K.	1977	L	87-402			3.15	0.15 O, < 0.01 Si, 0.005 Cu, 0.0028 C, 0.0018 H, and 0.0015 N; polycrystalline, photomicrograph showed specimen was not homogeneous single phase material; right circular cylindrical specimen 0.65 cm in diam and about 7.6 cm long; arc-cast, swaged, annealed in argon at 1223 K for 2 h, cooled to 873 K and held there for 20 h, and furnace-cooled to room temperature; electrical resistivity 6.66, 8.20, 9.72, 11.10, 12.55, 14.03, 15.57, 17.36, 17.39, 19.00, 20.80, 22.67, and 24.00 $\mu\Omega$ cm at 82.6, 116.7, 148.7, 176.6, 205.2, 233.7, 262.1, 294.5, 295.1, 322.5, 352.3, 381.4, and 401.5 K, respectively; thermoelectric power 4.00, 5.21, 5.85, 5.97, 5.71, 5.12, 4.41, 3.53, 2.85, 2.78, 1.61, 0.70, -0.36, -1.29 $\mu V\ K^{-1}$ at 86.9, 113.2, 139.6, 170.2, 193.4, 219.0, 243.3, 268.5, 294.3, 296.2, 328.4, 352.7, 379.7, and 402.1 K, respectively; ratio of resistance at 273.15 K to that at 4.2 K was 3.00; thermal conductivity, electrical resistivity, and thermoelectric power accurate to within $\pm 1.2\%$, $\pm 0.4\%$, and $\pm 0.1\ \mu V\ K^{-1}$, respectively; preliminary calculations indicated thermal conductivity and electrical resistivity altered by as much as 1% by the presence of Fe_3O_4; data extracted from table.

* Not shown in figure.

TABLE 27. THERMAL CONDUCTIVITY OF NICKEL + IRON ALLOYS -- SPECIMEN CHARACTERIZATION AND MEASUREMENT INFORMATION

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) Ni	Fe	Composition (continued), Specifications, and Remarks
1	98	Ingersall, L.R.	1920	L	293,373	166 Q	75.06		<0.1 C; prepared from 99.97 pure iron and high-purity nickel by forging; 0.98 cm in diameter and 5.1 to 6.7 cm long; electrical resistivity 23.4, 31.3, 40.0, 51.0, 62.0, 70.2, 75.0, and 78.3 $\mu\Omega$ cm at 0, 100, 200, 300, 400, 500, 600, and 700 C, respectively.
2	132	Silverman, L.	1953	C	323-1173		50.85	48.5	0.12 Mn, 0.024 C, and 0.003 S; annealed at 950 C; Advance (55 Cu, 45 Ni) used as comparative material.
3	108	Shelton, S.M. and Swanger, W.H.	1933	C	512-685	N.S. nickel, commercial	99+	0.6	0.14 Cu, 0.09 Mn, and 0.014 S; 2 cm in diameter and 15 cm long; lead used as comparative material.
4	108	Shelton, S.M. and Swanger, W.H.	1933	C	313.2	N.S. nickel, commercial			Similar to the above specimen.
5	108	Shelton, S.M. and Swanger, W.H.	1933	C	339-864	N.S. nickel, commercial			Similar to the above specimen except nickel used as comparative material.
6	166	Bell, I.P. and MacDonald, J.J.	1953	L	328-472	Nickel, commercial	99.4	0.2	0.1 Mg, 0.05 Co, 0.03 Sn, 0.026 C, 0.02 Si, 0.01 Cr, 0.01 Mn, 0.005 S, 0.003 Ti, and 0.002 each of Al and Pb; cylindrical specimen.
7	107	Berger, L. and Rivier, D.	1962	L	4.2,80		85.2	14.8	0.2 cm diameter and 5.2 cm long; fused in an induction furnace under vacuo of 10^{-3} torr; the mixture of Ni and Fe supplied by Johnson-Matthey; cold-rolled, annealed at 1173 K for 2 hr, slowly cooled; electrical resistivity 3.78, 4.60, and 13.22 $\mu\Omega$ cm at 4.18, 80.5, and 292.7 K, respectively.
8	107	Berger, L. and Rivier, D.	1962	L	4.2				The above specimen measured in transverse magnetic fields ranging from 0.150 to 1.92 W m^{-2}.
9	107	Berger, L. and Rivier, D.	1962	L	80				The above specimen measured in transverse magnetic fields ranging from 0.373 to 1.92 W m^{-2}.
10	107	Berger, L. and Rivier, D.	1962	L	4.2				The above specimen measured in longitudinal magnetic fields ranging from 0.079 to 1.76 W m^{-2}.
11	107	Berger, L. and Rivier, D.	1962	L	80				The above specimen measured in longitudinal magnetic fields ranging from 0.051 to 1.41 W m^{-2}.
12	81	Farrell, T. and Greig, D.	1969	L	1.3-106			0.8	About 3 mm in diameter and 9 cm long; chill-cast under vacuum; annealed at 850 C for 15 hr; residual electrical resistivity 0.307 $\mu\Omega$ cm.
13	81	Farrell, T. and Greig, D.	1969	L	2.8-100			1.7	Similar to the above specimen except residual electrical resistivity 0.713 $\mu\Omega$ cm; electrical resistivity 7.99 $\mu\Omega$ cm at 0 C.
14	81	Farrell, T. and Greig, D.	1969	L	4.5-105			4.4	Similar to the above specimen except residual electrical resistivity 1.80 $\mu\Omega$ cm; electrical resistivity 9.84 $\mu\Omega$ cm at 0 C.
15	105	Yelon, W.B. and Berger, L.	1970	L	1.3-4.1	Permalloy	82	18	Calculated composition.
16	105	Yelon, W.B. and Berger, L.	1970	L	1.5-4.1	Permalloy	71	29	Calculated composition.
17	105	Yelon, W.B. and Berger, L.	1970	L	1.5-4.0	Permalloy			The above specimen measured in a longitudinal magnetic field of 0.781 T.
18*	105	Yelon, W.B. and Berger, L.	1970	L	1.5-4.0	Permalloy			The above specimen measured in a longitudinal magnetic field of 3.3 T.

*Not shown in figure.

TABLE 27. THERMAL CONDUCTIVITY OF NICKEL + IRON ALLOYS -- SPECIMEN CHARACTERIZATION AND MEASUREMENT INFORMATION (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) Ni	Fe	Composition (continued), Specifications, and Remarks
19	105	Yelon, W.B. and Berger, L.	1970	L	1.5-4.0	Permalloy			The above specimen measured in a longitudinal magnetic field of 5.94 T.
20	106, 177	Yelon, W.B. and Berger, L.	1970	L	1.6-4.4			29.8	Prepared by fusing Johnson-Matthey metals in argon atmosphere, remelting and casting into 0.5 in. rods in helium, swaging to 0.3125 in. in diameter, homogenizing in hydrogen at 1200 C for 38 hr, cooling to 900 C in vacuum and annealing for 2 hr; grain size 0.1 ~ 0.5 mm; electrical resistivity 4.24 $\mu\Omega$ cm at 4.2 K; run 7.
21	106, 177	Yelon, W.B. and Berger, L.	1970	L	1.5-4.4				The above specimen measured in a parallel magnetic field of 7.81 kG.
22	106, 177	Yelon, W.B. and Berger, L.	1970	L	1.6-4.4				The above specimen measured in a parallel magnetic field of 33.00 kG.
23	106, 177	Yelon, W.B. and Berger, L.	1970	L	1.6-4.4				The above specimen measured in a parallel magnetic field of 59.40 kG.
24	106, 177	Yelon, W.B. and Berger, L.	1970	L	1.5-4.3				The above specimen, no magnetic field; run 8.
25	106, 177	Yelon, W.B. and Berger, L.	1970	L	1.3-4.4				The above specimen measured in a parallel magnetic field of 7.81 kG.
26	106, 177	Yelon, W.B. and Berger, L.	1970	L	1.5-4.4				The above specimen measured in a parallel magnetic field of 59.40 kG.
27	106, 177	Yelon, W.B. and Berger, L.	1970	L	1.3-4.7			18.9	Same preparation method as the above specimen; grain size 0.1-0.5 mm; electrical resistivity 4.32 $\mu\Omega$ cm at 4.2 K; run 2.
28	106, 177	Yelon, W.B. and Berger, L.	1970	L	1.3-4.6				The above specimen measured in a parallel magnetic field of 7.15 kG.
29	106, 177	Yelon, W.B. and Berger, L.	1970	L	1.4-4.6				The above specimen measured in a parallel magnetic field of 59.40 kG.
30	106, 177	Yelon, W.B. and Berger, L.	1970	L	1.3-4.6				The above specimen measured in a parallel magnetic field of 7.15 kG; run 3.
31	106, 177	Yelon, W.B. and Berger, L.	1970	L	1.2-4.6				The above specimen measured in a parallel magnetic field of 33.00 kG.
32	106, 177	Yelon, W.B. and Berger, L.	1970	L	1.3-4.6				The above specimen measured in the same magnetic field; run 4.
33	106, 177	Yelon, W.B. and Berger, L.	1970	L	1.3-4.6				The above specimen measured in a parallel magnetic field of 59.40 kG.
34	102	Watson, T.W. and Robinson, H.E.	1965	L	123-813	HyMu 80	79.24	15.283	0.71 Mn, 0.19 Si, 0.08 Cr, and 0.049 C; 2.54 cm diameter and 37 cm long; supplied by International Nickel Co.; powder packed in, annealed in hydrogen at 922 K (1200 F) for 5 hr and at 1450 K (2150 F) for 5 hr, furnace cooled to 700 K (800 F), then cooled in hydrogen; smoothed values reported.
35	100	de Nobel, J.	1951	L	15-93	5277	57.5		1.31 Mn, 0.34 C, and 0.14 Si; as forged.

TABLE 27. THERMAL CONDUCTIVITY OF NICKEL + IRON ALLOYS -- SPECIMEN CHARACTERIZATION AND MEASUREMENT INFORMATION (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) Ni	Fe	Composition (continued), Specifications, and Remarks
36	187	Moore, J.P., Kollie, T.G., Graves, R.S., and McElroy, D.L.	1971	L	80-400	D1	75.4	24.2	<0.1 total impurities; 2.5 cm diameter x 7.5 cm long; cast, machined, swaged, and lapped; annealed at 1375 K for 24 h and then quenched in ice water; electrical resistivity 42.5, 5.05, 5.55, 6.18, 6.90, 7.70, 8.65, 9.64, 10.78, 11.99, 13.35, 14.75, 16.20, 17.75, 19.44, 21.15, 22.95, and 24.77 $\mu\Omega$ cm at 4.2, 80, 100, 120, 140, 160, 180, 200, 220, 240, 260, 280, 300, 320, 340, 360, 380, and 400 K, respectively; smooth values reported.
37	187	Moore, J.P., et al.	1971	L	80-400	O1			The above specimen heated to 1350 K in a vacuum of 10^{-7} torr and cooled at a rate of 5 K min^{-1} to room temperature; with high degree of local order; electrical resistivity 4.00, 4.77, 5.24, 5.80, 6.46, 7.19, 8.03, 9.00, 10.07, 11.22, 12.48, 13.78, 15.13, 16.56, 18.08, 19.69, 21.45, and 23.17 $\mu\Omega$ cm at 4.2, 80, 100, 120, 140, 160, 180, 200, 220, 240, 260, 280, 300, 320, 340, 360, 380, and 400 K, respectively; smooth values reported.

4.10. Silver-Palladium Alloy System

The silver-palladium alloy system exhibits complete solid solubility and is analogous to the copper-nickel alloy system, but without the complications of ferromagnetic effects and with an electronic specific heat that is better behaved [109].

There are 32 sets of experimental data available for the thermal conductivity of this alloy system. However, of the 18 data sets availabel for Ag+Pd alloys listed in table 29 and shown in figure 63, six sets are merely single data points, and of the 14 sets for Pd+Ag alloys listed in table 30 and shown in figure 64 seven sets are single data points.

This alloy system is the most extensively studied among the noble metal-palladium alloy systems, but the only reliable experimental data on thermal conductivity are the low temperature measurements by Kemp et al. [110] (Pd+Ag curves 6-8 and Ag+Pd curves 6-14), Tainsh and White [111] (Ag+Pd curves 16-18), and Fletcher and Greig [84] (Pd+Ag curves 11-14). The early measurements by Schulze [93] (Pd+Ag curves 1-5 and Ag+Pd curves 1-5) of the room-temperature thermal conductivity of these alloys at intervals of 10% gave values that are considerable above the actual values in some cases. Even after correcting for the lattice component, the Lorenz ratios corresponding to Schulze's values for the 60, 70, and 80% Pd alloys are respectively 30, 44 and 35% greater than the classical value; it is unlikely that band structure effects could cause such large Lorenz ratios in these alloys at 298 K. On the other hand, the more recent measurements by Zolotukhin [112] at somewhat higher temperatures on specimens containing 25 and 50% Ag (Pd+Ag curves 9 and 10 and Ag+Pd curve 15) appear to be too low, in the second instance by approximately 25%.

This alloy system is one of the few in which the thermal conductivity has been measured over a very wide range of compositions from liquid helium temperatures to 100 K. The measurements by Kemp et al. were undertaken to obtain fundamental information about the electron-phonon interaction, in particular to see whether electrons interact with lattice waves of all polarizations, to determine the dependence of the interaction on electron concentration and to deduce, by interpolation between these and similar measurements on silver-cadmium alloys, the contribution of the electron-phonon interaction to the lattice thermal resistivity of silver. The study revealed the cusp-like behavior of the low temperature lattice conductivity as a function of composition, as discusssed in section 2 on Theoretical Background, and led to additional measurments by Tainsh and White following further annealing at higher temperatures to determine whether or not this behavior was caused by the locking in of dislocations by solute atoms. While the cusp-like behavior persisted, it was found that an increase in the annealing temperature from 883 K to 1213 K resulted in increases of 30% or more in the lattice thermal conductivities of these specimens at liquid helium temperatures.

A comparison of the initial values calculated from eqs (12) and (35) in the region above the lattice component maximum with the experimental values of Kemp et al. revealed that the calculated values for the silver-rich alloys were too low, the total conductivity by as much as 8% and the lattice component by as much as 25%. It was found that both the total and lattice thermal conductivities could be brought into good agreement with the experimental data for all compositions from 2 to 30% Pd by increasing the value of the lattice thermal conductivity of pure silver by 50%. Although such an increase does not require unreasonable values for the Debye temperature or the Grüneisen parameter in the equation used to estimate the lattice thermal conductivity of the elements, it raises considerable doubt as to the reliability of such estimates. While the separation of the electronic and lattice components of very dilute alloys at temperatures above that of the maximum of the lattice component involves some uncertainty, a 50% error in the lattice component is unlikely. Although excellent agreement was obtained for the lattice conductivities of both 2 and 5% Pd alloys, it was decided, in view of the conflicting evidence, not to report even provisional values for the lattice thermal conductivity of the dilute silver-rich alloys. In addition, while the measurments of Tainsh and White established that, in the region below its maximum, the lattice thermal conductivity of well-annealed samples is substantially greater than the values obtained from the first set of measurments, these later measurements were limited to temperatures below 10 K and to compositions of 2, 5, and 10% Pd and could, therefore, only serve as a rough guide for correcting the values of the lattice component obtained from measurements on specimens annealed at 883 K; accordingly, the values for the silver-rich alloys at temperatures below the maximum are provisional.

The lattice thermal conductivity of the palladium-rich alloys of this system was investigated by Fletcher and Greig, who measured the thermal conductivity of specimens containing 5, 10, 15, and 20% Ag from liquid helium temperatures to about 100 K. Their study showed that the strong electron-phonon interactions in these alloys greatly reduce the low temperature lattice thermal conductivity, causing its maximum to occur at much higher temperatures than in the silver-rich alloys. The increase in the temperature of the maximum of the lattice component is even greater than that shown in their graph because, at the higher temperatures, the method used to separate the electronic and lattice components yields values of the latter which are below the true values by an amount which increases with temperature, so that the lattice components of these alloys are still increasing at 100 K. This is consistent with the temperature of the maximum of k_g (100 K) deduced from the measurements by Kemp et al. on a specimen containing 30% Ag. Since the measurements on the Pd-rich alloys did not extend to temperatures above those of the lattice thermal conductivity maxima, the values of the lattice component in this region were obtained by smoothly joining plots of the values deduced from measurements to those calculated from eq (35). In doing this we were guided by the shapes of the lattice thermal conductivity curves of the analogous Cu-Ni alloy system.

A graphical comparison of the recommended total thermal conductivity values with some of the experimental data is given in figures 59 and 60. The smooth solid curves in these figures were obtained by interpolating the recommended values of table 28 in order to obtain thermal conductivity values for the desired alloy compositions. For silver-rich

alloys shown in figure 59, the recommended values are in agreement with the data of Kemp et al. [110] (Ag+Pd curves 6, 8, 9, and 11-14) to within 7 to 12%. For palladium-rich alloys shown in figure 60, the recommended values agree with the data of Kemp et al. [110] (Pd+Ag curve 7) to within 5%, and with the data above 10 K of Fletcher and Greig [84] (Pd+Ag curves 11-14) to within 5 to 7%.

The recommended values for k, k_e, and k_g are tabulated in table 28 for 25 alloy compositions covering the full range of temperature from 4 to 1200 K for most cases. These values are for alloys which have not been severely cold worked or quenched. The values for k are also presented in figures 61 and 62. In order to show more clearly the systematic variation of the thermal conductivity with alloy composition and to clarify the confusion in figure 62 due to crossover of curves, the recommended curves for palladium-rich alloys with 55 to 65% Pd are also shown in figure 61. The values of residual electrical resistivity for the alloys are also given in table 28. The uncertainties of the k values are stated in a footnote to table 28, while the uncertainties of the k_e and k_g values are indicated by their being designated as recommended or provisional values. The ranges of uncertainties of recommended and provisional values are less than ±15% and between ±15 and ±30%, respectively.

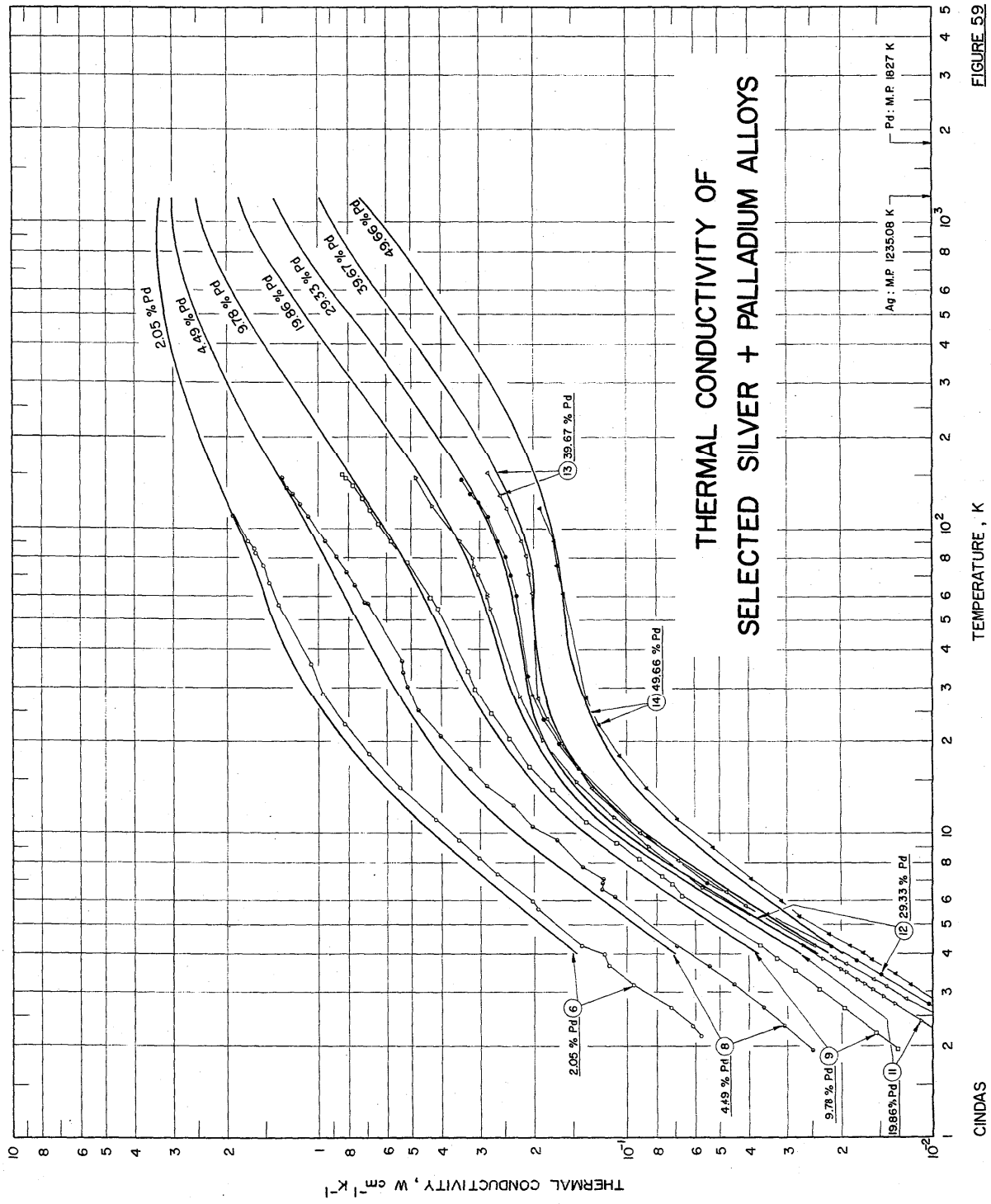
THERMAL CONDUCTIVITY OF
SELECTED SILVER + PALLADIUM ALLOYS
THERMAL CONDUCTIVITY, W cm⁻¹ K⁻¹
TEMPERATURE, K
Ag : M.P. 1235.08 K
Pd : M.P. 1827 K
2.05 % Pd
4.49 % Pd
9.78 % Pd
19.86 % Pd
29.33 % Pd
39.67 % Pd
49.66 % Pd
(13) 39.67 % Pd
(14) 49.66 % Pd
(12) 29.33 % Pd
(6) 2.05 % Pd
(8) 4.49 % Pd
(9) 9.78 % Pd
(11) 19.86% Pd
CINDAS

FIGURE 59

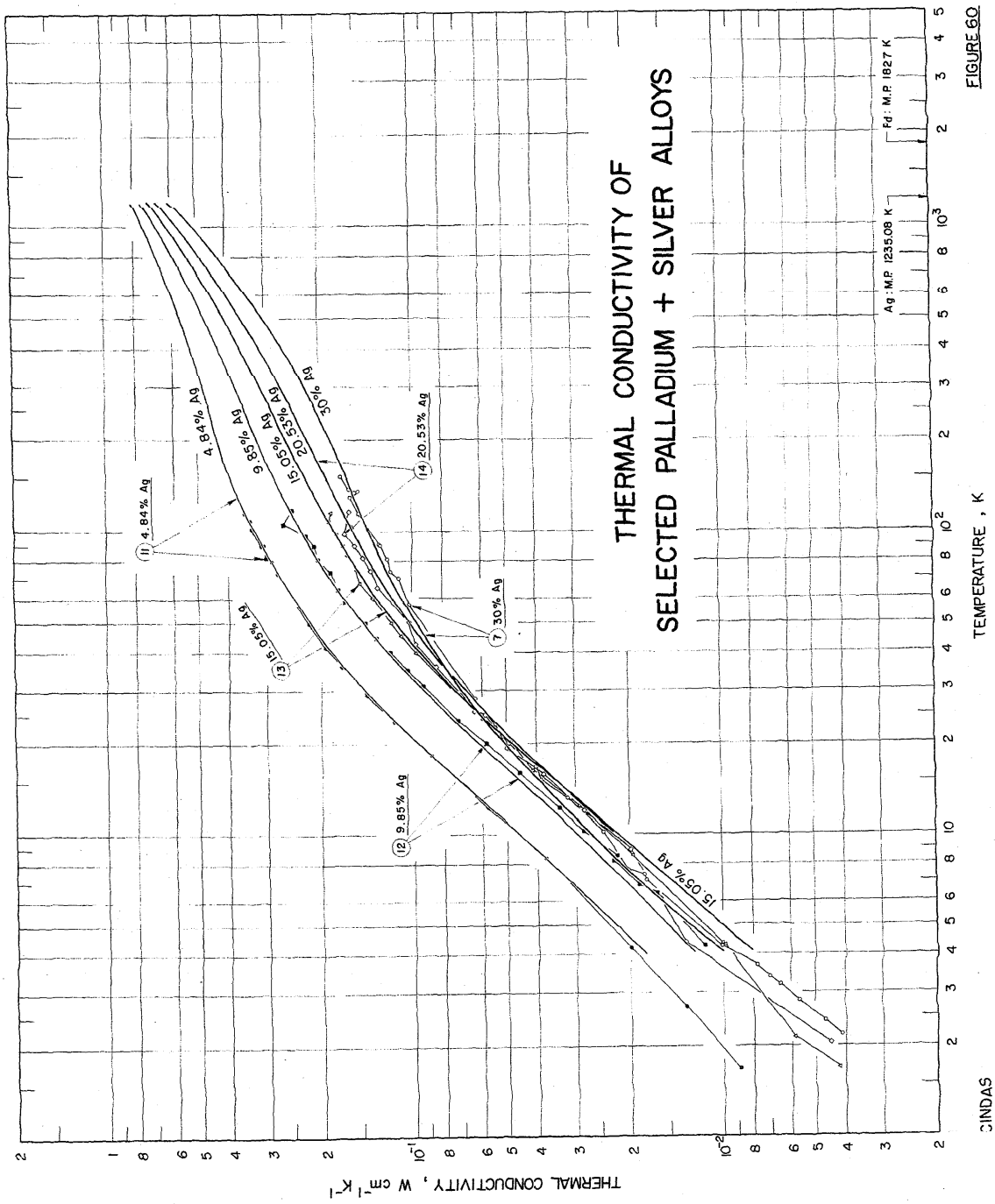

FIGURE 60

CINDAS

TABLE 28. RECOMMENDED THERMAL CONDUCTIVITY OF SILVER-PALLADIUM ALLOY SYSTEM†

[Temperature, T, K; Thermal Conductivity, k, W cm^{-1} K^{-1}; Electronic Thermal Conductivity, k_e, W cm^{-1} K^{-1}; Lattice Thermal Conductivity, k_g, W cm^{-1} K^{-1}]

Ag: 99.50% (99.49 At.%) Pd: 0.50% (0.51 At.%)				Ag: 99.00% (98.99 At.%) Pd: 1.00% (1.01 At.%)				Ag: 97.00% (96.96 At.%) Pd: 3.00% (3.04 At.%)				Ag: 95.00% (94.93 At.%) Pd: 5.00% (5.07 At.%)			
ρ_o = 0.2400 μΩ cm				ρ_o = 0.4900 μΩ cm				ρ_o = 1.390 μΩ cm				ρ_o = 2.260 μΩ cm			
T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g
4	0.449*	0.407	0.0415‡	4	0.230*‡	0.199	0.0310‡	4	0.0963‡	0.0703	0.0260‡	4	0.0634‡	0.0432	0.0202‡
6	0.698*	0.611	0.0865‡	6	0.365*‡	0.299	0.0655‡	6	0.159‡	0.105	0.0535‡	6	0.109‡	0.0649	0.0445‡
8	0.949*	0.814	0.135‡	8	0.505*‡	0.399	0.106‡	8	0.228‡	0.141	0.0870‡	8	0.160‡	0.0865	0.0735‡
10	1.20*	1.02	0.180‡	10	0.644*‡	0.499	0.145‡	10	0.300‡	0.176	0.124‡	10	0.212‡	0.108	0.104‡
15	1.78*	1.53	0.246‡	15	0.963*‡	0.748	0.215‡	15	0.453‡	0.264	0.189‡	15	0.319‡	0.162	0.157‡
20	2.33*	2.04	0.285‡	20	1.25*‡	0.997	0.254‡	20	0.571‡	0.352	0.219‡	20	0.405‡	0.216	0.189‡
25	2.65*	2.35	0.298‡	25	1.47*‡	1.20	0.272‡	25	0.665‡	0.433	0.232‡	25	0.467‡	0.262	0.205‡
30	2.84*	2.54	0.300‡	30	1.67*‡	1.39	0.276‡	30	0.748‡	0.513	0.235‡	30	0.521‡	0.311	0.210‡
40	3.03*	2.73	0.295‡	40	1.96*‡	1.69	0.272‡	40	0.892‡	0.661	0.231‡	40	0.612‡	0.404	0.208‡
50	3.04*			50	2.11*			50	1.01			50	0.685		
60	2.98*			60	2.18*			60	1.09			60	0.750		
70	3.00*			70	2.26*			70	1.18			70	0.814		
80	3.07*			80	2.35*			80	1.25			80	0.877		
90	3.10*			90	2.44*			90	1.33			90	0.938		
100	3.19*			100	2.52*			100	1.41			100	0.998		
150	3.40*			150	2.87*			150	1.76			150	1.27		
200	3.59*			200	3.12*			200	2.02*			200	1.51*		
250	3.74*			250	3.27*			250	2.24*			250	1.71*		
273	3.78*			273	3.33*			273	2.33*			273	1.80*		
300	3.82*			300	3.41*			300	2.43*			300	1.88*		
350	3.88*			350	3.50*			350	2.57*			350	2.04*		
400	3.90*			400	3.57*			400	2.69*			400	2.18*		
500	3.91*			500	3.63*			500	2.89*			500	2.41*		
600	3.90*			600	3.69*			600	3.03*			600	2.58*		
700	3.84*			700	3.67*			700	3.12*			700	2.72*		
800	3.81*			800	3.67*			800	3.18*			800	2.83*		
900	3.74*			900	3.62*			900	3.21*			900	2.89*		
1000	3.67*			1000	3.57*			1000	3.22*			1000	2.93*		
1100	3.60*			1100	3.51*			1100	3.22*			1100	2.96*		
1200	3.55*			1200	3.46*			1200	3.22*			1200	2.98*		

† Uncertainties in the total thermal conductivity, k, are as follows:
99.50 Ag - 0.50 Pd: ±10% below 40 K, ±7% between 40 and 300 K, and ±10% above 300 K.
99.00 Ag - 1.00 Pd: ±15% below 40 K and ±10% above 40 K.
97.00 Ag - 3.00 Pd: ±15% below 40 K and ±10% above 40 K.
95.00 Ag - 5.00 Pd: ±15% below 40 K and ±10% above 40 K.

‡ Provisional value.

* In temperature range where no experimental thermal conductivity data are available.

TABLE 28. RECOMMENDED THERMAL CONDUCTIVITY OF SILVER-PALLADIUM ALLOY SYSTEM (continued) †

[Temperature, T, K; Thermal Conductivity, k, W cm^{-1} K^{-1}; Electronic Thermal Conductivity, k_e, W cm^{-1} K^{-1}; Lattice Thermal Conductivity, k_g, W cm^{-1} K^{-1}]

Ag: 90.00% (89.88 At.%) Pd: 10.00% (10.12 At.%)				Ag: 85.00% (84.82 At.%) Pd: 15.00% (15.18 At.%)				Ag: 80.00% (79.78 At.%) Pd: 20.00% (20.22 At.%)				Ag: 75.00% (74.74 At.%) Pd: 25.00% (25.26 At.%)			
ρ_o = 4.46 μΩ cm				ρ_o = 6.46 μΩ cm				ρ_o = 8.41 μΩ cm				ρ_o = 10.60 μΩ cm			
T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g
4	0.0364‡	0.0219	0.0145‡	4	0.0299*‡	0.0151	0.0148‡	4	0.0270‡	0.0116	0.0154‡	4	0.0253*‡	0.00922	0.0161‡
6	0.0662‡	0.0329	0.0333‡	6	0.0553*‡	0.0227	0.0326‡	6	0.0518‡	0.0174	0.0344‡	6	0.0483*‡	0.0138	0.0345‡
8	0.100‡	0.0438	0.0562‡	8	0.0853*‡	0.0303	0.0550‡	8	0.0812‡	0.0232	0.0580‡	8	0.0764*‡	0.0184	0.0580‡
10	0.135‡	0.0578	0.0775‡	10	0.119*‡	0.0378	0.0810‡	10	0.112‡	0.0290	0.0825‡	10	0.107*‡	0.0230	0.0840‡
15	0.201‡	0.0822	0.119‡	15	0.182*‡	0.0567	0.125‡	15	0.165‡	0.0436	0.121‡	15	0.159*‡	0.0346	0.124‡
20	0.253‡	0.110	0.143‡	20	0.224*‡	0.0756	0.148‡	20	0.200‡	0.0581	0.142‡	20	0.192*‡	0.0461	0.146‡
25	0.292‡	0.135	0.157‡	25	0.251*‡	0.0931	0.158‡	25	0.224‡	0.0717	0.152‡	25	0.213*‡	0.0569	0.156‡
30	0.324‡	0.161	0.163‡	30	0.272*‡	0.111	0.161‡	30	0.241‡	0.0856	0.155‡	30	0.223*‡	0.0680	0.155‡
40	0.374‡	0.213	0.161‡	40	0.301*‡	0.147	0.154‡	40	0.263‡	0.113	0.150‡	40	0.238*‡	0.0901	0.148‡
50	0.417	0.261	0.156	50	0.326*	0.181	0.145	50	0.281	0.140	0.141	50	0.248*	0.112	0.136
60	0.454	0.307	0.147	60	0.351*	0.215	0.136	60	0.298	0.167	0.131	60	0.259*	0.133	0.126
70	0.491	0.352	0.139	70	0.375*	0.248	0.127	70	0.316	0.193	0.123	70	0.271*	0.154	0.117
80	0.527	0.396	0.131	80	0.400*	0.281	0.119	80	0.333	0.219	0.114	80	0.285*	0.175	0.110
90	0.565	0.441	0.124	90	0.427*	0.314	0.113	90	0.352	0.245	0.107	90	0.299*	0.195	0.104
100	0.602	0.485	0.117	100	0.452*	0.346	0.106	100	0.371	0.270	0.101	100	0.314*	0.216	0.0975
150	0.780	0.687	0.0930	150	0.581*	0.497	0.0840	150	0.472	0.392	0.0800	150	0.393*	0.316	0.0770
200	0.943*	0.866	0.0775	200	0.706*	0.636	0.0700	200	0.573*	0.506	0.0670	200	0.475*	0.410	0.0645
250	1.10*	1.03	0.0665	250	0.827*	0.766	0.0610	250	0.671*	0.613	0.0580	250	0.556*	0.500	0.0560
273	1.16*	1.10	0.0627	273	0.881*	0.823	0.0575	273	0.716*	0.661	0.0545	273	0.593*	0.540	0.0530
300	1.24	1.18	0.0586	300	0.942*	0.888	0.0539	300	0.766	0.715	0.0511	300	0.635*	0.586	0.0494
350	1.38*	1.32	0.0526	350	1.05*	1.00	0.0487	350	0.858*	0.812	0.0463	350	0.711*	0.667	0.0448
400	1.50*	1.45	0.0479	400	1.16*	1.11	0.0444	400	0.946*	0.904	0.0424	400	0.782*	0.741	0.0411
500	1.72*	1.68	0.0406	500	1.35*	1.31	0.0380	500	1.11*	1.07	0.0364	500	0.922*	0.886	0.0354
600	1.91*	1.88	0.0354	600	1.52*	1.49	0.0333	600	1.26*	1.23	0.0320	600	1.05*	1.02	0.0313
700	2.07*	2.04	0.0313	700	1.68*	1.65	0.0297	700	1.39*	1.36	0.0287	700	1.17*	1.14	0.0281
800	2.21*	2.18	0.0282	800	1.82*	1.80	0.0268	800	1.52*	1.50	0.0260	800	1.29*	1.26	0.0255
900	2.32*	2.30	0.0256	900	1.93*	1.91	0.0245	900	1.62*	1.60	0.0238	900	1.38*	1.36	0.0234
1000	2.41*	2.39	0.0235	1000	2.02*	2.00	0.0226	1000	1.71*	1.69	0.0220	1000	1.45*	1.43	0.0216
1100	2.47*	2.45	0.0217	1100	2.10*	2.08	0.0209	1100	1.78*	1.76	0.0204	1100	1.53*	1.51	0.0201
1200	2.53*	2.51	0.0201	1200	2.16*	2.14	0.0195	1200	1.84*	1.82	0.191	1200	1.60*	1.58	0.0188

† Uncertainties in the total thermal conductivity, k, are as follows:
90.00 Ag - 10.00 Pd: ±15% below 40 K and ±10% above 40 K.
85.00 Ag - 15.00 Pd: ±20% below 40 K and ±10% above 40 K.
80.00 Ag - 20.00 Pd: ±20% below 40 K and ±10% above 40 K.
75.00 Ag - 25.00 Pd: ±20% below 40 K and ±10% above 40 K.

‡ Provisional value.

* In temperature range where no experimental thermal conductivity data are available.

TABLE 28. RECOMMENDED THERMAL CONDUCTIVITY OF SILVER-PALLADIUM ALLOY SYSTEM (continued) †

[Temperature, T, K; Thermal Conductivity, k, W cm^{-1} K^{-1}; Electronic Thermal Conductivity, k_e, W cm^{-1} K^{-1}; Lattice Thermal Conductivity, k_g, W cm^{-1} K^{-1}]

Ag: 70.00% (69.71 At.%) Pd: 30.00% (30.29 At.%)				Ag: 65.00% (64.69 At.%) Pd: 35.00% (35.31 At.%)				Ag: 60.00% (59.67 At.%) Pd: 40.00% (40.33 At.%)				Ag: 55.00% (54.66 At.%) Pd: 45.00% (45.34 At.%)			
ρ_o = 13.01 μΩ cm				ρ_o = 15.62 μΩ cm				ρ_o = 18.44 μΩ cm				ρ_o = 21.56 μΩ cm			
T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g
4	0.0241‡	0.00751	0.0166‡	4	0.0231*‡	0.00626	0.0168‡	4	0.0222‡	0.00530	0.0169‡	4	0.0212*‡	0.00453	0.0167‡
6	0.0472‡	0.0113	0.0359‡	6	0.0439*‡	0.00938	0.0345‡	6	0.0410‡	0.00795	0.0330‡	6	0.0382*‡	0.00680	0.0314‡
8	0.0755‡	0.0150	0.0605‡	8	0.0690*‡	0.0125	0.0565‡	8	0.0646‡	0.0106	0.0540‡	8	0.0576*‡	0.00907	0.0485‡
10	0.102‡	0.0188	0.0835‡	10	0.0945*‡	0.0156	0.0789‡	10	0.0881‡	0.0132	0.0749‡	10	0.0778*‡	0.0113	0.0665‡
15	0.154‡	0.0282	0.126‡	15	0.144*‡	0.0235	0.121‡	15	0.134‡	0.0199	0.114‡	15	0.118*‡	0.0170	0.101‡
20	0.186‡	0.0376	0.148‡	20	0.175*‡	0.0313	0.144‡	20	0.163‡	0.0265	0.136‡	20	0.144*‡	0.0227	0.121‡
25	0.201‡	0.0464	0.155‡	25	0.191*‡	0.0387	0.152‡	25	0.179‡	0.0328	0.146‡	25	0.162*‡	0.0280	0.134‡
30	0.212‡	0.0555	0.156‡	30	0.201*‡	0.0463	0.155‡	30	0.189‡	0.0393	0.150‡	30	0.173*‡	0.0335	0.139‡
40	0.221‡	0.0736	0.147‡	40	0.210*‡	0.0614	0.149‡	40	0.197‡	0.0521	0.145‡	40	0.183*‡	0.0445	0.138‡
50	0.227	0.0913	0.136	50	0.214*	0.0763	0.138	50	0.200	0.0648	0.135	50	0.183*	0.0553	0.128‡
60	0.235	0.109	0.126	60	0.216*	0.0909	0.125	60	0.201	0.0772	0.124	60	0.185*	0.0659	0.119
70	0.243	0.126	0.117	70	0.220*	0.106	0.114	70	0.201	0.0896	0.115	70	0.187*	0.0764	0.111
80	0.252	0.143	0.109	80	0.227*	0.120	0.107	80	0.205	0.102	0.107	80	0.191*	0.0870	0.104
90	0.263	0.161	0.102	90	0.235*	0.134	0.101	90	0.211	0.111	0.100	90	0.195*	0.0974	0.0975
100	0.275	0.178	0.0965	100	0.245*	0.149	0.0960	100	0.219	0.125	0.0940	100	0.200*	0.108	0.0920
150	0.338	0.261	0.0765	150	0.294*	0.219	0.0750	150	0.260	0.186	0.0740	150	0.232*	0.158	0.0740
200	0.404*	0.340	0.0640	200	0.349*	0.286	0.0625	200	0.304*	0.242	0.0620	200	0.268*	0.206	0.0620
250	0.471*	0.415	0.0555	250	0.403*	0.349	0.0540	250	0.350*	0.296	0.0540	250	0.305*	0.251	0.0540
273	0.501*	0.449	0.0520	273	0.428*	0.377	0.0510	273	0.371*	0.320	0.0510	273	0.323*	0.272	0.0510
300	0.534	0.486	0.0484	300	0.457*	0.409	0.0479	300	0.396	0.348	0.0479	300	0.343*	0.295	0.0482
350	0.598*	0.555	0.0439	350	0.511*	0.468	0.0436	350	0.441*	0.397	0.0435	350	0.380*	0.336	0.0439
400	0.661*	0.621	0.0403	400	0.563*	0.523	0.0400	400	0.484*	0.444	0.0400	400	0.416*	0.376	0.0403
500	0.780*	0.745	0.0349	500	0.664*	0.629	0.0346	500	0.567*	0.532	0.0347	500	0.482*	0.447	0.0349
600	0.891*	0.860	0.0308	600	0.758*	0.727	0.0307	600	0.643*	0.613	0.0307	600	0.543*	0.512	0.0310
700	0.998*	0.970	0.0277	700	0.846*	0.818	0.0276	700	0.715*	0.687	0.0278	700	0.599*	0.571	0.0279
800	1.10*	1.07	0.0252	800	0.926*	0.901	0.0252	800	0.780*	0.754	0.0252	800	0.651*	0.626	0.0255
900	1.18*	1.16	0.0232	900	0.997*	0.974	0.0231	900	0.837*	0.813	0.0232	900	0.701*	0.677	0.0235
1000	1.26*	1.24	0.0215	1000	1.06*	1.04	0.0215	1000	0.889*	0.867	0.0216	1000	0.750*	0.728	0.0218
1100	1.32*	1.30	0.0200	1100	1.12*	1.10	0.0200	1100	0.938*	0.917	0.0201	1100	0.798*	0.778	0.0204
1200	1.39*	1.37	0.0187	1200	1.18*	1.16	0.0188	1200	0.984*	0.965	0.0189	1200	0.846*	0.827	0.0191

† Uncertainties in the total thermal conductivity, k, are as follows:
70.00 Ag - 30.00 Pd: ±20% below 40 K and ±10% above 40 K.
65.00 Ag - 35.00 Pd: ±20% below 40 K and ±10% above 40 K.
60.00 Ag - 40.00 Pd: ±20% below 40 K and ±10% above 40 K.
55.00 Ag - 45.00 Pd: ±20% below 40 K and ±10% above 40 K.

‡ Provisional value.

* In temperature range where no experimental thermal conductivity data are available.

TABLE 28. RECOMMENDED THERMAL CONDUCTIVITY OF SILVER-PALLADIUM ALLOY SYSTEM (continued) †

[Temperature, T, K; Thermal Conductivity, k, W cm^{-1} K^{-1}; Electronic Thermal Conductivity, k_e, W cm^{-1} K^{-1}; Lattice Thermal Conductivity, k_g, W cm^{-1} K^{-1}]

Ag: 50.00% (49.66 At.%) Pd: 50.00% (50.34 At.%)				Ag: 45.00% (44.66 At.%) Pd: 55.00% (55.34 At.%)				Ag: 40.00% (39.67 At.%) Pd: 60.00% (60.33 At.%)				Ag: 35.00% (34.69 At.%) Pd: 65.00% (65.31 At.%)			
ρ_o = 27.44 μΩ cm				ρ_o = 36.50 μΩ cm				ρ_o = 40.15 μΩ cm				ρ_o = 39.40 μΩ cm			
T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g
4	0.0197‡	0.00356	0.0161‡	4	0.0174*‡	0.00268	0.0147‡	4	0.0150*‡	0.00243	0.0126‡	4	0.0132*‡	0.00248	0.0107‡
6	0.0347‡	0.00534	0.0294‡	6	0.0292*‡	0.00402	0.0252‡	6	0.0243*‡	0.00365	0.0206‡	6	0.0200*‡	0.00372	0.0163‡
8	0.0502‡	0.00712	0.0431‡	8	0.0411*‡	0.00536	0.0356‡	8	0.0335*‡	0.00487	0.0286‡	8	0.0268*‡	0.00496	0.0218‡
10	0.0654‡	0.00890	0.0565‡	10	0.0527*‡	0.00669	0.0460‡	10	0.0423*‡	0.00609	0.0362‡	10	0.0332*‡	0.00620	0.0270‡
15	0.0974‡	0.0134	0.0840‡	15	0.0755*‡	0.0100	0.0655‡	15	0.0611*‡	0.00913	0.0520‡	15	0.0476*‡	0.00930	0.0383‡
20	0.118‡	0.0178	0.100‡	20	0.0914*‡	0.0134	0.0780‡	20	0.0757*‡	0.0122	0.0635‡	20	0.0599*‡	0.0124	0.0475‡
25	0.131‡	0.0220	0.109‡	25	0.103*‡	0.0166	0.0860‡	25	0.0866*‡	0.0151	0.0715‡	25	0.0703*‡	0.0153	0.0550‡
30	0.141‡	0.0264	0.115‡	30	0.111*‡	0.0199	0.0910‡	30	0.0946*‡	0.0181	0.0765‡	30	0.0793*‡	0.0183	0.0610‡
40	0.152‡	0.0349	0.117‡	40	0.123*‡	0.0264	0.0965‡	40	0.106*‡	0.0240	0.0820‡	40	0.0933*‡	0.0243	0.0690‡
50	0.157	0.0434	0.114	50	0.131*‡	0.0327	0.0985‡	50	0.115*‡	0.0298	0.0850‡	50	0.104*‡	0.0302	0.0740‡
60	0.162	0.0518	0.110	60	0.137*‡	0.0390	0.0980‡	60	0.122*‡	0.0356	0.0865‡	60	0.113*‡	0.0359	0.0770‡
70	0.165	0.0598	0.105	70	0.141*	0.0452	0.0960	70	0.128*‡	0.0414	0.0870‡	70	0.121*‡	0.0417	0.0790‡
80	0.168	0.0680	0.0995	80	0.144*	0.0514	0.0930	80	0.133*‡	0.0469	0.0860‡	80	0.127*‡	0.0474	0.0795‡
90	0.171	0.0760	0.0945	90	0.148*	0.0576	0.0900	90	0.138*	0.0526	0.0850	90	0.133*‡	0.0531	0.0800‡
100	0.175	0.0841	0.0905	100	0.151*	0.0637	0.0870	100	0.142*	0.0582	0.0835	100	0.138*‡	0.0585	0.0800‡
150	0.198*	0.123	0.0745	150	0.167*	0.0935	0.0735	150	0.159*	0.0859	0.0730	150	0.158*	0.0854	0.0730
200	0.222*	0.159	0.0630	200	0.186*	0.122	0.0635	200	0.175*	0.111	0.0640	200	0.177*	0.111	0.0655
250	0.250*	0.194	0.0555	250	0.206*	0.150	0.0560	250	0.193*	0.136	0.0570	250	0.195*	0.136	0.0590
273	0.263*	0.210	0.0525	273	0.216*	0.162	0.0535	273	0.202*	0.148	0.0543	273	0.204*	0.147	0.0565
300	0.278	0.228	0.0489	300	0.226*	0.176	0.0499	300	0.212	0.161	0.0513	300	0.214*	0.161	0.0532
350	0.304*	0.259	0.0445	350	0.249*	0.204	0.0454	350	0.233*	0.186	0.0467	350	0.233*	0.185	0.0484
400	0.330	0.289	0.0409	400	0.272*	0.231	0.0418	400	0.255*	0.212	0.0429	400	0.253*	0.208	0.0445
500	0.381	0.346	0.0354	500	0.318*	0.281	0.0362	500	0.297*	0.260	0.372	500	0.293*	0.254	0.0385
600	0.430*	0.398	0.0314	600	0.362*	0.330	0.0321	600	0.339*	0.306	0.0330	600	0.334*	0.299	0.0342
700	0.477*	0.449	0.0284	700	0.407*	0.378	0.0290	700	0.381*	0.352	0.0298	700	0.375*	0.344	0.0308
800	0.524*	0.498	0.0259	800	0.453*	0.426	0.0264	800	0.424*	0.397	0.0272	800	0.417*	0.389	0.0281
900	0.573*	0.549	0.0239	900	0.499*	0.474	0.0244	900	0.468*	0.443	0.0250	900	0.461*	0.435	0.0259
1000	0.622*	0.600	0.0221	1000	0.545*	0.522	0.0226	1000	0.511*	0.488	0.0232	1000	0.505*	0.481	0.0240
1100	0.672*	0.651	0.0207	1100	0.591*	0.570	0.0211	1100	0.556*	0.535	0.0217	1100	0.551*	0.529	0.0224
1200	0.723*	0.704	0.0194	1200	0.637*	0.617	0.0198	1200	0.602*	0.582	0.0204	1200	0.598*	0.577	0.0211

† Uncertainties in the total thermal conductivity, k, are as follows:
50.00 Ag - 50.00 Pd: ±15% below 40 K, and ±10% above 40 K.
45.00 Ag - 55.00 Pd: ±15% below 60 K, and ±10% above 40 K.
40.00 Ag - 60.00 Pd: ±15% below 80 K, and ±10% above 80 K.
35.00 Ag - 65.00 Pd: ±15% below 100 K, and ±10% above 100 K.

‡ Provisional value.

* In temperature range where no experimental thermal conductivity data are available.

TABLE 28. RECOMMENDED THERMAL CONDUCTIVITY OF SILVER-PALLADIUM ALLOY SYSTEM (continued) †

[Temperature, T, K; Thermal Conductivity, k, W cm^{-1} K^{-1}; Electronic Thermal Conductivity, k_e, W cm^{-1} K^{-1}; Lattice Thermal Conductivity, k_g, W cm^{-1} K^{-1}]

Ag: 30.00% (29.71 At.%) Pd: 70.00% (70.29 At.%)				Ag: 25.00% (24.74 At.%) Pd: 75.00% (75.26 At.%)				Ag: 20.00% (19.78 At.%) Pd: 80.00% (80.22 At.%)				Ag: 15.00% (14.83 At.%) Pd: 85.00% (85.17 At.%)			
ρ_o = 35.11 μΩ cm				ρ_o = 29.95 μΩ cm				ρ_o = 24.13 μΩ cm				ρ_o = 18.15 μΩ cm			
T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g
4	0.0108	0.00278	0.00800	4	0.00906*	0.00326	0.00580	4	0.00805	0.00405	0.00400	4	0.00807	0.00538	0.00269
6	0.0163	0.00418	0.0121	6	0.0140*	0.00489	0.00910	6	0.0127	0.00608	0.00665	6	0.0127	0.00808	0.00465
8	0.0218	0.00557	0.0162	8	0.0190*	0.00653	0.0125	8	0.0175	0.00810	0.00940	8	0.0177	0.0108	0.00685
10	0.0273	0.00696	0.0203	10	0.0241*	0.00816	0.0159	10	0.0225	0.0101	0.0124	10	0.0228	0.0135	0.00925
15	0.0399	0.0104	0.0295	15	0.0362*	0.0122	0.0240	15	0.0350	0.0152	0.0198	15	0.0359	0.0202	0.0157
20	0.0516	0.0139	0.0377	20	0.0480*	0.0163	0.0317	20	0.0472	0.0202	0.0270	20	0.0490	0.0244	0.0226
25	0.0618	0.0170	0.0448	25	0.0583*	0.0198	0.0385	25	0.0583	0.0243	0.0340	25	0.0620	0.0325	0.0295
30	0.0712	0.0203	0.0509	30	0.0681*	0.0236	0.0445	30	0.0690	0.0289	0.0401	30	0.0748	0.0383	0.0365
40	0.0868	0.0268	0.0600	40	0.0855*	0.0310	0.0545	40	0.0889	0.0379	0.0510	40	0.0979	0.0499	0.0480
50	0.0995	0.0332	0.0663	50	0.0995*	0.0383	0.0612	50	0.105	0.0465	0.0585	50	0.117	0.0608	0.0565
60	0.110	0.0394	0.0708	60	0.111*	0.0452	0.0660	60	0.119	0.0548	0.0645	60	0.134	0.0711	0.0625
70	0.119	0.0455	0.0735	70	0.121*	0.0521	0.0685	70	0.131	0.0629	0.0680	70	0.147	0.0809	0.0665
80	0.127	0.0516	0.0750	80	0.131*	0.0589	0.0718	80	0.142	0.0708	0.0710	80	0.160	0.0906	0.0695
90	0.134	0.0577	0.0760	90	0.138*	0.0657	0.0720	90	0.152	0.0787	0.0730	90	0.172	0.100	0.0720
100	0.140	0.0637	0.0760	100	0.145*	0.0723	0.0725	100	0.159	0.0864	0.0740	100	0.183	0.109	0.0740
150	0.165	0.0918	0.0735	150	0.176*	0.103	0.0725	150	0.197*	0.121	0.0760	150	0.227*	0.149	0.0780
200	0.187*	0.119	0.0675	200	0.201*	0.133	0.0685	200	0.226*	0.153	0.0725	200	0.261*	0.184	0.0770
250	0.207*	0.145	0.0615	250	0.224*	0.160	0.0635	250	0.250*	0.182	0.0680	250	0.289*	0.215	0.0740
273	0.215*	0.156	0.0590	273	0.234*	0.172	0.0615	273	0.261*	0.195	0.0655	273	0.301*	0.229	0.0720
300	0.225	0.170	0.0556	300	0.246*	0.187	0.0589	300	0.274	0.211	0.0632	300	0.314*	0.245	0.0693
350	0.245*	0.195	0.0506	350	0.266*	0.213	0.0535	350	0.296*	0.239	0.0573	350	0.338*	0.275	0.0628
400	0.265*	0.219	0.0465	400	0.287*	0.238	0.0491	400	0.319*	0.266	0.0526	400	0.362*	0.305	0.0575
500	0.305*	0.265	0.0402	500	0.329	0.287	0.0425	500	0.364*	0.319	0.0454	500	0.409*	0.360	0.0494
600	0.346*	0.310	0.0357	600	0.373*	0.335	0.0376	600	0.410*	0.370	0.0401	600	0.454*	0.411	0.0435
700	0.387*	0.355	0.0321	700	0.417*	0.384	0.0338	700	0.455*	0.419	0.0360	700	0.499*	0.460	0.0390
800	0.430*	0.401	0.0293	800	0.461*	0.430	0.0308	800	0.499*	0.466	0.0327	800	0.541*	0.506	0.0353
900	0.474*	0.447	0.0270	900	0.504*	0.476	0.0283	900	0.543*	0.513	0.0300	900	0.585*	0.552	0.0324
1000	0.518*	0.493	0.0250	1000	0.547*	0.521	0.0262	1000	0.586*	0.558	0.0278	1000	0.627*	0.597	0.0299
1100	0.565*	0.541	0.0233	1100	0.593*	0.569	0.0245	1100	0.630*	0.604	0.0259	1100	0.669*	0.641	0.0277
1200	0.613*	0.591	0.0219	1200	0.640*	0.617	0.0229	1200	0.675*	0.651	0.0242	1200	0.712*	0.686	0.0259

† Uncertainties in the total thermal conductivity, k, are as follows:
30.00 Ag - 70.00 Pd: ±10% below 100 K, ±7% between 100 and 300 K, and ±10% above 300 K.
25.00 Ag - 75.00 Pd: ±10% below 150 K, ±7% between 150 and 300 K, and ±10% above 300 K.
20.00 Ag - 80.00 Pd: ±10% below 150 K, ±7% between 150 and 300 K, and ±10% above 300 K.
15.00 Ag - 85.00 Pd: ±10% below 150 K, ±7% between 150 and 300 K, and ±10% above 300 K.

* In temperature range where no experimental thermal conductivity data are available.

TABLE 28. RECOMMENDED THERMAL CONDUCTIVITY OF SILVER-PALLADIUM ALLOY SYSTEM (continued) †

[Temperature, T, K; Thermal Conductivity, k, W cm^{-1} K^{-1}; Electronic Thermal Conductivity, k_e, W cm^{-1} K^{-1}; Lattice Thermal Conductivity, k_g, W cm^{-1} K^{-1}]

Ag: 10.00% (9.88 At.%) Pd: 90.00% (90.12 At.%)				Ag: 5.00% (4.94 At.%) Pd: 95.00% (95.06 At.%)				Ag: 3.00% (2.96 At.%) Pd: 97.00% (97.04 At.%)				Ag: 1.00% (0.99 At.%) Pd: 99.00% (99.01 At.%)			
ρ_o = 12.16 μΩcm				ρ_o = 6.08 μΩcm				ρ_o = 3.670 μΩcm				ρ_o = 1.270 μΩcm			
T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g
4	0.00955	0.00804	0.00151	4	0.0170	0.0161	0.000900	4		0.0266		4		0.0769	
6	0.0151	0.0121	0.00301	6	0.0261	0.0241	0.00199	6		0.0399		6		0.115	
8	0.0209	0.0161	0.00480	8	0.0355	0.0321	0.00342	8		0.0533		8		0.154	
10	0.0270	0.0201	0.00685	10	0.0454	0.0402	0.00515	10		0.0666		10		0.192	
15	0.0428	0.0301	0.0127	15	0.0708	0.0603	0.0105	15		0.0999		15		0.289	
20	0.0588	0.0394	0.0194	20	0.0969	0.0799	0.0170	20		0.133		20		0.385	
25	0.0744	0.0483	0.0261	25	0.120	0.0955	0.0240	25		0.153		25		0.416	
30	0.0898	0.0566	0.0332	30	0.143	0.112	0.0311	30		0.177		30		0.459	
40	0.119	0.0728	0.0460	40	0.184	0.139	0.0452	40		0.214		40		0.499	
50	0.144	0.0875	0.0560	50	0.217	0.159	0.0579	50		0.237		50		0.495	
60	0.165	0.101	0.0640	60	0.245	0.177	0.0682	60		0.254		60		0.482	
70	0.184	0.114	0.0700	70	0.269	0.192	0.0770	70		0.269		70		0.471	
80	0.200	0.126	0.0740	80	0.292	0.208	0.0842	80		0.285		80		0.472	
90	0.216	0.138	0.0780	90	0.312	0.222	0.0898	90		0.301		90		0.475	
100	0.230	0.149	0.0810	100	0.330	0.236	0.0940	100		0.313		100		0.479	
150	0.283*	0.195	0.0875	150	0.393*	0.287	0.106	150		0.358		150		0.482	
200	0.321*	0.233	0.0875	200	0.433*	0.325	0.108	200		0.389		200		0.490	
250	0.349*	0.265	0.0840	250	0.459*	0.356	0.103	250		0.417		250		0.502	
273	0.362*	0.280	0.0815	273	0.470*	0.370	0.0995	273		0.422		273		0.510	
300	0.376	0.297	0.0788	300	0.483*	0.387	0.0958	300	0.553*	0.445	0.108	300	0.651*	0.523	0.127
350	0.400*	0.329	0.0711	350	0.504*	0.419	0.0858	350	0.572*	0.477	0.0958	350	0.663*	0.552	0.111
400	0.424*	0.359	0.0649	400	0.525*	0.447	0.0777	400	0.589*	0.503	0.0862	400	0.675*	0.576	0.0989
500	0.469*	0.414	0.0554	500	0.563*	0.497	0.0654	500	0.624*	0.553	0.0718	500	0.705*	0.624	0.0808
600	0.514*	0.465	0.0485	600	0.602*	0.546	0.0566	600	0.661*	0.599	0.0615	600	0.740*	0.671	0.0682
700	0.555*	0.511	0.0432	700	0.641*	0.591	0.0499	700	0.699*	0.645	0.0538	700	0.777*	0.718	0.0591
800	0.595*	0.556	0.0390	800	0.676*	0.632	0.0446	800	0.733*	0.685	0.0479	800	0.814*	0.762	0.0521
900	0.636*	0.600	0.0356	900	0.713*	0.673	0.0404	900	0.769*	0.726	0.0431	900	0.852*	0.806	0.0465
1000	0.675*	0.642	0.0327	1000	0.746*	0.709	0.0369	1000	0.799*	0.760	0.0392	1000	0.885*	0.843	0.0421
1100	0.715*	0.684	0.0303	1100	0.779*	0.745	0.0339	1100	0.831*	0.795	0.0359	1100	0.920*	0.881	0.0384
1200	0.755*	0.727	0.0282	1200	0.812*	0.781	0.0314	1200	0.862*	0.829	0.0332	1200	0.955*	0.920	0.0353

† Uncertainties in the total thermal conductivity, k, are as follows:
10.00 Ag - 90.00 Pd: ±10%.
5.00 Ag - 95.00 Pd: ±10%.
3.00 Ag - 97.00 Pd: ±10%.
1.00 Ag - 99.00 Pd: ±10%.

* In temperature range where no experimental thermal conductivity data are available.

TABLE 28. RECOMMENDED THERMAL CONDUCTIVITY OF SILVER-PALLADIUM ALLOY SYSTEM (continued) †

[Temperature, T, K; Thermal Conductivity, k, W cm^{-1} K^{-1}; Electronic Thermal Conductivity, k_e, W cm^{-1} K^{-1}; Lattice Thermal Conductivity, k_g, W cm^{-1} K^{-1}]

Ag: 0.50% (.49 At.%) Pd: 99.50% (99.51 At.%)			
ρ_o = 0.660 μΩ cm			
T	k	k_e	k_g
4		0.148	
6		0.222	
8		0.296	
10		0.370	
15		0.555	
20		0.740	
25		0.703	
30		0.743	
40		0.757	
50		0.705	
60		0.642	
70		0.601	
80		0.577	
90		0.572	
100		0.563	
150		0.534	
200		0.529	
250		0.534	
273		0.540	
300	0.686*	0.551	0.134
350	0.694*	0.577	0.117
400	0.705*	0.602	0.103
500	0.732*	0.648	0.0837
600	0.767*	0.697	0.0704
700	0.802*	0.742	0.0607
800	0.838*	0.785	0.0533
900	0.878*	0.831	0.0475
1000	0.912*	0.869	0.0429
1100	0.949*	0.910	0.0391
1200	0.988*	0.952	0.0359

† Uncertainties in the total thermal conductivity, k, are as follows:
0.50 Ag - 99.50 Pd: ±10%.

* In temperature range where no experimental thermal conductivity data are available.

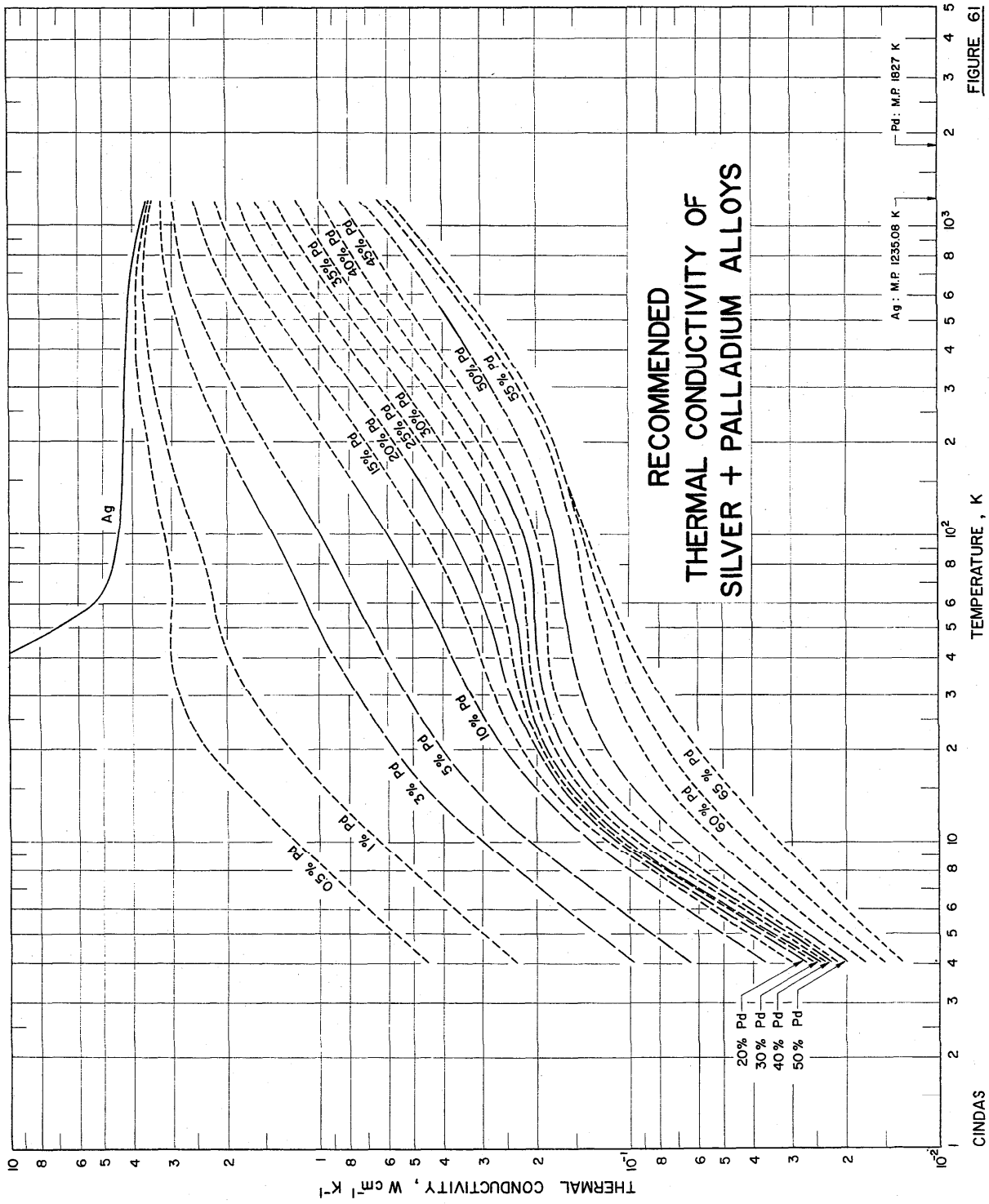
RECOMMENDED
THERMAL CONDUCTIVITY OF
SILVER + PALLADIUM ALLOYS
Ag : M.P. 1235.08 K
Pd : M.P. 1827 K
Ag
0.5% Pd
1% Pd
3% Pd
5% Pd
10% Pd
15% Pd
20% Pd
25% Pd
30% Pd
35% Pd
40% Pd
45% Pd
50% Pd
55% Pd
60% Pd
65% Pd
20% Pd
30% Pd
40% Pd
50% Pd
THERMAL CONDUCTIVITY , W cm⁻¹ K⁻¹
TEMPERATURE , K
CINDAS

FIGURE 61

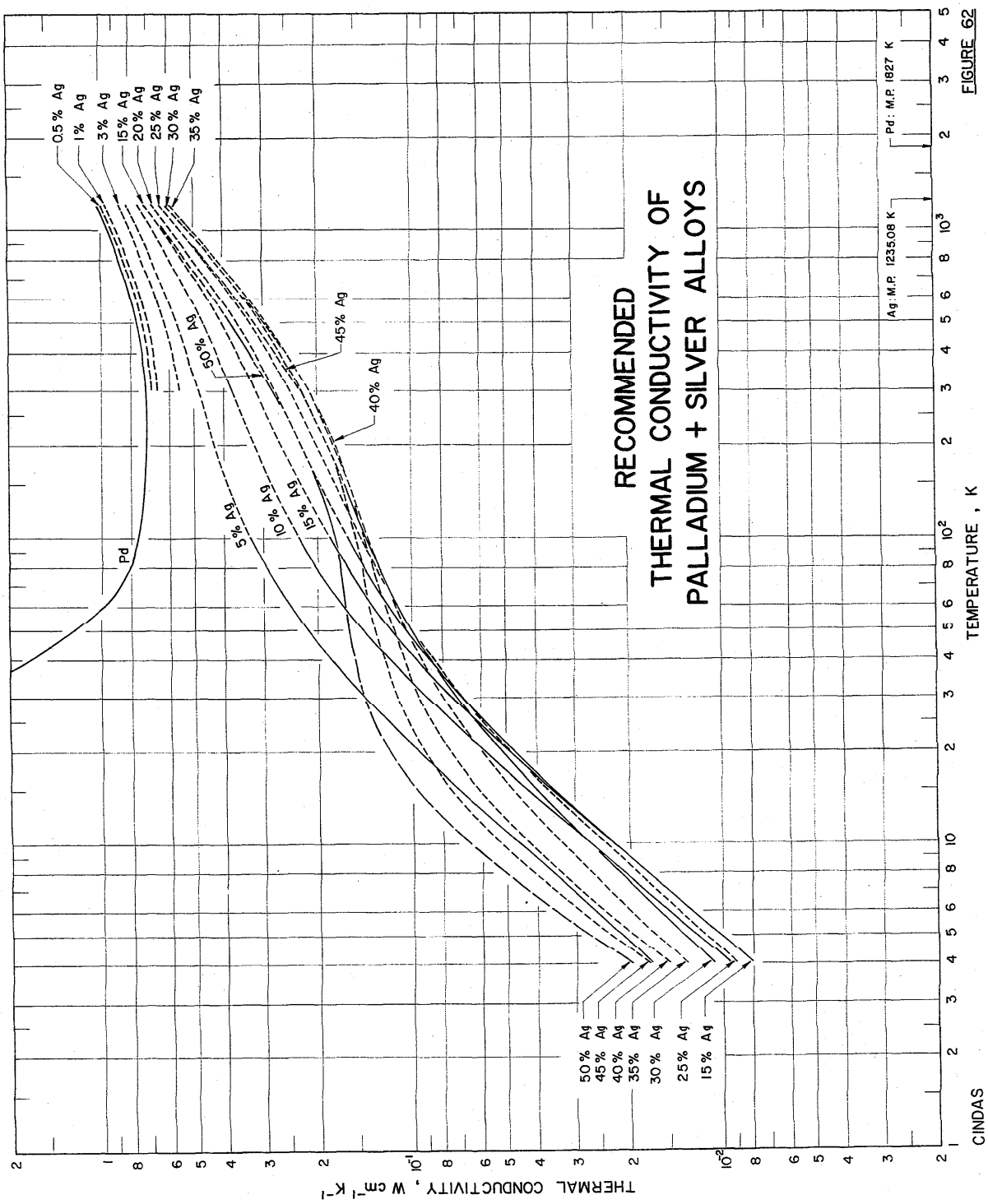
RECOMMENDED
THERMAL CONDUCTIVITY OF
PALLADIUM + SILVER ALLOYS
0.5 % Ag
1 % Ag
3% Ag
15% Ag
20% Ag
25% Ag
30% Ag
35% Ag
45% Ag
40% Ag
50% Ag
5% Ag
10% Ag
15% Ag
Pd
50 % Ag
45% Ag
40 % Ag
35% Ag
30 % Ag
25% Ag
15 % Ag
Ag: M.P. 1235.08 K
Pd: M.P. 1827 K
THERMAL CONDUCTIVITY , W cm⁻¹ K⁻¹
TEMPERATURE , K
CINDAS

FIGURE 62

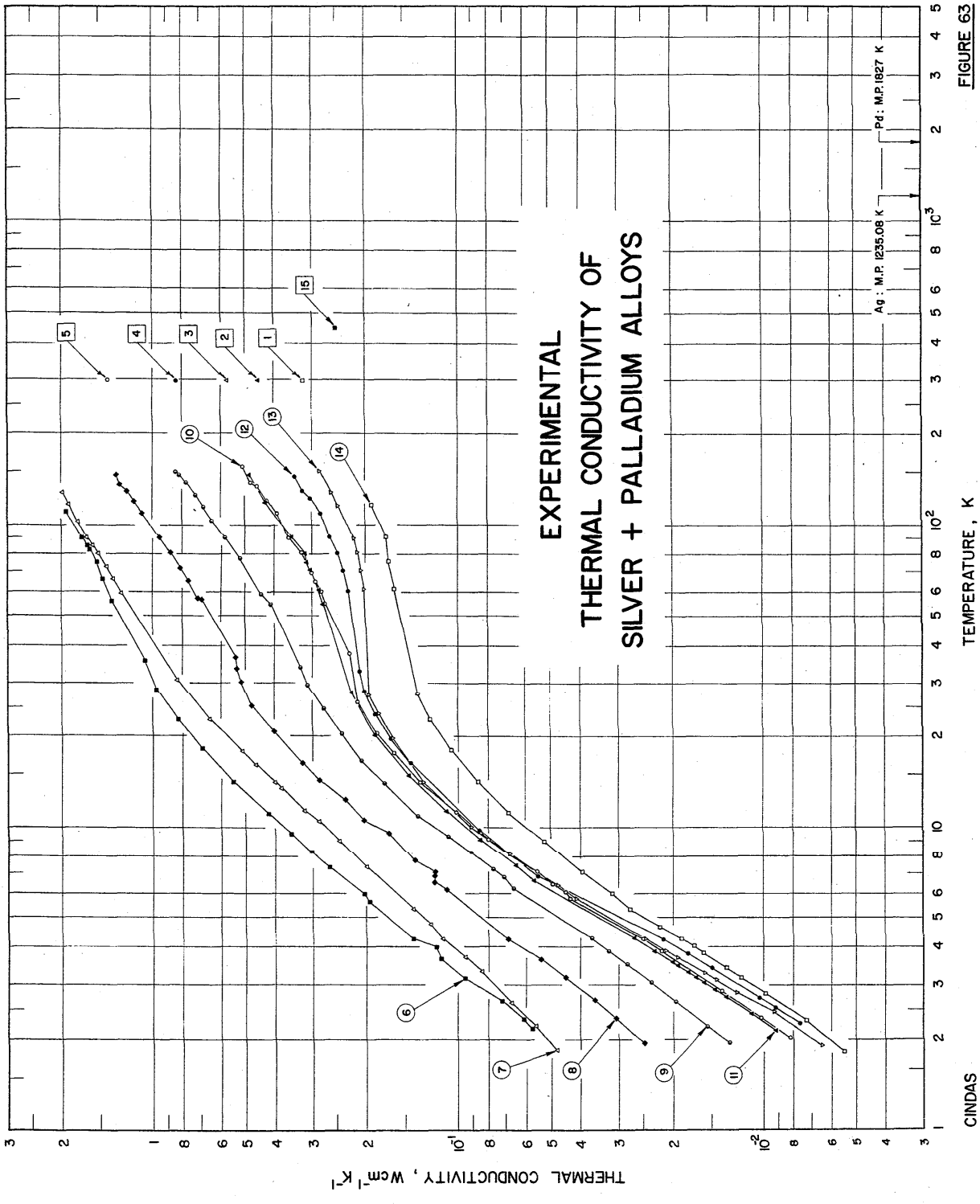
EXPERIMENTAL
THERMAL CONDUCTIVITY OF
SILVER + PALLADIUM ALLOYS
Ag : M.P. 1235.08 K
Pd : M.P. 1827 K
THERMAL CONDUCTIVITY , $W cm^{-1} K^{-1}$
TEMPERATURE , K
CINDAS
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

FIGURE 63

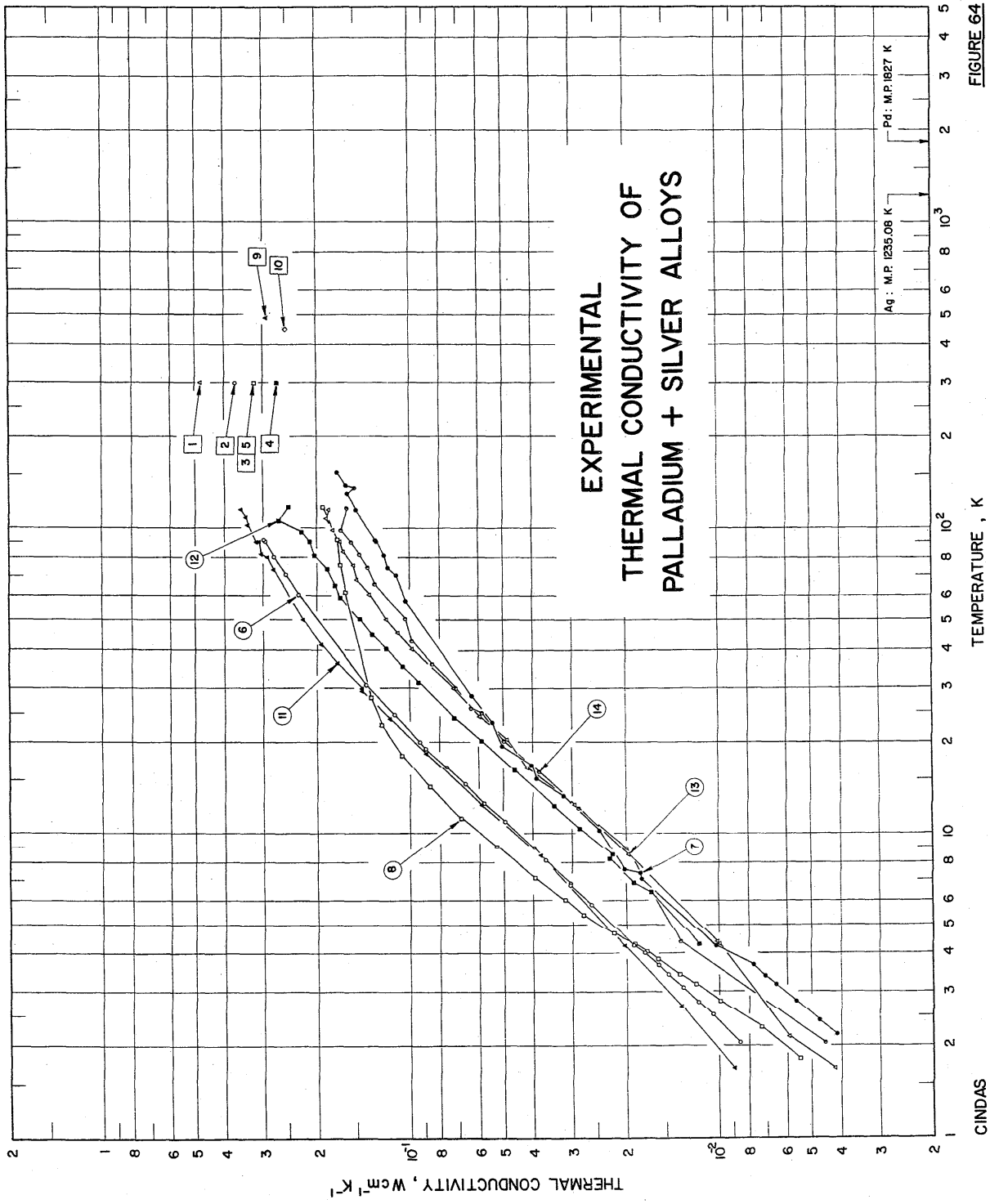
EXPERIMENTAL
THERMAL CONDUCTIVITY OF
PALLADIUM + SILVER ALLOYS
Ag : M.P. 1235.08 K
Pd : M.P. 1827 K
THERMAL CONDUCTIVITY , W cm⁻¹ K⁻¹
TEMPERATURE , K
CINDAS

FIGURE 64

TABLE 29. THERMAL CONDUCTIVITY OF SILVER + PALLADIUM ALLOYS -- SPECIMEN CHARACTERIZATION AND MEASUREMENT INFORMATION

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) Ag	Pd	Composition (continued), Specifications, and Remarks
1	93	Schulze, F.A.	1911	E	298.2		50	50	1 mm wire specimen obtained from Firma Heracus; electrical conductivity $3.03 \times 10^4\ \Omega^{-1}\ cm^{-1}$ at 25 C.
2	93	Schulze, F.A.	1911	E	298.2		60	40	1 mm wire specimen obtained from Firma Heracus; electrical conductivity $4.56 \times 10^4\ \Omega^{-1}\ cm^{-1}$ at 25 C.
3	93	Schulze, F.A.	1911	E	298.2		70	30	1 mm wire specimen obtained from Firma Heracus; electrical conductivity $6.43 \times 10^4\ \Omega^{-1}\ cm^{-1}$ at 25 C.
4	93	Schulze, F.A.	1911	E	298.2		80	20	1 mm wire specimen obtained from Firma Heracus; electrical conductivity $9.47 \times 10^4\ \Omega^{-1}\ cm^{-1}$ at 25 C.
5	93	Schulze, F.A.	1911	E	298.2		90	10	1 mm wire specimen obtained from Firma Heracus; electrical conductivity $16.14 \times 10^4\ \Omega^{-1}\ cm^{-1}$ at 25 C.
6	110	Kemp, W.R.G., Klemens, P.G., Sreedhar, A.K. and White, G.K.	1956	L	2.2-112		97.95	2.05	Rod specimen supplied by Johnson, Matthey and Co., Ltd.; annealed at 610 C; residual electrical resistivity 0.89 $\mu\Omega$ cm; electrical resistivity 2.52 $\mu\Omega$ cm at 293 K.
7	110	Kemp, W.R.G., et al.	1956	L	1.8-128				The above specimen; strained; residual electrical resistivity 0.94 $\mu\Omega$ cm; electrical resistivity 2.54 $\mu\Omega$ cm at 293 K.
8	110	Kemp, W.R.G., et al.	1956	L	1.9-147		95.01	4.99	Rod specimen supplied by Johnson, Matthey and Co., Ltd.; annealed at 610 C; residual electrical resistivity 2.20 $\mu\Omega$ cm; electrical resistivity 3.91 $\mu\Omega$ cm at 293 K.
9	110	Kemp, W.R.G., et al.	1956	L	2.0-150		90.22	9.78	Rod specimen supplied by Johnson, Matthey and Co., Ltd.; annealed at 650 C; residual electrical resistivity 4.15 $\mu\Omega$ cm; electrical resistivity 6.0 $\mu\Omega$ cm at 293 K.
10	110	Kemp, W.R.G., et al.	1956	L	2.3-157		80.14	19.86	Rod specimen supplied by Johnson, Matthey and Co., Ltd.; annealed at 650 C.
11	110	Kemp, W.R.G., et al.	1956	L	2.1-147		80.14	19.86	Rod specimen supplied by Johnson, Matthey and Co., Ltd.; annealed at 800 C; residual electrical resistivity 8.45 $\mu\Omega$ cm; electrical resistivity 10.0 $\mu\Omega$ cm at 293 K.
12	110	Kemp, W.R.G., et al.	1956	L	2.2-145		70.67	29.33	Rod specimen supplied by Johnson, Matthey and Co., Ltd.; annealed at 800 C; residual electrical resistivity 12.78 $\mu\Omega$ cm; electrical resistivity 14.66 $\mu\Omega$ cm at 293 K.
13	110	Kemp, W.R.G., et al.	1956	L	1.9-151		60.33	39.67	Rod specimen supplied by Johnson, Matthey and Co., Ltd.; annealed at 880 C; residual electrical resistivity 18.10 $\mu\Omega$ cm; electrical resistivity 21.1 $\mu\Omega$ cm at 293 K.
14	110	Kemp, W.R.G., et al.	1956	L	1.8-117		50.34	49.66	Rod specimen supplied by Johnson, Matthey and Co., Ltd.; annealed at 880 C; residual electrical resistivity 27.7 $\mu\Omega$ cm; electrical resistivity 27.7 $\mu\Omega$ cm at 293 K.
15	112	Zolotukhin, G.E.	1956	L	448.2		50.34	49.66	0.66 cm^2 in cross-section and 1.35 cm long.

TABLE 29. THERMAL CONDUCTIVITY OF SILVER + PALLADIUM ALLOYS -- SPECIMEN CHARACTERIZATION AND MEASUREMENT INFORMATION (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) Ag	Pd	Composition (continued), Specifications, and Remarks
16*	111	Tainsh, R.J. and White, G.K.	1962	L	2.2-7.9		97.95	2.05	The specimen for curve no. 6 has been reannealed at 940 C in an effort to ensure that dislocation density is reduced to a minimum; rod specimen of about 6 cm long and 3 to 5 mm in diameter; electrical resistivity reported as 0.962, 1.372, and 2.612 μΩ cm at 0, 90, and 293 K, respectively.
17*	111	Tainsh, R.J. and White, G.K.	1962	L	2.1-8.3		95.01	4.99	The specimen for curve no. 8 has been reannealed at 940 C in an effort to ensure that dislocation density is reduced to a minimum; rod specimen of about 6 cm long and 3 to 5 mm in diameter; electrical resistivity reported as 2.28, 2.68, and 3.87 μΩ cm at 0, 90, and 293 K, respectively.
18*	111	Tainsh, R.J. and White, G.K.	1962	L	2.3-7.9		90.22	9.78	The specimen for curve no. 9 has been reannealed to 940 C in an effort to ensure that dislocation density is reduced to a minimum; rod specimen of about 6 cm long and 3 to 5 mm in diameter; electrical resistivity reported as 4.37, 4.78, and 6.01 μΩ cm at 0, 90, and 293 K, respectively.

* Not shown in figure.

TABLE 30. THERMAL CONDUCTIVITY OF PALLADIUM + SILVER ALLOYS -- SPECIMEN CHARACTERIZATION AND MEASUREMENT INFORMATION

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) Pd	Ag	Composition (continued), Specifications, and Remarks
1	93	Schulze, F.A.	1911	E	298.2		90	10	1 mm thick wire specimen obtained from Heracus Co.; electrical conductivity $4.71 \times 10^4\ \Omega^{-1}\ cm^{-1}$ at 25 C.
2	93	Schulze, F.A.	1911	E	298.2		80	20	1 mm thick wire specimen obtained from Heracus Co.; electrical conductivity $3.21 \times 10^4\ \Omega^{-1}\ cm^{-1}$ at 25 C.
3	93	Schulze, F.A.	1911	E	298.2		70	30	1 mm thick wire specimen obtained from Heracus Co.; electrical conductivity $2.56 \times 10^4\ \Omega^{-1}\ cm^{-1}$ at 25 C.
4	93	Schulze, F.A.	1911	E	298.2		60	40	1 mm thick wire specimen obtained from Heracus Co.; electrical conductivity $2.38 \times 10^4\ \Omega^{-1}\ cm^{-1}$ at 25 C.
5	93	Schulze, F.A.	1911	E	298.2		50	50	1 mm thick wire specimen obtained from Heracus Co.; electrical conductivity $3.03 \times 10^4\ \Omega^{-1}\ cm^{-1}$ at 25 C.
6	110	Kemp, W.R.G., Klemens, P.G., Sreedhar, A.K. and White, G.K.	1956	L	2.1-92		95	5	Rod specimen supplied by Johnson, Matthey and Co., Ltd.; annealed at 880 C; residual electrical resistivity 5.81 $\mu\Omega$ cm; electrical resistivity 16.8 $\mu\Omega$ cm at 293 K.
7	110	Kemp, W.R.G., et al.	1956	L	2.2-152		70	30	Similar to the above specimen except residual electrical resistivity 35.6 $\mu\Omega$ cm and electrical resistivity 40.9 $\mu\Omega$ cm at 293 K.
8	110	Kemp, W.R.G., et al.	1956	L	1.8-117		50	50	Similar to the above specimen except residual electrical resistivity 27.7 $\mu\Omega$ cm and electrical resistivity 30.5 $\mu\Omega$ cm at 293 K.
9	112	Zolotukhin, G.E.	1956	L	486.7		75	25	Cylindrical specimen.
10	112	Zolotukhin, G.E.	1956	L	448.2		50	50	Cylindrical specimen.
11	84	Fletcher, R. and Greig, D.	1967	L	1.7-117			4.84	Calculated compositon from atomic percent; specimen lent by International Nickel Ltd.; annealed at 700 C for 24 hrs previously; outgassed at 500 C for 4-5 hrs; residual electrical resistivity reported as 5.92 $\mu\Omega$; original data obtained through private communication with author.
12	84	Fletcher, R. and Greig, D.	1967	L	4.3-118			9.85	Similar to the above specimen except the residual electrical resistivity reported as 12.18 $\mu\Omega$ cm.
13	84	Fletcher, R. and Greig, D.	1967	L	1.7-115			15.05	Similar to the above specimen except the residual electrical resistivity reported as 13.0 $\mu\Omega$ cm.
14	84	Fletcher, R. and Greig, D.	1967	L	2.1-116			20.53	Similar to the above specimen except the residual electrical resistivity reported as 21.5 $\mu\Omega$ cm.

5. Conclusions and Recommendations

As evidenced by the exhaustively compiled experimental thermal conductivity data presented in this work for the ten selected binary alloy systems which are among those investigated most extensively, it is clear that even for these alloy systems serious gaps still exist in the thermal conductivity data for both the temperature and composition dependences and that most of the available data are widely divergent and subject to large uncertainty. The resulting recommended self-consistent thermal conductivity values that cover the full range of composition and temperature, therefore, go far beyond the limited experimental data.

In addition to the total thermal conductivity, recommended values are given also separately for the electronic and lattice components, for the very procedure used in the present study is based on the existence of the two components of thermal conductivity and the need to trace the dependence of each component separately on temperature and composition. If there is a dispute about the separation of the conductivity into components, the present work will help to clarify the matter, for it looks, for the first time, at the totality of the existing data, and points out what is necessary to reconcile it. By giving the separate components, this work makes it possible for the reader to trace the procedure used to generate the recommended values, and makes it possible to estimate the effects on thermal conductivity of changes in electrical resistivity and changes due to imperfections which primarily affect the lattice component. Furthermore, by pointing out the relative contribution of each component, this work allows the reader to judge how critical some of the approximations are in different temperature regions.

The recommended values are for alloys which are not ordered and have not been cold worked severely; the values would be higher for ordered alloys and lower at low temperatures for cold-worked alloys. For each of the alloy systems except two, the recommended values are given for 25 alloy compositions, which greatly facilitates interpolation for alloys with intermediate compositions.

The recommended values are based upon both the critically evaluated, analyzed, and synthesized experimental data and the calculated values generated by using the methods developed in this study for the calculation of the thermal conductivity of alloys. The methods developed are essentially semi-empirical since they require experimental information as input for calculations and adjustments. The reliability of the methods has been extensively tested using selected key sets of experimental data, which are considered reliable through critical evaluation and analysis, on alloys in the various binary alloy systems.

The method for the calculation of the electronic thermal conductivity is applicable for all temperatures to all types of binary alloys: non-transition, transition, solid solution, mechanical mixture, ordered, and disordered. The method for the calculation of the lattice thermal conductivity is applicable only to disordered solid-solution alloys at moderate and high temperatures. For ordered alloys, alloys of mechanical mixture, and for solid-solution alloys at low temperatures in the region of the lattice conductivity maximum and below, there is no adequate method available for the calculation of the lattice thermal conductivity, and at present the lattice thermal conductivity must be derived from experimental data.

In the course of this study, a number of areas where further theoretical and experimental research is needed are identified. These areas of further research are recommended and listed below:

(1) Experimental and theoretical work on band structure effects in binary alloys of transition elements and noble elements—in particular measurements on Cu + Pd and Pd + Cu alloys to determine the validity of large Lorenz ratios reported for this system.

(2) Development of quantitative theory of impurity enhancement of phonon-electron interactions at low temperatures.

(3) Measurements of alloy thermal conductivity down to liquid ^{3}He temperatures to determine the extent to which residual dislocations cause the cusp-like behavior of the composition dependence of the low-temperature lattice thermal conductivity.

(4) Development of a theory of low-temperature lattice conduction in transition elements and high-residual-resistivity alloys.

(5) Experimental and theoretical efforts on the lattice conductivity outside the region of solid solubility.

6. Acknowledgments

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Contents—Continued

Nomenclature

a	Lattice constant
e	Electronic charge; base of natural logarithm (2.71828)
E	Electron energy
E_k	Energy of electron in **k**th state
$f(\mathbf{k})$	Distribution function representing the number of carriers in **k**th state
f^0	Fermi-Dirac distribution function at equilibrium
$\hbar$	Reduced Planck constant
I_a, I_b, I_c	Transport integrals
I_n	Modified transport integrals
J_n	Standard transport integrals
$\boldsymbol{k}$	Total thermal conductivity
k_e	Electronic thermal conductivity
k_{ei}	Intrinsic electronic thermal conductivity
k_g	Lattice thermal conductivity
k_u	Lattice thermal conductivity of a virtual crystal
k	Electron wave vector
K	Kelvin temperature unit
K_n	Electronic transport integrals
L	Lorenz function
L_0	Lorenz number ($2.443\times10^{-8}V^2K^{-2}$)
M	Average atomic mass
M_H	Atomic mass of the heavier element
M_L	Atomic mass of the lighter element
n	Number of conduction electrons per atom
S	Absolute thermoelectric power
T	Temperature
v	Speed of sound
$v(E)$	Electron velocity in spherical symmetry
$v(\mathbf{k})$	Velocity of electron in **k**th state
V	Average atomic volume
V_H	Atomic volume of the heavier element
V_L	Atomic volume of the lighter element
W_e	Electronic thermal resistivity
W_{ei}	Intrinsic electronic thermal resistivity
W_{e0}	Residual electronic thermal resistivity
W_{Hi}	Contribution to W_{ei} of electrons moving parallel to the Fermi surface
W_{Vi}	Contribution to W_{ei} of electrons moving perpendicular to the Fermi surface
ΔW	Deviation from thermal analog of Matthiessen's rule
x	Reduced phonon frequency
x_0	Reduced phonon frequency at which the relaxation times for point-defect scattering and U-processes are equal
y	Atomic fraction of the solute

y_H Atomic fraction of the heavier element
y_L Atomic fraction of the lighter element
α Ratio of reciprocal relaxation times for N- and U-processes
β Impurity-imperfection parameter of elements
γ Grüneisen parameter
ε Quantity characterizing the perturbation due to mass defects and lattice distortion
ζ Fermi energy
η Reduced electron energy
θ Debye temperature
$\varkappa$ Boltzmann constant
μ Ferromagnetic ordering parameter
ϱ Total electrical resistivity
ϱ^* Resistivity of ferromagnetic metal in the absence of ferromagnetic ordering
ϱ_0 Residual electrical resistivity
ϱ_i Intrinsic electrical resistivity
$\Delta\varrho$ Deviation of electrical resistivity from Matthiessen's rule
$\tau(\mathbf{k})$ Relaxation time for electron in **k**th state
$\tau(E)$ Relaxation time for electron with energy E in spherical symmetry
τ_c Combined relaxation time
τ_N Relaxation time for N-processes
τ_p Relaxation time for point-defect scattering
τ_U Relaxation time for U-processes
ω Frequency of lattice wave
ω_0 Phonon frequency at which the relaxation times for point-defect scattering and U-processes are equal

1. Introduction

The primary objective of this study was to critically evaluate, analyze, and synthesize all the available data and information on the thermal conductivity of ten selected binary alloy systems and to generate recommended values over the widest practicable ranges of temperature and alloy composition for each of the alloy systems. The ten binary alloy systems selected are the systems of aluminum-copper, aluminum-magnesium, copper-gold, copper-nickel, copper-palladium, copper-zinc, gold-palladium, gold-silver, iron-nickel, and silver-palladium. Most of these alloy systems are among those for which the largest amounts of experimental data are available. However, it will become evident that even for these alloy systems serious gaps still exist in the thermal conductivity data, as concerns dependence on both composition and temperature, and that most of the available experimental data show large uncertainties or wide divergences. It was, therefore, necessary to set additional objectives: (1) to develop reliable methods for the estimation of the thermal conductivity of alloys, (2) to determine the extent to which the methods of data estimation developed in this study are applicable in general, and (3) to identify those areas where further theoretical and experimental research is needed.

The systems selected include all three different kinds of binary alloy systems: nontransition-metal and nontransition-metal systems (aluminum-copper, aluminum-magnesium, copper-gold, copper-zinc, and gold-silver), nontransition-metal and transition-metal systems (copper-nickel, copper-palladium, gold-palladium, and silver-palladium), and a transition-metal and transition-metal system (iron-nickel). The inclusion of this wide range of alloy systems in this study has tested the broad applicability of the methods developed for data estimation and synthesis.

The resulting thermal conductivity values presented in this work include values of the total thermal conductivity, electronic thermal conductivity, and lattice thermal conductivity. These values are designated as recommended or provisional values depending upon the level of confidence placed on the values and, hence, upon the uncertainty of the values assigned. The ranges of uncertainties of recommended and provisional values are less than ±15% and between ±15% and ±30%, respectively. Some of the lattice thermal conductivity values are designated also as typical values, of which the uncertainty is greater than ±30%. It should be noted that most of the resulting values are designated as recommended values and the uncertainty of the values is generally of the order of ±10%.

The values generated are for alloys which are not ordered and have not been cold worked severely; the values would be higher for ordered alloys and lower at low temperatures for cold-worked alloys.

The methods developed for the estimation of the thermal conductivity of alloys are detailed in section 2. These methods have been extensively tested with selected key sets of experimental data that are considered reliable through critical evaluation and analysis of the data and the details of measurement and through careful examination of the internal consistency of the data and the consistency with other data. In these methods the electronic and lattice components of thermal conductivity are estimated separately.

In alloys the principal carriers of thermal energy are electrons and phonons or lattice waves. At low temperatures the electrons are scattered mainly by solute atoms, and at higher temperatures the scattering of electrons by lattice waves becomes significant. The electronic thermal conductivity of an alloy is calculated from the electrical resistivity and thermoelectric power of the alloy and the electrical resistivity and thermal conductivity of the constituent elements.

At the lowest temperatures the lattice thermal conductivity of an alloy is limited by the phonon-electron interaction and phonon scattering by residual dislocations anchored in place by solute atoms; both of these resistive mechanisms result in approximately a T^2 temperature dependence. At somewhat higher temperatures point-defect scattering and scattering by dislocation cores cause the lattice conductivity to depart from its T^2 temperature dependence, and at still higher temperatures the combination of three-phonon anharmonic interactions and point-defect scattering cause the conductivity to decrease approximately as $T^{-1/2}$. The lattice thermal conductivity of a solid-solution alloy at temperatures above the region of its maximum can be calculated semi-theoretically based upon the Klemens-Callaway theory. At temperatures in the region of lattice conductivity maximum and below, however, there is no adequate method available for the calculation of the lattice thermal conductivity because the knowledge of both the phonon-electron coupling constant and the residual dislocation densities is lacking, and at present the

lattice thermal conductivity must be derived from experimental data.

In section 3 the procedures for data evaluation, analysis, synthesis, and the generation of recommended values are outlined, including the procedures for data estimation using the methods detailed in section 2. The copper-nickel alloy system is used as an example for illustration.

The values generated for the total thermal conductivity, electronic thermal conductivity, and lattice thermal conductivity of each of the ten selected binary alloy systems and the experimental thermal conductivity data and information are presented in section 4. In the discussion of the thermal conductivity of each alloy system, individual pieces of available data and information are reviewed, details of data analysis and synthesis are given, the considerations involved in arriving at the final assessment and recommendation are discussed, the recommended values and the experimental data are compared, and the uncertainties in the recommended values are stated. For each of the alloy systems except two (aluminum-magnesium and copper-zinc), the values are given for 25 alloy compositions: 0.5, 1, 3, 5, 10(5)95, 97, 99, and 99.5%, which greatly facilitates the interpolation of values for alloys with intermediate compositions. For most of the alloy compositions, the values cover the temperature range from 4 K to the solidus temperature or 1200 K.

At first sight many of the recommendations seem to be merely extensive extrapolations from a few sets of scattered experimental data, but in fact the recommended values for the electronic thermal conductivity are calculated from a large body of electrical resistivity data and those for the lattice thermal conductivity are calculated from well tested semi-theoretical methods.

Conclusions of the present study and recommendations for further experimental and theoretical research are given in section 5. The complete bibliographic citations for the 191 references are given in section 7.

2. Theoretical Background

In metals and alloys the principal carriers of thermal energy are electrons and lattice waves, and it is commonly assumed that the total thermal conductivity is

$$k=k_e+k_g, \tag{1}$$

where k_e is the electronic thermal conductivity and k_g is the lattice thermal conductivity; these are the thermal conductivity components due to the transport of heat by the electrons and by the lattice waves or phonons, respectively.

In most of the pure non-transition metals, conduction by lattice waves is negligible in comparison with conduction by electrons at all temperatures, but in alloys the lattice component is often comparable to and sometimes even greater than the electronic component at low temperatures and is not negligible even at temperatures well above the Debye temperature in some cases. Hence, in order to estimate the thermal conductivity of an alloy it is necessary to estimate both the electronic and lattice components. Since the principal thermal resistance mechanisms differ in different temperature regions, it is necessary to devise different methods for making predictive estimates in different temperature regions. In the course of developing these methods a number of specific areas in which further experimental and theoretical studies are needed were identified.

2.1. Electronic Thermal Conductivity

In the alloys under consideration at temperatures below about 25 K the only significant contribution to the electronic thermal resistivity, W_e, is the scattering of electrons by solute atoms, so that the electronic thermal conductivity may be calculated from the Wiedemann-Franz-Lorenz relationship,

$$k_e=\frac{1}{W_e}\approx\frac{1}{W_{e0}}=\frac{L_0T}{\varrho_0}, \tag{2}$$

where W_{e0} is the residual electronic thermal resistivity due to impurity scattering of electrons, ϱ_0 is the residual electrical resistivity, T is the temperature, and L_0 is the classical theoretical Lorenz number and has a value of $2.443\times10^{-8}V^2K^{-2}$.

At higher temperatures the scattering of electrons by lattice waves becomes significant. At temperatures between about 25 K and 100 K the electronic thermal resistivity has commonly been estimated from the thermal analog of Matthiessen's rule,

$$W_e=W_{e0}+W_{ei}=\varrho_0/L_0T+W_{ei}, \tag{3}$$

where W_{ei} is the intrinsic electronic thermal resistivity, which is the reciprocal of the intrinsic electronic thermal conductivity, k_{ei}, of the "parent" element, and Matthiessen's rule states that the electrical resistivity is composed of a residual and an intrinsic component:

$$\varrho=\varrho_0+\varrho_i. \tag{4}$$

Equation (3) is based on the assumption that the deviations from Matthiessen's rule, $\Delta\varrho=\varrho-\varrho_0-\varrho_i$, and its thermal analog, $\Delta W=W_e-W_{e0}-W_{ei}$, can be neglected. This is not the case at higher temperatures; $\Delta\varrho$ and ΔW may be significant even at temperatures below 100 K. These deviations may be taken into account by assuming that they are related by the Wiedemann-Franz-Lorenz law: $\Delta\varrho/\Delta W=LT$, where L is the Lorenz ratio which may or may not be equal to L_0. This assumption is based on an argument by Klemens [1][1] which may be summarized as follows.

The intrinsic electrical and thermal resistivities arise from interactions between electrons and phonons which take electrons from regions of momentum space where there are too many into regions where there are too few electrons relative to the equilibrium concentration. Since the phonon energies are relatively small, the electron energies are little changed by these interactions, and their initial and final states must both lie near the Fermi surface.

[1] Numbers in brackets designate references listed in section 7.

In the case of electrical conduction the deviation of the distribution function from the equilibrium distribution due to the electric field is proportional [2] to a function, $f(\mathbf{k})$, of the direction of the electron wave vector, the sign of the deviation depending on the direction of the electron wave vector. The intrinsic electrical resistivity, ϱ_i, is the result of the motion of electrons in $\mathbf{k}$ space through interactions with phonons to distant regions of the Fermi surface, involving substantial changes in the direction of $\mathbf{k}$, which is a "horizontal" movement on the Fermi surface.

In the case of thermal conduction, the deviation from the electronic equilibrium distribution due to the temperature gradient is proportional to the same function $f(\mathbf{k})$ of the direction of the electron wave vector but it is also proportional to the reduced electron energy, $\eta=(E-\zeta)/\varkappa T$, E being the electron energy, ζ the Fermi energy, and $\varkappa$ the Boltzmann constant. Thus the sign of the deviation of the distribution function can be changed not only by "horizontal" movement on the Fermi surface but also by changing the sign of η, which is a "vertical" movement through the Fermi surface. These motions in $\mathbf{k}$ space contribute approximately additively to the intrinsic electronic thermal resistivity: $W_{ei}\approx W_{Hi}+W_{Vi}$. Since $f(\mathbf{k})$ is the same for electrical and thermal conduction, horizontal movement is equally effective in both cases, so that ϱ_i and W_{Hi} are related by the Wiedemann-Franz-Lorenz law. Now W_{Vi} depends on a local property of the Fermi surface and is, therefore, relatively insensitive to changes in the band structure due to alloying. On the other hand W_{Hi}, being due to motion of the electrons over large distances on the Fermi surface, is sensitive to changes in its overall shape, particularly when these changes involve contact with the zone boundary which effectively short circuits the horizontal movement. Hence the change in W_{Hi} on alloying is much larger than the change in W_{Vi} and makes the dominant contribution to the deviations from Matthiessen's rule. Thus, to a good approximation, the deviations from Matthiessen's rule and its thermal analog are related by the Wiedemann-Franz-Lorenz Law,

$$W_e=(\varrho-\varrho_i)/LT+W_{ei} \tag{5}$$

or

$$k_e=\frac{1}{(\varrho-\varrho_i)/LT+W_{ei}}. \tag{6}$$

In applying eq (6), W_{ei} and ϱ_i are taken to be the intrinsic thermal and electrical resistivities of the virtual crystal obtained for alloys containing ordinary metals, by linear interpolation between the values for the elements. For alloys containing transition elements the intrinsic resistivities were interpolated according to Mott's theory [3,4]. In Mott's theory the holes in the d band of palladium, for example, are filled by the s electrons of the silver atoms. These d band holes act as traps into which the conduction electrons are scattered and account for the strong electron-phonon interaction in palladium-rich alloys. These holes are assumed to be filled when the silver concentration reaches 60 atomic percent so that the intrinsic resistivities for the silver-rich alloys are taken to be those of silver and to increase linearly with palladium content for alloys containing less than 60 atomic percent silver.

For most alloys W_{ei} is much smaller than the other term in eq (6) so that the error introduced in common practice by taking W_{ei} of the elements to be the reciprocals of their total thermal conductivities is also small. However, in dilute alloys of elements which do not have electronic thermal conductivities comparable to those of the noble elements this error is significant, and W_{ei} is therefore calculated in this work from the expression

$$W_{ei}=\frac{1}{k_{ei}}=\frac{1}{k_e}-\frac{\beta}{T}=\frac{1}{k-k_g}-\frac{\beta}{T}, \tag{7}$$

where β is the impurity-imperfection parameter of the element. The values of k and β of the elements are available from ref. [5][2] and the values of k_g of an element at moderate and high temperatures are calculated from eq (36). The values of electrical resistivities of the ten selected binary alloy systems and their nine constituent elements used in eq (6) are available from ref. [7].

From the argument leading to eq (6) it is clear that the value of L used therein should be that for horizontal motion on the Fermi surface, or for elastic scattering; the values of L appropriate for use in eq (6) and in the Wiedemann-Franz-Lorenz law, which one might expect to be valid at high temperatures where phonons scatter electrons through large angles, are discussed below.

It should be noted that eq (6) may not be valid in some cases. If the deviations from Matthiessen's rule are due to the fact that two bands of electrons, such as those on the neck and belly regions of the Fermi surface, contribute significantly to the electrical conduction, then, in general, the deviations from Matthiessen's rule and its thermal analog are not related by the Wiedemann-Franz-Lorenz law.

Significant deviations of the Lorenz ratio from its classical value can result from band structure effects and from electron-electron scattering.

The possibility of deviations due to band structure effects and the difficulties they present may be seen from the following. Assuming the existence of a relaxation time, the electronic transport properties can be expressed through integrals over reciprocal space of the form

$$K_n=-\tfrac{1}{3}\int\int\int v^2(\mathbf{k})\tau(\mathbf{k})(E_k-\zeta)^n\frac{\partial f^0}{\partial E_{\mathbf{k}}}d^3\mathbf{k} \tag{8}$$

which for spherical symmetry [182] reduces to

$$K_n=\frac{1}{12\pi^3\hbar}\int\int_{-\infty}^{\infty}v(E)\tau(E)(E-\zeta)^n\frac{\partial f^\circ}{\partial E}dA\,dE. \tag{9}$$

Here $\hbar$ is the reduced Planck constant, v is the electron velocity, τ is the relaxation time, E is the electron energy, f° is the Fermi-Dirac distribution function, ζ is the Fermi energy,

[2] The recommended values for the thermal conductivities of the elements given in ref. [5] in some cases are slightly different from those given in ref. [6], and the values given in ref. [5] are preferred and should be used whenever there is a difference.

and dA is an element of a constant energy surface in reciprocal space. In particular, the absolute thermoelectric power is given by

$$S=\frac{1}{eT}\frac{K_1}{K_0} \tag{10}$$

and the Lorenz ration by

$$L=\frac{1}{e^2T^2}\left[\frac{K_2}{K_0}-\frac{K_1^2}{K_0^2}\right]=\frac{1}{e^2T^2}\frac{K_2}{K_0}-S^2. \tag{11}$$

Because of the factor $\partial f^0/\partial E$ which is large only near ζ, the usual procedure is to expand each integrand in a Taylor series about ζ. Retaining only the leading term of the series leads to the result $L=L_0-S^2$, where L_0 is the classical theoretical Lorenz number. The values of L obtained from this result are used in eq (6) to give the equation employed in our calculations:

$$k_e=\frac{1}{\frac{\varrho-\varrho_i}{(L_0-S^2)\,T}+W_{ei}}. \tag{12}$$

The values of absolute thermoelectric powers of the ten selected binary alloy systems used in eq (12) are available from ref. [40].

There is some question about the choice of L_0 in the case of transition-element alloys. The difficulties occur also in the treatment of the pure transition metals, and will be reviewed briefly in that context.

If, as in the case of some transition metals, a narrow band with a high density of states overlaps the conduction band at the Fermi energy, then at high temperatures it is necessary to include higher order terms in the series and this will cause a deviation of the Lorenz ratio from the classical value. It is possible, at least in principle, to evaluate the second order terms from the thermoelectric power and the series expansion for the electrical conductivity (see Williams and Fulkerson, 1969 [8, pp. 443-7]). However, if the relaxation time is a strong function of energy, as is the case in transition metals on the assumption [9] that it may be written as the reciprocal of the product of the density of states and a scattering probability per unit time, then a Taylor series expansion about ζ may not be adequate to represent the integrand over the energy range $\varkappa T$ at high temperatures. In such cases the integrals must be evaluated numerically. This has been done for Pd [10] and reasonable agreement between theory and experiment was obtained; the discrepancies were presumably due to electron-electron scattering [11, p. 412] which occurs in both ordinary and transition metals. In ordinary metals, normal electron-electron scattering, in which electron quasi-momentum is conserved, contributes to the thermal resistivity but not to the electrical resistivity and thus causes a negative deviation of the Lorenz ratio. Such a deviation has been observed in Cu [12,13]. In transition metals normal electron-electron interactions between s and d band electrons contribute to the electrical resistivity as well as to the thermal resistivity; these processes are very strong [14,15] and are generally thought to be responsible for the T^2 temperature dependence of the electrical resistivity observed in these metals at low temperatures. The deviation of the Lorenz ratio due to electron-electron scattering may either enhance or partially cancel the effects of band structure. The latter appears to be the case in the group VIII elements [16]. The deviations of the Lorenz ratio of transition metals due to band structure effects are significant and cannot yet be calculated directly; further, in order to calculate correlations between the electrical resistivity and the Lorenz ratio, the density of states function of the material must be known and there are difficulties in including the effects of electron-electron scattering in such an analysis.

The Wiedemann-Franz-Lorenz law is valid in alloys at very low temperatures where one need consider only impurity scattering, and in both metals and alloys at high temperatures where phonons scatter electrons through large angles. Equation (12) was developed in order to calculate the electronic component at intermediate temperatues. However, as is clear from the preceding discussion, in the case of transition-metal alloys there is considerable uncertainty about the values of the Lorenz ratio to be used in the Wiedemann-Franz-Lorenz law at high temperatures. The method tried was to interpolate for the deviation from the classical value on the basis of the questionable assumption that the net deviation resulting from band structure effects and s-d electron-electron scattering is proportional to the number of holes in the d band. It was found that in the Cu-Ni system the resulting values of k_e nowhere differed from those obtained from eq (12) by more than 5 percent and it was decided to use eq (12) over the entire temperature range above 25 K.

In view of the uncertainties associated with eq (12), it is reassuring that the values obtained from it have been found to be in good agreement with the values of the electronic component obtained from experimental values of thermal conductivity considered to be reliable on the basis of the usual criteria.

While a considerable amount of effort has been concentrated on the study of deviations from Matthiessen's rule, far less attention has been given to their relation to the deviations from its thermal analog [1,17,18,185]. Work in this area is hindered by the failure of many authors to include the corresponding electrical resistivity data when reporting thermal conductivity values. Further work in this area would help to determine the limitations of eq (12) and very probably lead to improvements on it.

2.2. Lattice Thermal Conductivity

The processes limiting lattice conduction are different in the temperature regions below, about, and above the temperature at which it has its maximum value. At very low temperatures, typically below one twentieth of the Debye temperature, θ, these are the ordinary and impurity-induced electron-phonon interactions, and in strained specimens, phonon scattering by dislocations. These processes are also important in the temperature range in which the lattice component has its maximum value, typically between $\theta/20$ and $\theta/5$ for alloys of ordinary metals but considerably higher for some transition elements, but in this region point-defect scat-

tering and three-phonon anharmonic interactions also contribute to the thermal resistivity. At temperatures above this region the important resistive processes in alloys of ordinary metals are three-phonon anharmonic interactions and point-defect scattering; in alloys containing transition metals the effect of electron-phonon interactions may also be significant in the lower portion of this temperature range. This third region is the only one in which it is possible to estimate the lattice component on the basis of present theory.

a. Low Temperature Region

The problem of calculating the coupling constant for the electron-phonon interaction is a very difficult one even in the simplest cases; in fact, measurements of low temperature alloy termal conductivity were initially undertaken to obtain information about this interaction. From results reported by Lindenfeld and Pennebaker [19] for Cu alloys it appeared that it might be possible to estimate the lattice component from electrical resistivity data on the basis of present theory. This did not prove to be the case. It was found that values obtained from an expression which follows from the equations in ref. [19] differed from those obtained from measurements by as much as a factor of three. It is almost certain that these discrepancies are largely the result of the use of Pippard's early results [20] which are based on the free electron model; this simple model is inadequate for most metals and alloys.

At temperatures below $\theta/20$, the lattice thermal conductivity of a pure ordinary metal may be calculated from an expression derived by Klemens [21]

$$k_g = \frac{313\, k_{ei}\, T^4}{n^{4/3}\, \theta^4}, \tag{13}$$

where n is the number of conduction electrons per atom, θ is the Debye temperature, and k_{ei} is the intrinsic electronic thermal conductivity. Since in this region k_{ei} is inversely proportional to T^2, k_g has a T^2 temperature dependence. Equation (13) is based on the assumption of a reciprocal effect of the electron-phonon interaction on electronic and lattice conduction and therefore does not apply to transition elements in which electron-phonon interactions involving only d band electrons have little effect on electrical conductivity but may have a significant effect on lattice conduction. It also does not apply to alloys in which the electron mean free path is so short that the usual treatment of the electron-phonon interaction is invalid; typically, these are alloys in which the residual resistivity is 10 $\mu\Omega$ cm or greater.

However, if one attempts to estimate the k_g of an alloy from this expression the value obtained is greater than the experimental value by a factor which increases rapidly with solute concentration up to approximately 10 atomic percent. A possible explanation of this behavior is that it is due to phonon scattering by dislocations which are so strongly anchored by solute atoms that they remain even after prolonged annealing at high temperatures. The experimental support for this idea is some recent measurements on Cu-Al alloys at the University of Connecticut [22] which show that such behavior is not observed at temperatures below about 0.5K, where the dominant phonon wavelengths are larger than the range of the dislocation strain fields so that scattering by dislocations is greatly reduced [23].

Consequently, at present one cannot make reliable estimates of the k_g of alloys at low temperatures and it must be obtained by stubracting k_e from the measured total thermal conductivity. Further, one can obtain reliable values of the k_g from thermal conductivity measurments only in those cases in which the corresponding values of electrical resistivity are given, as there is often a significant variation in the resistivities of specimens having the same nominal composition. It is unfortunate that while there is a sizable body of experimental data showing strong composition dependence of the low-temperature thermal conductivity of alloys, in most cases the corresponding values of the electrical resistivity are not reported, so that it is not possible to relate the changes in the two quantities. Finally, in view of the probability that residual dislocations are responsible for a large portion of the thermal resistivity, one cannot reliabily extrapolate curves of the lattice component down to temperatures below about 1.5 K.

In order to make it possible to estimate the lattice component at low temperatures by other than empirical means, it is necessary to develop both a quantitative theory of impurity enhancement of the phonon scattering in alloys of ordinary metals and a theory of low temperature lattice conduction in transition element and high residual resistivity alloys. It seems that progress in these directions will involve the use of Pippard's more general equations [24] which apply to a non-spherical Fermi surface, taking into account changes in its shape with the addition of solutes. However, application of this theory to transition metals presents a difficult problem. Since electrical conduction is mainly by s band electrons, the residual resistivity is a measure of the mean free path of the s electrons and provides no information about the mean free path of the d band holes, which is probably very short.

b. Intermediate Temperatures

At temperatures near the maximum of the lattice component the resistive processes which limit lattice conduction at lower and higher temperatures are comparable in magnitude and the problem of estimating the lattice component in this region is a formidable one. It is, first, because of the difficulties associated with the electron-phonon interaction discussed above and, secondly, because the treatment of the resistive three-phonon anharmonic interaction in this region is complicated by the fact that here the strength of these interactions is a rapidly varying function of temperature.

At present there is no method available for the calculation of k_g in this temperature region. In this work the values of k_g in this region are derived from experimental data and the calculated values of k_e.

c. High Temperature Region

At temperatures above the region of the maximum of the lattice component, typically $\theta/5$ for alloys of ordinary metals but considerably higher for some transition-element alloys, it

is possible to estimate the lattice thermal conductivity on the basis of a theory developed by Klemens [25] and Callaway [26] assuming that the effect of the electron-phonon interaction can be neglected; this is not the case for some transition elements in the lower portion of this temperature range.

The reciprocal relaxation time for the thermally resistive three-phonon anharmonic interactions, U-processes, at frequencies not too close to the Debye limit is of the form $BT\omega^2$ where B is a constant determined from experiment, T is the temperature, and ω is the frequency of the lattice wave. The reciprocal relaxation time for point-defect scattering is of the form $(a^3/4\pi v^3)\,\varepsilon\,\omega^4$ where a^3 is the average volume per atom, v is the speed of sound, and ε is a quantity which characterizes the perturbation due to mass defects and distortions of the lattice. In addition, there are three-phonon anharmonic interactions, N-processes, which do not contribute directly to the thermal resistivity but do contribute indirectly by redistributing energy from the low frequency modes to the high frequency modes which are strongly scattered by the point defects. The reciprocal relaxation time for N-processes has the same form as that for the U-processes and, as argued by Klemens et al. [27], appears to have approximately the same magnitude in this temperature region.

Since N-processes do not contribute directly to the thermal resistivity, the effective total reciprocal relaxation time is not simply the sum of the individual reciprocal relaxation times. Callaway devised a formalism in which the N-processes are effectively taken into account for steady state lattice conduction.

Callaway found that the lattice thermal conductivity is given by

$$k_g=\frac{\kappa}{2\pi^2 v}\left(\frac{\kappa T}{\hbar}\right)^3\left(I_a+\frac{I_b^2}{I_c}\right), \tag{14}$$

where

$$I_a=\int_0^{\theta/T}\tau_c\frac{x^4e^x}{(e^x-1)^2}\,dx, \tag{15}$$

$$I_b=\int_0^{\theta/T}\frac{\tau_c}{\tau_N}\,\frac{x^4e^x}{(e^x-1)^2}\,dx, \tag{16}$$

$$I_c=\int_0^{\theta/T}\frac{1}{\tau_N}\left(1-\frac{\tau_c}{\tau_N}\right)\frac{x^4e^x}{(e^x-1)^2}\,dx, \tag{17}$$

and κ and $\hbar$ are the Boltzmann constant and the reduced Planck constant, v is the speed of sound, and $x=\hbar\omega/\kappa T$ is the reduced phonon frequency. Here τ_c is a combined relaxation time, obtained as the reciprocal of the sum of the reciprocal relaxation times for the various interactions, τ_N is the relaxation time for N-processes, and the term I_b^2/I_c occurs because of the difference between τ_c and the effective total relaxation time resulting from the fact that N-processes do not contribute directly to the thermal resistivity.

Writing the reciprocal relaxation times for point-defect scattering, U-processes and N-processes as $\tau_P^{-1}=A\omega^4$, $\tau_U^{-1}=BT\omega^2$, and $\tau_N^{-1}=\alpha BT\omega^2$ respectively, where α is the temperature-independent ratio of reciprocal relaxation times for N- and U-processes, the reciprocal combined relaxation time when the lattice thermal conductivity is limited by these interactions is

$$\tau_c^{-1}=\omega^2[A\omega^2+BT(1+\alpha)], \tag{18}$$

so that

$$\frac{\tau_c}{\tau_N}=\frac{\alpha BT}{A\omega^2+BT(1+\alpha)} \tag{19}$$

and

$$\frac{1}{\tau_N}\left(1-\frac{\tau_c}{\tau_N}\right)=\alpha BT\omega^2\left(1-\frac{\alpha BT}{A\omega^2+BT(1+\alpha)}\right) \tag{20}$$

$$=\frac{\alpha BT\omega^2(A\omega^2+BT)}{A\omega^2+BT(1+\alpha)}.$$

Upon denoting the frequency at which the reciprocal relaxation times for point-defect scattering and U-processes are equal by ω_0, noting that $\omega_0^2=BT/A$, and introducing the reduced frequency $x=\hbar\omega/\kappa T$, so that $x_0=\hbar\omega_0/\kappa T$, these relations become:

$$\tau_c^{-1}=BT\omega^2(1+\alpha+\omega^2/\omega_0^2) \tag{21}$$

$$=BT\left(\frac{\kappa T}{\hbar}\right)^2x^2(1+\alpha+x^2/x_0^2),$$

$$\frac{\tau_c}{\tau_N}=\frac{\alpha}{1+\alpha+\omega^2/\omega_0^2}=\frac{\alpha}{1+\alpha+x^2/x_0^2}, \tag{22}$$

and

$$\frac{1}{\tau_N}\left(1-\frac{\tau_c}{\tau_N}\right)=\frac{\alpha BT\omega^2(1+\omega^2/\omega_0^2)}{1+\alpha+\omega^2/\omega_0^2} \tag{23}$$

$$=\alpha BT\left(\frac{\kappa T}{\hbar}\right)^2x^2\,\frac{(1+x^2/x_0^2)}{1+\alpha+x^2/x_0^2}.$$

Thus, for the present case, eqs (15) to (17) become:

$$I_a=\left(\frac{\hbar}{\kappa T}\right)^2\frac{1}{BT}\int_0^{\theta/T}\frac{x^2e^x dx}{(e^x-1)^2(1+\alpha+x^2/x_0^2)}$$

$$=\left(\frac{\hbar}{\kappa T}\right)^2\frac{1}{(1+\alpha)BT}\int_0^{\theta/T}\frac{x^2e^x dx}{(e^x-1)^2\left[1+\frac{x^2}{x_0^2(1+\alpha)}\right]}$$

$$=\left(\frac{\hbar}{\kappa T}\right)^2\frac{1}{(1+\alpha)BT}I_2(\theta/T) \tag{24}$$

$$I_b=\alpha\int_0^{\theta/T}\frac{x^4e^x dx}{(e^x-1)^2(1+\alpha+x^2/x_0^2)}=\frac{\alpha}{(1+\alpha)}I_4(\theta/T) \tag{25}$$

$$I_c=\left(\frac{\kappa T}{\hbar}\right)^2\alpha BT\int_0^{\theta/T}\frac{x^6e^x(1+x^2/x_0^2)\,dx}{(e^x-1)^2(1+\alpha+x^2/x_0^2)}$$

$$=\left(\frac{\kappa T}{\hbar}\right)^2\frac{\alpha BT}{(1+\alpha)}\left[I_6(\theta/T)+\frac{I_8(\theta/T)}{x_0^2}\right] \tag{26}$$

Substituting eqs (24) to (26) into eq (14) yields

$$k_g = \frac{\kappa^2}{[2\pi^2\hbar v\,(1+\alpha)B]} \times \left[I_2(\theta/T) + \frac{\alpha I_4^2(\theta/T)}{I_6(\theta/T) + I_8(\theta/T)/x_0^2}\right] \quad (27)$$

where $I_n(\theta/T)$ is the modified transport integral given by

$$I_n(\theta/T) = \int_0^{\theta/T} \frac{x^n e^x dx}{(e^x-1)^2\left[1+\frac{x^2}{x_0^2(1+\alpha)}\right]} \quad (28)$$

and x_0 is the reduced frequency at which the reciprocal relaxation times for U-processes and point-defect scattering are equal; that is (see eq (32))

$$x_0 = \hbar\omega_0/\kappa T = \frac{\hbar}{\kappa}\sqrt{\frac{4\pi v^3 B}{a^3 \varepsilon T}} \quad (29)$$

Equation (27) is for the lattice thermal conductivity as limited by both point-defect scattering and three-phonon anharmonic interactions. In the limit of vanishing point-defect scattering, when the thermal conductivity is limited by three-phonon anharmonic interactions only (denoted by k_u), x_0 becomes infinite so that the modified transport integral $I_n(\theta/T)$ reduces to the standard transport integral $J_n(\theta/T)$ and eq (27) reduces to

$$k_u = \frac{\kappa^2}{[2\pi^2\hbar v(1+\alpha)B]}[J_2(\theta/T) + \alpha J_4^2(\theta/T)/J_6(\theta/T)], \quad (30)$$

where

$$J_n(\theta/T) = \int_0^{\theta/T} x^n e^x dx/(e^x-1)^2. \quad (31)$$

k_u is the high-temperature lattice thermal conductivity of an isotopically pure element; in the case of an alloy it is the lattice thermal conductivity of an idealized "virtual" crystal in which each atom has the same average mass and volume of the alloy. Point defect scattering is that scattering which results from the fact that the actual atoms do not have these masses and volumes. The tabulated values for J_n are available from the literature [186].

The quantity ε in the expression for the reciprocal relaxation time for point-defect scattering,

$$\tau_p^{-1} = \frac{a^3}{4\pi v^3}\varepsilon\omega^4 \quad (32)$$

is calculated from the expression

$$\varepsilon = y_L\left[\frac{M_L-M}{M} + \gamma\left(\frac{V_L-V}{V}\right)\right]^2 + y_H\left[\frac{M_H-M}{M_H} + \gamma\left(\frac{V_H-V}{V}\right)\right]^2, \quad (33)$$

where M and V are the average atomic mass and volume, y_L, M_L, and V_L are the atomic fraction, mass, and volume of the lighter element, y_H, M_H, and V_H are the corresponding values for the heavier element, and γ is the Grüneisen parameter. M is calculated in the usual way, γ is obtained by linear interpolation, and V is estimated from Vegard's law,

$$V^{1/3} = yV_1^{1/3} + (1-y)V_2^{1/3}, \quad (34)$$

where y is the atomic fraction of the solute and V_1 and V_2 are the atomic volumes of the solute and solvent elements respectively. The mass defect terms are based on the results of Klemens [28] and Tavernier [29] who respectively treated the case of a light atom in a heavy matrix and that of a heavy atom in a light matrix. The difference lies in the response of the atom to the driving frequency of a wave; in the former case the atom can respond rapidly enough that the speed of oscillation may be considered unaffected so that the perturbation is proportional to the deviation from the average mass while in the latter case it is better to consider the momentum as being unaffected so that the perturbation is proportional to the difference of the reciprocals of the average and impurity masses. The distortion terms and the form of ε are based on the results of Ackerman and Klemens [30] who rediscovered the fact, as Carruthers [31] first noted and contrary to what is often stated, that the displacement field of a spherical impurity in an elastic continuum has a non-vanishing non-uniform dilation and used a treatment that retained the phase relationship between the effects of the dilation and mass defect. Equation (33) does not take into account the difference, Δf, in the force constant due to the mismatch of atomic bonds; however, neutron scattering and Mössbauer experiments [32,33] indicate that Δf is very small.

The coefficient in eq (27) is the same as the coefficient in eq (30) and is estimated from the latter. This is done by estimating θ in the manner described below, estimating k_u of the virtual crystal at some temperature T' below the Debye temperature, for want of something better, by linear interpolation between the values for the elements, and taking α equal to unity; it has been found that the values of k_g are not sensitive to small changes in α. Then k_g is estimated from the expression

$$k_g = k_u(T') \times \frac{I_2(\theta/T) + I_4^2(\theta/T)/[I_6(\theta/T) + I_8(\theta/T)/x_0^2]}{J_2(\theta/T') + J_4^2(\theta/T')/J_6(\theta/T')}, \quad (35)$$

which, for a pure element, reduces to

$$k_g = k_u(T')\frac{J_2(\theta/T) + J_4^2(\theta/T)/J_6(\theta/T)}{J_2(\theta/T') + J_4^2(\theta/T')/J_6(\theta/T')}. \quad (36)$$

Equations (35) and (36) are the equations used in our calculations for the lattice thermal conductivity of alloys and of pure elements, respectively. It should be noted that eq (35) applies only to disordered solid-solution alloys.

The accuracy of the estimates obtained from eq (35) clearly depends on the accuracy of the values of k_u for the virtual crystal. Experimental values of k_u for the elements, which essentially are the values of the lattice component of very dilute alloys, are available for only three of the metals included in this study: Cu, Au, and Ag. However, it was found that the experimental values for these metals each differed from the values obtained from the modified [34] Leibfried-Schlömann [35] equation by approximately the same factor. Accordingly initial estimates of the values of k_u for the other elements were obtained from this equation multiplied by the reciprocal of that factor, i.e.,

$$k_u T' = 5.7 \times 10^{-8} \frac{M\ \theta^3\ V^{1/3}}{(\gamma + 0.5)^2}, \tag{37}$$

where M, θ, γ, and V have the same meanings as before. It is unfortunate that in this equation the Debye temperature is raised to the third power, as the high temperature values of the Debye temperature obtained from various physical properties differ considerably. The values of the Debye temperatures and other parameters used in eq (37) for the nine elements constituting the ten selected binary alloy systems covered in this work are given in table 1.

TABLE 1. Parameters for the calculation of lattice thermal conductivity of elements using equation (37)[a]

Element	M (g mol^{-1})	V (cm^{3}mol^{-1})	γ	θ (K)
Aluminum	26.98154	10.00[b]	2.18	385
Copper	63.54	7.114	1.97	313[e]
Gold	196.9665	10.22	3.09	160
Iron	55.847	7.094	1.81	373
Magnesium	24.305	14.00[c]	1.63	363
Nickel	58.71	6.593	2.00	355
Palladium	106.4	8.879	2.18	264
Silver	107.868	10.27	2.46	213[f]
Zinc	65.38	9.165[d]	2.05	326

[a] The values of γ and θ are selected from ref. [36] with some of the values adjusted in order to be consistent with the experimental thermal conductivity data.

[b] In calculating ε, the molar volumes used for aluminum were 8.576 and 9.032. The first value corresponds to the size of aluminum atoms in copper as determined from the change in the lattice parameter of copper upon the addition of aluminum [37, Vol. 1]. The second value was obtained from the change in the volume of the primitive cell upon the addition of aluminum to magnesium as calculated from the changes in the lattice parameters of magnesium upon the addition of aluminum [37, Vol. 2].

[c] In calculating ε, the molar volume used for magnesium was 13.77 corresponding to the size of magnesium atoms in aluminum as determined from the change in the lattice parameter of aluminum upon the addition of magnesium [37, Vol. 2].

[d] In calculating ε, the molar volume used for zinc was 8.534 corresponding to the size of zinc atoms in copper as determined from the change in the lattice parameter of copper upon the addition of zinc [37, Vol. 2].

[e] This value was not used for the Cu-Ni and Cu-Zn alloy systems (see sections 4.3 and 4.6).

[f] This value was not used for Ag-Pd alloy system (see section 4.10).

While in some cases it was possible to improve on the initial estimates of k_u for some elements on the basis of experimental data for a range of compositions, in others it was not, and the estimates of the lattice thermal conductivities of alloys containing the latter elements are accordingly less reliable than those containing the former. While measurements of the thermal conductivity of very dilute alloys of additional elements would make possible more reliable estimates of alloy lattice thermal conductivity, in view of the uncertainty of the separation of the electronic and lattice components of very dilute alloys at temperatures above that of the maximum of the lattice component, it would also be useful to have measurements of the thermal conductivity of some more concentrated alloys of pairs of these elements in this temperature range.

The value of the Debye temperature, Θ, for the upper limit of the integrals in eq (35) is estimated from the value of k_u for the virtual crystal by means of the modified Leibfried-Schlömann equation, adjusted to yield values for the lattice component in agreement with those obtained from experimental data on very dilute alloys as described above:

$$\theta = 260 \left[\frac{(\gamma + 0.5)^2\, k_u T}{M V^{1/3}}\right]^{1/3}, \tag{38}$$

where γ is the Grüneisen parameter, and M and V are the average molar mass and volume.

Agreement between the values obtained from eq (35) and those obtained from measurements of thermal conductivity for the various alloy systems is discussed in the text; in general, it was better for alloy systems exhibiting complete solid solubility. Another general result is that the values from eq (35) for dilute alloys tended to be too low at the low end of this temperature range. A possible explanation of this discrepancy is that the present treatment does not take into account the "freezing out" of U-processes which occurs when the temperature is reduced to the point at which there are few phonons having wave vectors of sufficient length to participate in such processes. Such a reduction in U-processes could significantly reduce the thermal resistivity of dilute alloys but cause only a small decrease in the thermal resistivity of dense alloys.

The most important deficiency of the present treatment is that the analysis leading to eq (35) does not include the electron-phonon interaction, for which an adequate theory has not yet been developed. It is for this reason that, in the absence of experimental data, the lattice component of the transition-element-rich alloys could be reported only at temperatures above their Debye temperature.

At high temperatures the values obtained from eq. (35) are nearly the same as those from an approximate expression derived independently by Abeles [38] and Parrott [39], but there are significant differences below the Debye temperature, where the high temperature approximation used by these authors,

$$x^2 e^x/(e^x - 1)^2 \cong 1$$

ceases to be valid. However, because of a partial cancellation of errors these differences are much smaller than might be

expected from the use of the high temperature approximation.

The use of eq (35) rather than an approximate expression for the calculation of the lattice thermal conductivity is to some extent a reflection of the present availability of high-speed digital computers. The expression for the quantity ε, eq (33), which takes into account the point-defect scattering due to both the mass difference and the distortion of the lattice and is first derived and given in the present work, is definitely an improvement of the theory.

3. Data Evaluation and Generation of Recommended Values

Due to the difficulties in accurate measurement of the thermal conductivity of solids and in adequate characterization of test specimens, the available experimental data on the thermal conductivity of solids from the world literature are in many cases widely divergent and subject to large uncertainty. It is, therefore, very important to critically evaluate the validity and reliability of the available data and related information, to resolve and reconcile the disagreements in conflicting data, and to generate recommended values. For the thermal conductivity of alloys, furthermore, there are serious gaps in the experimental data for either the temperature dependence or composition dependence or both. Hence, in addition to the critical evaluation and analysis of the existing data, methods for the calculation of the thermal conductivity of alloys were developed, as detailed in section 2, in order to generate estimated or synthesized values for filling the gaps in data and for checking the validity, consistency, and reliability of experimental data. These methods are essentially semi-empirical and require experimental information as input for calculations and adjustments. The reliability of these methods has been extensively tested by using selected key sets of reliable experimental data on alloys in various binary alloy systems.

In the critical evaluation of the validity and reliability of a particular set of thermal conductivity data, the temperature dependence of the data was examined and any unusual dependence or anomaly carefully investigated, the experimental technique was reviewed to see whether the actual boundary conditions in the measurement agreed with those assumed in the theory and whether all the stray heat flows and losses were prevented or minimized and accounted for, the reduction of data was examined to see whether all the necessary corrections had been appropriately applied, and the estimation of uncertainties was checked to ensure that all the possible sources of errors had been considered.

Experimental data could probably be judged to be reliable only if all sources of systematic error had been eliminated or minimized and accounted for. Major sources of systematic error include unsuitable experimental method, poor experimental technique, poor instrumentation and poor sensitivity of measuring devices, sensors, or circuits, specimen and/or thermocouple contamination, unaccounted for stray heat flows, incorrect form factor, and perhaps most important, the mismatch between actual experimental boundary conditions and those assumed in the analytical model used to derive the values of thermal conductivity. These and other possible sources of errors were carefully considered in critical evaluation of experimental data.

The uncertainty of a set of data depends, however, not only on the estimated error or inaccuracy of the data but also on the inadequacy of characterization of the material for which the data are reported. For instance, suppose a set of thermal conductivity data obtained for a severely cold-worked specimen of brass with a composition of 70.06% Cu, 28.77% Zn, and 1.17% Pb is accurate to within 5% at low temperatures. If the author knew and reported his specimen only as 70:30 brass, the uncertainty of his data for a 70:30 brass would not be just 5% but might exceed 20%. It was found in this and other studies that the chemical composition of a specimen reported by the author is often unreliable. This may be because in many cases the stated composition was the result of ladle analysis which the author obtained from the company who supplied the specimen and it could at best represent only the nominal composition; the actual composition varied from sample to sample. In other cases there was a strong tendency for only certain elements to be detected by a particular chemical analysis which could miss other important constituents. Furthermore, the chemical composition of a specimen might change when it was measured at high temperatures. For binary alloys it was found that in many cases the actual composition of a specimen might better be inferred from its electrical resistivity if reported.

In the process of critical evaluation of experimental data described above, erroneous data were eliminated. The remaining data were then subjected to further analysis and used for data synthesis. For those test specimens for which experimental data on both the thermal conductivity and electrical resistivity were reported, the electrical resistivity data were used for the calculation of electronic thermal conductivity values using eq (12). Lattice thermal conductivity values were derived as the differences of the experimental k data and the calculated k_e values. These "experimental" k_g values derived from different sets of experimental k data were then intercompared with one another and also compared with the calculated values from eq (35) regarding their temperature dependence and magnitude. During these comparisons, the validity and reliability of the available experimental data could further be judged. The electrical resistivity data reported for the test specimens on which thermal conductivity measurements were made were also evaluated critically in connection with evaluation of all the electrical resistivity data available from the literature for each of the alloy systems, from which the recommended electrical resistivity values were generated.

As detailed in section 2, values of the electronic thermal conductivity of alloys were calculated from eq (12), which is applicable to alloys in both the solid solution region and the mechanical mixture region. In this calculation, the recommended electrical resistivity values for the selected compositions of the present ten alloy systems and their constituent elements are available from ref. [7], the recommended thermoelectric power values are available from ref. [40], the recommended thermal conductivity values and the values of β for the elements are available from ref. [5], and the lattice thermal conductivity values of the elements used as correc-

tions in the calculation of W_{ei} from eq (7) are calculated from eq (36).

Values of the lattice thermal conductivity of alloys in the region of solid solubility were calculated from eq (35). The values of k_u of the virtual crystals of alloys used in eq (35) for calculations were obtained by linear interpolation between the values of k_u of the two constituent elements. In the initial calculations, the k_u values of elements used for generating the k_u values of alloys were either the experimental values if available or the calculated values from eq (37). The values of the Debye temperature for the upper limit of the integrals in eq (35) were estimated from eq (38). It is important to note that eq (35) is applicable only to disordered solid-solution alloys and only for moderate and high temperatures. Beyond the solid solution region and at low temperatures, the lattice thermal conductivity was first obtained as the difference of the experimental total thermal conductivity and the calculated electronic thermal conductivity. The "experimental" k_g values so obtained were then graphically smoothed and synthesized to obtain the k_g values for alloys of the selected compositions. In the solid-solution region and at moderate and high temperatures, the "experimental" k_g values were used to check the k_g values calculated from eq (35). If there were disagreements and the "experimental" k_g values were considered reliable, the k_u values of elements would be adjusted so that the calculated k_g values of alloys were in agreement with the "experimental" k_g values.

In some instances only the total thermal conductivity, obtained by smoothing experimental data, and the electronic component, obtained from eq (12), are given. In these cases the user is cautioned against obtaining the lattice component by subtraction as this may lead to unphysical values for the lattice component due to the uncertainties in the tabulated values.

For alloys not consisting of a continuous series of solid solutions the values of the thermal conductivity are derived from the experimental data on specimens in which the solid solution phase is presumably frozen in. This may not be the case for all specimens and the results may not be quite reproducible; this is particularly true for the Al-Cu and Al-Mg alloy systems. For this reason, the values in the temperature range in which the phase structure is uncertain are provisional rather than recommended.

In graphical smoothing and synthesis of data, cross-plotting from conductivity versus temperature to conductivity versus composition and vice versa was often used. Smooth curves were drawn which approximate the best fit to the conductivity data versus temperature, and points from the smoothed curves were used to construct conductivity versus composition curves for a convenient set of selected temperatures. In the conductivity versus composition graph, the families of isotherms were similar and any required smoothing of the data could be done more easily and with greater confidence than when working directly with the conductivity-temperature curves. The points from the smoothed curves were then used to construct conductivity-temperature curves for the selected compositions, and these curves were further smoothed. In the graphical smoothing process it is extremely important that the alloy phase diagrams [104,183,184] be constantly consulted and the phase boundaries between solid solutions and/or mechanical mixtures and the boundaries of magnetic transitions be kept in mind, so as to be aware of any possible discontinuity or sudden change of slope in the thermal conductivity curves.

The total thermal conductivity values were thus obtained as the sum of the k_e values calculated from eq (12) and the k_g values derived from the "experimental" k_g values or calculated from eq (35), which might have been adjusted to fit the "experimental" k_g values if such values were available and reliable.

The copper-nickel alloy system is here used as an example to show some of the input data used for calculations and to illustrate some of the points discussed above. The recommended electrical resistivity values for the Cu+Ni alloys and for the Ni+Cu alloys are shown separately in figures 1 and 2; these were used in eq (12) for the calculation of the electronic thermal conductivity values. These electrical resistivity values were generated from both the electrical resistivity data reported for the test specimens on which thermal conductivity measurements were made and those extracted from the electrical resistivity literature for all other alloys of the copper-nickel system. As shown in figure 2, the electrical resistivity versus temperature curves for Ni+Cu alloys change slope abruptly at the Curie temperature of the alloys. The Curie temperature decreases as the concentration of copper in the alloy increases. The ferromagnetism disappears and the Curie temperature drops to zero as the concentration of copper reaches 61.88% (60 At.%). The insert in figure 2 shows the Curie temperature as a function of percent copper in nickel, which is a straight line for the atomic percent of copper. Since the behavior of the electrical resistivity of these alloys has a direct bearing on the behavior of the thermal conductivity, the knowledge of the former is important to the understanding of the latter.

The recommended thermoelectric power values for the Cu + Ni alloys and for the Ni + Cu alloys are shown separately in figures 3 and 4; these were likewise used in eq (12) for calculation. Figure 4 shows also the Curie temperature of each alloy as the point at which the slope of the curve changes abruptly.

In order to demonstrate the validity and reliability of the methods developed for the calculation of the thermal conductivity of alloys, a graphical comparison of the calculated values with the experimental data for the thermal conductivity of some of the alloys of the copper-nickel alloy system is given in figure 5. The calculated values for each alloy are shown as a short-dashed curve which is paired with the experimental curve for the same alloy. For each of these alloys both the experimental thermal conductivity and electrical resistivity data are available, and the calculated thermal conductivity values were obtained by using the author's electrical resistivity data directly for the calculation of the electronic component, with the lattice component obtained by quadratic interpolation of the lattice thermal conductivity values given in table 11 for the selected fixed compositions. The measurement information on these alloys can be found in table 12 for the Cu+Ni alloys and table 13 for the Ni+Cu alloys by referring to the corresponding curve numbers indicated in figure 5.

It can be seen from figure 5 that the calculated values agree very well with the data of Smith and Palmer [49] (Cu+Ni curves 6 and 7), of Berman [70] (Cu+Ni curve 21), of Mikryukov [144] (Cu+Ni curve 43), and of Kierspe [83] (Cu+Ni curve 67) to within 1 to 2%, agree with the data of Barratt [127] (Cu+Ni curve 12), of Zimmerman [130] (Cu+Ni curve 17), and of Aoyama and Ito [134] (Cu+Ni curve 36) to within 3 to 5%, and agree with the data of Smith [45] (Ni+Cu curve 3) to within 6%. The calculated values are in agreement to within 4% with the data of Grüneisen and Goens [128] (Cu+Ni curve 13) at 83 K but are 10% above their data at 21 K. Their experimental data at 21 K is believed to be low since this thermal conductivity data is inconsistent with their electrical resistivity data and since their other similar measurements at 21 K on Cu+Au, Au+Cu, Cu+Pd, and Pd+Cu alloys are also low.

The data of Sager [77] (Cu+Ni curves 10 and 11) are good examples for showing the inconsistency between the thermal conductivity and the electrical resistivity data and for convincing that calculated thermal conductivity values can be much more accurate than the experimental data. At the lower temperature end the differences between Sager's data and the thermal conductivity values calculated from his own electrical resistivity data for the two alloys are only 3% (Cu+Ni curve 10) and 7% (Cu+Ni curve 11). At higher temperatures, however, his data increase very rapidly, and the differences reach 31% and 104% at 990 K. By comparing the slopes of his two experimental curves with those of other curves, it is apparent that his thermal conductivity measurements were much in error, which might very well be due to radiation heat loss in his measurements.

Greig and Harrison [78] did not report electrical resistivity data for their alloys directly and the data used for calculation were derived from reported Lorenz number and thermal conductivity data. This may cause some of the differences between their experimental thermal conductivity data (Ni+Cu curves 11 and 12) and the calculated values, which mostly amount to 5 to 15%. The discontinuity at 15 K in the calculated thermal conductivity values for Ni+Cu curve 11 is due to the discontinuity in the electrical resistivity data used for calculation, but in reality there should be no such discontinuity at 15 K.

As mentioned earlier, for those alloys for which experimental data on both thermal conductivity and electrical resistivity were reported, the electrical resistivity data were used for the calculation of k_e values from eq (12), and k_g values were derived as the differences of the experimental k data and the calculated k_e values. Such derived "experimental" k_g values for the copper-nickel alloy system at 300 K are shown in figure 6 as data points, together with the calculated k_g values from eq (35) shown as a solid curve. The magnitude of the calculated k_g values depends on the selected k_u values for the elements copper and nickel, from which the k_u values of the virtual crystals of alloys were determined. As stated in section 2.2, experimental data on k_u are available for copper but not for nickel. White [91] reported an experimental value of k_uT for copper as 35.0 W cm^{-1} at temperatures above 60 K and this value was used in eq (35) for calculation. The value of k_uT for nickel estimated from the modified Leibfried-Schlömann equation (37) varies considerably depending upon the selected value of the Debye temperature used in the calculation. It can be seen from figure 6 that a higher value of k_u for nickel, which would make the calculated k_g values higher especially on the nickel-rich side, would render the calculated curve better fitting to the experimental k_g values for nickel-rich alloys. However, this would make the calculated k_g values too high for the copper-rich alloys. The experimental k_g values for nickel-rich alloys as shown in figure 6 are known to be very uncertain and those for copper-rich alloys are much more reliable. Between the two k_uT values 52.5 and 45.0 W cm^{-1} for copper and nickel, the k_u values of the virtual crystals of alloys were obtained by linear interpolation and used in eq (35) for the calculation of k_g values for all the alloys at temperatures above the region of the maximum in k_g.

Since it is of interest to observe the variation of thermal conductivity with alloy composition at various temperatures, the conductivity-composition isotherms for the copper-nickel alloy system are presented in figure 7 together with some of the experimental data.

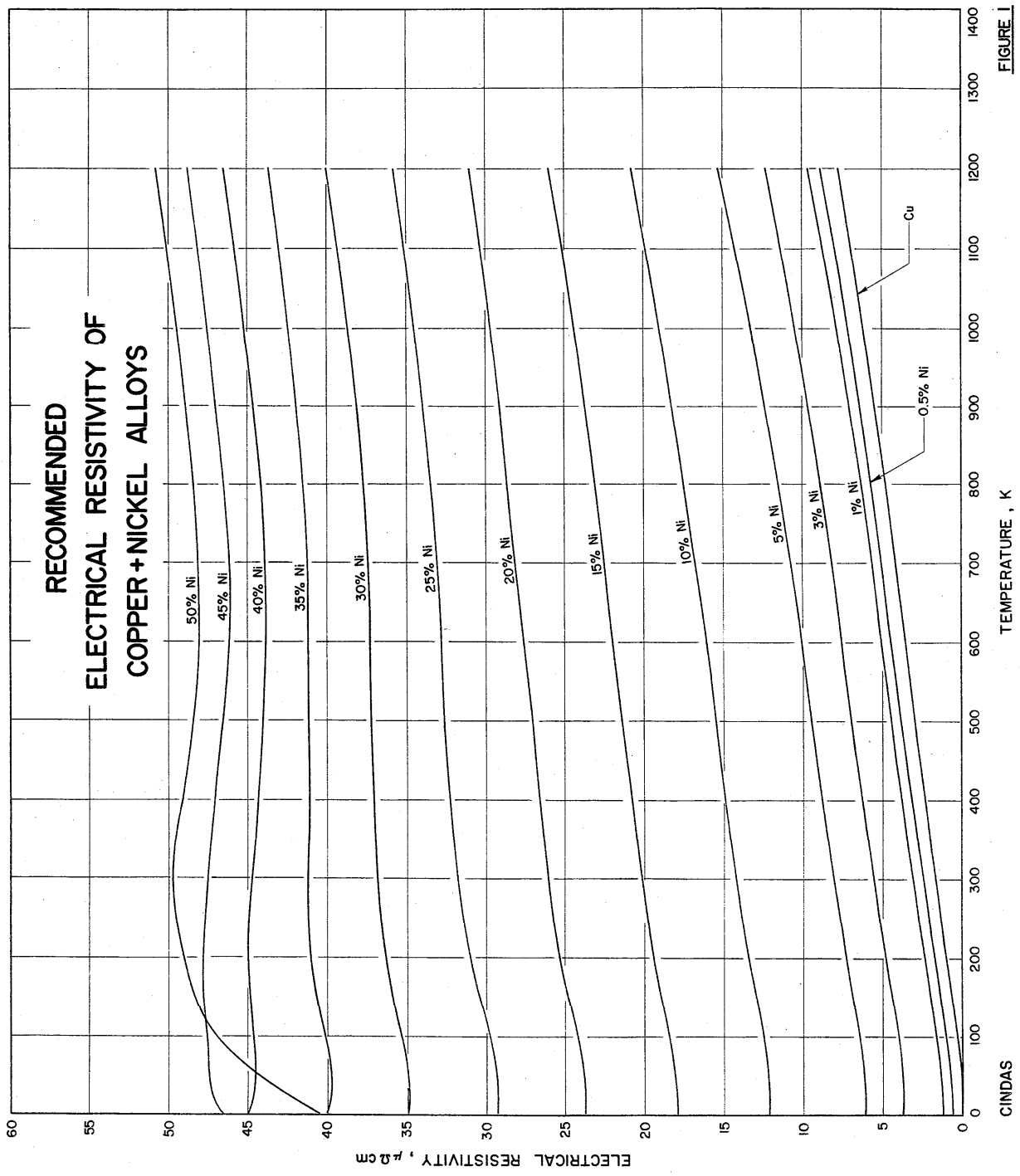
RECOMMENDED
ELECTRICAL RESISTIVITY OF
COPPER+NICKEL ALLOYS
50% Ni
45% Ni
40% Ni
35% Ni
30% Ni
25% Ni
20% Ni
15% Ni
10% Ni
5% Ni
3% Ni
1% Ni
0.5% Ni
Cu
ELECTRICAL RESISTIVITY , μΩ cm
TEMPERATURE , K
CINDAS

FIGURE 1

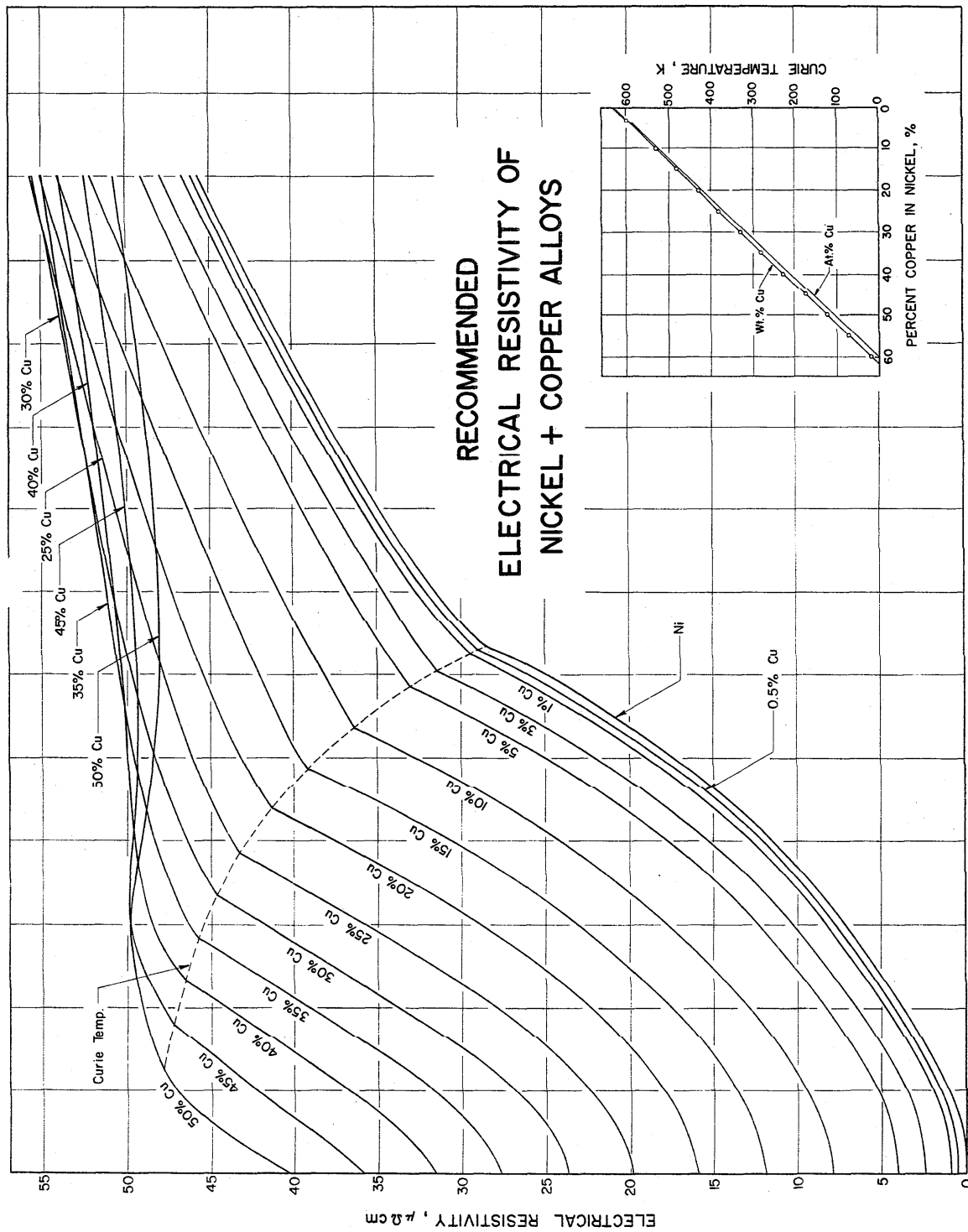
RECOMMENDED
ELECTRICAL RESISTIVITY OF
NICKEL + COPPER ALLOYS
ELECTRICAL RESISTIVITY , μΩ cm
TEMPERATURE , K
CURIE TEMPERATURE , K
PERCENT COPPER IN NICKEL, %
Wt.% Cu
At.% Cu
Ni
0.5% Cu
1% Cu
3% Cu
5% Cu
10% Cu
15% Cu
20% Cu
25% Cu
30% Cu
35% Cu
40% Cu
45% Cu
50% Cu
Curie Temp.
CINDAS

FIGURE 2

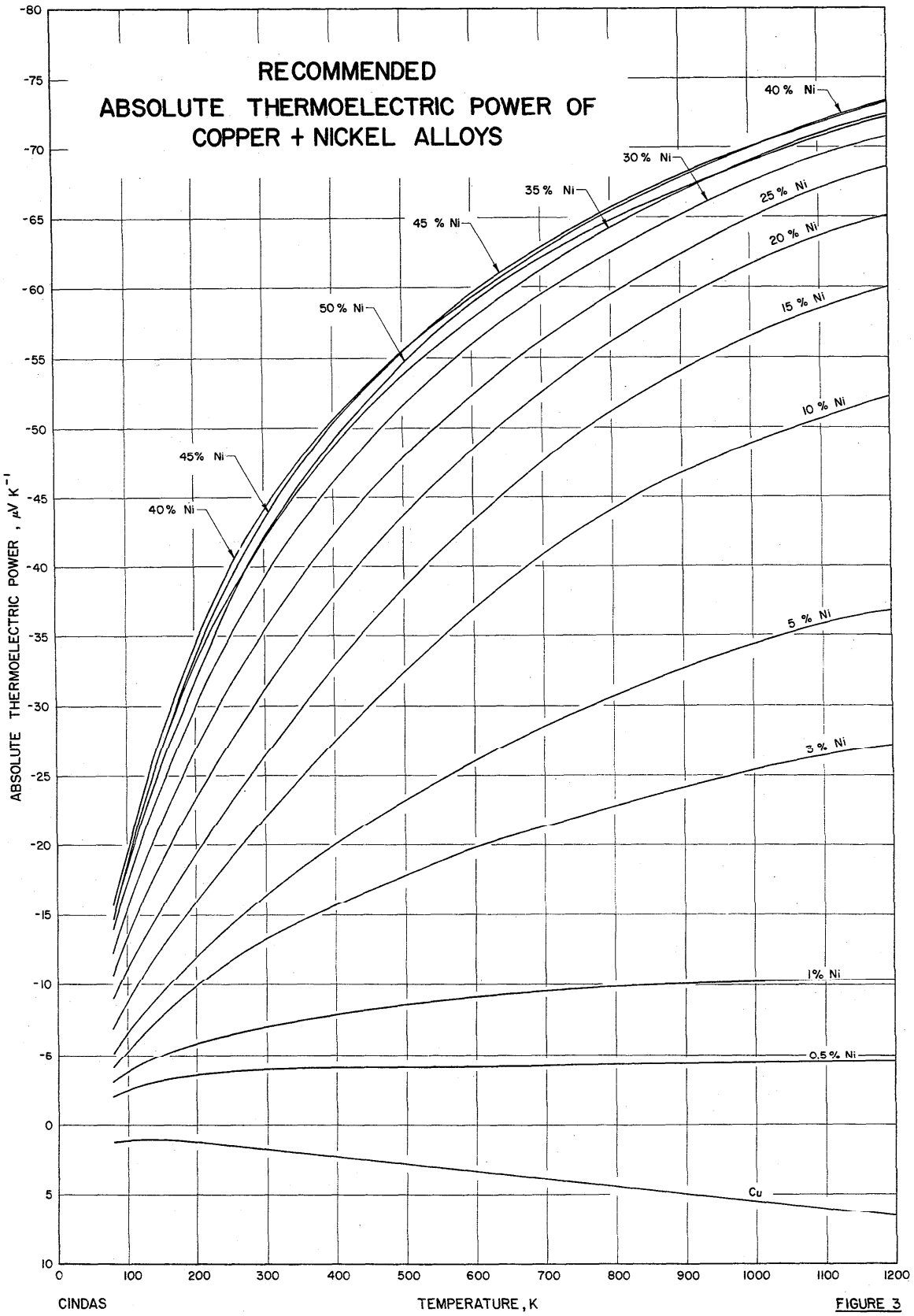
RECOMMENDED
ABSOLUTE THERMOELECTRIC POWER OF
COPPER + NICKEL ALLOYS
40 % Ni
30 % Ni
35 % Ni
25 % Ni
45 % Ni
20 % Ni
50 % Ni
15 % Ni
10 % Ni
45% Ni
40% Ni
5 % Ni
3 % Ni
1% Ni
0.5 % Ni
Cu
ABSOLUTE THERMOELECTRIC POWER , μV K⁻¹
-80
-75
-70
-65
-60
-55
-50
-45
-40
-35
-30
-25
-20
-15
-10
-6
0
5
10
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
CINDAS
TEMPERATURE , K

FIGURE 3

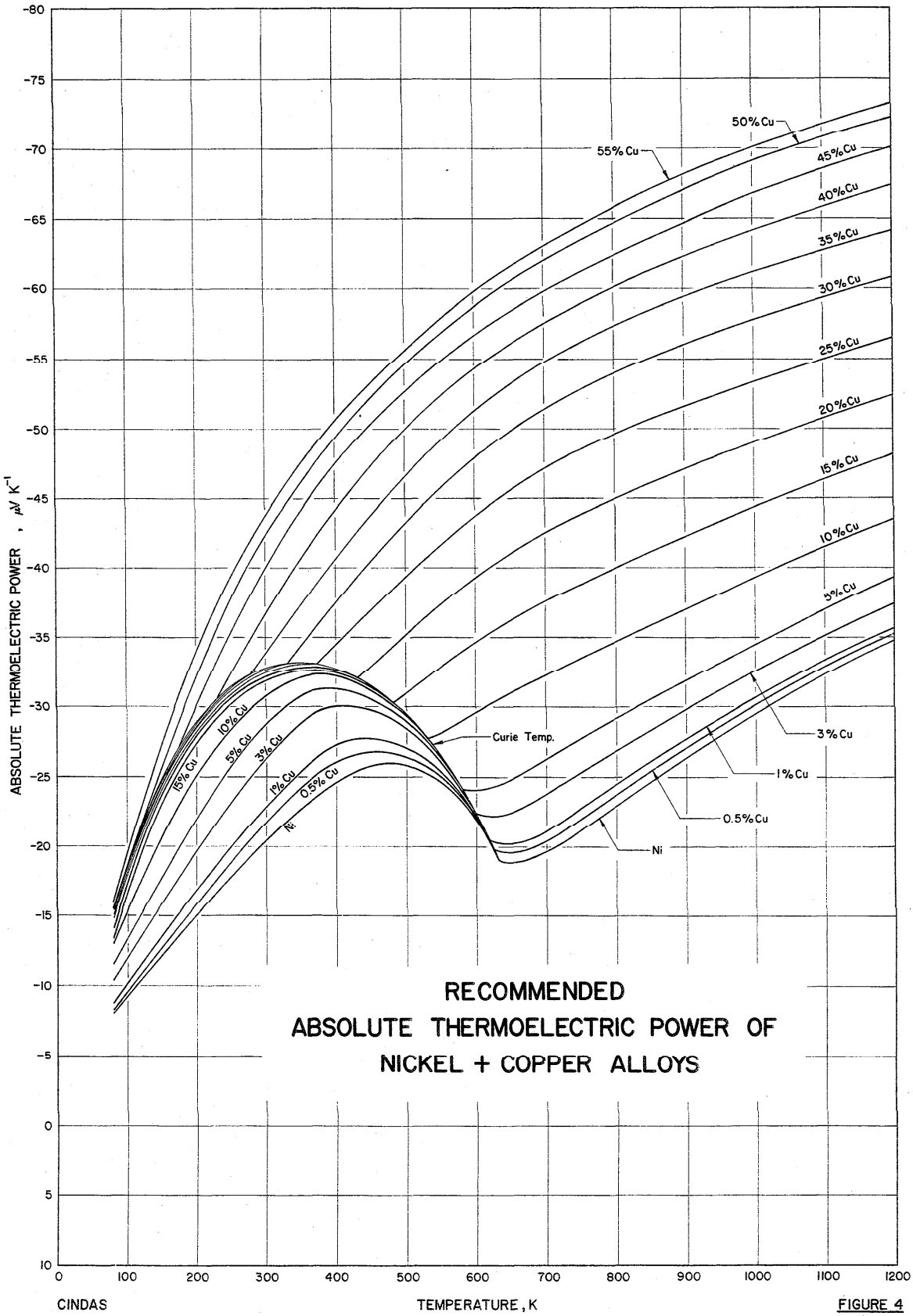
ABSOLUTE THERMOELECTRIC POWER , μV K⁻¹
-80
-75
-70
-65
-60
-55
-50
-45
-40
-35
-30
-25
-20
-15
-10
-5
0
5
10
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
CINDAS
TEMPERATURE , K
50% Cu
55% Cu
45% Cu
40% Cu
35% Cu
30% Cu
25% Cu
20% Cu
15% Cu
10% Cu
5% Cu
3% Cu
1% Cu
0.5% Cu
Ni
Curie Temp.
RECOMMENDED
ABSOLUTE THERMOELECTRIC POWER OF
NICKEL + COPPER ALLOYS

FIGURE 4

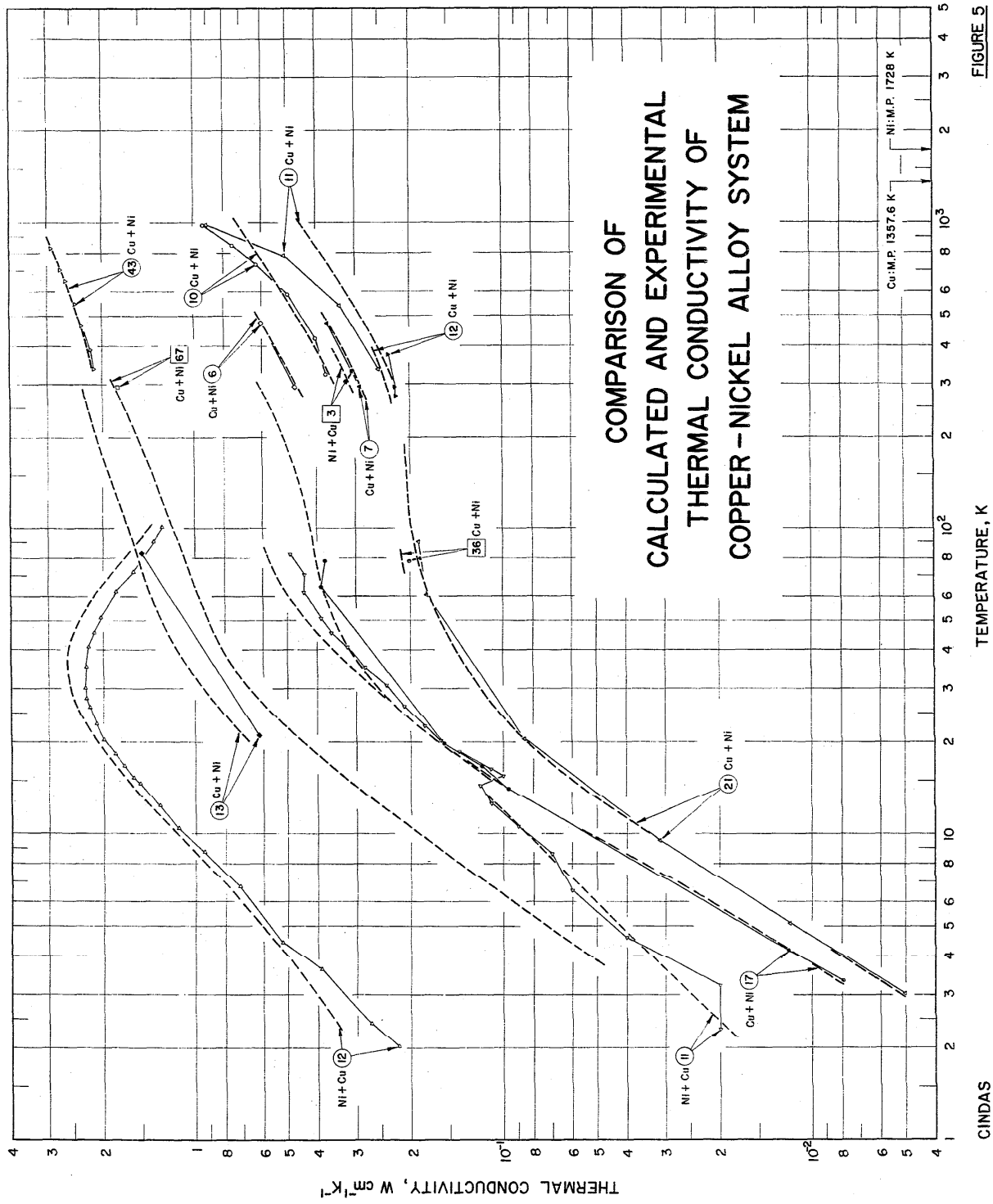
COMPARISON OF
CALCULATED AND EXPERIMENTAL
THERMAL CONDUCTIVITY OF
COPPER–NICKEL ALLOY SYSTEM
Cu: M.P. 1357.6 K
Ni: M.P. 1728 K
(43) Cu + Ni
(10) Cu + Ni
(11) Cu + Ni
(12) Cu + Ni
Cu + Ni (67)
Cu + Ni (6)
Ni + Cu (3)
Cu + Ni (7)
36 Cu + Ni
(13) Cu + Ni
(21) Cu + Ni
Ni + Cu (12)
Ni + Cu (11)
Cu + Ni (17)
THERMAL CONDUCTIVITY, W cm⁻¹K⁻¹
TEMPERATURE, K
CINDAS

FIGURE 5

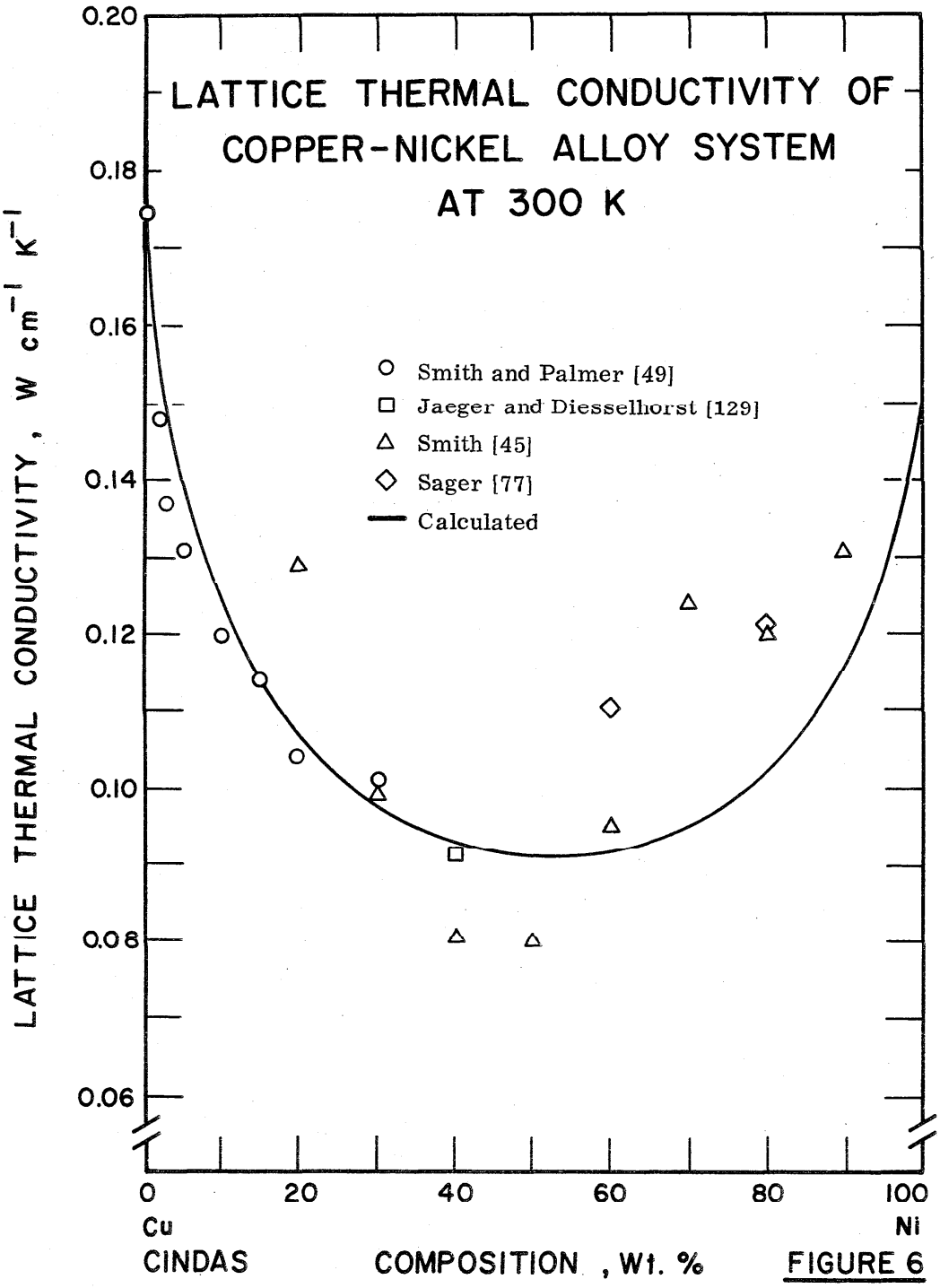
LATTICE THERMAL CONDUCTIVITY OF
COPPER-NICKEL ALLOY SYSTEM
AT 300 K
Smith and Palmer [49]
Jaeger and Diesselhorst [129]
Smith [45]
Sager [77]
Calculated
LATTICE THERMAL CONDUCTIVITY, W cm⁻¹ K⁻¹
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0
20
40
60
80
100
Cu
Ni
COMPOSITION, Wt. %
CINDAS

FIGURE 6

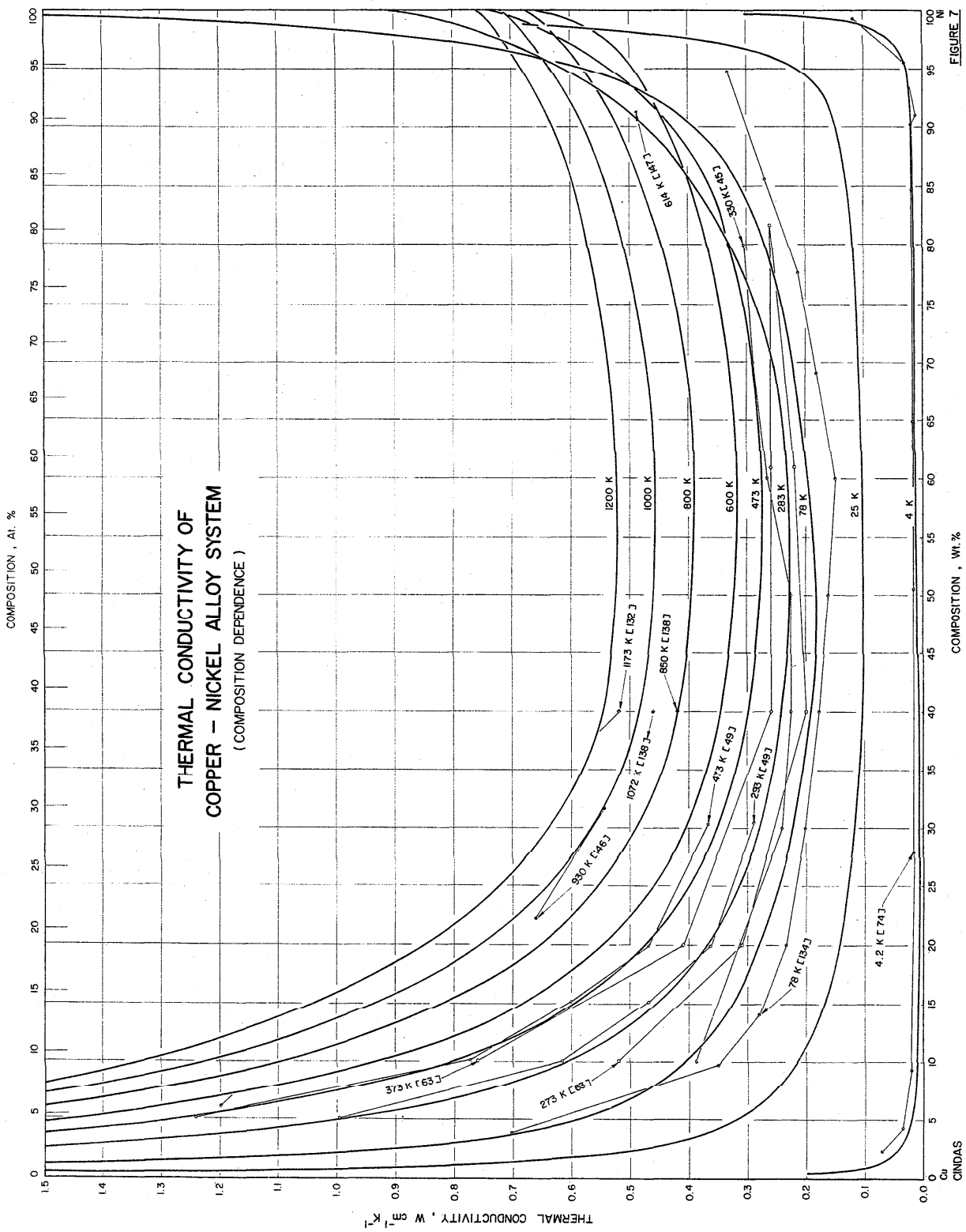
THERMAL CONDUCTIVITY OF
COPPER – NICKEL ALLOY SYSTEM
(COMPOSITION DEPENDENCE)
COMPOSITION , At. %
COMPOSITION , Wt. %
THERMAL CONDUCTIVITY , W cm⁻¹ K⁻¹
1200 K
1000 K
800 K
600 K
473 K
283 K
78 K
25 K
4 K
1173 K [32.]
850 K [38.]
1072 K [38.]
930 K [46.]
473 K [49.]
283 K [49.]
373 K [63.]
273 K [63.]
78 K [134.]
4.2 K [74.]
CINDAS

FIGURE 7

4. Thermal Conductivity of Binary Alloy Systems

In this work, the term "binary alloy system" refers to the full range of composition of two alloying elements and is signified by a hyphen between the two elements, such as aluminum-copper alloy system. The term "binary alloys" refers to a group of binary alloys in which the first alloying element is predominant and is signified by a plus between the two elements, such as aluminum + copper alloys. In specifying the composition of an alloy, weight percent is denoted by % and atomic percent by At.%.

In each of the subsections that follow, the thermal conductivity data and information for each alloy system are presented in the following order: discussion text, figures for comparing recommended curves with experimental data for selected alloys, tables of recommended values, figures presenting recommended curves, figures presenting experimental data, and tables on specimen characterization and measurement information.

In the discussion text on the thermal conductivity of each alloy system, individual pieces of available data and information are reviewed, details of data analysis and synthesis are given, the considerations involved in arriving at the final assessment and recommendation are discussed, the recommended values and the experimental data are compared, and the uncertainties of the recommended values are stated.

In the figures for comparing recommended thermal conductivity values with experimental data for selected alloys mentioned in the discussion text, the recommended thermal conductivity values for the specific alloy compositions shown as smooth solid curves were obtained by quadratic interpolation of the recommended total thermal conductivity values given in the table for the selected fixed alloy compositions.

The values given in the tables of recommended values include those of the total thermal conductivity, electronic thermal conductivity, and lattice thermal conductivity. These values are designated either as recommended or provisional values depending upon the level of confidence placed on the values and, hence, upon the uncertainty assigned. The ranges of uncertainties of recommended and provisional values are less than ±15% and between ±15% and ±30%, respectively. Some of the lattice thermal conductivity values are designated also as typical values, of which the uncertainty is greater than ±30%. In the tables the third significant figure is given for the thermal conductivity values; this, however, is only for internal comparison and for tabular smoothness and should not be considered indicative of the degree of accuracy or uncertainty. The uncertainty of the values is always explicitly stated. For each of the alloy systems except two, the values are given for 25 alloy compositions: 0.5, 1, 3, 5, 10(5)95, 97, 99, and 99.5%. The corresponding atomic percent of each weight percent composition is also given. For most of the alloy compositions, the values cover the temperature range from 4K to the solidus temperature or 1200 K. The residual electrical resistivity of each alloy composition is also given in the table, which is for the purpose of helping to characterize and identify the alloy for which the thermal conductivity values are given. The uncertainties of the total thermal conductivity values for each alloy in different temperature ranges are stated in a footnote to the table.

The recommended thermal conductivity values presented in this work are for alloys which are not ordered and have not been cold worked severely. The values would be higher for ordered alloys and lower at low temperatures for cold-worked alloys.

In the figures presenting recommended thermal conductivity curves, continuous (solid) curves represent recommended values and long-dashed curves represent provisional values. The short-dashed portion of any of the above two kinds of curves represents values in the temperature range where no experimental thermal conductivity data are available. In six of the 19 figures presenting the recommended curves, some of the curves belonging to the other alloy group of the same alloy system are also shown in the figure in order to show more clearly the systematic variation of the thermal conductivity with alloy composition and to clarify the confusion in the figure for the other group due to crossover of curves.

In the figures presenting experimental data, a data set consisting of a single point is denoted by a number enclosed by a square, and a curve that connects a set of two or more data points is denoted by a ringed number. These numbers correspond to those given in the accompanying tables on specimen characterization and measurement information. When several sets of data are too close together to be distinguishable, some of the data sets, though listed in the table, are omitted from the figure for the sake of clarity.

The tables on specimen characterization and measurement information give for each set of experimental data the following information: the publication reference number, author's name (or names), year of publication, experimental method used for the measurement, temperature range covered by the data, alloy name and specimen designation, alloy composition, specification and characterization of the specimen and information on measurement conditions, which are contained in the original paper. Whenever available, information on the electrical resistivity has also been included. In these tables the code designations used for the experimental methods for thermal conductivity determinations are as follows:

C Comparative method
E Direct electrical heating method
F Forbes' bar method
L Longitudinal heat flow method
P Periodic or transient heat flow method
R Radial heat flow method
T Thermoelectrical method

The thermal conductivity data and information for the ten selected binary alloy systems are presented in the following ten subsections.

4.1. Aluminum-Copper Alloy System

The aluminum-copper alloy system does not form a continuous series of solid solutions. The maximum solid solubility of copper in aluminum is 5.70% (2.50 At.%) at 821 K and the solubility decreases to 0.1–0.2% (0.04–0.08 At. %) at 523 K. The maximum solid solubility of aluminum in copper is 9.4% (19.6 At.%) in the range from about 650 to 838 K and the solubility decreases at higher and lower temperatures. Thus the region of solid solution is limited. However, the equation derived for the calculation of the electronic component of thermal conductivity, eq (12), is applicable to all phases, though the equation for the calculation of the lattice component, eq (35), can be used only for solid solutions, as noted before in sections 2 and 3. As noted in section 3 the values for the thermal conductivity of part of this alloy system are derived from experimental data on specimens in which the solid-solution phase was presumably frozen in. Hence, these values may not always be reproducible and are therefore provisional rather than recommended.

There are 188 sets of experimental data available for the thermal conductivity of this alloy system. However, of the 49 data sets for Al + Cu alloys listed in table 3 and shown in figure 12, ten sets are merely single data points around room temperature and 27 sets cover only a narrow temperature range from around room temperature to about 500 K. Of the 139 data sets for Cu + Al alloys listed in table 4 and shown in figure 13, 20 sets are single data points, 15 sets cover the narrow temperature range from around room temperature to about 500 K, and 84 sets are for temperatures below 4.5 K.

For the Al + Cu alloys, all measurements were made between room temperature and 800 K except four (Al + Cu curves 6–8, and 16) which were measured down to about 80 K for specimens containing 4.0, 8.0 and 15.0% Cu [41, 42] and except the two (Al + Cu curves 25 and 26) of Satterthwaite [43] who investigated the thermal conductivity of a specimen containing 0.3% Cu in both the superconducting and normal states between 0.4 and 1.2 K. In the present data analysis and synthesis, a thermal conductivity versus composition curve for 300 K was constructed following mainly the data of Griffiths and Schofield [44] (Al + Cu curves 1–5), of Aliev [116,168] (Al + Cu curves 31–33), and of Smith [45] (Al + Cu curves 12–15). The measurements of Griffiths and Schofield were selected because their specimens were well annealed and their electrical resistivity data are consistent with their thermal conductivity measurements. Smith did not report the heat treatment, but his data are compatible in magnitude to those of Griffiths and Schofield. The other measurements were discounted either because the specimens were unannealed or unspecified, or due to some experimental or theoretical considerations. For instance, Mannchen's data [41] (Al + Cu curves 6–8) were not taken into consideration since his corresponding Lorenz function values were believed to be too low. In the meantime, electronic thermal conductivity values at 300 K for the selected alloys were calculated from eq (12) and these k_e values were also plotted on the conductivity-composition graph. The difference between the experimental total thermal conductivity k and the calculated electronic component k_e is the lattice component k_g, and the k_g values at 300 K for the various compositions were thus obtained from the graph. These k_g values were extrapolated to higher temperatures up to the solidus temperatures according to the temperature dependence of eq (35) and to lower temperatures according to the pattern of k_g curves of aluminum-copper system derived from the available experimental k and the calculated k_e around the region of maximum k_g and according to T^2 dependence at lower temperatures assuming k_g to be negligible at 1 K. The values were then adjusted so that the extrapolated k_g values plus their corresponding k_e values yield total k values which fit the experimental data in those regions. The total thermal conductivity values were then obtained by adding the calculated values of k_e to the adjusted extrapolated values of k_g.

For the Cu + Al alloys, several measurements were made between 4 K and 80 K [48,50] (Cu + Al curves 111–126) for alloys containing 0.43, 4.07, and 6.97% Al. The conductivity-composition curve at 300 K was constructed, based mainly on the data of Smith and Palmer [49] (Cu + Al curves 2–9), Aliev [116,168] (Cu + Al curves 59–67), and Smith [45] (Cu + Al curves 16 and 17). The specimens of Smith and Palmer were well-annealed and the results from [45] and [116] complement those of Smith and Palmer in forming the conductivity-composition isotherm. The k_e values were calculated from eq (12) and those at 300 K were plotted on the conductivity-composition graph. The differences k_g between k and k_e were obtained for all compositions. These k_g values were adjusted so that their extrapolations to lower temperatures, according to the method described above for Al + Cu alloys, fit the k_g values derived from experimental data of Chu and Lipschultz [48] (Cu + Al curves 111–121) and of Friedman [50] (Cu + Al curves 122–126). Above 300 K the k_g values were extrapolated to the solidus temperatures. The total thermal conductivity values were then obtained by adding the calculated values of k_e to the adjusted extrapolated values of k_g. Because of the lack of experimental electrical resistivity data, no total k values are given below 200 K for the alloy with 10% Al, below 300 K for the alloy with 15% Al, and at temperatures other than 300 K for the alloy with 20% Al.

A graphical comparison of the recommended total thermal conductivity values with selected experimental data is given in figures 8 and 9. The smooth solid curves in these figures were obtained by interpolating the recommended values of table 2 in order to obtain thermal conductivity values for the desired alloy compositions. For aluminum-rich alloys shown in figure 8, the recommended values above room temperature are in agreement with the data of Griffiths and Schofield [44] (Al + Cu curves 1, 2, 4, and 5), of Smith [45] (Al + Cu curves 12–14), and of Mikryukov and Karagezyan [58] (Al + Cu curves 20 and 21) to within 5%, and with the data of Smith [45] for an alloy containing 50% Cu (Al + Cu curve 15) to within 8%. No appropriate comparison can be made below room temperature. For the copper-rich alloys shown in figure 9, the recommended values at low temperatures are in agreement with the data of Salter and Charsley [51] (Cu + Al curves 20, 22–25), of Chu and Lipschultz [48] (Cu + Al curves 111 and 116), and of Friedman [50] (Cu + Al curve 122) to within 6%, and those at higher temperatures are in agreement with the data of Smith and Palmer [49] (Cu + Al curves 2–9 and

78) and of Aliev [116] (Cu + Al curves 65 and 67) to within 10%.

The resulting recommended values for k, k_e, and k_g are tabulated in table 2 for 25 alloy compositions. These values are for alloys which have not been severely cold worked or quenched. The values for k are also presented in figures 10 and 11. The recommended curves for copper-rich alloys containing 25 to 45% Al are also shown in figure 10 in order to show more clearly the systematic variation of the thermal conductivity with alloy composition and to clarify the confusion in figure 11 due to crossover of curves. For most of the alloy compositions, the temperature range covered is from 4 K to the solidus temperature where melting starts. The values of residual electrical resistivity for the alloys are also given in table 2. The uncertainties of the k values are stated in a footnote to table 2, while the uncertainties of the k_e and k_g values are indicated by their being designated as recommended, provisional or typical values. The ranges of uncertainties of recommended, provisional, and typical values are less than ±15%, between ±15 and ±30%, and greater than ±30%, respectively. The k_g values are very uncertain and are merely to serve as correction terms for the derivation of the total thermal conductivities.

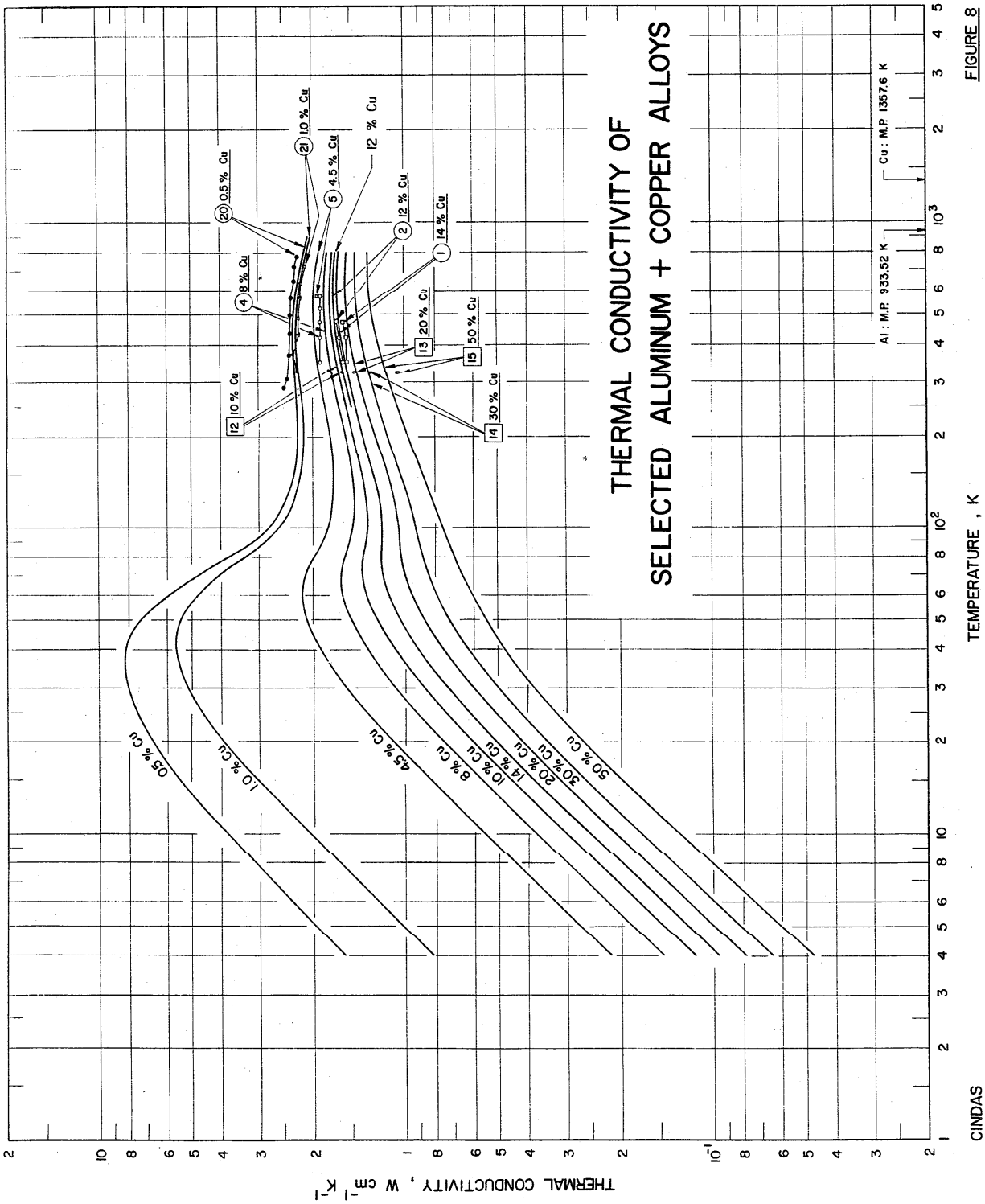
THERMAL CONDUCTIVITY OF
SELECTED ALUMINUM + COPPER ALLOYS
Al : M.P. 933.52 K
Cu : M.P. 1357.6 K
0.5 % Cu
1.0 % Cu
4.5 % Cu
8 % Cu
10 % Cu
14 % Cu
20 % Cu
30 % Cu
50 % Cu
0.5 % Cu
1.0 % Cu
4.5 % Cu
8 % Cu
10 % Cu
12 % Cu
14 % Cu
20 % Cu
50 % Cu
30 % Cu
THERMAL CONDUCTIVITY , W cm⁻¹ K⁻¹
TEMPERATURE , K
CINDAS

FIGURE 8

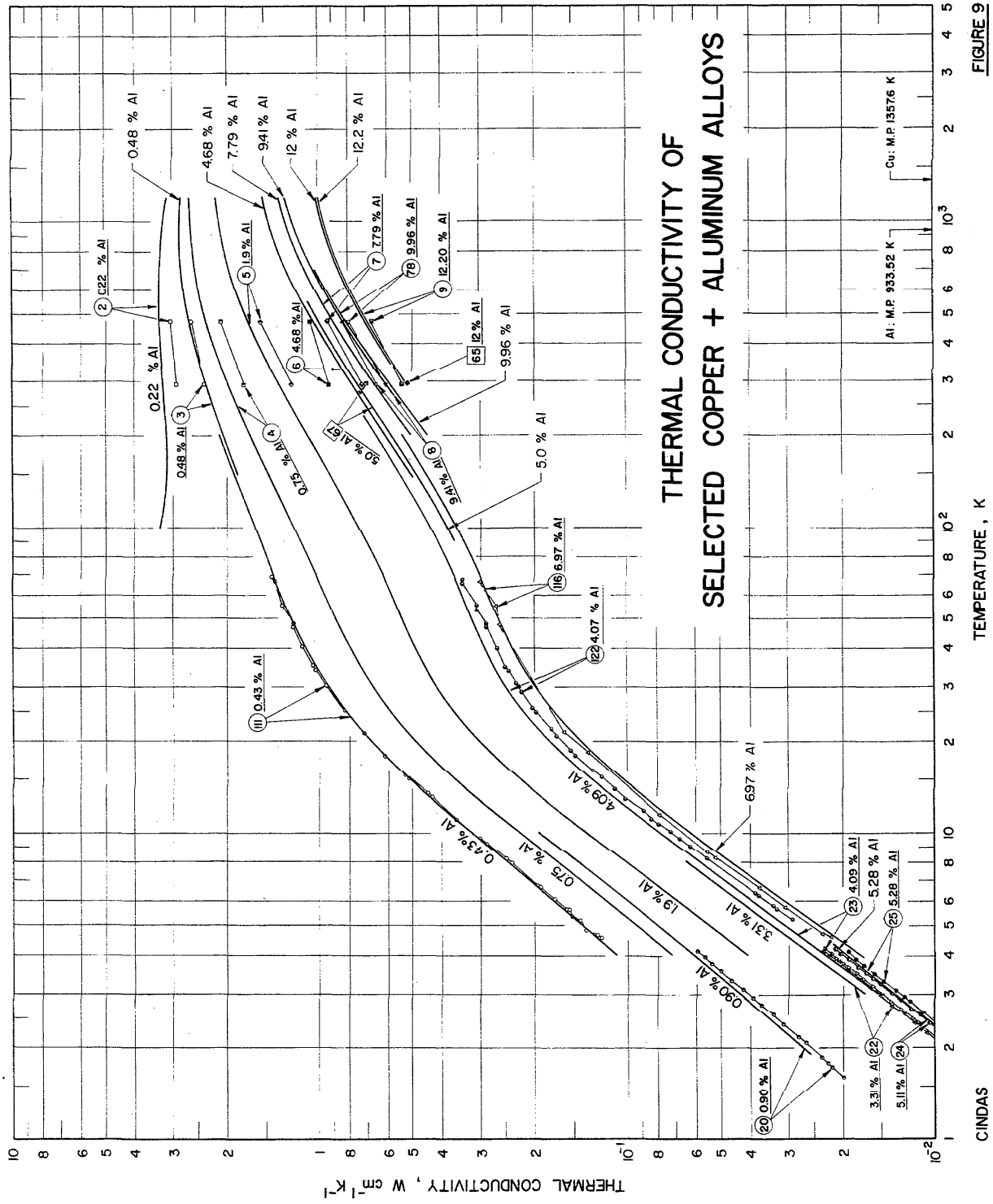
THERMAL CONDUCTIVITY OF
SELECTED COPPER + ALUMINUM ALLOYS
THERMAL CONDUCTIVITY , W cm⁻¹ K⁻¹
TEMPERATURE , K
Al : M.P. 933.52 K
Cu : M.P. 1357.6 K
0.48 % Al
4.68 % Al
7.79 % Al
9.41 % Al
12 % Al
12.2 % Al
0.22 % Al
0.48 % Al
0.75 % Al
4.68 % Al
7.79 % Al
9.96 % Al
12.20 % Al
12 % Al
9.96 % Al
5.0 % Al
9.41 % Al
50 % Al
6.97 % Al
4.07 % Al
0.43 % Al
6.97 % Al
4.09 % Al
0.75 % Al
0.43 % Al
1.9 % Al
3.31 % Al
5.28 % Al
0.90 % Al
4.09 % Al
5.28 % Al
3.31 % Al
5.11 % Al
0.90 % Al
CINDAS

FIGURE 9

TABLE 2. RECOMMENDED THERMAL CONDUCTIVITY OF ALUMINUM-COPPER ALLOY SYSTEM†

[Temperature, T, K; Thermal Conductivity, k, W cm^{-1} K^{-1}; Electronic Thermal Conductivity, k_e, W cm^{-1} K^{-1}; Lattice Thermal Conductivity, k_g, W cm^{-1} K^{-1}]

Al: 99.50% (99.79 At.%) Cu: 0.50% (0.21 At.%)				Al: 99.00% (99.57 At.%) Cu: 1.00% (0.43 At.%)				Al: 97.00% (98.70 At.%) Cu: 3.00% (1.30 At.%)				Al: 95.00% (97.81 At.%) Cu: 5.00% (2.19 At.%)			
ρ_o = 0.0600 μΩ cm				ρ_o = 0.1203 μΩ cm				ρ_o = 0.340 μΩ cm				ρ_o = 0.532 μΩ cm			
T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g
4	1.58*‡			4	0.814*‡			4	0.292*‡			4	0.189*	0.183	0.00578‡
6	2.36*‡			6	1.23*‡			6	0.442*‡			6	0.288*	0.275	0.0130‡
8	3.11*‡			8	1.65*‡			8	0.593*‡			8	0.388*	0.366	0.0222‡
10	3.81*‡			10	2.05*‡			10	0.741*‡			10	0.489*	0.456	0.0330‡
15	5.46*‡			15	3.04*‡			15	1.10*‡			15	0.738*	0.677	0.0610‡
20	6.73*‡			20	3.92*‡			20	1.45*‡			20	0.977*	0.892	0.0849‡
25	7.56*‡	7.30‡	0.265‡	25	4.64*‡	4.42‡	0.221‡	25	1.75*‡	1.61‡	0.139‡	25	1.19*	1.09	0.102‡
30	8.06*‡	7.78‡	0.285‡	30	5.14*‡	4.90‡	0.239‡	30	2.02*‡	1.87‡	0.152‡	30	1.39*	1.28	0.112‡
40	8.22*‡	7.94‡	0.285‡	40	5.64*‡	5.40‡	0.239‡	40	2.44*‡	2.28‡	0.155‡	40	1.71*	1.59	0.117‡
50	7.36*‡	7.09‡	0.265‡	50	5.45*‡	5.23‡	0.221‡	50	2.68*‡	2.53‡	0.147‡	50	1.92*	1.81	0.112‡
60	5.99*‡	5.75‡	0.241‡	60	4.80*‡	4.60‡	0.202‡	60	2.70*‡	2.56‡	0.138‡	60	2.00*	1.89	0.106‡
70	4.74*‡	4.52‡	0.218‡	70	4.04*‡	3.85‡	0.185‡	70	2.54*‡	2.41‡	0.127‡	70	1.98*	1.88	0.0985‡
80	3.77*‡	3.57‡	0.199‡	80	3.35*‡	3.18‡	0.170‡	80	2.33*‡	2.21‡	0.118‡	80	1.89*	1.80	0.0916‡
90	3.11*‡	2.93‡	0.183‡	90	2.85*‡	2.69‡	0.157‡	90	2.11*‡	2.00‡	0.110‡	90	1.79*	1.70	0.0857‡
100	2.78*‡	2.61‡	0.169‡	100	2.58*‡	2.43‡	0.145‡	100	1.99*‡	1.89‡	0.102‡	100	1.72*	1.64	0.0804‡
150	2.30*‡	2.18‡	0.123‡	150	2.20*‡	2.09‡	0.107‡	150	1.89*‡	1.81‡	0.0758‡	150	1.67*	1.61	0.0612‡
200	2.24*‡	2.14‡	0.0968‡	200	2.15*‡	2.07‡	0.0847‡	200	1.90*‡	1.84‡	0.0607‡	200	1.72*	1.67	0.0495‡
250	2.25*‡	2.17‡	0.0801‡	250	2.17*‡	2.10‡	0.0704‡	250	1.94*‡	1.89‡	0.0509‡	250	1.79*	1.75	0.0416‡
273	2.26*‡	2.19‡	0.0745‡	273	2.18*‡	2.12‡	0.0652‡	273	1.97*‡	1.92‡	0.0474‡	273	1.82*	1.78	0.0389‡
300	2.28‡	2.21‡	0.0685‡	300	2.21‡	2.15‡	0.0602‡	300	1.99*‡	1.95‡	0.0438‡	300	1.85	1.81	0.0360‡
350	2.31‡	2.25‡	0.0596‡	350	2.25‡	2.20‡	0.0525‡	350	2.04‡	2.00‡	0.0386‡	350	1.90	1.87	0.0319‡
400	2.32‡	2.27‡	0.0530‡	400	2.26‡	2.21‡	0.0467‡	400	2.07‡	2.04‡	0.0345‡	400	1.93	1.90	0.0285‡
500	2.29‡	2.25‡	0.0430‡	500	2.24‡	2.20‡	0.0382‡	500	2.07‡	2.04‡	0.0285‡	500	1.95	1.93	0.0237‡
600	2.25‡	2.21‡	0.0362‡	600	2.19‡	2.16‡	0.0322‡	600	2.05‡	2.03‡	0.0243‡	600	1.94	1.92	0.0203‡
700	2.19	2.16	0.0312‡	700	2.15	2.12	0.0279‡	700	2.02	2.00	0.0212‡	700	1.92	1.90	0.0177‡
800	2.13*	2.10	0.0273‡	800	2.08*	2.06	0.0245‡	800	1.97*	1.95	0.0189‡	800	1.89*	1.87	0.0157‡
900	2.06*	2.04	0.0243‡	900	2.02*	2.00	0.0219‡	873	1.94*	1.92	0.0177‡	833	1.88*	1.86	0.0152‡
923	2.05*	2.03	0.0238‡	913	2.01*	1.99	0.0217‡								

† Uncertainties in the total thermal conductivity, k, are as follows:
99.50 Al - 0.50 Cu: ± 15% up to 600 K and ± 6% above 600 K.
99.00 Al - 1.00 Cu: ± 15% up to 600 K and ± 6% above 600 K.
97.00 Al - 3.00 Cu: ± 15% up to 600 K and ± 6% above 600 K.
95.00 Al - 5.00 Cu: ± 8% below 100 K, ± 5% between 100 and 500 K, and ± 6% above 500 K.

‡ Provisional value.

‡ Typical value.

* In temperature range where no experimental thermal conductivity data are available.

TABLE 2. RECOMMENDED THERMAL CONDUCTIVITY OF ALUMINUM-COPPER ALLOY SYSTEM (continued) †

[Temperature, T, K; Thermal Conductivity, k, W cm^{-1} K^{-1}; Electronic Thermal Conductivity, k_e, W cm^{-1} K^{-1}; Lattice Thermal Conductivity, k_g, W cm^{-1} K^{-1}]

Al: 90.00% (95.49 At.%) Cu: 10.00% (4.51 At.%)				Al: 85.00% (93.03 At.%) Cu: 15.00% (6.97 At.%)				Al: 80.00% (90.40 At.%) Cu: 20.00% (9.60 At.%)				Al: 75.00% (87.60 At.%) Cu: 25.00% (12.40 At.%)			
ρ_o = 0.888 μΩ cm				ρ_o = 1.118 μΩ cm				ρ_o = 1.312 μΩ cm				ρ_o = 1.482 μΩ cm			
T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g
4	0.115*	0.110	0.00466‡	4	0.0913*	0.0870	0.00426‡	4	0.0786*	0.0745	0.00406‡	4	0.0699*	0.0659	0.00398‡
6	0.176*	0.165	0.0105‡	6	0.140*	0.130	0.00956‡	6	0.121*	0.112	0.00912‡	6	0.108*	0.0993	0.00894‡
8	0.238*	0.220	0.0179‡	8	0.189*	0.173	0.0163‡	8	0.165*	0.149	0.0156‡	8	0.147*	0.132	0.0153‡
10	0.300*	0.273	0.0266‡	10	0.240*	0.216	0.0243‡	10	0.209*	0.186	0.0232‡	10	0.188*	0.165	0.0227‡
15	0.455*	0.406	0.0491‡	15	0.365*	0.320	0.0449‡	15	0.317*	0.274	0.0428‡	15	0.285*	0.243	0.0420‡
20	0.604*	0.536	0.0684‡	20	0.484*	0.421	0.0625‡	20	0.420*	0.360	0.0597‡	20	0.378*	0.319	0.0585‡
25	0.741*	0.659	0.0823‡	25	0.594*	0.519	0.0752‡	25	0.515*	0.443	0.0718‡	25	0.462*	0.392	0.0704‡
30	0.865*	0.774	0.0905‡	30	0.694*	0.611	0.0827‡	30	0.602*	0.522	0.0789‡	30	0.540*	0.463	0.0774‡
40	1.08*	0.982	0.0942‡	40	0.862*	0.776	0.0861‡	40	0.749*	0.667	0.0822‡	40	0.674*	0.593	0.0806‡
50	1.24*	1.15	0.0905‡	50	0.993*	0.910	0.0827‡	50	0.866*	0.787	0.0789‡	50	0.777*	0.700	0.0774‡
60	1.35*	1.26	0.0853‡	60	1.09*	1.01	0.0779‡	60	0.951*	0.877	0.0744‡	60	0.857*	0.784	0.0729‡
70	1.38*	1.30	0.0794‡	70	1.14*	1.07	0.0725‡	70	1.01*	0.938	0.0692‡	70	0.911*	0.843	0.0679‡
80	1.38*	1.31	0.0738‡	80	1.16*	1.09	0.0674‡	80	1.03*	0.970	0.0644‡	80	0.943*	0.880	0.0631‡
90	1.35	1.28	0.0691‡	90	1.16	1.10	0.0631‡	90	1.04*	0.984	0.0602‡	90	0.960*	0.901	0.0591‡
100	1.33	1.27	0.0647‡	100	1.16	1.10	0.0592‡	100	1.06*	1.00	0.0565‡	100	0.978*	0.923	0.0554‡
150	1.39	1.34	0.0493‡	150	1.26	1.21	0.0451‡	150	1.15*	1.11	0.0430‡	150	1.09*	1.05	0.0422‡
200	1.47	1.43	0.0399‡	200	1.34	1.30	0.0365‡	200	1.25*	1.22	0.0348‡	200	1.18*	1.15	0.0341‡
250	1.55	1.52	0.0335‡	250	1.42	1.39	0.0306‡	250	1.33*	1.30	0.0292‡	250	1.27*	1.24	0.0287‡
273	1.58	1.55	0.0313‡	273	1.45	1.42	0.0286‡	273	1.37*	1.34	0.0273‡	273	1.30*	1.27	0.0268‡
300	1.61	1.58	0.0290‡	300	1.49	1.46	0.0265‡	300	1.40	1.37	0.0253‡	300	1.33*	1.31	0.0248‡
350	1.67	1.64	0.0257‡	350	1.54	1.52	0.0235‡	350	1.46	1.44	0.0224‡	350	1.39*	1.37	0.0219‡
400	1.71	1.69	0.0229‡	400	1.58	1.56	0.0209‡	400	1.50*	1.48	0.0200‡	400	1.43*	1.41	0.0196‡
500	1.74	1.72	0.0191‡	500	1.62	1.60	0.0174‡	500	1.54*	1.52	0.0166‡	500	1.47*	1.45	0.0163‡
600	1.75	1.73	0.0163‡	600	1.64*	1.63	0.0149‡	600	1.56*	1.55	0.0142‡	600	1.50*	1.49	0.0140‡
700	1.74	1.73	0.0142‡	700	1.64*	1.63	0.0130‡	700	1.56*	1.55	0.0124‡	700	1.50*	1.49	0.0122‡
800	1.72	1.71	0.0127‡	800	1.62*	1.61	0.0116‡	800	1.55*	1.54	0.0111‡	800	1.50*	1.49	0.0108‡
821	1.72	1.71	0.0124‡	821	1.62*	1.61	0.0113‡	821	1.55*	1.54	0.0109‡	821	1.50*	1.49	0.0106‡

† Uncertainties in the total thermal conductivity, k, are as follows:
90.00 Al - 10.00 Cu: ±8% below 100 K, ±5% between 100 and 500 K, and ±6% above 500 K.
85.00 Al - 15.00 Cu: ±10% below 100 K, ±5% between 100 and 500 K, and ±6% above 500 K.
80.00 Al - 20.00 Cu: ±10% below 100 K, ±5% between 100 and 500 K, and ±7% above 500 K.
75.00 Al - 25.00 Cu: ±10% below 100 K, ±5% between 100 and 500 K, and ±7% above 500 K.

‡ Typical value.

* In temperature range where no experimental thermal conductivity data are available.

TABLE 2. RECOMMENDED THERMAL CONDUCTIVITY OF ALUMINUM-COPPER ALLOY SYSTEM (continued) †

[Temperature, T, K; Thermal Conductivity, k, W cm^{-1} K^{-1}; Electronic Thermal Conductivity, k_e, W cm^{-1} K^{-1}; Lattice Thermal Conductivity, k_g, W cm^{-1} K^{-1}]

Al: 70.00% (84.60 At.%) Cu: 30.00% (15.40 At.%)				Al: 65.00% (81.39 At.%) Cu: 35.00% (18.61 At.%)				Al: 60.00% (77.94 At.%) Cu: 40.00% (22.06 At.%)				Al: 55.00% (74.22 At.%) Cu: 45.00% (25.78 At.%)			
ρ_o = 1.623 μΩ cm				ρ_o = 1.754 μΩ cm				ρ_o = 1.883 μΩ cm				ρ_o = 2.02 μΩ cm			
T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g
4	0.0641*	0.0602	0.00392‡	4	0.0596*	0.0557	0.00392‡	4	0.0558*	0.0519	0.00394‡	4	0.0524*	0.0484	0.00395‡
6	0.0993*	0.0905	0.00880‡	6	0.0924*	0.0836	0.00880‡	6	0.0866*	0.0778	0.00884‡	6	0.0812*	0.0723	0.00887‡
8	0.135*	0.120	0.0150‡	8	0.127*	0.112	0.0150‡	8	0.118*	0.103	0.0151‡	8	0.111*	0.0955	0.0152‡
10	0.172*	0.150	0.0223‡	10	0.160*	0.138	0.0223‡	10	0.150*	0.128	0.0224‡	10	0.142*	0.119	0.0225‡
15	0.262*	0.221	0.0413‡	15	0.244*	0.203	0.0413‡	15	0.228*	0.187	0.0415‡	15	0.217*	0.175	0.0417‡
20	0.348*	0.290	0.0575‡	20	0.324*	0.267	0.0575‡	20	0.306*	0.248	0.0578‡	20	0.290*	0.232	0.0580‡
25	0.425*	0.356	0.0693‡	25	0.399*	0.330	0.0693‡	25	0.377*	0.307	0.0696‡	25	0.357*	0.287	0.0798‡
30	0.497*	0.421	0.0761‡	30	0.466*	0.390	0.0761‡	30	0.439*	0.363	0.0764‡	30	0.416*	0.339	0.0768‡
40	0.618*	0.539	0.0793‡	40	0.579*	0.500	0.0793‡	40	0.546*	0.466	0.0796‡	40	0.517*	0.437	0.0799‡
50	0.724*	0.638	0.0861‡	50	0.669*	0.593	0.0761‡	50	0.631*	0.555	0.0764‡	50	0.597*	0.520	0.0768‡
60	0.787*	0.715	0.0718‡	60	0.740*	0.668	0.0718‡	60	0.700*	0.628	0.0721‡	60	0.662*	0.590	0.0724‡
70	0.841*	0.774	0.0668‡	70	0.793*	0.726	0.0668‡	70	0.751*	0.684	0.0670‡	70	0.711*	0.644	0.0673‡
80	0.877*	0.815	0.0621‡	80	0.830*	0.768	0.0621‡	80	0.787*	0.725	0.0623‡	80	0.748*	0.685	0.0626‡
90	0.900*	0.842	0.0581‡	90	0.856*	0.798	0.0581‡	90	0.813*	0.755	0.0583‡	90	0.778*	0.719	0.0586‡
100	0.924*	0.869	0.0545‡	100	0.880*	0.825	0.0545‡	100	0.850*	0.785	0.0547‡	100	0.805*	0.750	0.0549‡
150	1.04*	0.998	0.0415‡	150	0.998*	0.957	0.0415‡	150	0.963*	0.921	0.0417‡	150	0.929*	0.887	0.0418‡
200	1.14*	1.11	0.0336‡	200	1.10*	1.07	0.0336‡	200	1.06*	1.03	0.0337‡	200	1.03*	0.993	0.0338‡
250	1.22*	1.19	0.0282‡	250	1.17*	1.14	0.0282‡	250	1.14*	1.11	0.0283‡	250	1.10*	1.07	0.0284‡
273	1.25*	1.22	0.0263‡	273	1.21*	1.18	0.0263‡	273	1.17*	1.14	0.0264‡	273	1.13*	1.10	0.0266‡
300	1.28	1.26	0.0244‡	300	1.24*	1.22	0.0244‡	300	1.20	1.18	0.0245‡	300	1.17	1.15	0.0246‡
350	1.34	1.32	0.0216‡	350	1.29*	1.27	0.0216‡	350	1.25	1.23	0.0217‡	350	1.22	1.20	0.0218‡
400	1.38*	1.36	0.0193‡	400	1.33*	1.31	0.0193‡	400	1.29*	1.27	0.0194‡	400	1.26*	1.24	0.0194‡
500	1.42*	1.40	0.0160‡	500	1.38*	1.36	0.0160‡	500	1.34*	1.32	0.0161‡	500	1.32*	1.30	0.0162‡
600	1.45*	1.44	0.0137‡	600	1.40*	1.39	0.0137‡	600	1.37*	1.36	0.0138‡	600	1.34*	1.33	0.0138‡
700	1.46*	1.45	0.0120‡	700	1.42*	1.41	0.0120‡	700	1.38*	1.37	0.0120‡	700	1.35*	1.34	0.0121‡
800	1.45*	1.44	0.0107‡	800	1.41*	1.40	0.0107‡	800	1.38*	1.37	0.0107‡	800	1.35*	1.34	0.0108‡
821	1.45*	1.44	0.0105‡	821	1.41*	1.40	0.0105‡	821	1.38*	1.37	0.0105‡	821	1.35*	1.34	0.0106‡

† Uncertainties in the total thermal conductivity, k, are as follows:
70.00 Al - 30.00 Cu: ±10% below 100 K, ±5% between 100 and 500 K, and ±7% above 500 K.
65.00 Al - 35.00 Cu: ±12% below 100 K, ±5% between 100 and 500 K, and ±7% above 500 K.
60.00 Al - 40.00 Cu: ±12% below 100 K, ±5% between 100 and 500 K, and ±7% above 500 K.
55.00 Al - 45.00 Cu: ±12% below 80 K, ±5% between 80 and 500 K, and ±7% above 500 K.

‡ Typical value.

* In temperature range where no experimental thermal conductivity data are available.

TABLE 2. RECOMMENDED THERMAL CONDUCTIVITY OF ALUMINUM-COPPER ALLOY SYSTEM (continued) †

[Temperature, T, K; Thermal Conductivity, k, W cm^{-1} K^{-1}; Electronic Thermal Conductivity, k_e, W cm^{-1} K^{-1}; Lattice Thermal Conductivity, k_g, W cm^{-1} K^{-1}]

Al: 50.00% (70.20 At.%) Cu: 50.00% (29.80 At.%)				Al: 45.00% (65.83 At.%) Cu: 55.00% (34.17 At.%)				Al: 40.00% (61.09 At.%) Cu: 60.00% (38.91 At.%)				Al: 35.00% (55.91 At.%) Cu: 65.00% (44.09 At.%)			
ρ_o = 2.25 μΩ cm				ρ_o = 2.59 μΩ cm				ρ_o = 3.25 μΩ cm				ρ_o = 4.42 μΩ cm			
T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g
4	0.0474*	0.0434	0.00398‡	4	0.0420*‡	0.0380	0.00400‡	4	0.0342*‡	0.0302	0.00402‡	4	0.0269*‡	0.0228	0.00409‡
6	0.0736*	0.0647	0.00894‡	6	0.0659*‡	0.0569	0.00900‡	6	0.0541*‡	0.0450	0.00909‡	6	0.0430*‡	0.0338	0.00922‡
8	0.101*	0.0857	0.0153‡	8	0.0909*‡	0.0755	0.0154‡	8	0.0753*‡	0.0597	0.0156‡	8	0.0605*‡	0.0447	0.0158‡
10	0.130*	0.107	0.0227‡	10	0.117*‡	0.0942	0.0229‡	10	0.0974*‡	0.0744	0.0230‡	10	0.0786*‡	0.0552	0.0234‡
15	0.200*	0.158	0.0420‡	15	0.181*‡	0.139	0.0422‡	15	0.154*‡	0.111	0.0426‡	15	0.125*‡	0.0816	0.0434‡
20	0.266*	0.208	0.0585‡	20	0.242*‡	0.183	0.0590‡	20	0.206*‡	0.146	0.0595‡	20	0.168*‡	0.108	0.0603‡
25	0.328*	0.258	0.0704‡	25	0.296*‡	0.225	0.0708‡	25	0.252*‡	0.181	0.0714‡	25	0.206*‡	0.133	0.0726‡
30	0.383*	0.306	0.0774‡	30	0.344*‡	0.267	0.0775‡	30	0.293*‡	0.215	0.0782‡	30	0.237*‡	0.158	0.0793‡
40	0.475*	0.394	0.0806‡	40	0.426*‡	0.345	0.0810‡	40	0.361*‡	0.279	0.0817‡	40	0.290*‡	0.207	0.0830‡
50	0.548*	0.471	0.0774‡	50	0.494*‡	0.416	0.0779‡	50	0.415*‡	0.337	0.0784‡	50	0.332*‡	0.252	0.0797‡
60	0.609*	0.536	0.0729‡	60	0.550*‡	0.477	0.0730‡	60	0.463*‡	0.389	0.0737‡	60	0.368*‡	0.293	0.0748‡
70	0.658*	0.590	0.0679‡	70	0.596*‡	0.528	0.0680‡	70	0.499*‡	0.430	0.0686‡	70	0.400*‡	0.330	0.0697‡
80	0.695*	0.632	0.0631‡	80	0.631*	0.568	0.0634‡	80	0.535*	0.471	0.0640‡	80	0.431*	0.366	0.0650‡
90	0.726*	0.667	0.0591‡	90	0.661*	0.602	0.0594‡	90	0.565*	0.505	0.0599‡	90	0.457*	0.396	0.0610‡
100	0.753*	0.698	0.0554‡	100	0.689*	0.633	0.0558‡	100	0.594*	0.538	0.0562‡	100	0.483*	0.426	0.0571‡
150	0.880*	0.838	0.0422‡	150	0.814*	0.772	0.0425‡	150	0.722*	0.679	0.0429‡	150	0.598*	0.555	0.0435‡
200	0.979*	0.945	0.0341‡	200	0.915*	0.881	0.0343‡	200	0.820*	0.785	0.0345‡	200	0.691*	0.656	0.0350‡
250	1.06*	1.03	0.0287‡	250	0.996*	0.967	0.0289‡	250	0.902*	0.873	0.0291‡	250	0.772*	0.742	0.0296‡
273	1.09*	1.06	0.0268‡	273	1.03*	1.00	0.0270‡	273	0.933*	0.906	0.0271‡	273	0.804*	0.776	0.0276‡
300	1.12	1.10	0.0248‡	300	1.06	1.04	0.0250‡	300	0.968	0.943	0.0252‡	300	0.840	0.814	0.0256‡
350	1.18	1.16	0.0219‡	350	1.12*	1.10	0.0220‡	350	1.02*	1.00	0.0223‡	350	0.897*	0.874	0.0226‡
400	1.22*	1.20	0.0196‡	400	1.16*	1.14	0.0197‡	400	1.07*	1.05	0.0199‡	400	0.943*	0.923	0.0202‡
500	1.28*	1.26	0.0163‡	500	1.22*	1.20	0.0164‡	500	1.14*	1.12	0.0165‡	500	1.01*	0.997	0.0168‡
600	1.30*	1.29	0.0140‡	600	1.25*	1.24	0.0140‡	600	1.17*	1.16	0.0141‡	600	1.06*	1.05	0.0144‡
700	1.32*	1.31	0.0122‡	700	1.27*	1.26	0.0122‡	700	1.20*	1.19	0.0123‡	700	1.10*	1.09	0.0126‡
800	1.32*	1.31	0.0108‡	800	1.28*	1.27	0.0109‡	800	1.22*	1.21	0.0109‡	800	1.12*	1.11	0.0111‡
821	1.32*	1.31	0.0106‡	864	1.29*	1.28	0.0101‡	864	1.23*	1.22	0.0102‡	864	1.14*	1.13	0.0104‡

† Uncertainties in the total thermal conductivity, k, are as follows:
50.00 Al - 50.00 Cu: ±12% below 80 K, ±5% between 80 and 500 K, and ±7% above 500 K.
45.00 Al - 55.00 Cu: ±15% below 80 K, ±10% between 80 and 200 K, and ±7% above 200 K.
40.00 Al - 60.00 Cu: ±15% below 80 K, ±10% between 80 and 200 K, and ±8% above 200 K.
35.00 Al - 65.00 Cu: ±20% below 80 K, ±10% between 80 and 200 K, and ±8% above 200 K.

‡ Provisional value.

‡ Typical value.

* In temperature range where no experimental thermal conductivity data are available.

TABLE 2. RECOMMENDED THERMAL CONDUCTIVITY OF ALUMINUM-COPPER ALLOY SYSTEM (continued) †

[Temperature, T, K; Thermal Conductivity, k, W cm^{-1} K^{-1}; Electronic Thermal Conductivity, k_e, W cm^{-1} K^{-1}; Lattice Thermal Conductivity, k_g, W cm^{-1} K^{-1}]

Al: 30.00% (50.23 At.%) Cu: 70.00% (49.77 At.%)				Al: 25.00% (43.98 At.%) Cu: 75.00% (56.02 At.%)				Al: 20.00% (37.06 At.%) Cu: 80.00% (62.94 At.%)				Al: 15.00% (29.36 At.%) Cu: 85.00% (70.64 At.%)			
ρ_o = 6.61 μΩ cm				ρ_o = 12.4 μΩ cm											
T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g
4	0.0191*‡	0.0149	0.00416‡	4	0.0121*‡	0.00788	0.00424‡	4			0.00440‡	4			0.00471‡
6	0.0318*‡	0.0224	0.00938‡	6	0.0214*‡	0.0118	0.00955‡	6			0.00991‡	6			0.0107‡
8	0.0457*‡	0.0297	0.0160‡	8	0.0321*‡	0.0158	0.0163‡	8			0.0169‡	8			0.0182‡
10	0.0608*‡	0.0370	0.0238‡	10	0.0439*‡	0.0197	0.0242‡	10			0.0251‡	10			0.0269‡
15	0.0987*‡	0.0547	0.0440‡	15	0.0743*‡	0.0294	0.0449‡	15			0.0464‡	15			0.0498‡
20	0.134*‡	0.0723	0.0614‡	20	0.102*‡	0.0391	0.0627‡	20			0.0650‡	20			0.0696‡
25	0.163*‡	0.0896	0.0737‡	25	0.124*‡	0.0485	0.0750‡	25			0.0709‡	25			0.0834‡
30	0.188*‡	0.107	0.0806‡	30	0.140*‡	0.0580	0.0822‡	30			0.0851‡	30			0.0913‡
40	0.224*‡	0.140	0.0842‡	40	0.163*‡	0.0766	0.0860‡	40			0.0891‡	40			0.0954‡
50	0.253*‡	0.172	0.0810‡	50	0.177*‡	0.0947	0.0825‡	50			0.0852‡	50			0.0917‡
60	0.277*‡	0.201	0.0760‡	60	0.190*‡	0.112	0.0775‡	60			0.0801‡	60			0.0860‡
70	0.299*‡	0.228	0.0710‡	70	0.201*‡	0.129	0.0722‡	70			0.0748‡	70			0.0801‡
80	0.322*	0.256	0.0662‡	80	0.213*	0.145	0.0676‡	80			0.0699‡	80			0.0749‡
90	0.343*	0.281	0.0620‡	90	0.224*	0.161	0.0631‡	90			0.0653‡	90			0.0700‡
100	0.363*	0.305	0.0580‡	100	0.235*	0.176	0.0592‡	100			0.0613‡	100			0.0658‡
150	0.455*	0.411	0.0442‡	150	0.293*	0.248	0.0451‡	150			0.0467‡	150			0.0501‡
200	0.534*	0.499	0.0357‡	200	0.347*	0.311	0.0364‡	200			0.0377‡	200			0.0404‡
250	0.606*	0.576	0.0300‡	250	0.399*	0.368	0.0306‡	250			0.0317‡	250			0.0340‡
273	0.635*	0.607	0.0280‡	273	0.422*	0.393	0.0286‡	273			0.0296‡	273			0.0318‡
300	0.668	0.642	0.0260‡	300	0.446	0.420	0.0265‡	300	0.278*‡	0.250‡	0.0275‡	300	0.442‡	0.412	0.0295‡
350	0.722*	0.699	0.0230‡	350	0.489*	0.466	0.0234‡	350			0.0243‡	350	0.477‡	0.451	0.0260‡
400	0.768*	0.748	0.0205‡	400	0.529*	0.508	0.0209‡	400			0.0217‡	400	0.507‡	0.484	0.0233‡
500	0.842*	0.825	0.0170‡	500	0.596*	0.579	0.0174‡	500			0.0180‡	500	0.556‡	0.537	0.0193‡
600	0.898*	0.883	0.0146‡	600	0.652*	0.637	0.0148‡	600			0.0154‡	600	0.593*‡	0.576	0.0166‡
700	0.941*	0.928	0.0127‡	700	0.698*	0.685	0.0130‡	700			0.0135‡	700	0.620*‡	0.606	0.0144‡
800	0.971*	0.960	0.0113‡	800	0.735*	0.723	0.0116‡	800			0.0120‡	800	0.642*‡	0.629	0.0128‡
864	0.983*	0.972	0.0106‡	900	0.763*	0.753	0.0104‡	900			0.0108‡	900	0.659*‡	0.647	0.0116‡
				939	0.773*	0.763	0.0101‡	1000			0.00980‡	1000	0.671*‡	0.660	0.0106‡
								1100			0.00902‡	1200	0.686*‡	0.677	0.00896‡
								1232			0.00821‡	1310	0.691*‡	0.683	0.00832‡

† Uncertainties in the total thermal conductivity, k, are as follows:
30.00 Al - 70.00 Cu: ±25% below 80 K, ±10% between 80 and 200 K, and ±8% above 200 K.
25.00 Al - 75.00 Cu: ±30% below 80 K, ±10% between 80 and 200 K, and ±8% above 200 K.
20.00 Al - 80.00 Cu: ±20% at 300 K.
15.00 Al - 85.00 Cu: ±20% above 300 K.

‡ Provisional value.

‡ Typical value.

* In temperature range where no experimental thermal conductivity data are available.

TABLE 2. RECOMMENDED THERMAL CONDUCTIVITY OF ALUMINUM-COPPER ALLOY SYSTEM (continued)†

[Temperature, T, K; Thermal Conductivity, k, W cm^{-1} K^{-1}; Electronic Thermal Conductivity, k_e, W cm^{-1} K^{-1}; Lattice Thermal Conductivity, k_g, W cm^{-1} K^{-1}]

Al: 10.00% (20.74 At.%) Cu: 90.00% (79.26 At.%)				Al: 5.00% (11.03 At.%) Cu: 95.00% (88.97 At.%)				Al: 3.00% (6.79 At.%) Cu: 97.00% (93.21 At.%)				Al: 1.00% (2.32 At.%) Cu: 99.00% (97.68 At.%)			
				ρ_o = 7.23 μΩ cm				ρ_o = 5.53 μΩ cm				ρ_o = 2.36 μΩ cm			
T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g
4			0.00522‡	4	0.0197	0.0134	0.00628‡	4	0.0259	0.0177	0.00816‡	4	0.0531	0.0412	0.0119‡
6			0.0118‡	6	0.0345	0.0204	0.0141‡	6	0.0450	0.0265	0.0185‡	6	0.0885	0.0618	0.0267‡
8			0.0201‡	8	0.0509	0.0268	0.0241‡	8	0.0669	0.0352	0.0317‡	88	0.129	0.0824	0.0468‡
10			0.0299‡	10	0.0694	0.0336	0.0358‡	10	0.0896	0.0441	0.0455‡	10	0.173	0.103	0.0700‡
15			0.0551‡	15	0.116	0.0495	0.0662‡	15	0.151	0.0654	0.0856‡	15	0.284	0.153	0.131‡
20			0.0772‡	20	0.159	0.0665	0.0922‡	20	0.207	0.0867	0.120‡	20	0.382	0.201	0.181‡
25			0.0924‡	25	0.193	0.0824	0.111‡	25	0.249	0.106	0.143‡	25	0.463	0.250	0.213‡
30			0.101‡	30	0.220	0.0984	0.122‡	30	0.282	0.128	0.157‡	30	0.528	0.298	0.230‡
40			0.106‡	40	0.257	0.130	0.127‡	40	0.329	0.169	0.160‡	40	0.619	0.389	0.230‡
50			0.102‡	50	0.283	0.161	0.122‡	50	0.361	0.209	0.152‡	50	0.687	0.474	0.213‡
60			0.0952‡	60	0.304	0.189	0.115‡	60	0.388	0.246	0.142‡	60	0.746	0.551	0.195‡
70			0.0890‡	70	0.324	0.217	0.107‡	70	0.414	0.283	0.131‡	70	0.800	0.622	0.178‡
80			0.0831‡	80	0.344*	0.244	0.0995‡	80	0.440*	0.318	0.122‡	80	0.852*	0.688	0.164‡
90			0.0778‡	90	0.364*	0.271	0.0931‡	90	0.465*	0.352	0.113‡	90	0.903*	0.752	0.151‡
100			0.0730‡	100	0.385*	0.298	0.0873‡	100	0.491*	0.386	0.105‡	100	0.953*	0.813	0.140‡
150			0.0555‡	150	0.486*	0.420	0.0665‡	150	0.618*	0.540	0.0782‡	150	1.18*	1.08	0.103‡
200	0.442*	0.397	0.0448‡	200	0.581*	0.527	0.0538‡	200	0.740*	0.677	0.0626‡	200	1.38*	1.30	0.0816‡
250	0.522*	0.484	0.0377‡	250	0.673*	0.628	0.0452‡	250	0.854*	0.802	0.0525‡	250	1.55*	1.48	0.0678‡
273	0.555*	0.520	0.0352‡	273	0.713*	0.671	0.0422‡	273	0.903*	0.854	0.0489‡	273	1.63*	1.57	0.0628‡
300	0.596	0.563	0.0327‡	300	0.757	0.718	0.0391‡	300	0.960	0.915	0.0452‡	300	1.71	1.65	0.0580‡
350	0.665	0.636	0.0288‡	350	0.835	0.800	0.0346‡	350	1.06	1.02	0.0398‡	350	1.83	1.78	0.0506‡
400	0.730	0.704	0.0258‡	400	0.905	0.874	0.0309‡	400	1.15	1.11	0.0356‡	400	1.94	1.89	0.0450‡
500	0.843	0.822	0.0214‡	500	1.03	1.00	0.0257‡	500	1.30	1.27	0.0294‡	500	2.10	2.06	0.0368‡
600	0.941	0.923	0.0183‡	600	1.13	1.11	0.0220‡	600	1.43*	1.40	0.0251‡	600	2.22*	2.19	0.0310‡
700	1.03	1.01	0.0160‡	700	1.22	1.20	0.0192‡	700	1.51*	1.49	0.0219‡	700	2.31*	2.28	0.0269‡
800	1.09	1.08	0.0143‡	800	1.30	1.28	0.0171‡	800	1.59*	1.57	0.0195‡	800	2.37*	2.35	0.0236‡
900	1.14	1.13	0.0123‡	900	1.36	1.34	0.0154‡	900	1.66*	1.64	0.0175‡	900	2.41*	2.39	0.0211‡
1000	1.18	1.17	0.0117‡	1000	1.39	1.38	0.0140‡	1000	1.70*	1.68	0.0158‡	1000	2.44*	2.42	0.0190‡
1200	1.25	1.24	0.00991‡	1200	1.47*	1.46	0.0119‡	1200	1.77*	1.76	0.0135‡	1200	2.48*	2.46	0.0159‡
1313	1.27	1.26	0.00918‡	1331	1.50*	1.49	0.0108‡	1343	1.80*	1.79	0.0123‡	1352	2.49*	2.48	0.0142‡

† Uncertainties in the total thermal conductivity, k, are as follows:
10.00 Al - 90.00 Cu: ±10% above 200 K.
5.00 Al - 95.00 Cu: ±8% below 80 K, ±6% between 80 and 500 K, and ±8% above 500 K.
3.00 Al - 97.00 Cu: ±8% below 80 K, ±5% between 80 and 500 K, and ±7% above 500 K.
1.00 Al - 99.00 Cu: ±8% below 80 K, ±5% between 80 and 500 K, and ±6% above 500 K.

‡ Provisional value.

‡ Typical value.

* In temperature range where no experimental thermal conductivity data are available.

TABLE 2. RECOMMENDED THERMAL CONDUCTIVITY OF ALUMINUM-COPPER ALLOY SYSTEM (continued) †

[Temperature, T, K; Thermal Conductivity, k, W cm^{-1} K^{-1}; Electronic Thermal Conductivity, k_e, W cm^{-1} K^{-1}; Lattice Thermal Conductivity, k_g, W cm^{-1} K^{-1}]

Al: 0.50% (1.17 At.%) Cu: 99.50% (98.83 At.%)			
ρ_o = 1.270 μΩ cm			
T	k	k_e	k_g
4	0.0911	0.0771	0.0140
6	0.146	0.115	0.0314
8	0.209	0.154	0.0552
10	0.277	0.192	0.0854
15	0.445	0.282	0.163
20	0.591	0.369	0.222
25	0.715	0.455	0.260
30	0.819	0.539	0.280
40	0.975	0.695	0.280
50	1.09	0.832	0.260
60	1.18	0.948	0.236
70	1.26	1.05	0.214
80	1.34*	1.15	0.195
90	1.41*	1.22	0.180
100	1.47*	1.30	0.166
150	1.74*	1.62	0.121‡
200	1.96*	1.87	0.0950‡
250	2.14*	2.06	0.0786‡
273	2.21*	2.14	0.0731‡
300	2.28	2.21	0.0672‡
350	2.39	2.33	0.0585‡
400	2.49	2.44	0.0520‡
500	2.63*	2.59	0.0422‡
600	2.73*	2.69	0.0355‡
700	2.76*	2.73	0.0306‡
800	2.79*	2.76	0.0268‡
900	2.80*	2.78	0.0238‡
1000	2.80*	2.78	0.0215‡
1200	2.79*	2.77	0.0180‡
1354	2.76*	2.74	0.0160‡

† Uncertainties in the total thermal conductivity, k, are as follows:
0.50 Al - 99.50 Cu: ±6% below 80 K, ±5% between 30 and 500 K, and ±6% above 500 K.

‡ Typical value.

* In temperature range where no experimental thermal conductivity data are available.

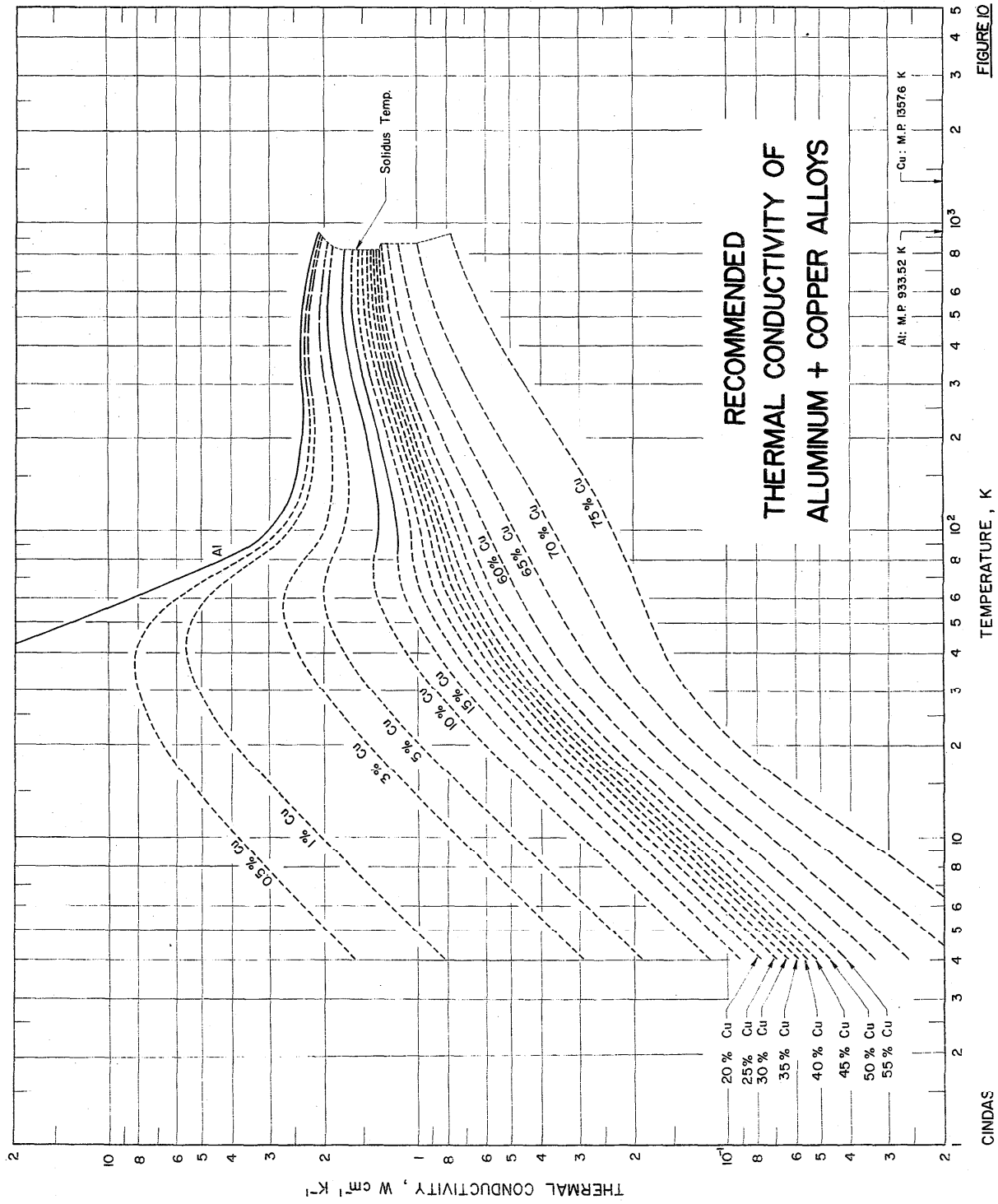

FIGURE 10

CINDAS

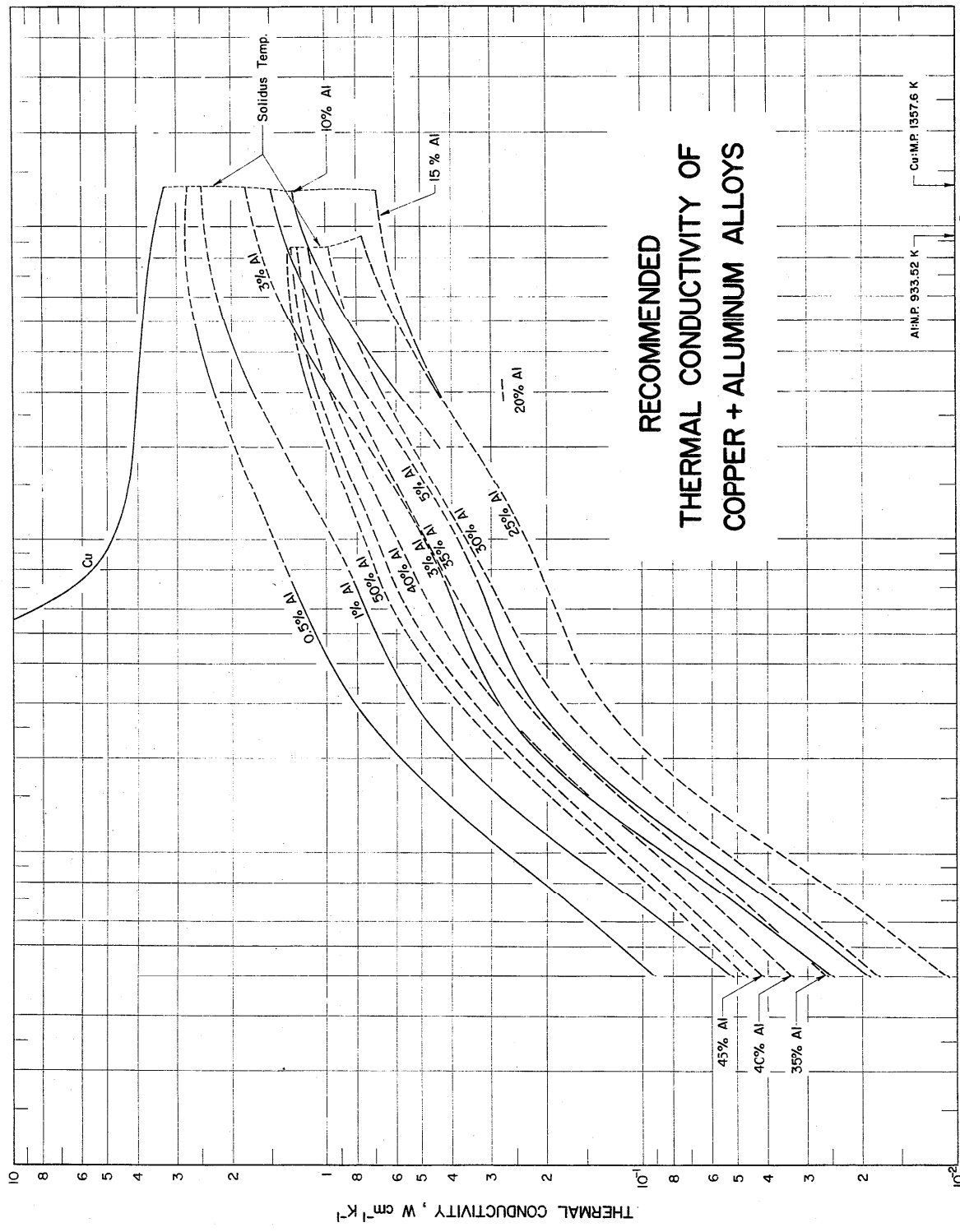
RECOMMENDED
THERMAL CONDUCTIVITY OF
COPPER + ALUMINUM ALLOYS
Solidus Temp.
Cu
0.5% Al
1% Al
3% Al
5% Al
10% Al
15 % Al
20% Al
25% Al
30% Al
32.5% Al
35% Al
40% Al
45% Al
50% Al
Cu: M.P. 1357.6 K
Al: M.P. 933.52 K
THERMAL CONDUCTIVITY , W cm⁻¹ K⁻¹
TEMPERATURE , K
CINDAS

FIGURE 11

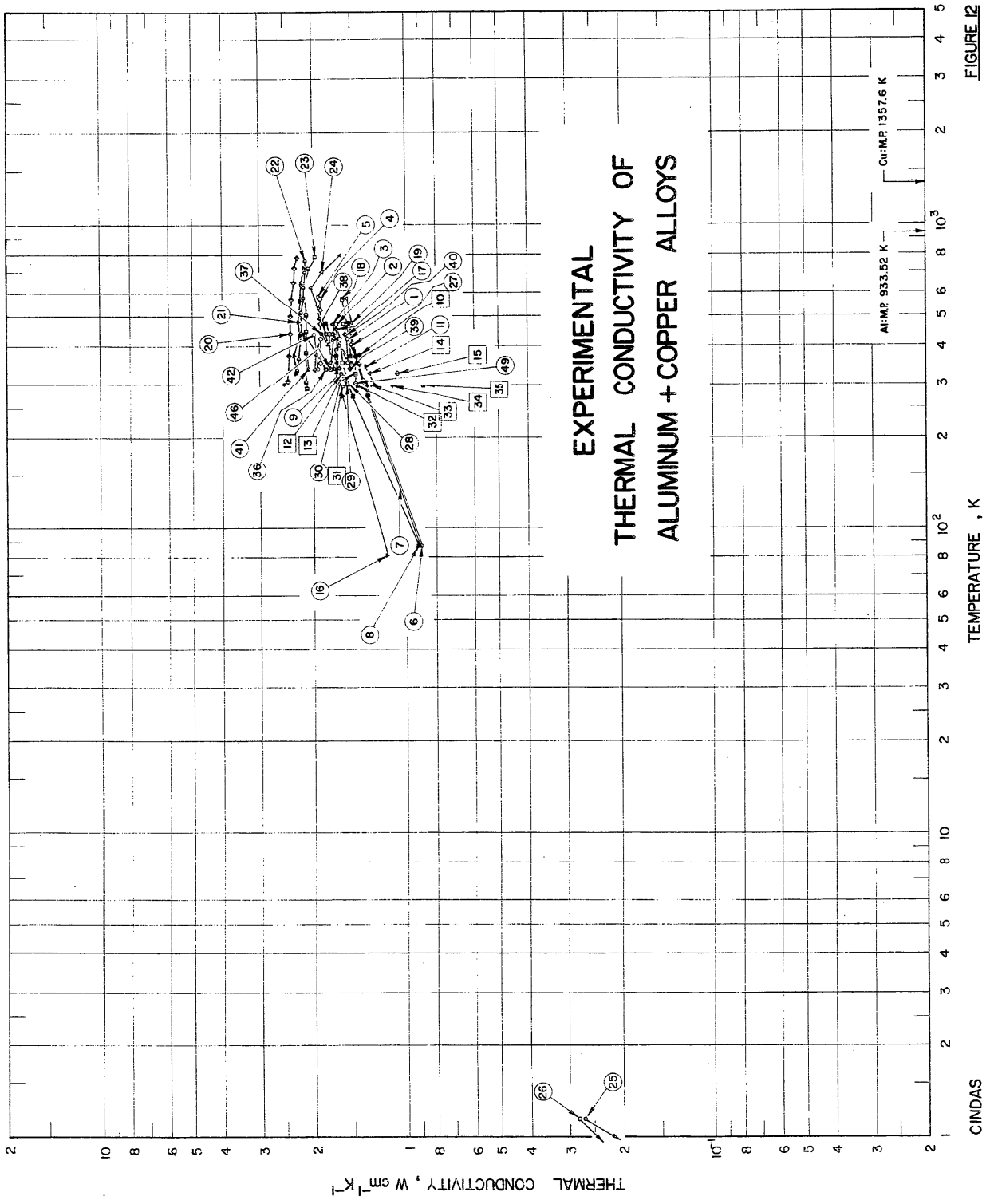
EXPERIMENTAL
THERMAL CONDUCTIVITY OF
ALUMINUM + COPPER ALLOYS
Al: M.P. 933.52 K
Cu: M.P. 1357.6 K
THERMAL CONDUCTIVITY , W cm⁻¹ K⁻¹
TEMPERATURE , K
CINDAS

FIGURE 12

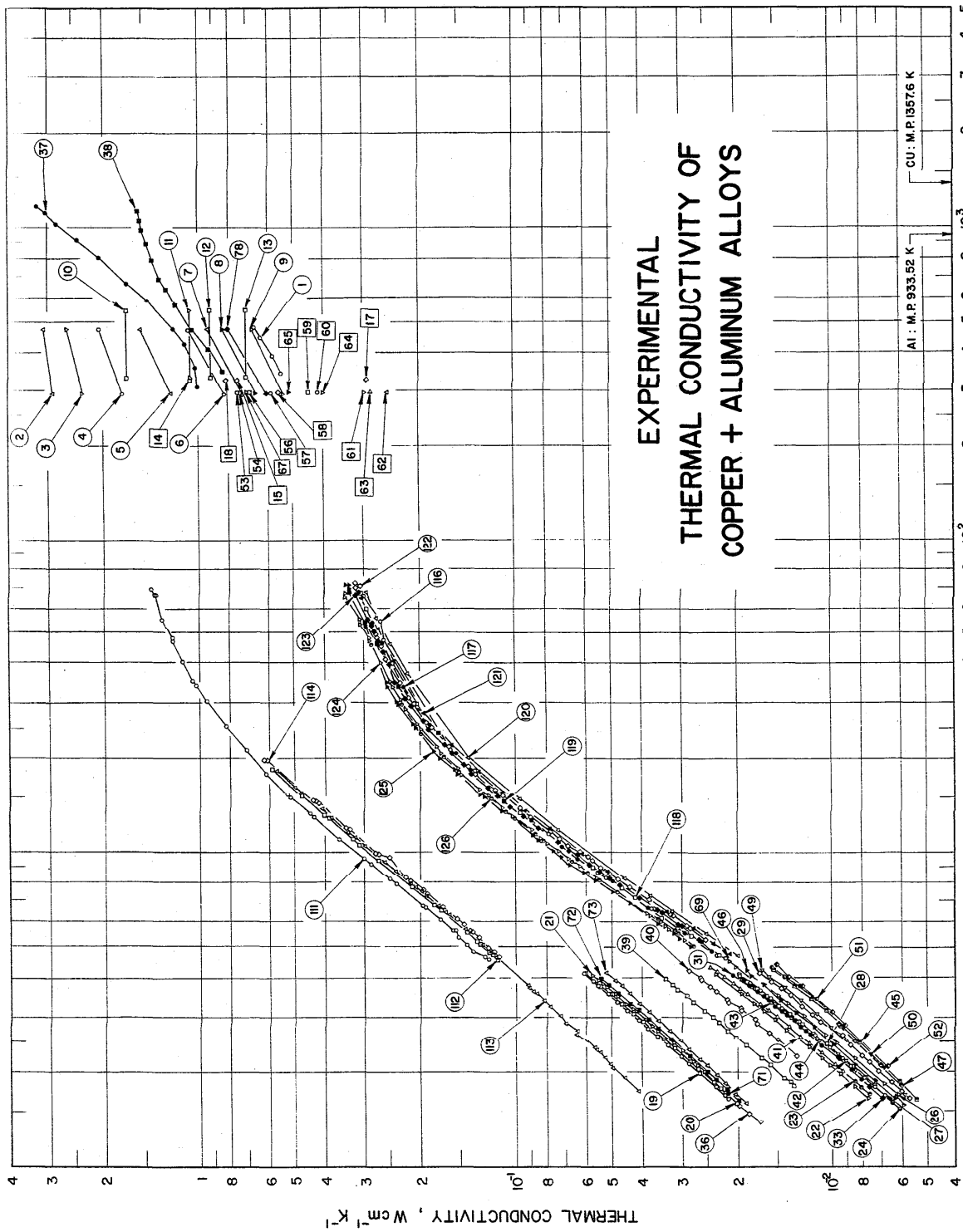
EXPERIMENTAL
THERMAL CONDUCTIVITY OF
COPPER + ALUMINUM ALLOYS
CU : M.P. 1357.6 K
AI : M.P. 933.52 K
THERMAL CONDUCTIVITY , W cm⁻¹ K⁻¹
TEMPERATURE , K
CINDAS

FIGURE 13

TABLE 3. THERMAL CONDUCTIVITY OF ALUMINUM + COPPER ALLOYS -- SPECIMEN CHARACTERIZATION AND MEASUREMENT INFORMATION

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) Al	Cu	Composition (continued), Specifications, and Remarks
1	44	Griffiths, E. and Schofield, F.H.	1928	L	353-473	No. 655	86.0	14.0	1.125 in. diameter and 15.5 in. long; 2 specimens chill-cast and 2 specimens sand-cast; one of each annealed at 450 C for 1 hr; electrical resistivity reported as 5.24, 6.25, 6.97, 7.69, 8.40, and 9.14 $\mu\Omega$ cm at 353, 423, 473, 523, 573, and 623 K, respectively; smoothed values reported.
2	44	Griffiths, E. and Schofield, F.H.	1928	L	353-473	No. 671	88.0	12.0	Similar to above except electrical resistivity reported as 5.20, 5.96, 6.51, 7.03, 7.57, and 8.11 $\mu\Omega$ cm at 353, 423, 473, 523, 573, and 623 K, respectively.
3	44	Griffiths, E. and Schofield, F.H.	1928	L	353-473	No. 921	~88.0	~12.0	Trace Fe; 1.125 in. diameter and 15.5 in. long; 2 specimens chill-cast; one of which annealed at 450 C for 1 hr; electrical resistivity reported as 4.64, 5.61, 6.34, 7.12, 7.95, and 8.82 $\mu\Omega$ cm at 353, 423, 473, 523, 573, and 623 K, respectively; smoothed values reported.
4	44	Griffiths, E. and Schofield, F.H.	1928	L	353-573	No. 2313	92.0	8.0	Similar to above except electrical resistivity reported as 4.96, 4.77, 5.40, 6.16, 7.03, and 8.08 $\mu\Omega$ cm at 353, 423, 473, 523, 573, and 623 K, respectively.
5	44	Griffiths, E. and Schofield, F.H.	1928	L	353-573	No. 2312	95.5	4.5	Similar to above except electrical resistivity reported as 4.94, 4.96, 5.61, 6.26, 6.92, and 7.58 $\mu\Omega$ cm at 353, 423, 473, 523, 573, and 623 K, respectively.
6	41	Mannchen, W.	1931	L	87-476		92.0	8.0	Cast; electrical conductivity reported as 65.1, 29.3, 20.2, and 14.6 x 10^4 Ω^{-1} cm^{-1} at 87, 273, 373, and 476 K, respectively; Lorenz function 1.549, 1.650, 1.891, and 2.18 x 10^{-8} V^2 K^{-2} at the above temperatures, respectively.
7	41	Mannchen, W.	1931	L	87-476				The above specimen; Lorenz function 1.58, 1.64, 1.94, and 2.20 x 10^{-8} V^2 K^{-2} at the above temperatures, respectively.
8	41	Mannchen, W.	1931	L	87-476		85.0	15.0	Cast; electrical conductivity reported as 59.6, 22.3, 16.0, and 14.2 x 10^4 Ω^{-1} cm^{-1} at 87, 273, 373, and 476 K, respectively; Lorenz function 1.74, 2.43, 2.79, and 2.67 x 10^{-8} V^2 K^{-2} at the above temperatures, respectively.
9	113	Grard, C. and Villey, J.	1927	E	353-423		96.0	4.0	Approximate composition; cast.
10	113	Grard, C. and Villey, J.	1927	E	373.2		88.0	12.0	Cast; density 2.95 g cm^{-3}; electrical conductivity 0.16 x 10^6 Ω^{-1} cm^{-1} at 100 C.
11	114	Czochralski, J.	1921		301-346		92.0	~8.0	Trace Si; density 2.85 to 2.9 g cm^{-3}.
12	45	Smith, A.W.	1925	L	326.2		90.0	10.0	1.9 cm in diameter and 10 cm long; prepared by fusing 99.97+ pure aluminum and copper supplied by Baker; electrical conductivity 26.0 x 10^4 Ω^{-1} cm^{-1} at 23 C.
13	45	Smith, A.W.	1925	L	326.2		80.0	20.0	Similar to above except electrical conductivity 20.9 x 10^4 Ω^{-1} cm^{-1} at 23 C.
14	45	Smith, A.W.	1925	L	326.2		70.0	30.0	Similar to above except electrical conductivity 18.5 x 10^4 Ω^{-1} cm^{-1} at 23 C.
15	45	Smith, A.W.	1925	L	326.2		50.0	50.0	Similar to above except electrical conductivity 15.3 x 10^4 Ω^{-1} cm^{-1} at 23 C.
16	42	Eucker, A. and Warrentrup, H.	1935	R	81, 273		96.0	4.0	Cast sheet; annealed at 510 C for 45 min and quenched in ice water; electrical resistivity 1.409 and 3.600 $\mu\Omega$ cm at -192 and 0 C, respectively.

* Not shown in figure.

TABLE 3. THERMAL CONDUCTIVITY OF ALUMINUM + COPPER ALLOYS -- SPECIMEN CHARACTERIZATION AND MEASUREMENT INFORMATION (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) Al	Cu	Composition (continued), Specifications, and Remarks
17	46	Griffiths, E. and Shakespear, G.A.	1922	L	353-453	V 671 A	88.0	12.0	15 in. long and 1 in. in diameter; supplied by Metallurgical Dept. of National Physical Laboratory (England); chill-cast.
18	46	Griffiths, E. and Shakespear, G.A.	1922	L	373-573	V 671 D	88.0	12.0	Prepared from commercially pure aluminum; 15 in. long and 1 in. in diameter; supplied by Metallurgical Dept. of National Physical Lab.; annealed at 450 C.
19	46	Griffiths, E. and Shakespear, G.A.	1922	L	373-573	V 671 C	88.0	12.0	Similar to above specimen except sand-cast.
20	58	Mikryukov, V.E. and Karagezyan, A.G.	1961	E	288-777		99.5	0.5	3 mm diameter and 300 mm long; prepared from 99.9 pure Al.
21	58	Mikryukov, V.E. and Karagezyan, A.G.	1961	E	328-723		99.0	1.0	Similar to above.
22	58	Mikryukov, V.E. and Karagezyan, A.G.	1961	E	333-762		96.0	4.0	Similar to above.
23	58	Mikryukov, V.E. and Karagezyan, A.G.	1961	E	288-781		93.0	7.0	Similar to above.
24	58	Mikryukov, V.E. and Karagezyan, A.G.	1961	E	334-792		90.0	10.0	Similar to above.
25	43	Satterthwaite, C.B.	1962	L	0.4-1.2	Al-26		0.3	Bar specimen with end sections machined to 0.5 in. diameter and 0.375 in. long, and with center portion 3.2 cm long milled to 0.5 mm thick and 2 mm wide; electrical resistivity ratio $\rho(273K)/\rho(1.2K) = 26$; transition temperature (s.c.) $T_c = 1.149$ K; in superconducting state.
26	43	Satterthwaite, C.B.	1962	L	0.4-1.2	Al-26			The above specimen measured in normal state; reported values calculated from the given formula $k = 0.242\ T$ (W cm^{-1} K^{-1}) in the same temperature range as above.
27	115	Elflein, M.	1937	L	298-393	I,1		5	Cylindrical specimen 1.5 cm in diameter and 3.0 cm in length; cast from 98 to 99 pure Al bar (contamination: <1.0 Fe, <0.9 Si, and <0.1 Cu + Zn) and key alloy (50 Al and 50 Cu) at 750 C, and then cooled in air; electrical resistivity reported as 5.00 $\mu\Omega$ cm at 20 C.
28	115	Elflein, M.	1937	L	298-393	I,5		5	Similar to the above specimen except 99.5 pure Al notch bar (contamination: 0.28 Fe and 0.22 Si) used for the melting; electrical resistivity reported as 4.56 $\mu\Omega$ cm at 20 C.
29	115	Elflein, M.	1937	L	298-393	I,5A		5	Similar to the above specimen except electrical resistivity reported as 4.66 $\mu\Omega$ cm at 20 C.
30	115	Elflein, M.	1937	L	298-393	I,5B		5	Similar to the above specimen except electrical resistivity reported as 4.42 $\mu\Omega$ cm at 20 C.
31	116, 168	Aliev, N.A.	1953	L	295.2	1		10.24	1.25 cm^2 in cross-section and 0.64 cm thick; electrical conductivity $21.18 \times 10^4\ \Omega^{-1}$ cm^{-1}; total Lorenz function 2.564×10^{-8} V^2 K^{-2}.
32	116, 168	Aliev, N.A.	1953	L	295.2	2		20.78	1.25 cm^2 in cross-section and 0.79 cm thick; electrical conductivity $18.79 \times 10^4\ \Omega^{-1}$ cm^{-1}; total Lorenz function 2.594×10^{-8} V^2 K^{-2}.
33	116, 168	Aliev, N.A.	1953	L	295.2	3		30.32	1.25 cm^2 in cross-section and 0.90 cm thick; electrical conductivity $16.72 \times 10^4\ \Omega^{-1}$ cm^{-1}; total Lorenz function 2.652×10^{-8} V^2 K^{-2}.

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TABLE 3. THERMAL CONDUCTIVITY OF ALUMINUM + COPPER ALLOYS -- SPECIMEN CHARACTERIZATION AND MEASUREMENT INFORMATION (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) Al	Cu	Composition (continued), Specifications, and Remarks
34	116, 168	Aliev, N.A.	1953	L	295.2	4		40.82	1.25 cm^2 in cross-section and 0.68 cm thick; electrical conductivity 15.26 x 10^4 Ω^{-1} cm^{-1}; total Lorenz function 2.455 x 10^{-8} V^2 K^{-2}.
35	116, 168	Aliev, N.A.	1953	L	295.2	5		48.00	1.25 cm^2 in cross-section and 0.70 cm thick; electrical conductivity 12.41 x 10^4 Ω^{-1} cm^{-1}; total Lorenz function 2.378 x 10^{-8} V^2 K^{-2}.
36	47	Hanson, D. and Rodgers, C.E.	1932	L	338, 438	3	98.47	1.01	0.209 Fe; original composition reported as 98.99 Al (containing 0.21 Fe and 0.29 Si) and 0.287 Si; as cast.
37	47	Hanson, D. and Rodgers, C.E.	1932	L	338, 438	5	94.47	5.06	0.199 Fe; original composition reported as 94.94 Al (containing 0.21 Fe and 0.29 Si) and 0.275 Si; as cast.
38	47	Hanson, D. and Rodgers, C.E.	1932	L	338, 438	6	92.34	7.20	0.195 Fe; original composition reported as 92.80 Al (containing 0.21 Fe and 0.29 Si) and 0.269 Si; as cast.
39	47	Hanson, D. and Rodgers, C.E.	1932	L	338, 438	8	88.05	11.51	0.186 Fe; original composition reported as 88.49 Al (containing 0.21 Fe and 0.29 Si) and 0.257 Si; as cast.
40	47	Hanson, D. and Rodgers, C.E.	1932	L	338, 438	9	79.52	15.46	0.78 Fe; original composition reported as 84.54 Al (containing 0.21 Fe and 0.29 Si) and 0.245 Si; as cast.
41	47	Hanson, D. and Rodgers, C.E.	1932	L	338, 438	3A	98.49	1.01	0.209 Fe; original composition reported as 98.49 Al (containing 0.21 Fe and 0.29 Si) and 0.287 Si; as cast.
42	47	Hanson, D. and Rodgers, C.E.	1932	L	338, 438	5A	94.47	5.06	0.199 Fe; original composition reported as 94.94 Al (containing 0.21 Fe and 0.29 Si) and 0.275 Si; annealed at 500 C for 24 hr, furnace cooled.
43*	47	Hanson, D. and Rodgers, C.E.	1932	L	338, 438	6A	92.34	7.20	0.195 Fe; original composition reported as 92.80 Al (containing 0.21 Fe and 0.29 Si) and 0.269 Si; annealed at 500 C for 24 hr, furnace cooled.
44*	47	Hanson, D. and Rodgers, C.E.	1932	L	338, 438	8A	88.05	11.51	0.186 Fe; original composition reported as 88.49 Al (containing 0.21 Fe and 0.29 Si) and 0.257 Si; annealed at 500 C for 24 hr, furnace cooled.
45*	47	Hanson, D. and Rodgers, C.E.	1932	L	338, 438	9A	84.12	15.46	0.178 Fe; original composition reported as 84.54 Al (containing 0.21 Fe and 0.29 Si) and 0.245 Si; annealed at 500 C for 24 hr, furnace cooled.
46	47	Hanson, D. and Rodgers, C.E.	1932	L	338, 438	10A	79.52	20.08	0.168 Fe; original composition reported as 79.92 Al (containing 0.21 Fe and 0.29 Si) and 0.232 Si; annealed at 500 C for 24 hr, furnace cooled.
47*	47	Hanson, D. and Rodgers, C.E.	1932	L	338, 438	11A	74.03	25.60	0.156 Fe; original composition reported as 74.40 Al (containing 0.21 Fe and 0.29 Si) and 0.216 Si; annealed at 500 C for 24 hr, furnace cooled.
48*	47	Hanson, D. and Rodgers, C.E.	1932	L	338, 438	12A	69.17	30.46	0.146 Fe; original composition reported as 69.54 Al (containing 0.21 Fe and 0.29 Si) and 0.202 Si; annealed at 500 C for 24 hr, furnace cooled.
49	47	Hanson, D. and Rodgers, C.E.	1932	L	303, 373	10	79.52	20.08	0.168 Fe; original composition reported as 79.92 Al (containing 0.21 Fe and 0.29 Si) and 0.232 Si; as cast.

* Not shown in figure.

TABLE 4. THERMAL CONDUCTIVITY OF COPPER + ALUMINUM ALLOYS -- SPECIMEN CHARACTERIZATION AND MEASUREMENT INFORMATION

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) Cu	Al	Composition (continued), Specifications, and Remarks
1	44	Griffiths, E. and Schofield, F.H.	1928	L	343-480	Aluminum bronze; 6	90.0	10.0	2.53 cm in diameter and 38 cm long; chill-cast and annealed; electrical resistivity reported as 14.7, 15.6, 16.0, 16.7, 17.5, and 18.3 $\mu\Omega$ cm at 293, 348, 373, 423, 473, and 523 K, respectively.
2	49	Smith, C.S. and Palmer, E.W.	1935	L	293,473	100	99.77	0.22	0.01 Fe; 0.75 in. in diameter and 8 in. long; rolled, annealed, and cold-drawn; heat-treated at 750 C for 2 hr; electrical conductivity reported as 41.91 and 27.59 x 10^4 Ω^{-1} cm^{-1} at 20 and 200 C, respectively.
3	49	Smith, C.S. and Palmer, E.W.	1935	L	293,473	101	99.47	0.47	0.02 Fe; similar to the above specimen except electrical conductivity reported as 32.10 and 22.91 x 10^4 Ω^{-1} cm^{-1} at 20 and 200 C, respectively.
4	49	Smith, C.S. and Palmer, E.W.	1935	L	293,473	76	99.20	0.71	0.09 Fe; similar to the above specimen except heat-treated at 700 C; electrical conductivity reported as 23.40 and 17.95 x 10^4 Ω^{-1} cm^{-1} at 20 and 200 C, respectively.
5	49	Smith, C.S. and Palmer, E.W.	1935	L	293,473	77	98.08	1.89	0.03 Fe; similar to the above specimen except electrical conductivity reported as 15.91 and 13.00 x 10^4 Ω^{-1} cm^{-1} at 20 and 200 C, respectively.
6	49	Smith, C.S. and Palmer, E.W.	1935	L	293,473	45	95.25	4.61	0.14 Fe; similar to the above specimen except electrical conductivity reported as 10.26 and 8.824 x 10^4 Ω^{-1} cm^{-1} at 20 and 200 C, respectively.
7	49	Smith, C.S. and Palmer, E.W.	1935	L	293,473	46	92.15	7.72	0.13 Fe; 0.75 in. in diameter and 8 in. long; rolled, annealed, and cold-drawn; heat-treated at 750 C for 3.5 hr; slowly cooled in furnace; electrical conductivity reported as 8.834 and 7.65 x 10^4 Ω^{-1} cm^{-1} at 20 and 200 C, respectively.
8	49	Smith, C.S. and Palmer, E.W.	1935	L	293,473	102	90.56	9.37	0.07 Fe; similar to the above specimen except heat-treated at 750 C for 2 hr, then very slowly cooled in furnace to 550 C, held for 4 hr, again furnace-cooled to 450 C, held for 16 hr, cooled to room temperature; electrical conductivity reported as 8.24 and 7.056 x 10^4 Ω^{-1} cm^{-1} at 20 and 200 C, respectively.
9	49	Smith, C.S. and Palmer, E.W.	1935	L	293,473	130	87.76	12.15	0.09 Fe; similar to the above specimen except electrical conductivity reported as 6.925 and 5.738 x 10^4 Ω^{-1} cm^{-1} at 20 and 200 C, respectively.
10	47	Hanson, D. and Rodgers, C.E.	1932	L	333,543	30a	98.25	1.75	Prepared from Al (containing 0.21 Fe, 0.29 Si) and high grade Cu; 0.5 in. diameter and 6.5 in. long; cast in iron mould 7 in. long and 9/16 in. in diameter, machined to size; annealed at 500 C.
11	47	Hanson, D. and Rodgers, C.E.	1932	L	333,543	28	94.90	5.10	Similar to the above specimen.
12	47	Hanson, D. and Rodgers, C.E.	1932	L	333,543	27a	91.55	8.45	Similar to the above specimen.
13	47	Hanson, D. and Rodgers, C.E.	1932	L	333,543	25	87.22	12.78	Similar to the above specimen.
14	45	Smith, A.W.	1925	L	326.2		50.0	50.0	1.9 cm in diameter and 10 cm long; prepared by double-fusing the Baker's analyzed copper and aluminum; electrical conductivity 15.3 x 10^4 Ω^{-1} cm^{-1} at 23 C.
15	45	Smith, A.W.	1925	L	326.2		60.0	40.0	Similar to the above specimen except electrical conductivity 10.6 x 10^4 Ω^{-1} cm^{-1} at 23 C.
16*	45	Smith, A.W.	1925	L	326.2		70.0	30.0	Similar to the above specimen except electrical conductivity 9.76 x 10^4 Ω^{-1} cm^{-1} at 23 C.

* Not shown in figure.

TABLE 4. THERMAL CONDUCTIVITY OF COPPER + ALUMINUM ALLOYS -- SPECIMEN CHARACTERIZATION AND MEASUREMENT INFORMATION (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) Cu	Al	Composition (continued), Specifications, and Remarks
17	45	Smith, A.W.	1925	L	326.2		80.0	20.0	Similar to the above specimen except electrical conductivity $3.60 \times 10^4\ \Omega^{-1}\ cm^{-1}$ at 23 C.
18	45	Smith, A.W.	1925	L	326.2		90.0	10.0	Similar to the above specimen except electrical conductivity $9.98 \times 10^4\ \Omega^{-1}\ cm^{-1}$ at 23 C.
19	51	Salter, J.A.M. and Charsley, P.	1967	L	1.7-4.2	2S	99.17	0.83	Calculated composition; single crystal; grown in a sealed graphite mould using the Bridgman technique; annealed in vacuo at 750 C for 14 hr; residual electrical resistivity 2.07 $\mu\Omega$ cm.
20	51	Salter, J.A.M. and Charsley, P.	1967	L	1.6-4.2	2	99.10	0.90	Calculated composition; polycrystalline; rod specimen 3 mm in diameter; annealed in vacuo at 750 C for 14 hr; residual electrical resistivity 2.12 $\mu\Omega$ cm; grain size 0.008 cm.
21	51	Salter, J.A.M. and Charsley, P.	1967	L	1.8-4.1	2AR	99.17	0.83	Calculated composition; polycrystalline; rod specimen 3 mm in diameter; residual electrical resistivity 2.10 $\mu\Omega$ cm; grain size 0.0015 cm.
22	51	Salter, J.A.M. and Charsley, P.	1967	L	1.7-4.2	8S	96.69	3.31	Calculated composition; single crystal; grown in a sealed graphite mould using the Bridgman technique; annealed in vacuo at 750 C for 14 hr; residual electrical resistivity 6.50 $\mu\Omega$ cm.
23	51	Salter, J.A.M. and Charsley, P.	1967	L	1.7-4.2	8	95.91	4.09	Calculated composition; polycrystalline; rod specimen 3 mm in diameter; annealed in vacuo at 750 C for 14 hr; grain size 0.0063 cm; residual electrical resistivity 6.63 $\mu\Omega$ cm.
24	51	Salter, J.A.M. and Charsley, P.	1967	L	1.5-4.2	12	94.89	5.11	Calculated composition; similar to the above specimen except residual electrical resistivity 7.21 $\mu\Omega$ cm and grain size 0.011 cm.
25*	51	Salter, J.A.M. and Charsley, P.	1967	L	1.9-4.1	12(550)	94.72	5.28	Calculated composition; polycrystalline; rod specimen 3 mm in diameter; annealed in vacuo at 550 C for 14 hr; grain size 0.0025 cm; residual electrical resistivity 7.41 $\mu\Omega$ cm.
26	51	Salter, J.A.M. and Charsley, P.	1967	L	1.7-4.0	12(450)	94.72	5.28	Calculated composition; polycrystalline; rod specimen 3 mm in diameter; annealed in vacuo at 450 C for 14 hr; residual electrical resistivity 7.57 $\mu\Omega$ cm; grain size 0.0009 cm.
27	117	Charsley, P., Leaver, A.D.W. and Salter, J.A.M.	1968	L	1.7-4.1		94.87	5.13	Single crystal; 0.2 x 10 x 2.5 cm; prepared by International Research and Development Co.; grown in graphite mould using Bridgman technique; measured in jig in the relaxed condition.
28	117	Charsley, P., et al.	1968	L	1.8-4.1		94.87	5.13	The above specimen; measured in jig under a stress of 7 kg mm^{-2}.
29	117	Charsley, P., et al.	1968	L	1.7-4.2		94.87	5.13	Polycrystalline; prepared by International Research and Development Co.; measured in jig in the relaxed condition.
30*	117	Charsley, P., et al.	1968	L	1.7-4.1		94.87	5.13	The above specimen; annealed at 750 C for 15 hr and measured in jig under a stress of 7 kg mm^{-2}.
31	117	Charsley, P., et al.	1968	L	1.9-4.1	A_1A_2; cross 1	94.87	5.13	Single crystal; grown in graphite mould using Bridgman technique; prepared by International Research and Development Co.; cross shape specimen obtained by cutting perpendicular to the large face of the crystal (0.2 x 10 x 2.5 cm); the orientation of the cross was chosen such that the primary edge dislocations made equal angles with both arms A_1A_2 and B_1B_2, the angle between the screw dislocations and these two directions however differed; heat flow in the arm A_1A_2 direction (angle to edges 55°, and angle to screws 35°).

* Not shown in figure.

TABLE 4. THERMAL CONDUCTIVITY OF COPPER + ALUMINUM ALLOYS -- SPECIMEN CHARACTERIZATION AND MEASUREMENT INFORMATION (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) Cu	Al	Composition (continued), Specifications, and Remarks
32*	117	Charsley, P., Leaver, A.D.W. and Salter, J.A.M.	1968	L	2.0-4.2	A_1A_2; cross 1	94.87	5.13	The above specimen measured in different cryostats.
33	117	Charsley, P., et al.	1968	L	1.7-4.1	B_1B_2; cross 1			The above specimen; heat flow in the arm B_1B_2 direction (angle to edges 63°, and angle to screws 73°).
34*	117	Charsley, P., et al.	1968	L	1.7-4.2	A_1A_2; cross 2	94.87	5.13	Similar to the above specimen except the orientation of the cross was chosen such that the primary edge dislocations made different angles with both arms A_1A_2 and B_1B_2, the angle between the screw dislocations and these two directions however equal; heat flow in the arm A_1A_2 direction (angle to edges 80°, and angle to screws 52°).
35*	117	Charsley, P., et al.	1968	L	1.8-3.4	B_1B_2; cross 2			The above specimen; heat flow in the arm B_1B_2 direction (angle to edges 46°, and angle to screws 52°).
36	19	Lindenfeld, P. and Pennebaker, W.B.	1962	L	1.4-4.2			0.617	Calculated composition; 3 x 0.125 x 0.031 in.; prepared from 99.999 pure Cu and 99.99+ pure Al; materials melted, outgassed in vacuum, stirred for 0.5 hr, then cast; annealed at 700 C for 22 hr; residual electrical resistivity 2.10 $\mu\Omega$ cm.
37	55	Inouye, H.	1957	C	309-1171		94	6	Iron and alumina used as comparative materials; data taken from smoothed curve.
38	55	Inouye, H.	1957	C	348-1125		92	8	Similar to the above specimen.
39	118	Charsley, P. and Salter, J.A.M.	1965	L	1.8-4.0	4		1.84	Calculated composition; polycrystalline; 3 mm diameter and 12 cm long; prepared by International Research and Development Co., Ltd.; materials melted in pure argon, cast, machined, swaged, and drawn; annealed in vacuo at 750 C for 14 hr; residual electrical resistivity 3.88 $\mu\Omega$ cm.
40	118	Charsley, P. and Salter, J.A.M.	1965	L	2.3-4.2	6		2.68	Similar to the above specimen except residual electrical resistivity 5.20 $\mu\Omega$ cm.
41	118	Charsley, P. and Salter, J.A.M.	1965	L	2.0-4.4	10		4.22	Similar to the above specimen except residual electrical resistivity 6.62 $\mu\Omega$ cm.
42	118	Charsley, P. and Salter, J.A.M.	1965	L	1.8-3.1	12S		5.11	Calculated composition; single crystal; 3 mm diameter and 12 cm long; grown by the Bridgman technique; grain size 0.1 ~ 0.3 mm; residual electrical resistivity 7.49 $\mu\Omega$ cm.
43	118	Charsley, P. and Salter, J.A.M.	1965	L	2.2-4.2	12S			The above specimen; 2nd run.
44	118	Charsley, P. and Salter, J.A.M.	1965	L	2.5-4.0	12S			Similar to the above specimen.
45	53	Kusunoki, M. and Suzuki, H.	1939	L	1.7-4.3	Specimen No. 5	93.03	6.97	Calculated composition; single crystal; cross-sectional area 2.546 mm^2; prepared from 99.999 pure Cu (Mitsubishi-Kinzoku Co. Ltd.) and 99.99 pure Al (Sumitomo-Kinzoku Co. Ltd.) by melting in a high purity graphite crucible by induction heating; grown in a splitting graphite mould by the Bridgman method using a seed crystal; annealed at 1000 C for 48 hr in a vacuum better than 10^{-5} mm Hg; electrolytically polished in phosphoric acid-ethyl alcohol; dislocation density 5.8 x 10^{10} cm^{-2}; residual electrical resistivity 7.617 $\mu\Omega$ cm.

TABLE 4. THERMAL CONDUCTIVITY OF COPPER + ALUMINUM ALLOYS -- SPECIMEN CHARACTERIZATION AND MEASUREMENT INFORMATION (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) Cu	Al	Composition (continued), Specifications, and Remarks
46	53	Kusunoki, M. and Suzuki, H.	1969	L	1.7-4.3	Specimen No. 9	93.03	6.97	Similar to the above specimen except specimen cross-sectional area 2.924 mm^2, dislocation density 1.0×10^6 cm^{-2}, and residual electrical resistivity 7.108 $\mu\Omega$ cm.
47	53	Kusunoki, M. and Suzuki, H.	1969	L	1.8-4.3	Specimen No. 11			Similar to the above specimen except specimen cross-sectional area 1.535 mm^2, dislocation density 6.6×10^{10} cm^{-2}, and residual electrical resistivity 7.568 $\mu\Omega$ cm.
48*	53	Kusunoki, M. and Suzuki, H.	1969	L	1.7-4.3	Specimen No. 12(1)			Similar to the above specimen except specimen cross-sectional area 1.915 mm^2, dislocation density 2.0×10^{10} cm^{-2}, and residual electrical resistivity 7.562 $\mu\Omega$ cm.
49	53	Kusunoki, M. and Suzuki, H.	1969	L	1.7-4.3	Specimen No. 13(1)			Similar to the above specimen except specimen cross-sectional area 2.318 mm^2, dislocation density 3.6×10^9 cm^{-2}, and residual electrical resistivity 7.571 $\mu\Omega$ cm.
50	53	Kusunoki, M. and Suzuki, H.	1969	L	1.6-4.3	Specimen No. 13(2)			Similar to the above specimen except specimen cross-sectional area 2.055 mm^2, dislocation density 4.4×10^{10} cm^{-2}, and residual electrical resistivity 7.605 $\mu\Omega$ cm.
51	53	Kusunoki, M. and Suzuki, H.	1969	L	1.8-4.3	Specimen No. 14			Similar to the above specimen except specimen cross-sectional area 1.569 mm^2, dislocation density 8.4×10^{10} cm^{-2}, and residual electrical resistivity 7.641 $\mu\Omega$ cm.
52	53	Kusunoki, M. and Suzuki, H.	1969	L	1.7-4.4	Specimen No. 12(2)			Same fabrication method and heat-treatment as the above specimen except no other details reported.
53	116, 168	Aliev, N.A.	1953	L	295.2	6	50.45		1.25 cm^2 in cross-section and 0.50 cm thick; electrical conductivity 10.68×10^4 Ω^{-1} cm^{-1}; total Lorenz function 2.345×10^{-8} V^2K^{-2}.
54	116, 168	Aliev, N.A.	1953	L	295.2	7	53.00		1.25 cm^2 in cross-section and 0.96 cm thick; electrical conductivity 10.74×10^4 Ω^{-1} cm^{-1}; total Lorenz function 2.334×10^{-8} V^2K^{-2}.
55*	116, 168	Aliev, N.A.	1953	L	295.2	8	55.00		1.25 cm^2 in cross-section and 0.52 cm thick; electrical conductivity 10.82×10^4 Ω^{-1} cm^{-1}; total Lorenz function 2.348×10^{-8} V^2K^{-2}.
56	116, 168	Aliev, N.A.	1953	L	295.2	9	59.62		1.25 cm^2 in cross-section and 0.52 cm thick; electrical conductivity 9.98×10^4 Ω^{-1} cm^{-1}; total Lorenz function 2.994×10^{-8} V^2K^{-2}.
57	116, 168	Aliev, N.A.	1953	L	295.2	10	69.99		1.25 cm^2 in cross-section and 1.18 cm thick; electrical conductivity 8.85×10^4 Ω^{-1} cm^{-1}; total Lorenz function 2.233×10^{-8} V^2K^{-2}.
58	116, 168	Aliev, N.A.	1953	L	295.2	11	71.00		1.25 cm^2 in cross-section and 0.96 cm thick; electrical conductivity 7.75×10^4 Ω^{-1} cm^{-1}; total Lorenz function 2.438×10^{-8} V^2K^{-2}.
59	116, 168	Aliev, N.A.	1953	L	295.2	12	73.00		1.25 cm^2 in cross-section and 1.49 cm thick; electrical conductivity 6.71×10^4 Ω^{-1} cm^{-1}; total Lorenz function 2.247×10^{-8} V^2K^{-2}.
60	116, 168	Aliev, N.A.	1953	L	295.2	13	76.00		1.25 cm^2 in cross-section and 0.80 cm thick; electrical conductivity 6.02×10^4 Ω^{-1} cm^{-1}; total Lorenz function 2.438×10^{-8} V^2K^{-2}.
61	116, 168	Aliev, N.A.	1953	L	295.2	14	77.00		1.25 cm^2 in cross-section and 0.74 cm thick; electrical conductivity 4.25×10^4 Ω^{-1} cm^{-1}; total Lorenz function 2.438×10^{-8} V^2K^{-2}.
62	116, 168	Aliev, N.A.	1953	L	295.2	15	78.00		1.25 cm^2 in cross-section and 0.80 cm thick; electrical conductivity 3.54×10^4 Ω^{-1} cm^{-1}; total Lorenz function 2.392×10^{-8} V^2K^{-2}.

* Not shown in figure.

TABLE 4. THERMAL CONDUCTIVITY OF COPPER + ALUMINUM ALLOYS -- SPECIMEN CHARACTERIZATION AND MEASUREMENT INFORMATION (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) Cu	Al	Composition (continued), Specifications, and Remarks
63	116, 168	Aliev, N.A.	1953	L	295.2	16	79.58		1.25 cm^2 in cross-section and 0.98 cm thick; electrical conductivity 4.16 x 10^4 Ω^{-1} cm^{-1}; total Lorenz function 2.360 x 10^{-8} V^2K^{-2}.
64	116, 168	Aliev, N.A.	1953	L	295.2	17	83.00		1.25 cm^2 in cross-section and 1.16 cm thick; electrical conductivity 5.95 x 10^4 Ω^{-1} cm^{-1}; total Lorenz function 2.277 x 10^{-8} V^2K^{-2}.
65	116, 168	Aliev, N.A.	1953	L	295.2	18	88.00		1.25 cm^2 in cross-section and 1.35 cm thick; electrical conductivity 7.40 x 10^4 Ω^{-1} cm^{-1}; total Lorenz function 2.348 x 10^{-8} V^2K^{-2}.
66*	116, 168	Aliev, N.A.	1953	L	295.2	19	89.22		1.25 cm^2 in cross-section and 0.60 cm thick; electrical conductivity 10.04 x 10^4 Ω^{-1} cm^{-1}; total Lorenz function 2.304 x 10^{-8} V^2K^{-2}.
67	116, 168	Aliev, N.A.	1953	L	295.2	20	95.00		1.25 cm^2 in cross-section and 0.51 cm thick; electrical conductivity 10.50 x 10^4 Ω^{-1} cm^{-1}; total Lorenz function 2.258 x 10^{-8} V^2K^{-2}.
68*	169	Charsley, P. and Salter, J.A.M.	1965	L	1.6-4.1			5.47	Polycrystalline specimen; annealed.
69	169	Charsley, P. and Salter, J.A.M.	1965	L	1.6-4.5			5.47	Polycrystalline specimen; plastically deformed (6%).
70*	169	Charsley, P. and Salter, J.A.M.	1965	L	2.4-4.2			5.47	Polycrystalline specimen; plastically deformed (12%).
71	52	Charsley, P., Salter, J.A.M. and Leaver, A.D.W.	1968	L	1.6-4.2	2		0.90	Polycrystalline; 3 mm in diameter and 10 cm long; prepared by International Research and Development Co., Ltd.; annealed at 750 C for 15 hr in graphite tubes in vacuo and furnace cooled.
72	52	Charsley, P., et al.	1968	L	1.6-4.0	2 (2.9%)		0.90	Similar to the above specimen except 2.9% deformed.
73	52	Charsley, P., et al.	1968	L	1.6-4.2	2 (10%)		0.83	Similar to the above specimen except 10% deformed.
74*	52	Charsley, P., et al.	1968	L	1.7-4.2	8 (6%)		4.09	Similar to the above specimen except 6% deformed.
75*	52	Charsley, P., et al.	1968	L	1.6-4.4	12 (6.2%)		5.11	Similar to the above specimen except 6.2% deformed.
76*	52	Charsley, P., et al.	1968	L	2.4-4.2	12 (12.8%)		5.28	Similar to the above specimen except 12.8% deformed.
77*	49	Smith, C.S. and Palmer, E.W.	1935	L	293,473	Bar 50	89.88	9.90	0.22 Fe; 0.75 in. diameter and 8 in. long; rolled to 1.25 in. in diameter, annealed at 700-750 C, cold-drawn to size; heat-treated at 750 C for 3.5 hr, slowly air-cooled; electrical conductivity 7.923 and 6.724 x 10^4 Ω^{-1} cm^{-1} at 20 and 200 C, respectively.
78	49	Smith, C.S. and Palmer, E.W.	1935	L	293,473	Bar 49	89.38	9.41	0.52 Fe, 0.38 Sn, 0.31 Ni, and trace Zn; 0.75 in. diameter and 8 in. long; same fabrication method as the above specimen; heat-treated at 750 C for 3.5 hr, very slowly cooled; electrical conductivity 7.314 and 6.364 x 10^4 Ω^{-1} cm^{-1} at 20 and 200 C, respectively.
79*	119, 169	Friedman, A.J., Chu, T.K., Klemens, P.G., and Reynolds, C.A.	1972	L	1.7-4.0	A		4.07	Polycrystalline; form factor 37.50 cm^{-1}; prepared from 99.999 pure copper supplied by Johnsons and Matthey and from 99.99 pure aluminum supplied by Jarrell Ash Co. by melting in an evacuated quartz beat, casting into a quartz capillary and quenching in an ice bath; annealed in vacuo at 1273 K for 18 hr; average grain size 1 mm; residual electrical resistivity 7.51 $\mu\Omega$cm.

* Not shown in figure.

TABLE 4. THERMAL CONDUCTIVITY OF COPPER + ALUMINUM ALLOYS -- SPECIMEN CHARACTERIZATION AND MEASUREMENT INFORMATION (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) Cu	Composition (weight percent) Al	Composition (continued), Specifications, and Remarks
80*	119, 169	Friedman, A.J., Chu, T.K., Klemens, P.G., and Reynolds, C.A.	1972	L	1.5-3.8	A			The above specimen irradiated for 6 hr at 25 to 60 C at the Brookhaven National Laboratory BMRR facility for a total fast neutron (>1 MeV) dosage of 4×10^{17} n cm^{-2} and a total thermal dosage of 1×10^{15} n cm^{-2}; form factor 37.57 cm^{-1}; residual electrical resistivity 7.46 $\mu\Omega$ cm.
81*	119, 169, 170	Friedman, A.J., et al.	1972	L	1.7-3.8	B		4.07	Some fabrication method as the above specimen A; form factor 35.67 cm^{-1}; residual electrical resistivity 7.60 $\mu\Omega$ cm.
82*	119, 169, 170	Friedman, A.J., et al.	1972	L	1.3-3.7	B			The above specimen deformed in tension, 6.1%, at room temperature; form factor 47.4 cm^{-1}; residual electrical resistivity 7.89 $\mu\Omega$ cm.
83*	119, 169	Friedman, A.J., et al.	1972	L	1.3-3.8	B			The above specimen annealed in vacuo at 573 K for 24 hr; form factor 47.0 cm^{-1}; residual electrical resistivity 7.90 $\mu\Omega$ cm.
84*	119, 169	Friedman, A.J., et al.	1972	L	1.4-3.9	B			The above specimen irradiation treated same as the above specimen A for curve No. 73; form factor 46.9 cm^{-1}; residual electrical resistivity 7.83 $\mu\Omega$ cm.
85*	119, 169	Friedman, A.J., et al.	1972	L	1.6-3.8	B			The above specimen annealed in vacuo at 573 K for 24 hr; form factor 46.6 cm^{-1}; residual electrical resistivity 7.95 $\mu\Omega$ cm.
86*	54	Mitchell, M.A., Klemens, P.G., and Reynolds, C.A.	1971	L	1.3-4.1	A		4.5	Obtained from Materials Research Corp., Orangeburg, N.Y.; prepared from 99.999 pure Al and Cu by vacuum induction melting, then machining and swaging to 0.125 in. in diameter; cold-worked in liquid nitrogen, then kept at 293 K for 3 hr; residual electrical resistivity 7.995 $\mu\Omega$ cm.
87*	54	Mitchell, M.A., et al.	1971	L	1.4-4.1	B			Similar to the above specimen A but annealed at 1193 K for 48 hr after cold-work; residual electrical resistivity 7.461 $\mu\Omega$ cm.
88*	54	Mitchell, M.A., et al.	1971	L	1.3-4.2	C1			Similar to the above specimen A but annealed at 1123 K for 28 hr after cold-work, then given 9.5% torsional strain at 293 K, re-annealed at 300 K for 12 hr; residual electrical resistivity 7.468 $\mu\Omega$ cm.
89*	54	Mitchell, M.A., et al.	1971	L	1.4-4.1	C2			The above specimen re-annealed at 373 K for 48 hr; residual electrical resistivity 7.450 $\mu\Omega$ cm.
90*	54	Mitchell, M.A., et al.	1971	L	1.4-4.0	C3			The above specimen re-annealed at 693 K for 20 hr; residual electrical resistivity 7.463 $\mu\Omega$ cm.
91*	54	Mitchell, M.A., et al.	1971	L	1.3-4.1	C4			The above specimen re-annealed at 713 K for 48 hr; residual electrical resistivity 7.404 $\mu\Omega$ cm.
92*	54	Mitchell, M.A., et al.	1971	L	1.2-4.1	D			Same composition, supplier, and fabrication method as the above specimen A but swaged to 3/16 in. in diameter; annealed at 1205 K for 48 hr; residual electrical resistivity 7.350 $\mu\Omega$ cm.
93*	54	Mitchell, M.A., et al.	1971	L	1.5-4.1	E1			Similar to the above specimen D but given, after annealing, 9.33% tensile strain at 77 K with maximum stress 28.5 kg mm^{-2} and strain rate 0.0093 s^{-1}; then re-annealed at 300 K for 12 hr; residual electrical resistivity 7.586 $\mu\Omega$ cm.
94*	54	Mitchell, M.A., et al.	1971	L	1.3-4.1	E2			The above specimen re-annealed at 422 K for 48 hr; residual electrical resistivity 7.475 $\mu\Omega$ cm.
95*	54	Mitchell, M.A., et al.	1971	L	1.4-4.1	E3			The above specimen re-annealed at 552 K for 48 hr; residual electrical resistivity 7.498 $\mu\Omega$ cm.

* Not shown in figure.

TABLE 4. THERMAL CONDUCTIVITY OF COPPER + ALUMINUM ALLOYS -- SPECIMEN CHARACTERIZATION AND MEASUREMENT INFORMATION (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) Cu	Composition (weight percent) Al	Composition (continued), Specifications, and Remarks
96*	54	Mitchell, M.A., Klemens, P.G., and Reynolds, C.A.	1971	L	1.2-4.1	E4		4.5	The above specimen re-annealed at 673 K for 48 hr; residual electrical resistivity 7.542 μΩ cm.
97*	54	Mitchell, M.A., et al.	1971	L	1.2-4.2	E5			The above specimen re-annealed at 797 K for 48 hr; residual electrical resistivity 7.456 μΩ cm.
98*	54	Mitchell, M.A., et al.	1971	L	1.2-4.2	E6			The above specimen re-annealed at 920 K for 48 hr; residual electrical resistivity 7.453 μΩ cm.
99*	54	Mitchell, M.A., et al.	1971	L	1.4-4.1	E7			The above specimen re-annealed at 1202 K for 48 hr; residual electrical resistivity 7.441 μΩ cm.
100*	54	Mitchell, M.A., et al.	1971	L	1.3-4.2	F1			Similar to the above specimen E1 but annealed at 1202 K for 48 hr, then given 8.13% tensile strain at 77 K with maximum stress 29 kg mm^{-2} and strain rate 0.0081 s^{-1}, re-annealed at 360 K for 48 hr; residual electrical resistivity 7.567 μΩ cm.
101*	54	Mitchell, M.A., et al.	1971	L	1.4-4.2	F2			The above specimen re-annealed at 564 K for 0.5 hr; residual electrical resistivity 7.536 μΩ cm.
102*	54	Mitchell, M.A., et al.	1971	L	1.2-4.2	F3			The above specimen re-annealed at 565 K for 1.5 hr; residual electrical resistivity 7.536 μΩ cm.
103*	54	Mitchell, M.A., et al.	1971	L	1.5-4.2	F4			The above specimen re-annealed at 567 K for 48 hr; residual electrical resistivity 7.498 μΩ cm.
104*	54	Mitchell, M.A., et al.	1971	L	1.5-4.2	F5			The above specimen re-annealed at 570 K for 97 hr; residual electrical resistivity 7.498 μΩ cm.
105*	54	Mitchell, M.A., et al.	1971	L	1.3-4.2	G1			Similar to the above specimen F1 but given, after annealing, 9.26% tensile strain at 77 K with maximum stress 25.1 kg mm^{-2} and strain rate 0.004 s^{-1}, re-annealed at 344 K for 48 hr; residual electrical resistivity 7.644 μΩ cm.
106*	54	Mitchell, M.A., et al.	1971	L	1.2-4.2	G2			The above specimen re-annealed at 670 K for 0.5 hr; residual electrical resistivity 7.625 μΩ cm.
107*	54	Mitchell, M.A., et al.	1971	L	1.2-4.2	G3			The above specimen re-annealed at 661 K for 1.5 hr; residual electrical resistivity 7.612 μΩ cm.
108*	54	Mitchell, M.A., et al.	1971	L	1.2-4.1	G4			The above specimen re-annealed at 660 K for 48 hr; residual electrical resistivity 7.601 μΩ cm.
109*	54	Mitchell, M.A., et al.	1971	L	1.2-4.2	G5			The above specimen re-annealed at 732 K for 48 hr; residual electrical resistivity 7.553 μΩ cm.
110*	54	Mitchell, M.A., et al.	1971	L	1.2-4.1	G6			The above specimen re-annealed at 1308 K for 48 hr; residual electrical resistivity 7.576 μΩ cm.
111	48, 171	Chu, T.K. and Lipschultz, F.P.	1972	L	4.6-69	C1		0.43	Supplied by American Anaconda Brass Co.; 0.5 in. diameter x 8 in. long with central 5 in. machined to 0.25 in. in diameter; annealed at 1273 K for 48 hr; electrical resistivity 1.066, 1.066, 1.302, and 2.670 μΩ cm at 1.1, 4.2, 77, and 273 K, respectively.
112	48, 171	Chu, T.K. and Lipschultz, F.P.	1972	L	4.5-55	C2			The above specimen fatigued for 500 cycles with maximum load 6.4 kg mm^{-2}; electrical resistivity 1.071, 1.067, 1.301, and 2.664 μΩ cm at 1.1, 4.2, 77, and 273 K, respectively.

* Not shown in figure.

TABLE 4. THERMAL CONDUCTIVITY OF COPPER + ALUMINUM ALLOYS -- SPECIMEN CHARACTERIZATION AND MEASUREMENT INFORMATION (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) Cu	Composition (weight percent) Al	Composition (continued), Specifications, and Remarks
113	48, 171	Chu, T.K. and Lipschultz, F.P.	1972	L	1.7-72	C3		0.43	The above specimen fatigued for 10^4 cycles with maximum load 6.4 kg mm^{-2}; electrical resistivity 1.069, 1.069, 1.304, and 2.663 $\mu\Omega$ cm at 1.1, 4.2, 77, and 273 K, respectively.
114	48, 171	Chu, T.K. and Lipschultz, F.P.	1972	L	4.6-69	C5			Similar to the above specimen C1 but given a 5% plastic deform under uniaxial stress; electrical resistivity 1.066, 1.066, 1.294, and 2.660 $\mu\Omega$ cm at 1.1, 4.2, 77, and 273 K, respectively.
115*	48, 171	Chu, T.K. and Lipschultz, F.P.	1972	L	4.6-66	C6			The above specimen fatigued for 10^5 cycles with maximum load 6.4 kg mm^{-2}; electrical resistivity 1.064, 1.306, and 2.665 $\mu\Omega$cm at 4.2, 77, and 273 K, respectively.
116	48, 171	Chu, T.K. and Lipschultz, F.P.	1972	L	4.6-66	B1		6.97	Same supplier and dimensions as the above specimen C1; annealed at 1237 K for 48 hr; electrical resistivity 7.868, 7.867, 8.253, and 10.19 $\mu\Omega$ cm at 1.1, 4.2, 77, and 273 K, respectively.
117	48, 171	Chu, T.K. and Lipschultz, F.P.	1972	L	4.9-68	B2			The above specimen fatigued for 500 cycles with maximum load 8.3 kg mm^{-2}; electrical resistivity 7.850, 7.853, 8.250, and 10.16 $\mu\Omega$ cm at 1.1, 4.2, 77, and 273 K, respectively.
118	48, 171	Chu, T.K. and Lipschultz, F.P.	1972	L	4.7-68	B3			The above specimen fatigued for 10^4 cycles; electrical resistivity 7.806, 7.806, 8.204, and 10.10 $\mu\Omega$ cm at 1.1, 4.2, 77, and 273 K, respectively.
119	48, 171	Chu, T.K. and Lipschultz, F.P.	1972	L	5.4-68	B4			The above specimen fatigued for 10^5 cycles; electrical resistivity 7.813, 7.813, 8.217, and 10.14 $\mu\Omega$ cm at 1.1, 4.2, 77, and 273 K, respectively.
120	48, 171	Chu, T.K. and Lipschultz, F.P.	1972	L	4.7-68	B5		6.97	Similar to the above specimen B1 but given a 5% plastic deform under uniaxial stress; electrical resistivity 7.889, 7.889, 8.288, and 10.16 $\mu\Omega$ cm at 1.1, 4.2, 77, and 273 K, respectively.
121	48, 171	Chu, T.K. and Lipschultz, F.P.	1972	L	4.8-65	B6			The above specimen fatigued for 2 x 10^5 cycles with maximum load 8.3 kg mm^{-2}; electrical resistivity 7.891, 8.273, and 10.21 $\mu\Omega$ cm at 4.2, 77, and 273 K, respectively.
122	50	Friedman, A.J.	1974	L	5.3-73	5		4.07	The same irradiated specimen B for curve No. 82; electrical resistivity 7.832, 7.832, 8.204, and 10.033 $\mu\Omega$ cm at 1.2, 4.2, 77, and 273 K, respectively.
123	50	Friedman, A.J.	1974	L	5.3-70	5			The above specimen re-annealed at 573 K for 24 hr; electrical resistivity 7.949, 7.949, 8.314, and 10.150 K at 1.2, 4.2, 77, and 273 K, respectively.
124	50	Friedman, A.J.	1974	L	5.3-68	6		4.07	Form factor 37.497 cm^{-1}; annealed in vacuum at 1273 K for 18 hr; electrical resistivity 7.513, 7.513, 7.867, and 9.630 $\mu\Omega$ cm at 1.2, 4.2, 77, and 273 K, respectively.
125	50	Friedman, A.J.	1974	L	5.0-72	6			The above specimen.
126	50	Friedman, A.J.	1974	L	5.0-67	6			The above specimen given the same irradiation treatment as the specimen B for curve No. 82; form factor 37.569 cm^{-1}; electrical resistivity 7.461, 7.461, 7.812, and 9.564 $\mu\Omega$ cm at 1.2, 4.2, 77, and 273 K, respectively.
127*	120	Leaver, A.D.W. and Charsley, P.	1971	L	1.9-4.0	2 Al		0.83	Similar to the specimen for curve No. 73; annealed; residual electrical resistivity 2.080 $\mu\Omega$cm.
128*	120	Leaver, A.D.W. and Charsley, P.	1971	L	1.8-4.1	2 Al			The above specimen tensile strained 8.2% under a stress of 16.93 kg mm^{-2}; residual electrical resistivity 2.109 $\mu\Omega$cm.
129*	120	Leaver, A.D.W. and	1971	L	2.0-4.0	12 Al		5.56	Polycrystalline; obtained from International Research and Development Co., Ltd.; residual electrical resistivity 7.61 $\mu\Omega$cm.

* Not shown in figure.

TABLE 4. THERMAL CONDUCTIVITY OF COPPER + ALUMINUM ALLOYS -- SPECIMEN CHARACTERIZATION AND MEASUREMENT INFORMATION (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) Cu	Al	Composition (continued), Specifications, and Remarks
130*	120	Leaver, A.D.W. and Charsley, P.	1971	L	1.8-4.0	12 Al			The above specimen tensile strained 1.8% under a stress of 16.38 kg mm^{-2}; residual electrical resistivity 7.62 $\mu\Omega$ cm.
131*	120	Leaver, A.D.W. and Charsley, P.	1971	L	2.0-4.2	12 Al		5.56	Single crystal; grown in a graphite mold by the Bridgman technique; annealed.
132*	120	Leaver, A.D.W. and Charsley, P.	1971	L	2.2-4.1	12 Al			The above specimen tensile strained 7.3% under a stress of 3.03 kg mm^{-2}.
133*	120	Leaver, A.D.W. and Charsley, P.	1971	L	1.9-4.0	12 Al			The above specimen tensile strained 17.0% under a stress of 4.48 kg mm^{-2}.
134*	120	Leaver, A.D.W. and Charsley, P.	1971	L	2.0-4.1	12 Al			The above specimen tensile strained 22.5% under a stress of 6.73 kg mm^{-2}.
135*	121	Kogure, Y. and Hiki, Y.	1973	L	1.6-6.6		97.8	2.2	Calculated composition (5 a/o Al); 2.5 mm dia x 70 mm long; prepared from 99.99+ Cu and Al by vacuum melting and casting; annealed in vacuum at 850 C for 15 hrs.
136*	172	Kapoor, A., Rowlands, J.A., and Woods, S.B.	1974	L	0.48-3.9		95.5	4.5	Calculated composition (10 a/o Al); cylindrical specimen 3.6 mm in diameter; prepared by melting the pure materials in a quartz container in vacuum, resulted ingot swaged to size; cold-worked; residual electrical resistivity 7.54 $\mu\Omega$ cm.
137*	172	Kapoor, A., et al.	1974	L	0.52-4.0				The above specimen annealed in vacuum at 600 K for 12 hr; residual electrical resistivity 6.79 $\mu\Omega$ cm.
138*	172	Kapoor, A., et al.	1974	L	0.48-3.7				The above specimen reannealed in vacuum at 675 K for 12 hr; residual electrical resistivity 6.88 $\mu\Omega$ cm.
139*	172	Kapoor, A., et al.	1974	L	0.65-4.0				The above specimen reannealed in vacuum at 1000 K for 12 hr; residual electrical resistivity 6.69 $\mu\Omega$ cm.

* Not shown in figure.

4.2. Aluminum-Magnesium Alloy System

The aluminum-magnesium alloy system does not form a continuous series of solid solutions. The maximum solid solubility of magnesium in aluminum is 17.4% (18.9 At.%) at 723 K and the solubility decreases at higher and lower temperatures, being only 1.9% (2.1 At.%) at 373 K. The maximum solid solubility of aluminum in magnesium is 12.7% (11.6 At.%) at 710 K and likewise it decreases at higher and lower temperatures, being only about 1.5% (1.3 At.%) at 373 K. Thus the region of solid solution of this alloy system is even more limited than that of the aluminum-copper alloy system. As noted in section 3, the values for the thermal conductivity of much of this system are derived from experimental data on specimens in which the solid-solution phase was presumably frozen in. Hence, these values may not always be reproducible and are therefore provisional rather than recommended.

There are 50 sets of experimental thermal conductivity data available for this system. Of the 32 data sets for Al + Mg alloys listed in table 6 and shown in figure 18, seven sets are merely single data points. Of the data sets for Mg + Al alloys listed in table 7 and shown in figure 19, ten sets are single data points.

For the Al + Mg alloys, measurements were limited to specimens containing no more than 15% Mg. Recommended curves are, therefore, given for 0.5 to 10% Mg alloys only. They follow the slopes of the data of Johnson [56] (Al + Mg curves 5 and 6) and of Powell et al. [57] (Al + Mg curves 18–22) at low temperatures, and in this region the data of Mohan et al. [190] on a binary Al + Mg alloy (Al + Mg curve 28) are within 10% of the interpolated values from the recommended curves. At higher temperatures the recommended curves follow the trend of the high-temperature data of Mikryukov and Karagezyan [58] (Al + Mg curves 8–11). The alloys measured by Powell et al. are age hardened and since most of the impurities are heavier than Mg, there are fewer impurities per atom than indicated and the error incurred is in the effective Mg content scale. In addition, most of the weight of the analysis was given to the higher Mg content alloys. In a conductivity versus composition plot for 300 K, all the available data are shown to be congruous and complementary except those of Johnson [56] (Al + Mg curves 5 and 6) for specimens of uncertain composition and those from Materials Design Engineering [123] (Al + Mg curves 16 and 17) for as-cast specimens. A conductivity-composition curve at 300 K for 0 to 10% Mg is thus constructed based on those data which are in agreement with one another. The k_e values at 300 K were calculated from eq (12), and the k_g values at 300 K were derived as the differences between k and k_e values. These k_g values were extrapolated to higher temperatures up to the solidus temperatures according to the temperature dependence of eq (35) and to lower temperatures according to the pattern of k_g curves derived from the available experimental k and the calculated k_e around the region of maximum k_g and according to T^2 dependence at lower temperatures assuming k_g to be negligible at 1 K. The total thermal conductivity values were than obtained by adding the extrapolated k_g and the calculated k_e.

For the Mg+Al alloys, no measurements were made below 85 K and none for alloys containing more than 14% Al. The data of Smith [45] (Mg+Al curves 1 and 2) and of Kikuchi [59] (Mg+Al curves 8–13) were favored in constructing the conductivity-composition curve for 300 K. The data of Staebler and Mannchen [41,124] (Mg+Al curves 3–5) were rejected because the values of the total Lorenz function calculated from their thermal conductivity and electrical resistivity results are obviously too large (3.25 to 3.65 $10^{-8}V^2K^{-2}$ at 73 K), which leads to the conclusion that their thermal conductivity data are too high. Maybrey [60] did not measure electrical resistivity, but his thermal conductivity data are in the same neighborhood of magnitude as those of Staebler and Mannchen, and are hence taken out of consideration. The remaining measurements other than those of Smith and of Kikuchi were made on specimens of nonspecific composition, and, therefore, would be given less weight in constructing the conductivity-composition isotherm. It, then, left the data of Smith and of Kikuchi as the basis for the construction. The k_e values were calculated from eq (12) and those at 300 K were plotted on the conductivity-composition graph. The k_g values at 300 K were taken as the differences between k and k_e values. These k_g values were similarly extrapolated to lower and higher temperatures according to the appropriate temperature dependences. The total thermal conductivity values were obtained by adding these k_g to the calculated k_e. Since there is no information regarding where the maxima of the k_g curves occur, no k_g values are given below 100 K and hence no total k values are reported at low temperatures for the dilute alloys, even though the k_e values are known. The k values of the 5 and 10% Al alloys are given only in the range between 250 and 350 K, since electrical resistivity values are available only in this range.

A graphical comparison of the recommended total thermal conductivity values with selected experimental data is given in figures 14 and 15. The smooth solid curves in these figures were obtained by interpolating the recommended values of table 5 in order to obtain thermal conductivity values for the desired alloy compositions. For aluminum-rich alloys shown in figure 14, the recommended values are in agreement with the data of Powell et al. [57] (Al+Mg curves 18–20) at low temperatures to within 10% and with the data of Meyer-Rassler [122] (Al+Mg curve 7) and of Mikryukov and Karagezyan [58] (Al+Mg curves 8–11) at higher temperatures to within 8%. For magnesium-rich alloys shown in figure 15, the recommended values are in agreement with the data of Kikuchi [59] (Mg+Al curves 8–13), of Smith [45] (Mg+Al curves 1 and 2), and of Giuliani [135] (Mg+Al curve 14) to within 6%.

The resulting recommended values for k, k_e, and k_g are tabulated in table 5 for 10 alloy compositions. These values are for alloys which have not been severely cold worked or quenched. The k values are also presented in figures 16 and 17. The values of residual electrical resistivity for eight of the 10 alloys are also given in table 5. The uncertainties of the k values are stated in a footnote to table 5, while the uncertainties of the k_e and k_g values are indicated by their being designated as recommended, provisional, or typical values. The ranges of uncertainties of recommended, provisional, and typical values are less than ±15%, between ±15 and ±30%, and greater than ±30%, respectively. The k_g values are very uncertain and are merely to serve as correction terms for the derivation of the total thermal conductivities.

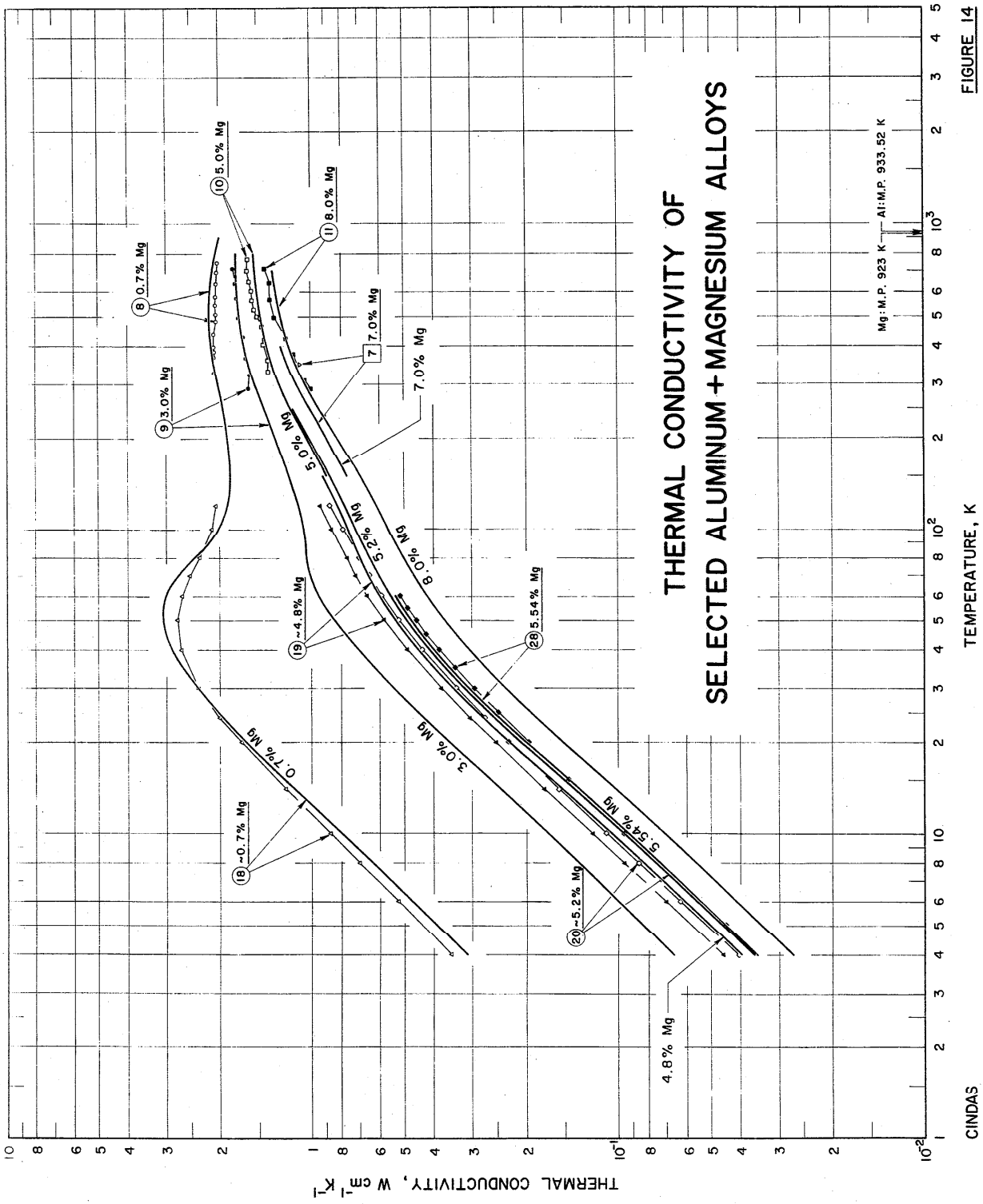
THERMAL CONDUCTIVITY OF
SELECTED ALUMINUM + MAGNESIUM ALLOYS
Mg: M.P. 923 K
Al: M.P. 933.52 K
THERMAL CONDUCTIVITY, W cm⁻¹ K⁻¹
TEMPERATURE, K
CINDAS
10
8
6
5
4
3
2
1
10⁻¹
10⁻²
10³
10²
(8) 0.7% Mg
(9) 3.0% Mg
(10) 5.0% Mg
(11) 8.0% Mg
7 7.0% Mg
(19) ~4.8% Mg
(28) 5.54% Mg
(18) ~0.7% Mg
(20) ~5.2% Mg
0.7% Mg
3.0% Mg
5.0% Mg
5.2% Mg
8.0% Mg
7.0% Mg
5.54% Mg
4.8% Mg

FIGURE 14

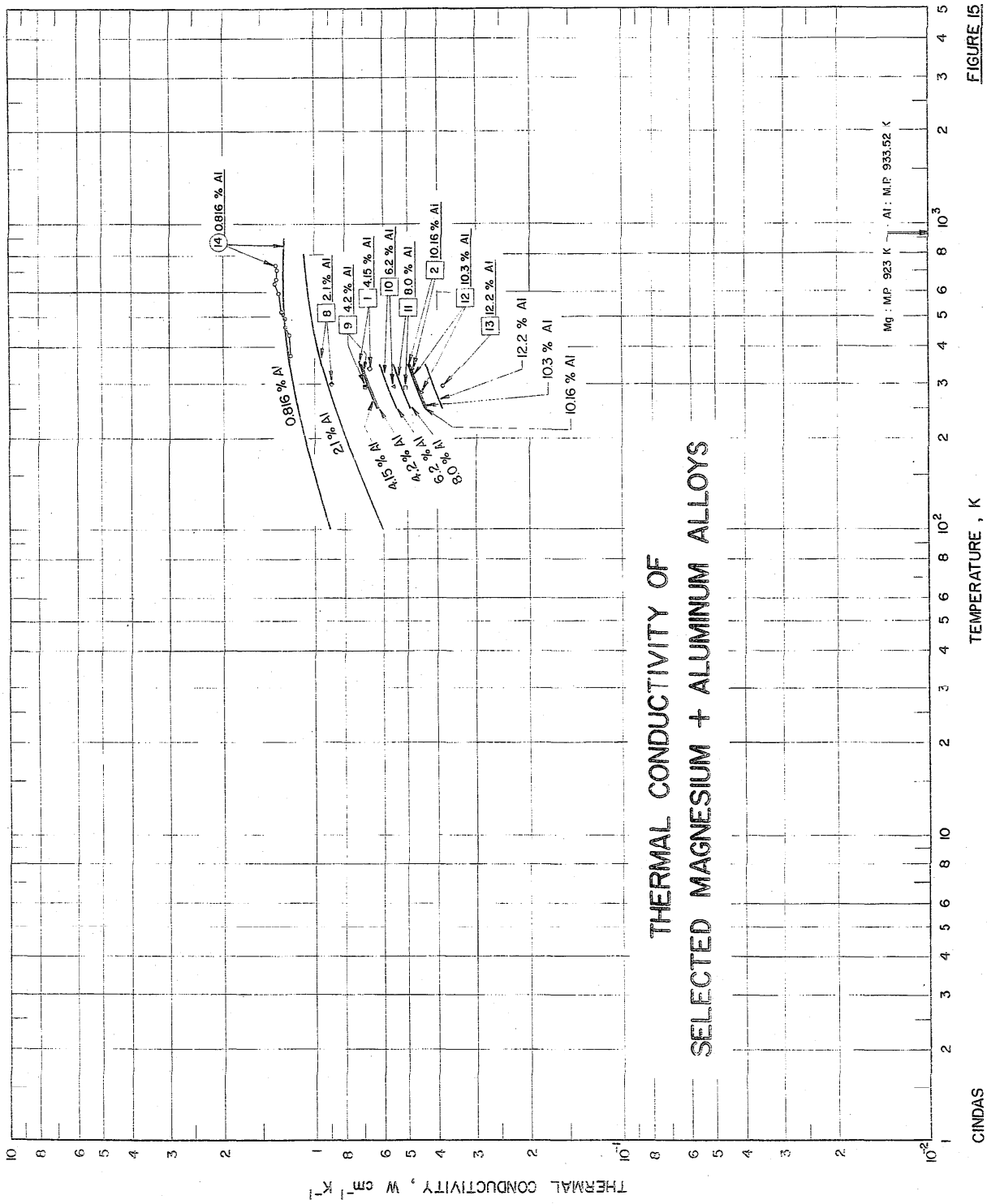
THERMAL CONDUCTIVITY OF
SELECTED MAGNESIUM + ALUMINUM ALLOYS
THERMAL CONDUCTIVITY , W cm⁻¹ K⁻¹
TEMPERATURE , K
CINDAS
Mg : M.P 923 K
Al : M.P 933.52 K
14 0.816 % Al
8 2.1% Al
9 4.2 % Al
1 4.15 % Al
10 6.2 % Al
11 8.0 % Al
2 10.16 % Al
12 10.3 % Al
13 12.2 % Al
0.816 % Al
2.1% Al
4.15 % Al
4.2 % Al
6.2 % Al
8.0 % Al
12.2 % Al
10.3 % Al
10.16 % Al

FIGURE 15

TABLE 5. RECOMMENDED THERMAL CONDUCTIVITY OF ALUMINUM-MAGNESIUM ALLOY SYSTEM†

[Temperature, T, K; Thermal Conductivity, k, W cm^{-1} K^{-1}; Electronic Thermal Conductivity, k_e, W cm^{-1} K^{-1}; Lattice Thermal Conductivity, k_g, W cm^{-1} K^{-1}]

Al: 99.50% (99.45 At.%) Mg: 0.50% (0.55 At.%)				Al: 99.00% (98.89 At.%) Mg: 1.00% (1.11 At.%)				Al: 97.00% (96.68 At.%) Mg: 3.00% (3.32 At.%)				Al: 95.00% (94.48 At.%) Mg: 5.00% (5.52 At.%)			
ρ_o = 0.253 μΩ cm				ρ_o = 0.511 μΩ cm				ρ_o = 1.53 μΩ cm				ρ_o = 2.54 μΩ cm			
T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g
4	0.391			4	0.195			4	0.066‡			4	0.037‡		
6	0.591			6	0.295			6	0.100‡			6	0.056‡		
8	0.796			8	0.397			8	0.135‡			8	0.077‡		
10	1.00			10	0.501			10	0.170‡			10	0.098‡		
15	1.54			15	0.767			15	0.264‡			15	0.154‡		
20	2.01			20	1.03			20	0.358‡			20	0.211‡		
25	2.46			25	1.28			25	0.451‡			25	0.268‡		
30	2.89			30	1.51			30	0.539‡			30	0.320‡		
40	3.50			40	1.89			40	0.699‡			40	0.417‡		
50	3.67			50	2.14			50	0.834‡			50	0.497‡		
60	3.52			60	2.23			60	0.937‡			60	0.560‡		
70	3.13			70	2.18			70	1.002‡			70	0.616‡		
80	2.71			80	2.02			80	1.032‡			80	0.660‡		
90	2.34			90	1.86			90	1.039‡			90	0.691‡		
100	2.16	2.05	0.107‡	100	1.78	1.69	0.086‡	100	1.06‡	0.990	0.065‡	100	0.723‡	0.669	0.054‡
150	1.96*	1.87	0.089‡	150	1.72*	1.65	0.074‡	150	1.19*‡	1.13	0.055‡	150	0.906‡	0.859	0.047‡
200	1.97*	1.90	0.074‡	200	1.79*	1.73	0.063‡	200	1.32*‡	1.27	0.048‡	200	1.04‡	1.00	0.041‡
250	2.01*	1.95	0.064‡	250	1.86*	1.80	0.055‡	250	1.42*‡	1.38	0.043‡	250	1.16‡	1.12	0.036‡
273	2.05*	1.99	0.060‡	273	1.90*	1.85	0.052‡	273	1.48*‡	1.44	0.040‡	273	1.21‡	1.18	0.034‡
300	2.08	2.02	0.056‡	300	1.94	1.89	0.049‡	300	1.53‡	1.49	0.038‡	300	1.27‡	1.24	0.033‡
350	2.11	2.06	0.050‡	350	1.99	1.95	0.043‡	350	1.61‡	1.58	0.034‡	350	1.35‡	1.32	0.030‡
400	2.17	2.12	0.045‡	400	2.06	2.02	0.040‡	400	1.67‡	1.64	0.031‡	400	1.41‡	1.38	0.027‡
500	2.18	2.14	0.037‡	500	2.08	2.05	0.033‡	500	1.72‡	1.69	0.027‡	500	1.46‡	1.44	0.024‡
600	2.16	2.13	0.032‡	600	2.08	2.05	0.029‡	600	1.74	1.72	0.024‡	600	1.50‡	1.48	0.021‡
700	2.12	2.09	0.028‡	700	2.06	2.03	0.025‡	700	1.76	1.74	0.021‡	700	1.53	1.51	0.019‡
800	2.07*	2.04	0.025‡	800	2.01*	1.99	0.023‡	800	1.76*	1.74	0.020‡	800	1.56*	1.54	0.017‡
900	2.00*	1.98	0.022‡	900	1.96*	1.94	0.021‡	881	1.76*	1.74	0.018‡	849	1.55*	1.53	0.016‡
922	1.99*	1.97	0.021‡	913	1.95*	1.93	0.021‡								

† Uncertainties in the total thermal conductivity, k, are as follows:
99.50 Al - 0.50 Mg: ± 10% up to 200 K and ± 6% above 200 K.
99.00 Al - 1.00 Mg: ± 10% up to 200 K and ± 6% above 200 K.
97.00 Al - 3.00 Mg: ± 15% up to 500 K and ± 8% above 500 K.
95.00 Al - 5.00 Mg: ± 15% up to 600 K and ± 8% above 600 K.

‡ Provisional value.

‡ Typical value.

* In temperature range where no experimental thermal conductivity data are available.

TABLE 5. RECOMMENDED THERMAL CONDUCTIVITY OF ALUMINUM-MAGNESIUM ALLOY SYSTEM (continued) †

[Temperature, T, K; Thermal Conductivity, k, W cm^{-1} K^{-1}; Electronic Thermal Conductivity, k_e, W cm^{-1} K^{-1}; Lattice Thermal Conductivity, k_g, W cm^{-1} K^{-1}]

Al: 90.00% (89.02 At.%) Mg: 10.00% (10.98 At.%)				Al: 10.00% (9.10 At.%) Mg: 90.00% (90.90 At.%)				Al: 5.00% (4.53 At.%) Mg: 95.00% (95.47 At.%)				Al: 3.00% (2.71 At.%) Mg: 97.00% (97.29 At.%)			
ρ_o = 4.98 μΩ cm												ρ_o = 4.78 μΩ cm			
T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g
4	0.020‡											4		0.0204‡	
6	0.031‡											6		0.0307‡	
8	0.041‡											8		0.0409‡	
10	0.052‡											10		0.0508‡	
15	0.081‡											15		0.0752‡	
20	0.113‡											20		0.0998‡	
25	0.143‡											25		0.124‡	
30	0.173‡											30		0.148‡	
40	0.230‡											40		0.192‡	
50	0.281‡											50		0.232‡	
60	0.326‡											60		0.266‡	
70	0.364‡											70		0.295‡	
80	0.395‡											80		0.318‡	
90	0.423‡											90		0.339‡	
100	0.447‡	0.404‡	0.043‡	100			0.0564‡	100			0.0723‡	100	0.453*‡	0.362‡	0.0911‡
150	0.576‡	0.538‡	0.038‡	150			0.0477‡	150			0.0613‡	150	0.553*‡	0.476‡	0.0771‡
200	0.690‡	0.657‡	0.033‡	200			0.0409‡	200			0.0527‡	200	0.634*‡	0.568‡	0.0658‡
250	0.795‡	0.765‡	0.030‡	250	0.444‡	0.408‡	0.0358‡	250	0.576‡	0.530‡	0.0460‡	250	0.699*‡	0.642‡	0.0572‡
273	0.840‡	0.812‡	0.028‡	273	0.461‡	0.427‡	0.0338‡	273	0.598‡	0.554‡	0.0435‡	273	0.728*‡	0.674‡	0.0540‡
300	0.891‡	0.864‡	0.027‡	300	0.477‡	0.445‡	0.0317‡	300	0.619‡	0.578‡	0.0407‡	300	0.756‡	0.705‡	0.0505‡
350	0.976‡	0.952‡	0.024‡	350	0.504‡	0.475‡	0.0285‡	350	0.653‡	0.616‡	0.0367‡	350	0.799*‡	0.754‡	0.0452‡
400	1.03‡	1.01‡	0.023‡	400			0.0259‡	400			0.0334‡	400	0.835*‡	0.794‡	0.0408‡
500	1.12‡	1.10‡	0.020‡	500			0.0220‡	500			0.0283‡	500	0.888*‡	0.854‡	0.0343‡
600	1.17‡	1.15‡	0.017‡	600			0.0191‡	600			0.0247‡	600	0.924*	0.894	0.0295‡
700	1.20	1.18	0.016‡	700			0.0170‡	700			0.0218‡	700	0.946*	0.920	0.0260‡
788	1.22	1.21	0.014‡	756			0.0159‡	800			0.0196‡	800	0.964*	0.941	0.0232‡
								839			0.0189‡	872	0.975*	0.953	0.0216‡

† Uncertainties in the total thermal conductivity, k, are as follows:
90.00 Al - 10.00 Mg: ± 15% up to 600 K and ± 8% above 600 K.
10.00 Al - 90.00 Mg: ± 15% between 250 and 350 K.
5.00 Al - 95.00 Mg: ± 15% between 250 and 350 K.
3.00 Al - 97.00 Mg: ± 15% up to 500 K and ± 8% above 500 K.

‡ Provisional value.

‡ Typical value.

* In temperature range where no experimental thermal conductivity data are available.

TABLE 5. RECOMMENDED THERMAL CONDUCTIVITY OF ALUMINUM-MAGNESIUM ALLOY SYSTEM (continued) †

[Temperature, T, K; Thermal Conductivity, k, W cm^{-1} K^{-1}; Electronic Thermal Conductivity, k_e, W cm^{-1} K^{-1}; Lattice Thermal Conductivity, k_g, W cm^{-1} K^{-1}]

Al: 1.00% (0.90 At.%) Mg: 99.00% (99.10 At.%)				Al: 0.50% (0.45 At.%) Mg: 99.50% (99.55 At.%)					
ρ_o = 1.960 $\mu\Omega$ cm				ρ_o = 0.980 $\mu\Omega$ cm					
T	k	k_e	k_g	T	k	k_e	k_g		
4		0.0500		4		0.0996			
6		0.0750		6		0.150			
8		0.100		8		0.200			
10		0.125		10		0.249			
15		0.186		15		0.369			
20		0.245		20		0.481			
25		0.301		25		0.586			
30		0.355		30		0.683			
40		0.451		40		0.838			
50		0.525		50		0.920			
60		0.573		60		0.950			
70		0.602		70		0.962			
80		0.619		80		0.971			
90		0.634		90		0.978			
100	0.793	0.660	0.133‡	100	1.07*	0.982	0.152‡		
150	0.904	0.792	0.112‡	150	1.18*	1.05	0.127‡		
200	0.989	0.896	0.0932‡	200	1.23*	1.13	0.104‡		
250	1.05	0.972	0.0797‡	250	1.27*	1.18	0.0874‡		
273	1.08	1.01	0.0746‡	273	1.29*	1.21	0.0816‡		
300	1.10	1.03	0.0692‡	300	1.30*	1.23	0.0756‡		
350	1.14	1.08	0.0613‡	350	1.32*	1.25	0.0661‡		
400	1.17	1.12	0.0546‡	400	1.33	1.27	0.0589‡		
500	1.19	1.15	0.0449‡	500	1.34	1.29	0.0481‡		
600	1.21	1.17	0.0382‡	600	1.34	1.30	0.0406‡		
700	1.22	1.19	0.0331‡	700	1.33	1.30	0.0350‡		
800	1.22	1.19	0.0292‡	800	1.33*	1.30	0.0308‡		
900	1.22	1.19	0.0262‡	900	1.32*	1.30	0.0274‡		
906	1.22	1.19	0.0260‡	914	1.32*	1.30	0.0270‡		

† Uncertainties in the total thermal conductivity, k, are as follows:
1.00 Al - 99.00 Mg: ±12% below 200 K, ±6% between 200 and 500 K, and ±8% above 500 K.
0.50 Al - 99.50 Mg: ±12% below 200 K, ±6% between 200 and 500 K, and ±8% above 500 K.

‡ Typical value.

* In temperature where no experimental thermal conductivity data are available.

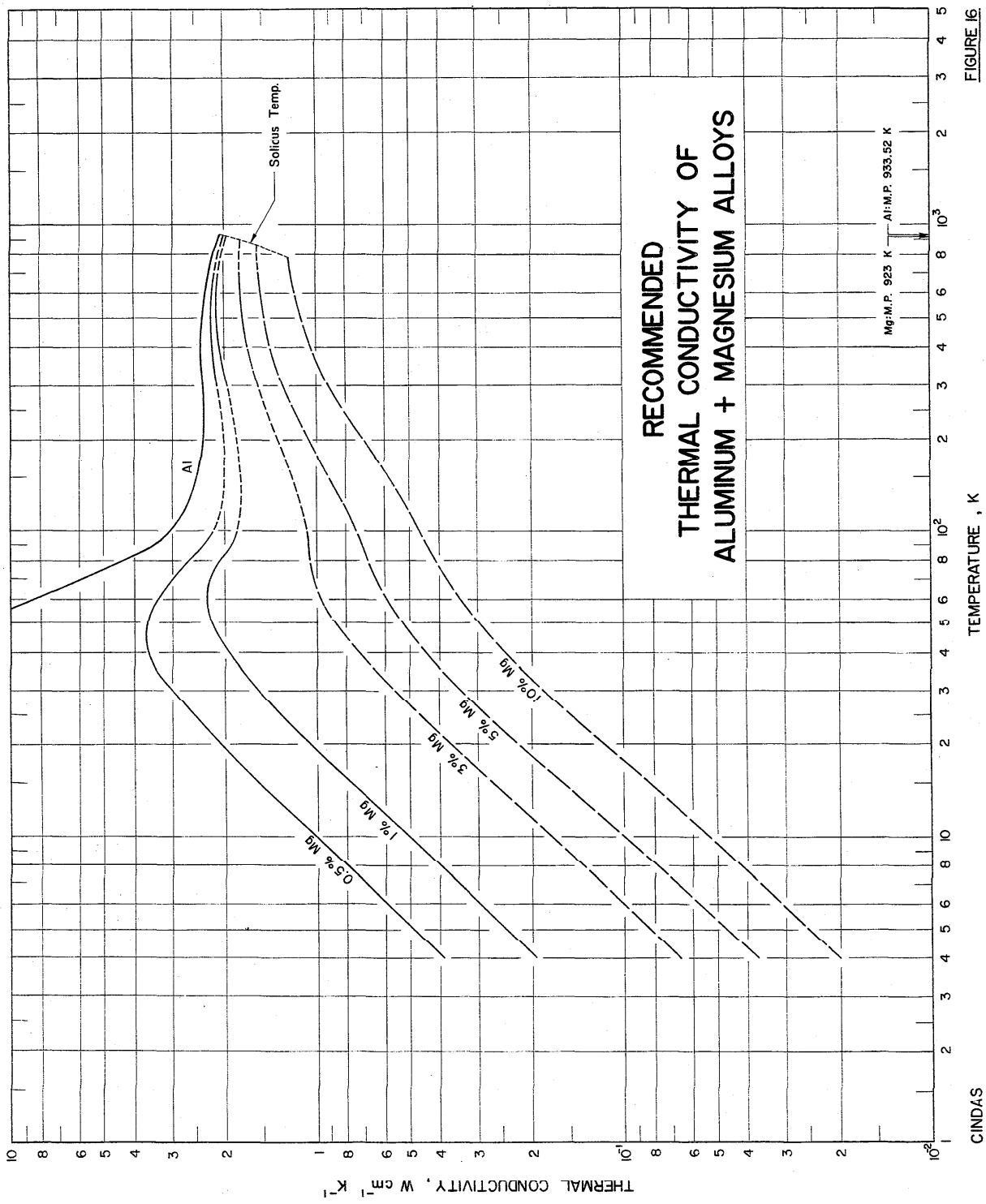
RECOMMENDED
THERMAL CONDUCTIVITY OF
ALUMINUM + MAGNESIUM ALLOYS
Solicus Temp.
Al
0.5% Mg
1% Mg
3% Mg
5% Mg
10% Mg
Mg: M.P. 923 K
Al: M.P. 933.52 K
THERMAL CONDUCTIVITY, W cm⁻¹ K⁻¹
TEMPERATURE, K
CINDAS

FIGURE 16

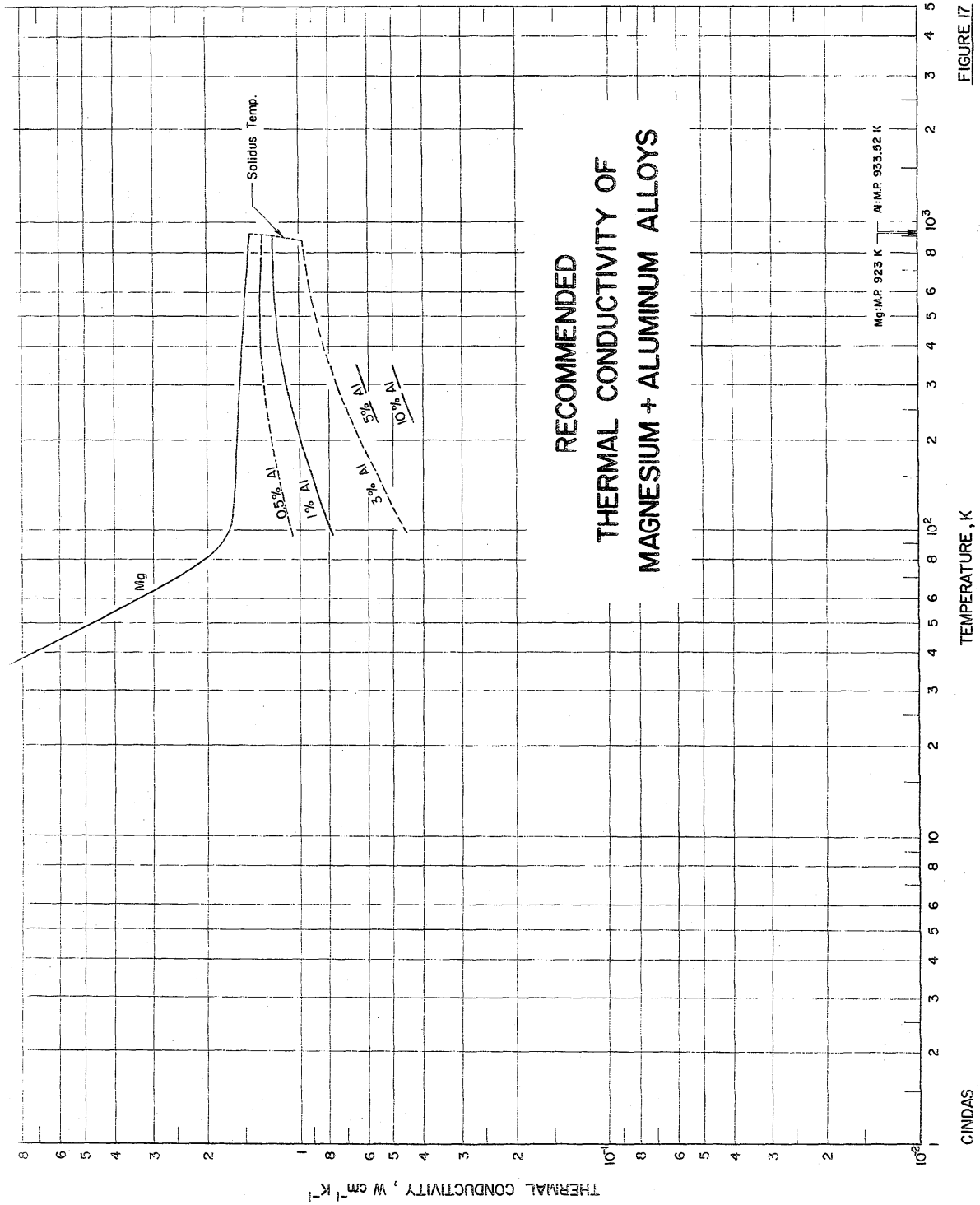
RECOMMENDED
THERMAL CONDUCTIVITY OF
MAGNESIUM + ALUMINUM ALLOYS
Solidus Temp.
Mg
0.5% Al
1% Al
3% Al
5% Al
10% Al
Mg:M.P. 923 K
Al:M.P. 933.52 K
THERMAL CONDUCTIVITY, W cm⁻¹ K⁻¹
TEMPERATURE, K
CINDAS

FIGURE 17

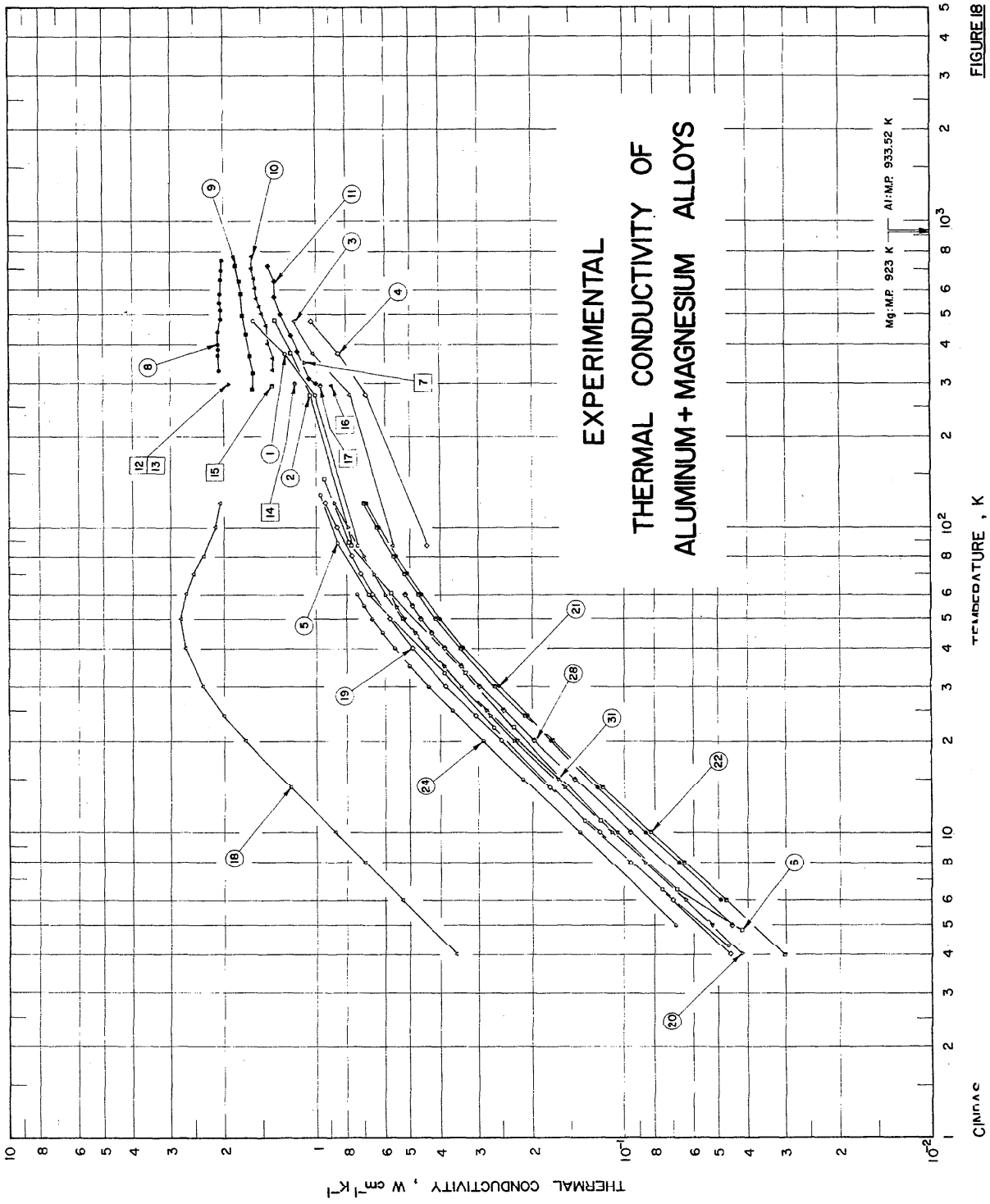
EXPERIMENTAL
THERMAL CONDUCTIVITY OF
ALUMINUM + MAGNESIUM ALLOYS
Mg: M.P. 923 K
Al: M.P. 933.52 K
THERMAL CONDUCTIVITY , W cm⁻¹ K⁻¹
TEMPERATURE , K

FIGURE 18

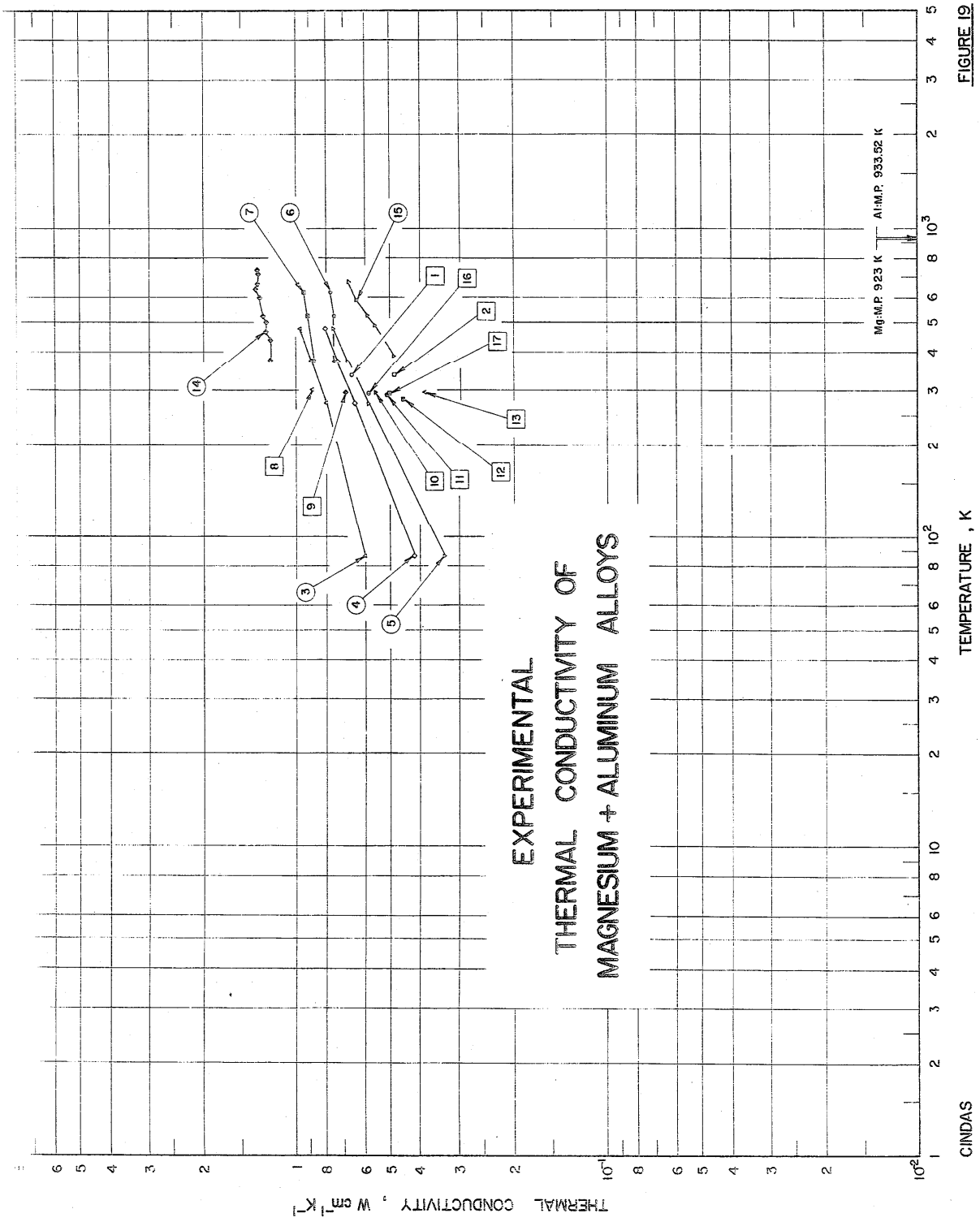
EXPERIMENTAL
THERMAL CONDUCTIVITY OF
MAGNESIUM + ALUMINUM ALLOYS
Mg:M.P. 923 K
Al:M.P. 933.52 K
THERMAL CONDUCTIVITY , W cm⁻¹ K⁻¹
TEMPERATURE , K
CINDAS

FIGURE 19

TABLE 6. THERMAL CONDUCTIVITY OF ALUMINUM + MAGNESIUM ALLOYS -- SPECIMEN CHARACTERIZATION AND MEASUREMENT INFORMATION

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) Al	Mg	Composition (continued), Specifications, and Remarks
1	41	Mannchen, W.	1931	L	87-476		92.0	8.0	Cast; electrical conductivity reported as 20.02, 13.21, 10.5, and 8.8 x 10^4 Ω^{-1} cm^{-1} at 87, 273, 373, and 476 K, respectively.
2	41	Mannchen, W.	1931	L	87-476		92.0	8.0	Annealed; electrical conductivity reported as 24.5, 15.05, 12.25, and 10.25 x 10^4 Ω^{-1} cm^{-1} at 87, 273, 373, and 476 K, respectively.
3	41	Mannchen, W.	1931	L	87-476		88.0	12.0	Cast; electrical conductivity reported as 19.6, 11.95, 9.4, and 7.85 x 10^4 Ω^{-1} cm^{-1} at 87, 273, 373, and 476 K, respectively.
4	41	Mannchen, W.	1931	L	87-476		86.0	14.0	Annealed; electrical conductivity reported as 12.7, 8.96, 8.05, and 7.6 x 10^4 Ω^{-1} cm^{-1} at 87, 273, 373, and 476 K, respectively.
5	56	Johnson, E.W.	1960		4.3-128	5052	97.7-97.1	2.2-2.8	0.10 Mn; annealed.
6	56	Johnson, E.W.	1960		4.8-144	5154	96.8-96.0	3.1-3.9	0.10 Mn; annealed.
7	122	Meyer-Rassler, E.	1940		348.2	Magnalium	93.0	7.0	15 mm in diameter and 72 mm long; density 2.63 g cm^{-3}.
8	58	Mikryukov, V.E. and Karagezyan, A.G.	1961	E	327-746		99.3	0.7	3 mm diameter and 300 mm long; prepared from 99.9 pure Al.
9	58	Mikryukov, V.E. and Karagezyan, A.G.	1961	E	285-716		97.0	3.0	Similar to the above specimen.
10	58	Mikryukov, V.E. and Karagezyan, A.G.	1961	E	330-766		95.0	5.0	Similar to the above specimen.
11	58	Mikryukov, V.E. and Karagezyan, A.G.	1961	E	289-717		92.0	8.0	Similar to the above specimen.
12	123	Materials in Design Engineering	1959		298.2	5005	Bal.	0.8	Nominal composition; annealed at 617 K; density 2.68 g cm^{-3}; electrical resistivity 3.4 $\mu\Omega$ cm at 20 C.
13	123	Materials in Design Engineering	1959		298.2	5050	Bal.	1.0~1.8	Nominal composition; annealed at 617 K; density 2.68 g cm^{-3}.
14	123	Materials in Design Engineering	1959		298.2	5056	Bal.	4.7~5.6	0.05~0.20 Cr and 0.05~0.20 Mn (nominal composition); annealed at 617 K; density 2.63 g cm^{-3}; electrical resistivity 5.94 $\mu\Omega$ cm at 20 C.
15	123	Materials in Design Engineering	1959		293.2	G4A	96.0	4.0	Nominal composition; as cast; density 2.63 g cm^{-3}.
16	123	Materials in Design Engineering	1959		293.2	G10A	96.0	4.0	Nominal composition; as cast; density 2.57 g cm^{-3}.
17	123	Materials in Design Engineering	1959		293.2	G8A	92.0	8.0	Nominal composition; as cast; density 2.57 g cm^{-3}.
18	57	Powell, R.L., Hall, W.J. and Roder, H.M.	1960	L	4-120	6063-T5	Bal.	0.65	0.38 Si, 0.1 each Fe, Ga, Mn, 0.01 each Cr, Cu, Ti, V, Zn, 0.001 Ca, and 0.001 Pb; 3.66 mm diameter rod specimen; grain size 0.052 mm x 0.048 mm (longitudinal) and 0.052 mm (transverse); precipitation heat-treated; electrical resistivity 0.28, 0.28, 0.33, 0.43, 0.8, 2.3, and 3.5 $\mu\Omega$ cm at 4, 10, 40, 60, 100, 200, and 300 K, respectively; smoothed values reported.

TABLE 6. THERMAL CONDUCTIVITY OF ALUMINUM + MAGNESIUM ALLOYS -- SPECIMEN CHARACTERIZATION AND MEASUREMENT INFORMATION (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) Al	Mg	Composition (continued), Specifications, and Remarks
19	57	Powell, R.L., Hall, W.J. and Roder, H.M.	1960	L	4-120	5052-O	Bal.	2.46	0.22 Cr, 0.1 each Cu, Fe, Si, Ga, Mn, Zn, 0.01 Ti, 0.01 V, 0.001 Ca, and 0.001 Zr; grain size 0.056 mm x 0.032 mm (longitudinal) and 0.040 mm (transverse); annealed in vacuum for 1 hr at 350 C; electrical resistivity 2.0, 2.1, 2.2, 2.7, 4.4, and 5.0 $\mu\Omega$ cm at 4, 20, 60, 100, 200, and 300 K, respectively; smoothed values reported.
20	57	Powell, R.L., et al.	1960	L	4-120	5154-O	Bal.	3.32	0.21 Cr, 0.1 each Cu, Fe, Si, Mn, 0.01 each Ti, V, Zn, 0.001 Ca, and 0.001 Pb; grain size 0.036 mm x 0.028 mm (longitudinal) and 0.032 mm (transverse); annealed in vacuum for 1 hr at 350 C; electrical resistivity 2.2, 2.3, 2.4, and 2.5 $\mu\Omega$ cm at 4, 10, 30, and 60 K, respectively; smoothed values reported.
21	57	Powell, R.L., et al.	1960	L	6-120	5083-O	Bal.	4.44	0.7 Mn, 0.1 each Cr, Fe, Si, 0.04 Cu; supplied by R.D. Olleman, Kaiser Aluminum and Chemical Co.; average crystal grain size 0.74 mm x 0.21 mm (longitudinal) and 0.54 mm x 0.14 mm (transverse); annealed in vacuum for 1 hr at 350 C.
22	57	Powell, R.L., et al.	1960	L	4-120	5086-F	Bal.	4.10	0.51 Mn, 0.28 Fe, 0.1 each Cr, Si, Zn, 0.07 Cu, and 0.02 Ti; average crystal grain size 0.061 mm x 0.022 mm (longitudinal) and 0.086 mm x 0.020 mm (transverse); as fabricated; electrical resistivity 3.0, 3.0, 3.1, 3.6, 5.0, and 5.7 $\mu\Omega$ cm at 4, 40, 60, 100, 200, and 300 K, respectively; smoothed values reported.
23*	190	Mohan, N.S., Klaffky, R.W., Harrington, L.C., and Damon, D.H.			5-60	2a	→	→	Starting composition 95.47 Al and 4.53 Mg; composition as determined from residual resistivity was 96.38 Al and 3.62 Mg; specimen made in the laboratory of the Institute of Materials Science at Storrs, Connecticut; annealed at 473 K for 96 h, at 623 K for 72 h, and further annealed at 733 K for 8.5 h; specimen swaged from 1/4 in to 1/8 in at room temperature; also quenched in water at room temperature after annealing; solute loss on heat treatment about 0.2%; residual resistivity $\rho_0 = 1.842 \times 10^{-8}\ \Omega$m, measured at 4.2 K; no resistivity minimum found between 1.5 and 4.2 K; composition of alloy was calculated from residual resistivity using Fickett's recommended value of $4.6 \times 10^{-9}\ \Omega$m per atomic percent of Mg; original data reported tabularly; obtained after smoothing the measured values using a standard least squares fit of the type $\lambda = X_1T^{-2} + X_2T^{-1} + X_3T + X_4T^2 + X_5T^3 + X_6T^4$; experimental accuracy about 3% for $T \lesssim 30$ K, and about 5% for $T \gtrsim 30$ K.
24	190	Mohan, N.S., et al.			5-60	2b	→	→	Similar to the above specimen except for the following: starting composition 95.47 Al and 4.53 Mg; composition as determined from residual resistivity was 96.41 Al and 3.59 Mg; specimen further annealed at 773 K for 20 h and slow-cooled in furnace to 293 K at a rate of 50 deg/h; solute loss on heat treatment about 0.75%; residual resistivity $\rho_0 = 1.828 \times 10^{-8}\ \Omega$m.
25*	190	Mohan, N.S., et al.			5-60	3	→	→	Similar to the above specimen except for the following: starting composition 95.47 Al and 4.53 Mg; composition as determined from residual resistivity was 95.97 Al and 4.03 Mg; no heat treatment and solute loss reported; residual resistivity $\rho_0 = 2.045 \times 10^{-8}\ \Omega$m.

* Not shown in figure.

TABLE 6. THERMAL CONDUCTIVITY OF ALUMINUM + MAGNESIUM ALLOYS -- SPECIMEN CHARACTERIZATION AND MEASUREMENT INFORMATION (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) Al	Mg	Composition (continued), Specifications, and Remarks
26*	190	Mohan, N.S., Klaffky, R.W., Harrington, L.C., and Damon, D.H.			5-60	3a	→	→	Similar to the above specimen except for the following: starting composition 95.47 Al and 4.53 Mg; composition as determined from residual resistivity was 96.33 Al and 3.67 Mg; specimen annealed at 843 K for 16 h and kept at 673 K for 24 h; solute loss on heat treatment about 0.2%; residual resistivity $\rho_0 = 1.869 \times 10^{-8}$ Ωm.
27	190	Mohan, N.S., et al.			5-60	3b	→	→	Similar to the above specimen except for the following: starting composition 95.47 Al and 4.53 Mg; composition as determined from residual resistivity was 96.34 Al and 3.66 Mg; specimen annealed at 843 K for 16 h, kept at 673 K for 24 h, further annealed at 876 K for 17 h and slow-cooled in furnace to 543 K at a rate of 1 deg/min; solute loss on heat treatment about 0.02%; residual resistivity $\rho_0 = 1.862 \times 10^{-8}$ Ωm.
28	190	Mohan, N.S., et al.			5-60	4	→	→	Similar to the above specimen except for the following: starting composition 93.65 Al and 6.35 Mg; composition as determined from residual resistivity was 94.65 Al and 5.54 Mg; specimen annealed at 876 K for 16 h and slow cooled in furnace to 708 K at a rate of 1 deg/min; solute loss on heat treatment about 0.2%; residual resistivity $\rho_0 = 2.812 \times 10^{-8}$ Ωm.
29*	190	Mohan, N.S., et al.			5-60	5	→	→	Similar to the above specimen except for the following: starting composition 93.65 Al and 6.35 Mg; composition as determined from residual resistivity was 94.59 Al and 5.41 Mg; specimen swaged from 3/8 in to 1/8 in; no heat treatment and solute loss reported; residual resistivity $\rho_0 = 2.744 \times 10^{-8}$ Ωm.
30*	190	Mohan, N.S., et al.			5-60	6	→	→	Similar to the above specimen except for the following: starting composition 93.65 Al and 6.35 Mg; composition as determined from residual resistivity was 95.14 Al and 4.96 Mg; specimen swaged from 3/16 in to 1/8 in; no heat treatment and solute loss reported; residual resistivity $\rho_0 = 2.521 \times 10^{-8}$ Ωm.
31	190	Mohan, N.S., et al.			5-60	6a	→	→	Similar to the above specimen except for the following: starting composition 93.65 Al and 6.35 Mg; composition as determined from residual resistivity was 95.23 Al and 4.77 Mg; specimen swaged from 3/16 in to 1/8 in; annealed at 673 K for 25 h and air quenched; no solute loss on heat treatment reported; residual resistivity 2.424×10^{-8} Ωm.
32	190	Mohan, N.S., et al.			5-60	7	→	→	Similar to the above specimen except for the following: starting composition 93.65 Al and 6.35 Mg; composition as determined from residual resistivity was 95.35 Al and 4.65 Mg; specimen swaged from 3/8 in to 1/8 in; annealed at 473 K for 96 h, further at 623 K for 72 h; further at 738 K for 85 h, further at 848 K for 10 h and kept at 273 K for 15 h; solute less on heat treatment about 1.9%; residual resistivity 2.359×10^{-8} Ωm.

* Not shown in figure.

TABLE 7. THERMAL CONDUCTIVITY OF MAGNESIUM + ALUMINUM ALLOYS -- SPECIMEN CHARACTERIZATION AND MEASUREMENT INFORMATION

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) Mg	Al	Composition (continued), Specifications, and Remarks
1	45	Smith, A.W.	1925	L	336.2		95.82	4.12	0.028 Fe and 0.019 Si; ~5 cm long and 0.3 cm^2 in cross-section; supplied by Aluminum Co. of America; electrical conductivity 9.06 x 10^4 Ω^{-1} cm^{-1} at 63 C.
2	45	Smith, A.W.	1925	L	336.2		89.82	10.12	0.023 Si and 0.028 Fe; similar to the above specimen except electrical conductivity 6.00 x 10^4 Ω^{-1} cm^{-1} at 63 C.
3	124, 41	Staebler, J.; Mannchen, W.	1929 1931	L	87-476		94.0	6.0	1.23 cm^2 in cross-section and 3 cm long; cast; electrical conductivity 14.7, 8.04, 6.47, and 5.99 x 10^4 Ω^{-1} cm^{-1} at 87, 273, 373, and 476 K, respectively.
4	124, 41	Staebler, J.; Mannchen, W.	1929 1931	L	87-476		92.0	8.0	1.23 cm^2 in cross-section and 3 cm long; electrical conductivity 13.32, 7.31, 5.95, and 5.55 x 10^4 Ω^{-1} cm^{-1} at 87, 273, 373, and 476 K, respectively.
5	124, 41	Staebler, J.; Mannchen, W.	1929 1931	L	87-476		88	12	1.23 cm^2 in cross-section and 3 cm long; electrical conductivity 9.65, 5.99, 5.27, and 4.90 x 10^4 Ω^{-1} cm^{-1} at 87, 273, 373, and 476 K, respectively.
6	60	Maybrey, H.J.	1928	L	373-623		94	6	12 in. long and 1 in. in diameter; annealed at 300 C for 3 hr.
7	60	Maybrey, H.J.	1928	L	373-623		89	11	Similar to the above specimen.
8	59	Kikuchi, R.	1932	E	300.2		97.9	2.1	3 mm diameter and 200 mm long; electrical conductivity 11.9 x $10^4$$\Omega^{-1}$ cm^{-1} at 27 C.
9	59	Kikuchi, R.	1932	E	295.5		95.8	4.2	3 mm diameter and 200 mm long; electrical conductivity 8.9 x $10^4$$\Omega^{-1}$ cm^{-1} at 22.3 C.
10	59	Kikuchi, R.	1932	E	295.1		93.8	6.2	3 mm diameter and 200 mm long; electrical conductivity 6.9 x $10^4$$\Omega^{-1}$ cm^{-1} at 21.9 C.
11	59	Kikuchi, R.	1932	E	291.5		91.8	8.2	3 mm diameter and 200 mm long; electrical conductivity 5.9 x $10^4$$\Omega^{-1}$ cm^{-1} at 18.3 C.
12	59	Kikuchi, R.	1932	E	281.5		89.7	10.3	3 mm diameter and 200 mm long; electrical conductivity 5.5 x $10^4$$\Omega^{-1}$ cm^{-1} at 19.3 C.
13	59	Kikuchi, R.	1932	E	296.5		87.8	12.2	3 mm diameter and 200 mm long; electrical conductivity 5.1 x $10^4$$\Omega^{-1}$ cm^{-1} at 23.1 C.
14	125	Giuliani, S.	1967	C	375-736	Magnox; Al 80		0.80	0.0050 Be, 0.0020 Mn, and 0.0004 Cu; 1.2 to 1.3 cm in diameter and 1.8 to 2.5 cm long; Armco iron used as comparative material.
15	125	Giuliani, S.	1967	C	387-674	Magnox; Atesia T		8-9	0.5-1 Zn and 0.2 Mn; 1.2 to 1.3 cm in diameter and 1.8 to 2.5 cm long; Armco iron used as comparative material.
16	123	Materials in Design Engineering	1959		293.2	AZ6aA-F		5.8-7.2	0.4-1.5 Zn and > 0.15 Mn (nominal composition); density 1.80 g cm^{-3}; electrical resistivity 12.5 $\mu\Omega$ cm at 20 C.
17	123	Materials in Design Engineering	1959		293.2	AZ80A-T		7.8-9.2	0.2-0.8 Zn and > 0.12 Mn (nominal composition); density 1.83 g cm^{-3}; electrical resistivity 14.5 $\mu\Omega$ cm at 20 C.
18*	173	Powell, R.W., Hickman, M.J., and Tye, R.P.	1964	C	323-773	Magnox B		1.0	0.002-0.003 Be; 2.5 cm diameter x 20+ cm long; electrical resistivity 6.05, 6.5, 7.3, 8.9, 10.6, 12.3, and 14.15 $\mu\Omega$ cm at 20, 50, 100, 200, 300, 400, and 500 C, respectively.

* Not shown in figure.

4.3. Copper-Gold Alloy System

The copper-gold alloy system forms a continuous series of solid solutions over the entire range of compositions. Ordered structures are formed at temperatures below about 663 K for compositions ranging from about 40 to 63% Au (17.7 to 35.5 At.% Au) and at temperatures below about 683 K for compositions ranging from about 63 to 94% Au (35.5 to 83.5 At.% Au). These ordered structures are due to the formation of the intermetallic compounds Cu_3Au (50.85% Au), CuAu (75.63% Au), and $CuAu_3$ (90.30% Au). In this work only the thermal conductivity data of disordered alloys are treated.

There are 75 sets of experimental data available for the thermal conductivity of this alloy system. Of the 17 data sets for Cu+Au alloys listed in table 9 and shown in figure 24, nine sets are merely single data points around room temperature. Of the 58 curves for Au+Cu alloys listed in table 10 and shown in figure 25, 35 sets are single data points.

For the Cu+Au alloys, the data can be separated into three groups: the low temperature data of Grüneisen and Reddemann [61] (Cu+Au curves 1 and 2) and of Kemp et al. [62] (Cu+Au curves 8 and 9), the data of Sedström [63] (Cu+Au curves 10-15) at the ice point, and the five points around 440 K measured by Zolotukhin [65] (Cu+Au curves 3-7) for a partially ordered 5% Au. No data are available above 470 K. Hence the experimental data are very limited. To derive recommended values, the electronic component k_e was calculated from eq (12) and the lattice component k_g was calculated from eq (35). The total k was obtained by adding k_g to k_e. The recommended curves were extended to the solidus points at high temperatures. The curves for alloys containing 10% Au or less were not extended to temperatures below 40 K because of the large uncertainties of the calculated k_g values at low temperatures. For denser alloys, however, the curves were extended to 4 K using k_g values derived from the data of Kemp et al. [62]. The k_g values for dilute alloys are extremely uncertain at low temperatures and are not reported below 60 K.

A graphical comparison of the recommended total thermal conductivities with some of the experimental data for Cu+Au alloys is given in figure 20. The smooth solid curves in the figure were obtained by interpolating the recommended values of table 8 in order to obtain thermal conductivities for the desired alloy compositions. The recommended values are in agreement with the data of Kemp et al. [62] (Cu+Au curves 8 and 9), of Leaver and Charsley [120] (Cu+Au curve 16), and of Grüneisen and Reddemann [61] (Cu+Au curve 2) to within 8%. Measurements of Sedström [63] (Cu+Au curves 12-15) at the ice point for a wide range of compositions differ from the recommendations by no more than 10%.

The data for Sedström's 44.76% Au specimen (Cu+Au curve 10) show poor agreement, especially at 373 K, with the recommendations and are not shown in figure 20. However, the temperature dependence of both the thermal and electrical conductivities of this specimen is at odds with all other experimental data and may be safely discounted as erroneous. Similarly, the measurements of Grüneisen and Reddemann [61] (Cu+Au curve 1) for a 24.8% Au specimen are 10-20% higher than the recommendation and are not shown in the figure. Since the recommended values are for disordered alloys only, there can be no valid comparison with the data of Zolotukhin [65] (Cu+Au curves 3-7) for a partially ordered alloy.

For the Au+Cu alloys, the experimental data were mostly obtained below the order-disorder transition temperature on specimens in the ordering range, except for two measurements made by Grüneisen and Reddemann [61] (Au+Cu curves 40 and 41) on specimens containing 1.57 and 3.10% Cu at low temperatures and one made by Goff et al. [66] (Au+Cu curve 56) on a disordered Cu_3Au specimen. The recommended values for disordered alloys were derived from k_g calculated from eq (35) and k_e calculated from eq (12) using electrical resistivity data for disordered alloys. The recommended curves were extended to the solidus points at the high temperature end, but not below 40 K at the low temperature end owing to the large uncertainties of the calculated k_g values at very low temperatures, except for the curves for alloys with 45 and 50% Cu, which were extended to 4 K using the k_g values derived from the data of Kemp et al. [62]. The k_g values for alloys containing 40% Cu or less are very uncertain at low temperatures and are not reported below 60 K.

The recommended total thermal conductivities for the Au+Cu alloys are compared with some of the experimental data in figure 21. Not all of the experimental data shown are for fully disordered specimens. Due to poor experimental data and a lack of data for disordered specimens, a detailed quantitative comparison of the calculated values is not practical. However, the recommended values are within 5% of the low temperature data of Grüneisen and Reddemann [61] (Au+Cu curves 38-41, 45, 46, and 48) for disordered specimens or specimens quenched from above the ordering transition temperature. Some of the data of Sedström [64] (Au+Cu curves 21, 23, 27, and 29) are within 5% of the recommendations. The agreement with the low-temperature results of Goff et al. [66](Au+Cu curves 56 and 58) is poor, but from 60-300 K their measurements fall within 10% of the recommendations.

The resulting recommended values for k, k_e, and k_g are tabulated in table 8 for 25 alloy compositions. These values are for disordered alloys which have not been severely cold worked or quenched. The values for k are also presented in figures 22 and 23. In order to clearly show the trend of the dependence of the thermal conductivity on solute concentration and to clarify the confusion in figure 23 due to crossover of curves, recommendations for alloys with 55-75% Au are also displayed in figure 22 along with recommendations for the Cu+Au alloys. The values of residual electrical resistivity for the alloys are also given in table 8. The uncertainties of the k values are stated in a footnote to table 8, while the uncertainties of the k_e and k_g values are indicated by their being designated as recommended or provisional values. The ranges of uncertainties of recommended and provisional values are less than ±15% and between ±15 and ±30%, respectively.

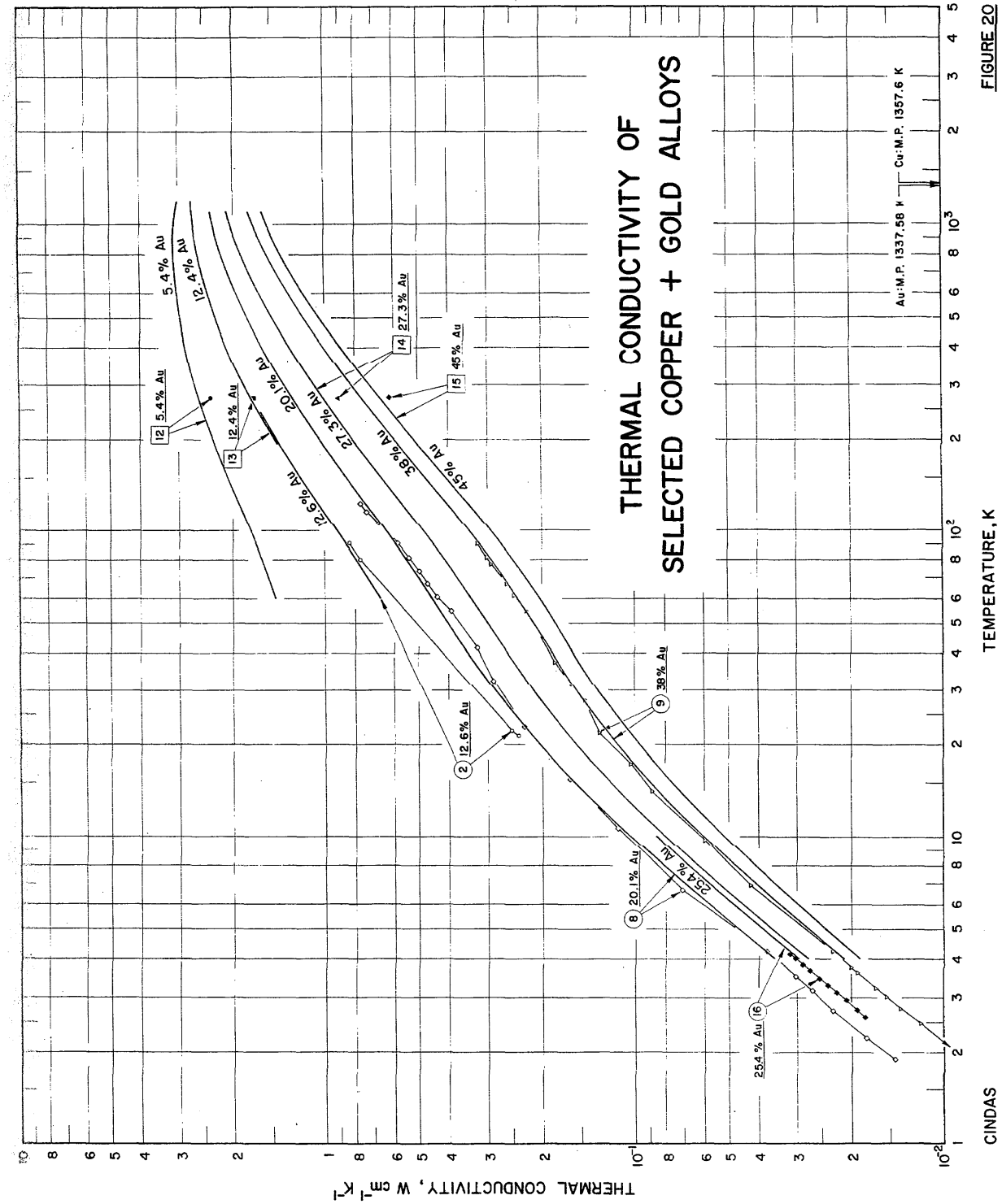
THERMAL CONDUCTIVITY OF
SELECTED COPPER + GOLD ALLOYS
Au: M.P. 1337.58 K
Cu: M.P. 1357.6 K
5.4% Au
12.4% Au
20.1% Au
27.3% Au
38% Au
45% Au
12.6% Au
25.4% Au
THERMAL CONDUCTIVITY, W cm⁻¹ K⁻¹
TEMPERATURE, K
CINDAS

FIGURE 20

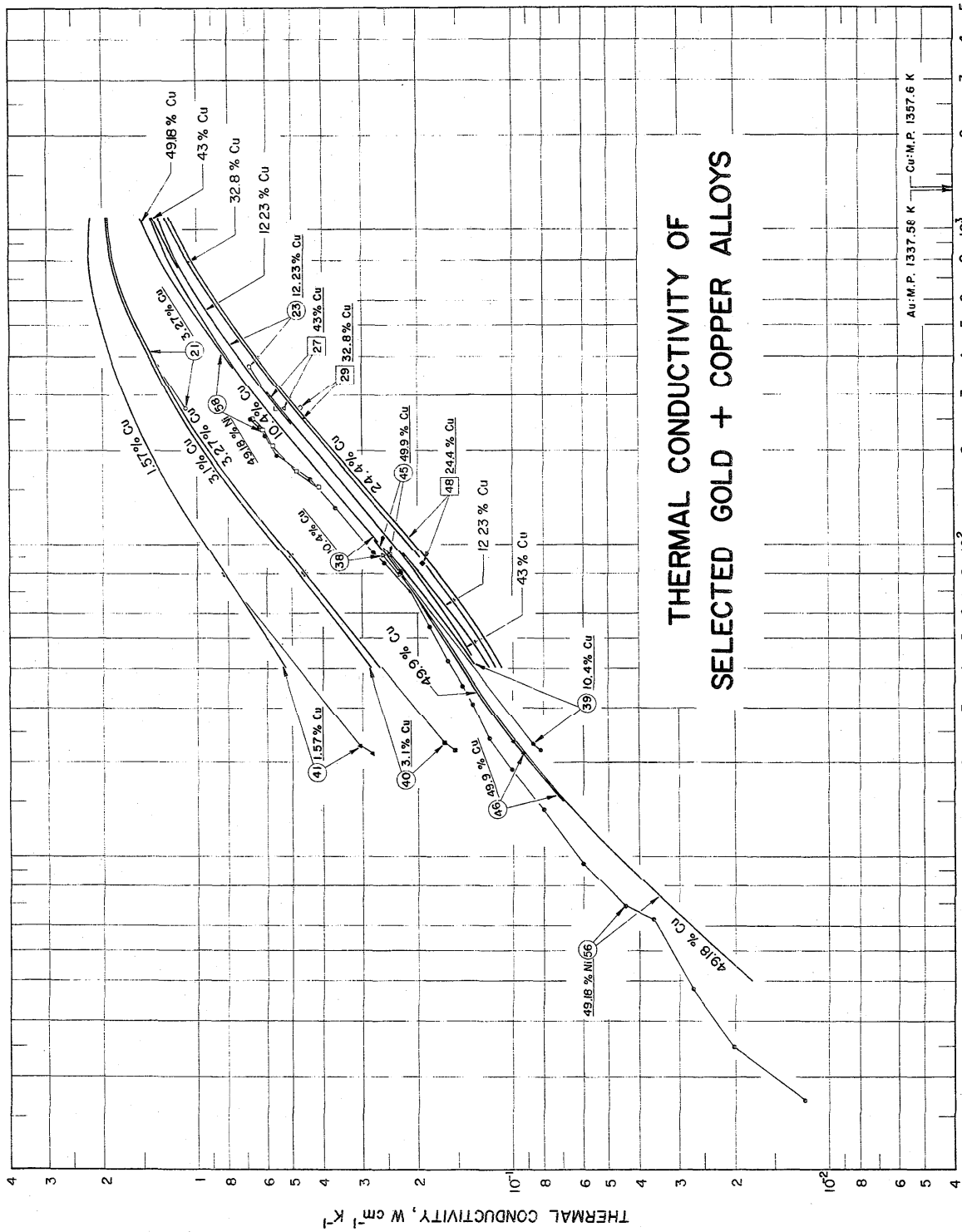

FIGURE 21

CINDAS

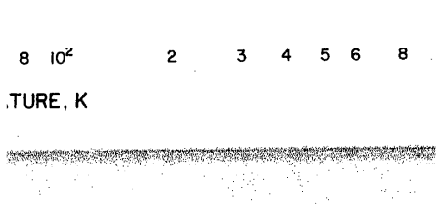

TABLE 8. RECOMMENDED THERMAL CONDUCTIVITY OF COPPER-GOLD ALLOY SYSTEM†

[Temperature, T, K; Thermal Conductivity, k, W cm^{-1} K^{-1}; Electronic Thermal Conductivity, k_e, W cm^{-1} K^{-1}; Lattice Thermal Conductivity, k_g, W cm^{-1} K^{-1}]

Cu: 99.50% (99.84 At.%) Au: 0.50% (0.16 At.%)				Cu: 99.00% (99.68 At.%) Au: 1.00% (0.32 At.%)				Cu: 97.00% (98.01 At.%) Au: 3.00% (0.99 At.%)				Cu: 95.00% (98.33 At.%) Au: 5.00% (1.67 At.%)			
ρ_o = 0.10 μΩ cm				ρ_o = 0.20 μΩ cm				ρ_o = 0.530 μΩ cm				ρ_o = 0.870 μΩ cm			
T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g
4		0.977		4		0.489		4		0.184		4		0.112	
6		1.47		6		0.733		6		0.276		6		0.168	
8		1.95		8		0.977		8		0.369		8		0.225	
10		2.44		10		1.22		10		0.461		10		0.281	
15		3.66		15		1.83		15		0.691		15		0.421	
20		4.89		20		2.44		20		0.922		20		0.562	
25		5.76		25		2.96		25		1.14		25		0.697	
30		6.11		30		3.49		30		1.36		30		0.832	
40		6.76		40		4.17		40		1.73		40		1.08	
50		6.30		50		4.46		50		1.99		50		1.28	
60	5.57*	5.26		60	4.34*	4.09		60	2.29*	2.12		60	1.55*	1.41	
70	4.80*	4.50		70	3.98*	3.74		70	2.34*	2.18		70	1.63*	1.50	
80	4.37*	4.09		80	3.75*	3.52		80	2.36*	2.21		80	1.70*	1.58	
90	4.12*	3.85		90	3.60*	3.38		90	2.39*	2.24		90	1.76*	1.64	
100	4.01*	3.75		100	3.55*	3.34		100	2.44*	2.30		100	1.83*	1.72	
150	3.92*	3.71	0.205‡	150	3.60*	3.44	0.165‡	150	2.74*	2.63	0.112‡	150	2.17*	2.08	0.0906‡
200	3.88*	3.71	0.170‡	200	3.65*	3.51	0.141‡	200	2.92*	2.82	0.0958‡	200	2.42*	2.34	0.0778‡
250	3.86*	3.71	0.147‡	250	3.68*	3.56	0.123‡	250	3.05*	2.97	0.0843‡	250	2.60*	2.53	0.0686‡
273	3.85*	3.71	0.138‡	273	3.70*	3.58	0.116‡	273	3.10*	3.02	0.0801‡	273	2.67	2.60	0.0652‡
300	3.85*	3.72	0.129‡	300	3.71*	3.60	0.109‡	300	3.15*	3.07	0.0757‡	300	2.74*	2.68	0.0618‡
350	3.85*	3.74	0.114‡	350	3.73*	3.63	0.0979‡	350	3.21*	3.14	0.0688‡	350	2.85*	2.79	0.0564‡
400	3.83*	3.73	0.103‡	400	3.72*	3.63	0.0890‡	400	3.26*	3.20	0.0633‡	400	2.92*	2.87	0.0520‡
500	3.77*	3.68	0.0861‡	500	3.69*	3.61	0.0755‡	500	3.32*	3.26	0.0548‡	500	3.03*	2.98	0.0453‡
600	3.71*	3.64	0.0738‡	600	3.65*	3.58	0.0656‡	600	3.34*	3.29	0.0486‡	600	3.08*	3.04	0.0403‡
700	3.65*	3.59	0.0647‡	700	3.60*	3.54	0.0581‡	700	3.35*	3.31	0.0437‡	700	3.12*	3.08	0.0365‡
800	3.60*	3.54	0.0575‡	800	3.55*	3.50	0.0521‡	800	3.34*	3.30	0.0398‡	800	3.14*	3.11	0.0335‡
900	3.55*	3.50	0.0518‡	900	3.50*	3.45	0.0473‡	900	3.31*	3.27	0.0366‡	900	3.14*	3.11	0.0309‡
1000	3.49*	3.44	0.0471‡	1000	3.45*	3.41	0.0433‡	1000	3.28*	3.25	0.0340‡	1000	3.13*	3.10	0.0288‡
1200	3.36*	3.32	0.0399‡	1200	3.33*	3.29	0.0370‡	1200	3.20*	3.17	0.0297‡	1200	3.09*	3.06	0.0254‡
1355	3.26*			1353	3.24*			1346	3.13*			1339	3.04*		

† Uncertainties in the total thermal conductivity, k, are as follows:
99.50 Cu - 0.50 Au: ±14% below 100 K, ±10% between 100 and 300 K, and ±8% above 300 K.
99.00 Cu - 1.00 Au: ±14% below 100 K, ±10% between 100 and 300 K, and ±8% above 300 K.
97.00 Cu - 3.00 Au: ±14% below 200 K and ±10% above 200 K.
95.00 Cu - 5.00 Au: ±14% below 200 K and ±10% above 200 K.

‡ Provisional value.

* In temperature range where no experimental thermal conductivity data are available.

TABLE 8. RECOMMENDED THERMAL CONDUCTIVITY OF COPPER-GOLD ALLOY SYSTEM (continued)†

[Temperature, T, K; Thermal Conductivity, k, W cm^{-1} K^{-1}; Electronic Thermal Conductivity, k_e, W cm^{-1} K^{-1}; Lattice Thermal Conductivity, k_g, W cm^{-1} K^{-1}]

Cu: 90.00% (96.54 At.%) Au: 10.00% (3.46 At.%)				Cu: 85.00% (94.61 At.%) Au: 15.00% (5.39 At.%)				Cu: 80.00% (92.54 At.%) Au: 20.00% (7.46 At.%)				Cu: 75.00% (90.29 At.%) Au: 25.00% (9.71 At.%)			
ρ_o = 1.72 μΩ cm				ρ_o = 2.53 μΩ cm				ρ_o = 3.52 μΩ cm				ρ_o = 4.45 μΩ cm			
T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g
4		0.0568		4	0.0462	0.0379	0.00829	4	0.0358	0.0278	0.00805	4	0.0299	0.0220	0.00788
6		0.0852		6	0.746	0.0568	0.0178	6	0.0580	0.0416	0.0164	6	0.0482	0.0329	0.0153
8		0.117		8	0.104	0.0758	0.0287	8	0.0811	0.0555	0.0256	8	0.0675	0.0439	0.0236
10		0.142		10	0.134	0.0947	0.0397	10	0.104	0.0694	0.0350	10	0.0867	0.0549	0.0318
15		0.213		15	0.205	0.142	0.0631	15	0.158	0.104	0.0542	15	0.131	0.0823	0.0486
20		0.284		20	0.269	0.189	0.0799	20	0.206	0.139	0.0674	20	0.170	0.110	0.0598
25		0.353		25	0.324	0.234	0.0901	25	0.248	0.173	0.0755	25	0.204	0.137	0.0665
30		0.421		30	0.375	0.280	0.0950	30	0.286	0.206	0.0795	30	0.233	0.163	0.0697
40		0.553		40	0.462	0.368	0.0942	40	0.351	0.272	0.0789	40	0.284	0.216	0.0684
50		0.666		50	0.534	0.446	0.0879	50	0.407	0.333	0.0743	50	0.332	0.267	0.0647
60	0.856	0.756		60	0.600	0.518	0.0816‡	60	0.458	0.389	0.0694‡	60	0.373	0.312	0.0606‡
70	0.932	0.838		70	0.658	0.582	0.0763‡	70	0.506	0.441	0.0649‡	70	0.414	0.358	0.0565‡
80	1.00	0.916		80	0.714	0.642	0.0719‡	80	0.552	0.491	0.0610‡	80	0.453	0.400	0.0532‡
90	1.07	0.982		90	0.769	0.701	0.0682‡	90	0.597	0.539	0.0578‡	90	0.491	0.441	0.0503‡
100	1.13*	1.05		100	0.824*	0.759	0.0649‡	100	0.643	0.588	0.0550‡	100	0.530	0.482	0.0478‡
150	1.44*	1.37	0.0657‡	150	1.08*	1.03	0.0532‡	150	0.861*	0.816	0.0450‡	150	0.717*	0.678	0.0391‡
200	1.70*	1.64	0.0565‡	200	1.31*	1.26	0.0457‡	200	1.06*	1.02	0.0388‡	200	0.882*	0.848	0.0337‡
250	1.90*	1.85	0.0500‡	250	1.50*	1.46	0.0406‡	250	1.22*	1.18	0.0344‡	250	1.03*	1.00	0.0299‡
273	1.98	1.93	0.0476‡	273	1.58	1.54	0.0386‡	273	1.29*	1.26	0.0328‡	273	1.09	1.06	0.0285‡
300	2.08*	2.03	0.0452‡	300	1.66*	1.62	0.0367‡	300	1.37*	1.34	0.0311‡	300	1.17	1.14	0.0271‡
350	2.22*	2.18	0.0414‡	350	1.80*	1.77	0.0336‡	350	1.50*	1.47	0.0286‡	350	1.29	1.26	0.0249‡
400	2.33*	2.29	0.0383‡	400	1.91*	1.88	0.0312‡	400	1.62*	1.59	0.0265‡	400	1.40*	1.38	0.0231‡
500	2.50*	2.47	0.0335‡	500	2.11*	2.08	0.0274‡	500	1.81*	1.79	0.0234‡	500	1.59*	1.57	0.0204‡
600	2.61*	2.58	0.0300‡	600	2.25*	2.23	0.0246‡	600	1.97*	1.95	0.0210‡	600	1.74*	1.72	0.0184‡
700	2.70*	2.67	0.0274‡	700	2.37*	2.35	0.0224‡	700	2.09*	2.07	0.0192‡	700	1.87*	1.85	0.0168‡
800	2.76*	2.73	0.0252‡	800	2.46*	2.44	0.0207‡	800	2.19*	2.17	0.0178‡	800	1.97*	1.95	0.0156‡
900	2.80*	2.78	0.0234‡	900	2.51*	2.49	0.0193‡	900	2.26*	2.24	0.0166‡	900	2.05*	2.04	0.0145‡
1000	2.82*	2.80	0.0219‡	1000	2.56*	2.54	0.0181‡	1000	2.33*	2.31	0.0155‡	1000	2.12*	2.11	0.0136‡
1200	2.84*	2.82	0.0195‡	1100	2.59*	2.57	0.0171‡	1100	2.39*	2.37	0.0147‡	1100	2.18*	2.17	0.0129‡
1320	2.83*			1303	2.63*			1289	2.47*			1277	2.27*		

† Uncertainties in the total thermal conductivity, k, are as follows:
90.00 Cu - 10.00 Au: ±12% below 100 K, ±8% between 100 and 400 K, and ±10% above 400 K.
85.00 Cu - 15.00 Au: ±12% below 100 K, ±8% between 100 and 400 K, and ±10% above 400 K.
80.00 Cu - 20.00 Au: ±10% below 200 K, ±8% between 200 and 500 K, and ±10% above 500 K.
75.00 Cu - 25.00 Au: ±10% below 200 K, ±8% between 200 and 500 K, and ±10% above 500 K.

‡ Provisional value.

* In temperature range where no experimental thermal conductivity data are available.

TABLE 8. RECOMMENDED THERMAL CONDUCTIVITY OF COPPER-GOLD ALLOY SYSTEM (continued) †

[Temperature, T, K; Thermal Conductivity, k, W cm^{-1} K^{-1}; Electronic Thermal Conductivity, k_e, W cm^{-1} K^{-1}; Lattice Thermal Conductivity, k_g, W cm^{-1} K^{-1}]

Cu: 70.00% (87.85 At.%) Au: 30.00% (12.15 At.%)				Cu: 65.00% (85.20 At.%) Au: 35.00% (14.80 At.%)				Cu: 60.00% (82.30 At.%) Au: 40.00% (17.70 At.%)				Cu: 55.00% (79.12 At.%) Au: 45.00% (20.88 At.%)			
ρ_o = 5.47 μΩ cm				ρ_o = 6.52 μΩ cm				ρ_o = 7.52 μΩ cm				ρ_o = 8.48 μΩ cm			
T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g
4	0.0256	0.0179	0.00772	4	0.0226	0.0150	0.00758	4	0.0205	0.0130	0.00746	4	0.0188	0.0115	0.00735
6	0.0413	0.0268	0.0145	6	0.0364	0.0225	0.0139	6	0.0327	0.0195	0.0132	6	0.0298	0.0173	0.0125
8	0.0575	0.0357	0.0218	8	0.0505	0.0300	0.0205	8	0.0452	0.0260	0.0192	8	0.0409	0.0230	0.0179
10	0.0739	0.0447	0.0292	10	0.0645	0.0375	0.0270	10	0.0575	0.0325	0.0250	10	0.0518	0.0288	0.0230
15	0.111	0.0670	0.0441	15	0.0962	0.0562	0.0400	15	0.0853	0.0487	0.0366	15	0.0765	0.0432	0.0333
20	0.143	0.0893	0.0539	20	0.124	0.0749	0.0488	20	0.109	0.0650	0.0444	20	0.0978	0.0576	0.0402
25	0.171	0.111	0.0596	25	0.147	0.0930	0.0540	25	0.130	0.0807	0.0491	25	0.116	0.0717	0.0445
30	0.195	0.133	0.0623	30	0.168	0.111	0.0566	30	0.148	0.0964	0.0515	30	0.132	0.0856	0.0468
40	0.236	0.175	0.0615	40	0.203	0.147	0.0559	40	0.178	0.127	0.0509	40	0.160	0.113	0.0467
50	0.275	0.217	0.0576	50	0.233	0.181	0.0522	50	0.204	0.157	0.0472	50	0.183	0.140	0.0430
60	0.309*	0.255	0.0537‡	60	0.262*	0.214	0.0482‡	60	0.230	0.186	0.0436‡	60	0.204*	0.164	0.0396‡
70	0.343*	0.293	0.0501‡	70	0.291*	0.246	0.0449‡	70	0.254	0.214	0.0405‡	70	0.228*	0.191	0.0369‡
80	0.376*	0.329	0.0470‡	80	0.319*	0.277	0.0421‡	80	0.279	0.241	0.0381‡	80	0.251*	0.216	0.0346‡
90	0.409*	0.364	0.0445‡	90	0.348*	0.308	0.0398‡	90	0.305	0.269	0.0360‡	90	0.274*	0.241	0.0327‡
100	0.442*	0.400	0.0423‡	100	0.377*	0.339	0.0379‡	100	0.331*	0.297	0.0342‡	100	0.296*	0.265	0.0311‡
150	0.603*	0.568	0.0346‡	150	0.518*	0.487	0.0309‡	150	0.456*	0.428	0.0279‡	150	0.410*	0.385	0.0254‡
200	0.750*	0.720	0.0298‡	200	0.651*	0.624	0.0267‡	200	0.576*	0.552	0.0241‡	200	0.520*	0.498	0.0219‡
250	0.886*	0.859	0.0265‡	250	0.773*	0.749	0.0237‡	250	0.687*	0.666	0.0214‡	250	0.622*	0.603	0.0194‡
273	0.942	0.917	0.0253‡	273	0.825*	0.802	0.0226‡	273	0.736	0.716	0.0204‡	273	0.666	0.647	0.0186‡
300	1.01	0.986	0.0240‡	300	0.886*	0.865	0.0215‡	300	0.791	0.772	0.0194‡	300	0.717	0.699	0.0176‡
350	1.12	1.10	0.0221‡	350	0.988*	0.968	0.0198‡	350	0.887	0.869	0.0179‡	350	0.807	0.791	0.0162‡
400	1.22*	1.20	0.0205‡	400	1.08*	1.06	0.0184‡	400	0.976	0.959	0.0166‡	400	0.890	0.875	0.0151‡
500	1.40*	1.38	0.0181‡	500	1.25*	1.23	0.0162‡	500	1.14*	1.13	0.0147‡	500	1.04*	1.03	0.0134‡
600	1.55*	1.53	0.0163‡	600	1.40*	1.39	0.0147‡	600	1.27*	1.26	0.0133‡	600	1.18*	1.17	0.0121‡
700	1.68*	1.67	0.0150‡	700	1.53*	1.52	0.0134‡	700	1.40*	1.39	0.0122‡	700	1.29*	1.28	0.0111‡
800	1.79*	1.78	0.0138‡	800	1.63*	1.62	0.0124‡	800	1.50*	1.49	0.0113‡	800	1.39*	1.38	0.0103‡
900	1.88*	1.87	0.0129‡	900	1.72*	1.71	0.0116‡	900	1.59*	1.58	0.0106‡	900	1.48*	1.47	0.00962‡
1000	1.96*	1.95	0.0122‡	1000	1.80*	1.79	0.0109‡	1000	1.67*	1.66	0.00993‡	1000	1.56*	1.55	0.00906‡
1100	2.03*	2.02	0.0115‡	1100	1.88*	1.87	0.0104‡	1100	1.74*	1.73	0.00939‡	1100	1.63*	1.62	0.00858‡
1265	2.12*			1255	1.97*			1245	1.82*			1236	1.71*		

† Uncertainties in the total thermal conductivity, k, are as follows:
70.00 Cu - 30.00 Au: ±10% below 200 K, ±8% between 200 and 500 K, and ±10% above 500 K.
65.00 Cu - 35.00 Au: ±10% below 200 K, ±7% between 200 and 500 K, and ±10% above 500 K.
60.00 Cu - 40.00 Au: ±10% below 200 K, ±7% between 200 and 500 K, and ±10% above 500 K.
55.00 Cu - 45.00 Au: ±10% below 200 K, ±7% between 200 and 500 K, and ±10% above 500 K.

‡ Provisional value.

* In temperature range where no experimental thermal conductivity data are available.

TABLE 8. RECOMMENDED THERMAL CONDUCTIVITY OF COPPER-GOLD ALLOY SYSTEM (continued) †

[Temperature, T, K; Thermal Conductivity, k, W cm^{-1} K^{-1}; Electronic Thermal Conductivity, k_e, W cm^{-1} K^{-1}; Lattice Thermal Conductivity, k_g, W cm^{-1} K^{-1}]

Cu: 50.00% (75.61 At.%) Au: 50.00% (24.39 At.%)				Cu: 45.00% (71.72 At.%) Au: 55.00% (28.28 At.%)				Cu: 40.00% (67.39 At.%) Au: 60.00% (32.61 At.%)				Cu: 35.00% (62.54 At.%) Au: 65.00% (37.46 At.%)			
ρ_o = 9.34 μΩ cm				ρ_o = 10.1 μΩ cm				ρ_o = 10.9 μΩ cm				ρ_o = 11.4 μΩ cm			
T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g
4	0.0178	0.0105	0.00725	4	0.0168	0.00964	0.00717	4		0.00898		4		0.00855	
6	0.0277	0.0157	0.0120	6	0.0259	0.0144	0.0115	6		0.0135		6		0.0128	
8	0.0376	0.0209	0.0167	8	0.0350	0.0193	0.0157	8		0.0180		8		0.0171	
10	0.0474	0.0262	0.0212	10	0.0437	0.0241	0.0196	10		0.0224		10		0.0214	
15	0.0694	0.0392	0.0302	15	0.0636	0.0361	0.0275	15		0.0337		15		0.0321	
20	0.0887	0.0523	0.0364	20	0.0811	0.0482	0.0329	20		0.0449		20		0.0427	
25	0.105	0.0649	0.0402	25	0.0961	0.0599	0.0362	25		0.0557		25		0.0532	
30	0.120	0.0777	0.0422	30	0.110	0.0716	0.0379	30		0.0669		30		0.0636	
40	0.145	0.108	0.0421‡	40	0.133	0.0947	0.0380‡	40	0.126*	0.0885		40	0.118*	0.0842	
50	0.166	0.127	0.0394‡	50	0.153	0.117	0.0360‡	50	0.143*	0.110		50	0.135*	0.104	
60	0.187	0.151	0.0362‡	60	0.172	0.139	0.0333‡	60	0.161*	0.130		60	0.152*	0.124	
70	0.207	0.173	0.0337‡	70	0.192	0.161	0.0309‡	70	0.179*	0.150		70	0.169*	0.143	
80	0.228	0.196	0.0316‡	80	0.211	0.182	0.0290‡	80	0.197*	0.170		80	0.187*	0.162	
90	0.250	0.220	0.0299‡	90	0.231	0.204	0.0274‡	90	0.216*	0.191		90	0.204*	0.181	
100	0.271	0.243	0.0284‡	100	0.250	0.224	0.0260‡	100	0.234*	0.210	0.0240‡	100	0.222*	0.200	0.0221‡
150	0.376	0.353	0.0232‡	150	0.348	0.327	0.0212‡	150	0.326*	0.306	0.0196‡	150	0.310*	0.292	0.0180‡
200	0.476	0.456	0.0200‡	200	0.441	0.423	0.0183‡	200	0.413*	0.396	0.0168‡	200	0.394*	0.378	0.0156‡
250	0.570	0.552	0.0178‡	250	0.530	0.514	0.0163‡	250	0.496*	0.481	0.0150‡	250	0.473*	0.459	0.0138‡
273	0.612	0.595	0.0170‡	273	0.569	0.553	0.0156‡	273	0.534	0.520	0.0143‡	273	0.509	0.496	0.0132‡
300	0.660*	0.644	0.0161‡	300	0.614	0.599	0.0148‡	300	0.575	0.561	0.0136‡	300	0.549	0.536	0.0126‡
350	0.743*	0.728	0.0149‡	350	0.692	0.678	0.0136‡	350	0.651	0.638	0.0125‡	350	0.621	0.609	0.0116‡
400	0.823	0.809	0.0138‡	400	0.768	0.755	0.0127‡	400	0.721	0.709	0.0117‡	400	0.688	0.677	0.0108‡
500	0.967	0.955	0.0122‡	500	0.904	0.893	0.0112‡	500	0.850*	0.840	0.0103‡	500	0.812*	0.802	0.00954‡
600	1.09	1.08	0.0110‡	600	1.02	1.01	0.0102‡	600	0.966*	0.957	0.00935‡	600	0.922*	0.913	0.00864‡
700	1.20*	1.20	0.0101‡	700	1.13*	1.12	0.00932‡	700	1.07*	1.06	0.00859‡	700	1.02*	1.01	0.00793‡
800	1.30*	1.29	0.00942‡	800	1.22*	1.21	0.00865‡	800	1.16*	1.15	0.00797‡	800	1.11*	1.10	0.00736‡
900	1.39*	1.38	0.00881‡	900	1.30*	1.29	0.00810‡	900	1.23*	1.22	0.00746‡	900	1.18*	1.17	0.00689‡
1000	1.46*	1.45	0.00829‡	1000	1.38	1.37	0.00763‡	1000	1.30*	1.29	0.00703‡	1000	1.25*	1.24	0.00649‡
1100	1.53*	1.52	0.00786‡	1100	1.44*	1.43	0.00722‡	1100	1.37*	1.36	0.00666‡	1100	1.31*	1.30	0.00615‡
1226	1.62*			1216	1.51*			1206	1.43*	1.42	0.00632‡	1196	1.37*	1.36	0.00587‡

† Uncertainties in the total thermal conductivity, k, are as follows:
50.00 Cu - 50.00 Au: ±10% below 200 K, ±7% between 200 and 500 K, and ±10% above 500 K.
45.00 Cu - 55.00 Au: ±10% below 200 K, ±8% between 200 and 500 K, and ±10% above 500 K.
40.00 Cu - 60.00 Au: ±10% below 200 K, ±8% between 200 and 500 K, and ±10% above 500 K.
35.00 Cu - 65.00 Au: ±10% below 200 K, ±8% between 200 and 500 K, and ±10% above 500 K.

‡ Provisional value.

* In temperature range where no experimental thermal conductivity data are available.

TABLE 8. RECOMMENDED THERMAL CONDUCTIVITY OF COPPER-GOLD ALLOY SYSTEM (continued) †

[Temperature, T, K; Thermal Conductivity, k, W cm^{-1} K^{-1}; Electronic Thermal Conductivity, k_e, W cm^{-1} K^{-1}; Lattice Thermal Conductivity, k_g, W cm^{-1} K^{-1}]

Cu: 30.00% (57.05 At.%) Au: 70.00% (42.95 At.%)				Cu: 25.00% (50.82 At.%) Au: 75.00% (49.18 At.%)				Cu: 20.00% (43.66 At.%) Au: 80.00% (56.34 At.%)				Cu: 15.00% (35.36 At.%) Au: 85.00% (64.63 At.%)			
ρ_o = 11.8 μΩ cm				ρ_o = 12.0 μΩ cm				ρ_o = 11.7 μΩ cm				ρ_o = 10.8 μΩ cm			
T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g
4		0.00827		4		0.00818		4		0.00834		4		0.00909	
6		0.0124		6		0.0123		6		0.0125		6		0.0136	
8		0.0165		8		0.0164		8		0.0167		8		0.0182	
10		0.0207		10		0.0204		10		0.0208		10		0.0227	
15		0.0310		15		0.0307		15		0.0313		15		0.0341	
20		0.0413		20		0.0409		20		0.0417		20		0.0454	
25		0.0514		25		0.0508		25		0.0518		25		0.0565	
30		0.0615		30		0.0607		30		0.0620		30		0.0675	
40	0.113*	0.0814		40	0.110	0.0803		40	0.110	0.0820		40	0.115	0.0892	
50	0.129*	0.100		50	0.127	0.0998		50	0.127	0.102		50	0.134	0.110	
60	0.146*	0.120		60	0.143	0.118		60	0.144	0.121		60	0.153	0.131	
70	0.163*	0.139		70	0.159	0.136		70	0.161	0.140		70	0.172	0.152	
80	0.180*	0.157		80	0.176	0.155		80	0.178	0.158		80	0.191	0.172	
90	0.197*	0.175		90	0.193*	0.173		90	0.196*	0.177		90	0.209	0.191	
100	0.214*	0.194	0.0205‡	100	0.209*	0.190	0.0191‡	100	0.213*	0.195	0.0178‡	100	0.228*	0.211	0.0169‡
150	0.299*	0.282	0.0167‡	150	0.294*	0.279	0.0155‡	150	0.299*	0.284	0.0145‡	150	0.321*	0.307	0.0137‡
200	0.381*	0.367	0.0144‡	200	0.375*	0.362	0.0134‡	200	0.381*	0.369	0.0125‡	200	0.409*	0.397	0.0118‡
250	0.458*	0.445	0.0128‡	250	0.452*	0.440	0.0119‡	250	0.459*	0.448	0.0111‡	250	0.492*	0.481	0.0105‡
273	0.492	0.480	0.0122‡	273	0.486	0.475	0.0114‡	273	0.493	0.482	0.0106‡	273	0.529	0.519	0.0100‡
300	0.531*	0.519	0.0116‡	300	0.525*	0.514	0.0108‡	300	0.532*	0.522	0.0101‡	300	0.570	0.560	0.00951‡
350	0.600*	0.589	0.0107‡	350	0.593*	0.583	0.00996‡	350	0.601*	0.592	0.00929‡	350	0.643	0.634	0.00875‡
400	0.666*	0.656	0.00997‡	400	0.658	0.649	0.00926‡	400	0.667	0.658	0.00864‡	400	0.712*	0.704	0.00814‡
500	0.786*	0.777	0.00884‡	500	0.775*	0.767	0.00820‡	500	0.785*	0.777	0.00765‡	500	0.836	0.829	0.00720‡
600	0.893*	0.885	0.00799‡	600	0.881*	0.874	0.00742‡	600	0.892*	0.885	0.00692‡	600	0.947*	0.940	0.00650‡
700	0.990*	0.983	0.00734‡	700	0.975*	0.968	0.00681‡	700	0.988*	0.982	0.00635‡	700	1.04*	1.03	0.00596‡
800	1.08*	1.07	0.00682‡	800	1.06*	1.05	0.00632‡	800	1.07*	1.06	0.00589‡	800	1.13*	1.12	0.00553‡
900	1.15*	1.14	0.00638‡	900	1.13*	1.12	0.00592‡	900	1.14*	1.13	0.00551‡	900	1.20*	1.20	0.00517‡
1000	1.21*	1.20	0.00601‡	1000	1.19*	1.18	0.00558‡	1000	1.21*	1.20	0.00520‡	1000	1.26*	1.26	0.00487‡
1100	1.27*	1.26	0.00570‡	1100	1.25*	1.24	0.00528‡	1100	1.26*	1.25	0.00492‡	1100	1.31*	1.31	0.00461‡
1188	1.32*	1.31	0.00547‡	1184	1.29*	1.28	0.00507‡	1182	1.30*	1.30	0.00473‡	1185	1.35*	1.35	0.00442‡

† Uncertainties in the total thermal conductivity, k, are as follows:
30.00 Cu - 70.00 Au: ±10% below 200 K, ± 8% between 200 and 500 K, and ± 10% above 500 K.
25.00 Cu - 75.00 Au: ±10% below 200 K, ± 8% between 200 and 500 K, and ± 10% above 500 K.
20.00 Cu - 80.00 Au: ±10% below 200 K, ± 8% between 200 and 500 K, and ± 10% above 500 K.
15.00 Cu - 85.00 Au: ±10% below 200 K, ± 8% between 200 and 500 K, and ± 10% above 500 K.

‡ Provisional value.

* In temperature range where no experimental thermal conductivity data are available.

TABLE 8. RECOMMENDED THERMAL CONDUCTIVITY OF COPPER-GOLD ALLOY SYSTEM (continued)†

[Temperature, T, K; Thermal Conductivity, k, W cm^{-1} K^{-1}; Electronic Thermal Conductivity, k_e, W cm^{-1} K^{-1}; Lattice Thermal Conductivity, k_g, W cm^{-1} K^{-1}]

Cu: 10.00% (25.62 At.%) Au: 90.00% (74.38 At.%)				Cu: 5.00% (14.03 At.%) Au: 95.00% (85.97 At.%)				Cu: 3.00% (8.75 At.%) Au: 97.00% (91.25 At.%)				Cu: 1.00% (3.04 At.%) Au: 99.00% (96.96 At.%)			
ρ_o = 8.72 μΩ cm				ρ_o = 5.27 μΩ cm				ρ_o = 3.44 μΩ cm				ρ_o = 1.40 μΩ cm			
T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g	T	k	k_e	k_g
4		0.0112		4		0.0185		4		0.0284		4		0.0698	
6		0.0168		6		0.0278		6		0.0426		6		0.105	
8		0.0224		8		0.0371		8		0.0568		8		0.140	
10		0.0280		10		0.0464		10		0.0701		10		0.174	
15		0.0420		15		0.0695		15		0.106		15		0.262	
20		0.0560		20		0.0927		20		0.142		20		0.349	
25		0.0696		25		0.114		25		0.174		25		0.420	
30		0.0832		30		0.136		30		0.206		30		0.492	
40	0.135	0.110		40	0.204	0.178		40	0.297	0.267		40	0.663	0.622	
50	0.158	0.135		50	0.242	0.218		50	0.351	0.324		50	0.758	0.721	
60	0.181	0.160		60	0.278	0.256		60	0.403	0.378		60	0.848	0.814	
70	0.205	0.185		70	0.314	0.294		70	0.453	0.430		70	0.932	0.901	
80	0.228	0.210		80	0.350	0.331		80	0.502	0.480		80	1.01	0.981	
90	0.251	0.234		90	0.385	0.367		90	0.549	0.529		90	1.09	1.06	
100	0.274*	0.258	0.0163‡	100	0.420*	0.403	0.0171‡	100	0.597*	0.578	0.0190‡	100	1.17*	1.14	0.0256‡
150	0.385*	0.372	0.0133‡	150	0.584*	0.570	0.0138‡	150	0.812*	0.797	0.0150‡	150	1.47*	1.45	0.0203‡
200	0.489*	0.478	0.0114‡	200	0.731*	0.719	0.0118‡	200	0.993*	0.980	0.0129‡	200	1.69*	1.68	0.0172‡
250	0.585*	0.575	0.0101‡	250	0.862*	0.852	0.0104‡	250	1.15*	1.14	0.0114‡	250	1.86*	1.84	0.0150‡
273	0.627	0.617	0.00964‡	273	0.918	0.908	0.00995‡	273	1.21	1.20	0.0108‡	273	1.92*	1.91	0.0142‡
300	0.675	0.666	0.00915‡	300	0.979	0.970	0.00943‡	300	1.28	1.27	0.0102‡	300	1.98*	1.97	0.0134‡
350	0.757	0.749	0.00841‡	350	1.08	1.07	0.00865‡	350	1.39	1.38	0.00935‡	350	2.08*	2.07	0.0122‡
400	0.834*	0.826	0.00781‡	400	1.17*	1.16	0.00801‡	400	1.49*	1.48	0.00865‡	400	2.16*	2.15	0.0112‡
500	0.967	0.960	0.00690‡	500	1.33*	1.32	0.00704‡	500	1.64*	1.63	0.00758‡	500	2.27*	2.26	0.00974‡
600	1.08*	1.07	0.00622‡	600	1.45*	1.44	0.00633‡	600	1.76*	1.75	0.00679‡	600	2.34*	2.33	0.00864‡
700	1.18*	1.17	0.00570‡	700	1.55*	1.54	0.00578‡	700	1.86*	1.85	0.00618‡	700	2.37*	2.36	0.00780‡
800	1.27*	1.26	0.00528‡	800	1.62*	1.61	0.00534‡	800	1.92*	1.91	0.00569‡	800	2.38*	2.37	0.00712‡
900	1.34*	1.34	0.00493‡	900	1.68*	1.68	0.00498‡	900	1.96*	1.95	0.00529‡	900	2.37*	2.36	0.00657‡
1000	1.39*	1.39	0.00464‡	1000	1.73*	1.73	0.00467‡	1000	1.98*	1.98	0.00495‡	1000	2.34*	2.33	0.00610‡
1100	1.44*	1.44	0.00439‡	1100	1.77*	1.77	0.00441‡	1100	1.99*	1.99	0.00466‡	1100	2.31*	2.30	0.00571‡
1199	1.48*	1.48	0.00417‡	1241	1.81*			1270	1.98*			1296	2.22*		

† Uncertainties in the total thermal conductivity, k, are as follows:
10.00 Cu - 90.00 Au: ±10% below 200 K, ±8% between 200 and 500 K, and ±10% above 500 K.
5.00 Cu - 95.00 Au: ±12% below 200 K, ±8% between 200 and 500 K, and ±10% above 500 K.
3.00 Cu - 97.00 Au: ±12% below 200 K, ±8% between 200 and 500 K, and ±10% above 500 K.
1.00 Cu - 99.00 Au: ±14% below 200 K and ±10% above 200 K.

‡ Provisional value.

* In temperature range where no experimental thermal conductivity data are available.

TABLE 8. RECOMMENDED THERMAL CONDUCTIVITY OF COPPER-GOLD ALLOY SYSTEM (continued) †

[Temperature, T, K; Thermal Conductivity, k, W cm^{-1} K^{-1}; Electronic Thermal Conductivity, k_e, W cm^{-1} K^{-1}; Lattice Thermal Conductivity, k_g, W cm^{-1} K^{-1}]

Cu: 0.50% (1.53 At.%) Au: 99.50% (98.47 At.%)			
ρ_o = 0.770 μΩ cm			
T	k	k_e	k_g
4		0.127	
6		0.190	
8		0.254	
10		0.317	
15		0.476	
20		0.634	
25		0.740	
30		0.843	
40	1.08*	1.03	
50	1.20*	1.15	
60	1.30*	1.26	
70	1.39*	1.35	
80	1.48*	1.44	
90	1.56*	1.52	
100	1.64*	1.61	0.0329‡
150	1.96*	1.93	0.0257‡
200	2.16*	2.14	0.0213‡
250	2.30*	2.28	0.0185‡
273	2.34*	2.32	0.0175‡
300	2.39*	2.37	0.0164‡
350	2.45*	2.43	0.0148‡
400	2.50*	2.49	0.0136‡
500	2.56*	2.55	0.0116‡
600	2.59*	2.58	0.0102‡
700	2.59*	2.58	0.00914‡
800	2.58*	2.57	0.00828‡
900	2.54*	2.53	0.00757‡
1000	2.50*	2.49	0.00698‡
1200	2.40*	2.39	0.00605‡
1323	2.32*		

† Uncertainties in the total thermal conductivity, k, are as follows:
0.50 Cu - 99.50 Au: ± 14% below 200 K and ± 10% above 200 K.

‡ Provisional value.

* In temperature range where no experimental thermal conductivity data are available.

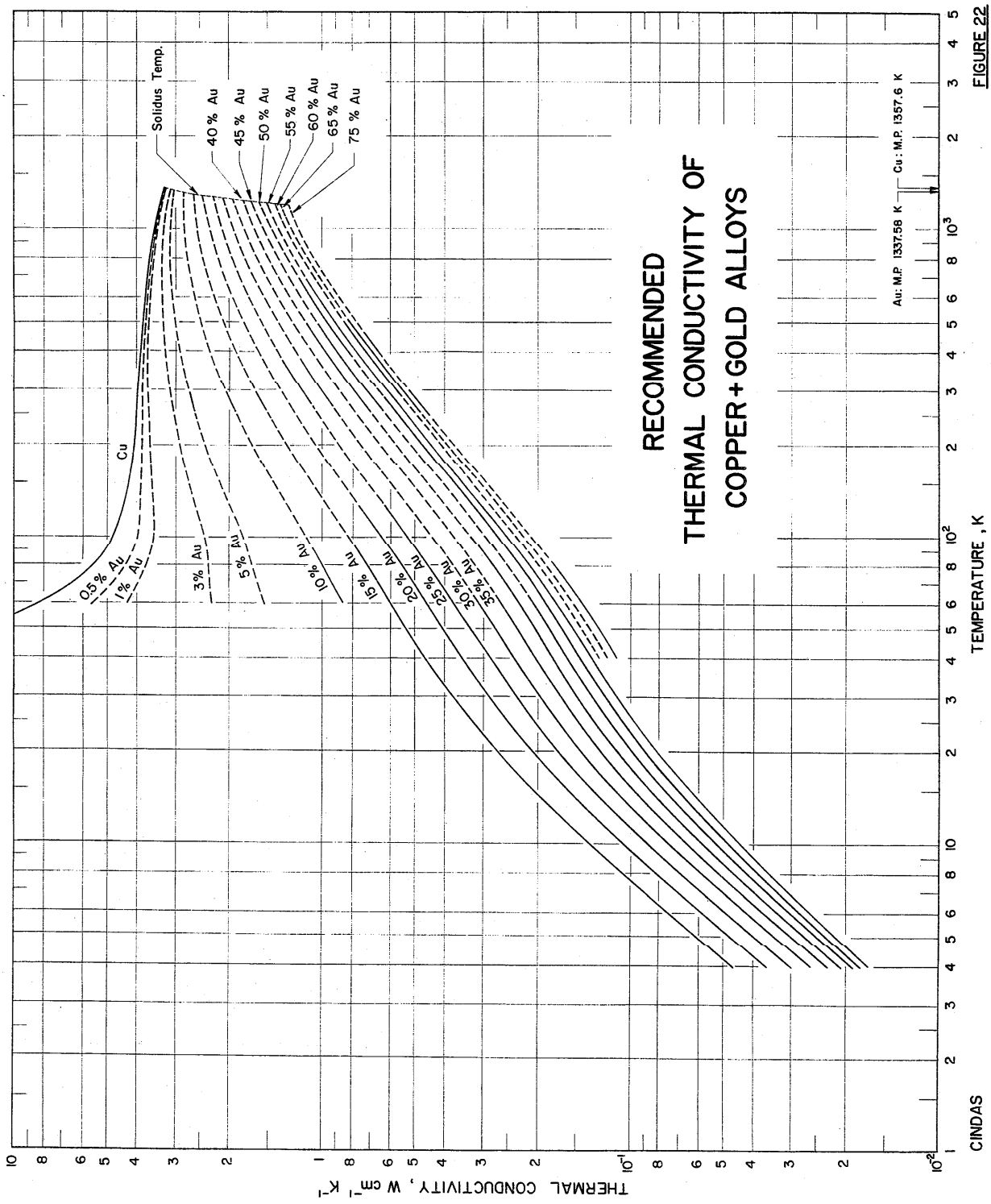
RECOMMENDED
THERMAL CONDUCTIVITY OF
COPPER + GOLD ALLOYS
Solidus Temp.
40 % Au
45 % Au
50 % Au
55 % Au
60 % Au
65 % Au
75 % Au
Cu
0.5 % Au
1 % Au
3 % Au
5 % Au
10 % Au
15 % Au
20 % Au
25 % Au
30 % Au
35 % Au
Au: M.P. 1337.58 K
Cu: M.P. 1357.6 K
THERMAL CONDUCTIVITY, W cm⁻¹ K⁻¹
TEMPERATURE, K
CINDAS

FIGURE 22

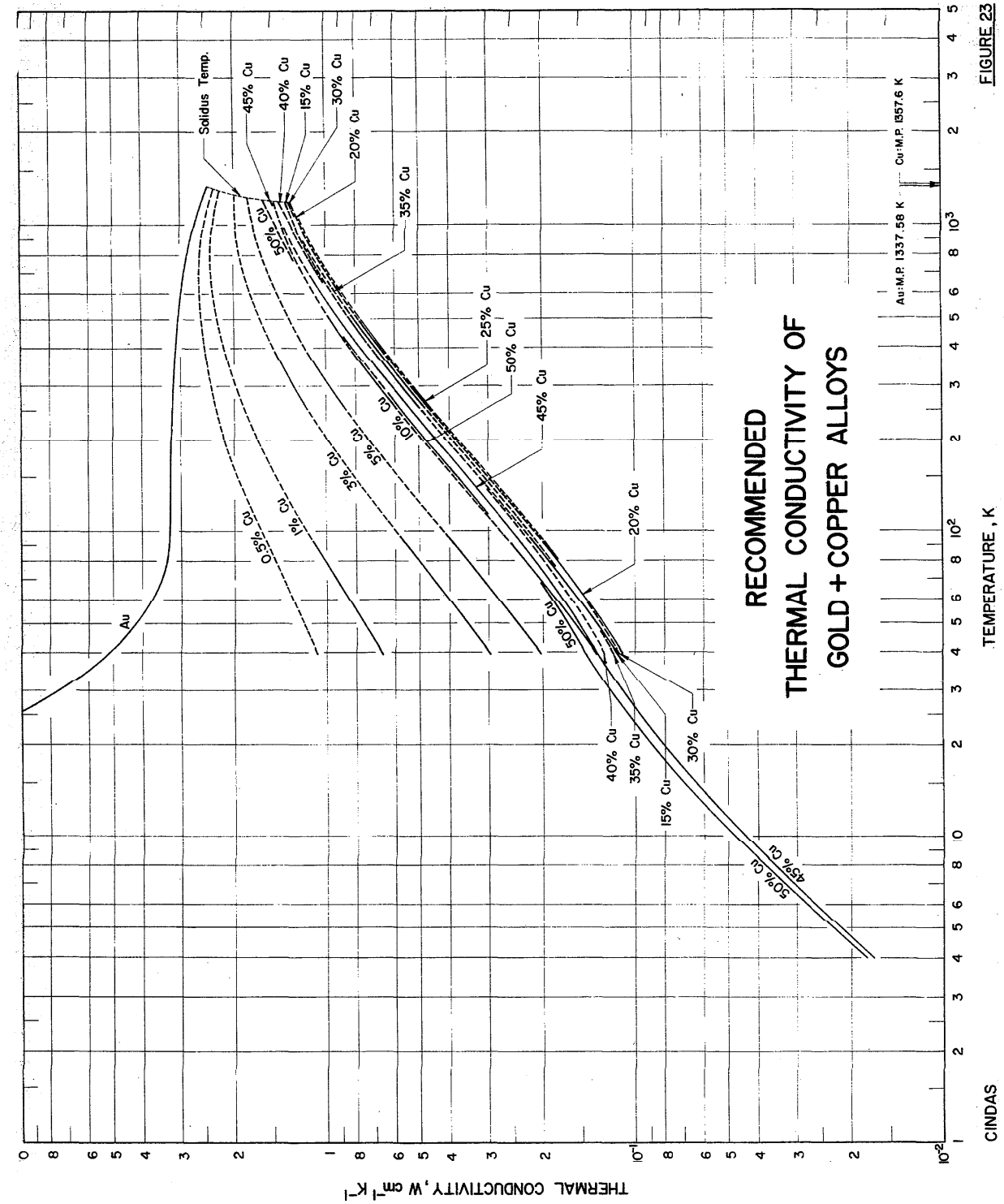
RECOMMENDED
THERMAL CONDUCTIVITY OF
GOLD + COPPER ALLOYS
Au: M.P. 1337.58 K
Cu: M.P. 1357.6 K
Solidus Temp.
Au
0.5% Cu
1% Cu
3% Cu
5% Cu
10% Cu
15% Cu
20% Cu
25% Cu
30% Cu
35% Cu
40% Cu
45% Cu
50% Cu
THERMAL CONDUCTIVITY, W cm⁻¹ K⁻¹
TEMPERATURE, K
CINDAS

FIGURE 23

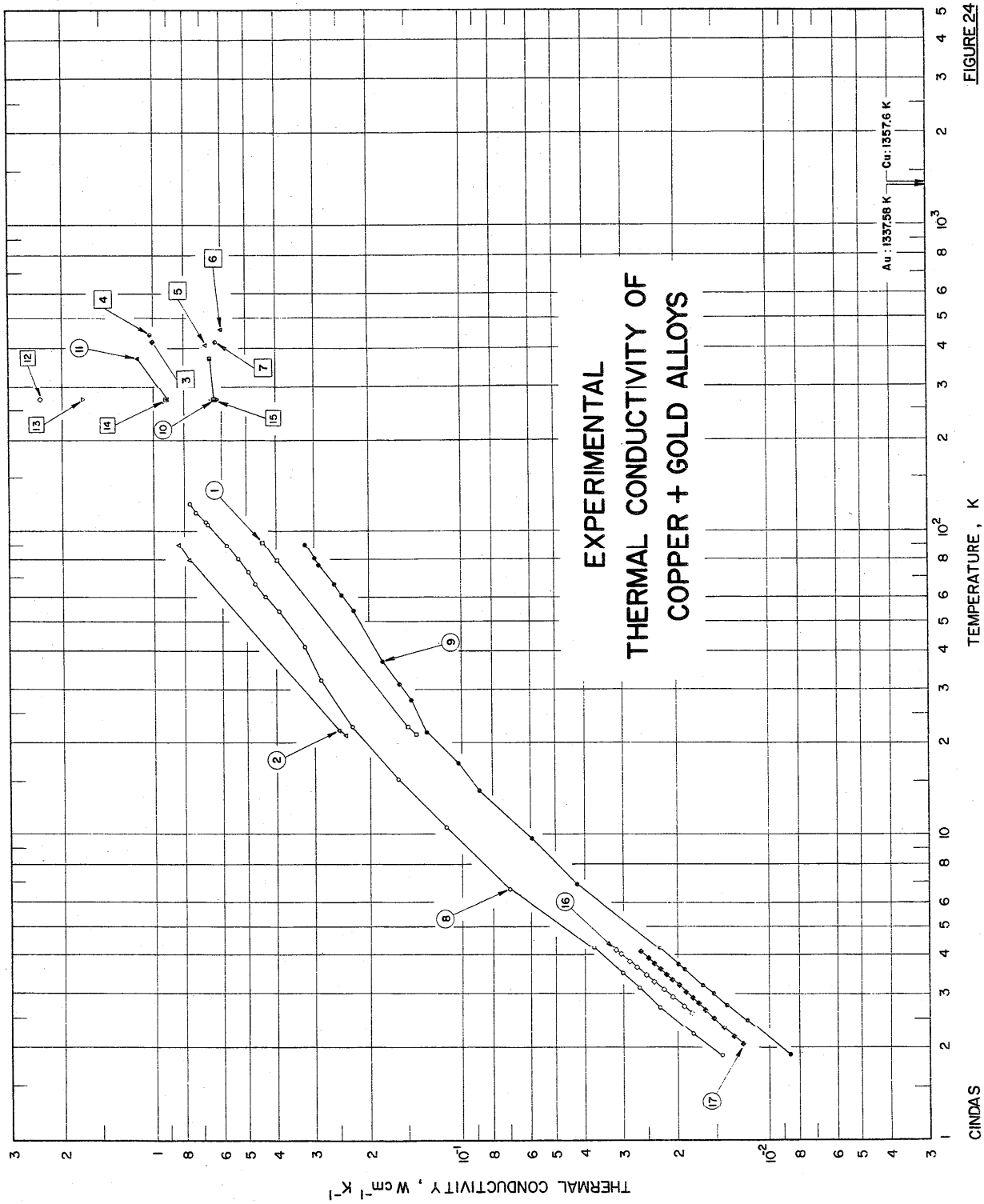
EXPERIMENTAL
THERMAL CONDUCTIVITY OF
COPPER + GOLD ALLOYS
Au : 1337.58 K
Cu: 1357.6 K
THERMAL CONDUCTIVITY , W cm⁻¹ K⁻¹
TEMPERATURE , K
CINDAS

FIGURE 24

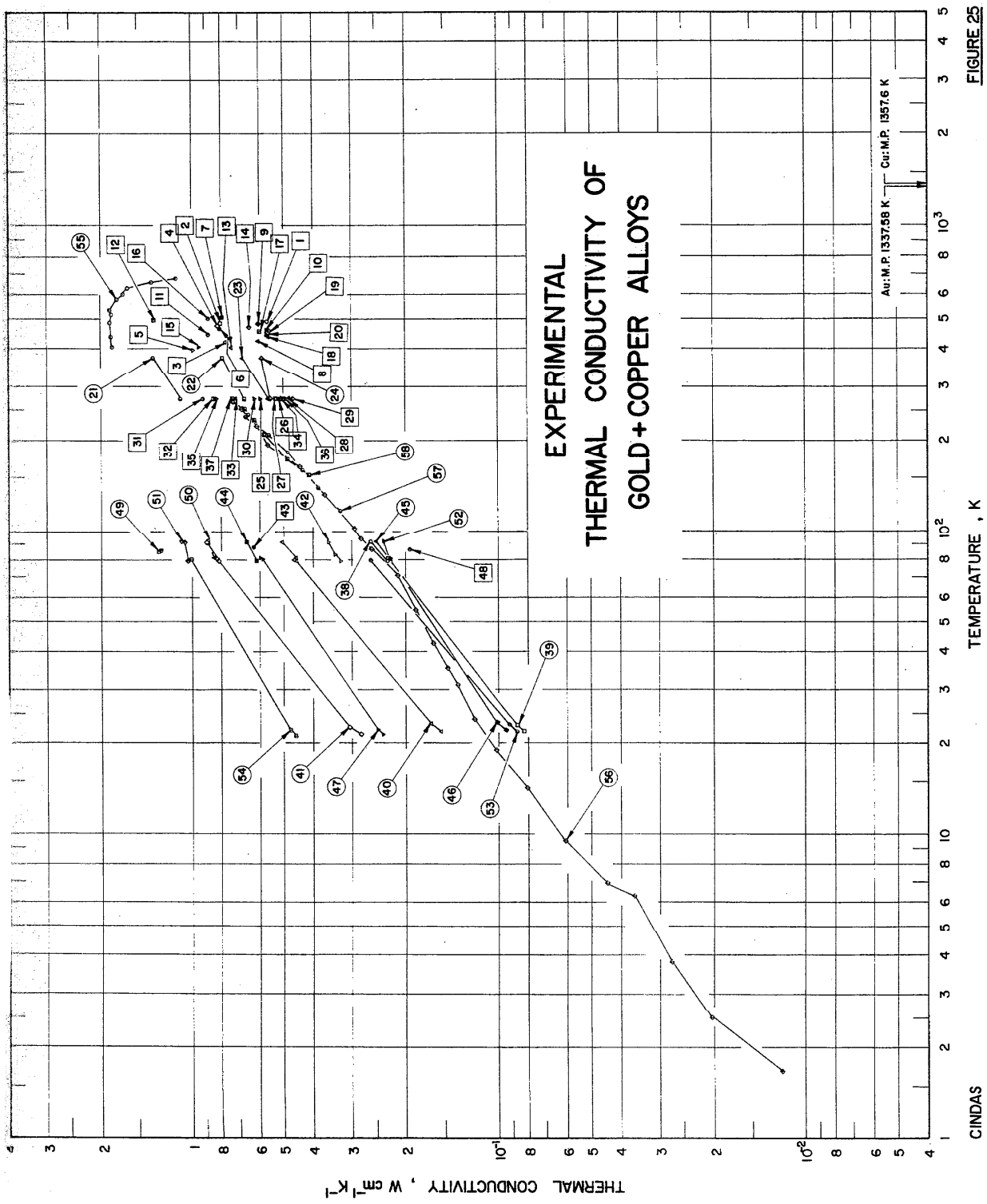
EXPERIMENTAL
THERMAL CONDUCTIVITY OF
GOLD + COPPER ALLOYS
Au: M.P. 1337.58 K
Cu: M.P. 1357.6 K
THERMAL CONDUCTIVITY , W cm⁻¹ K⁻¹
TEMPERATURE , K
CINDAS

FIGURE 25

TABLE 9. THERMAL CONDUCTIVITY OF COPPER + GOLD ALLOYS -- SPECIMEN CHARACTERIZATION AND MEASUREMENT INFORMATION

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) Cu	Au	Composition (continued), Specifications, and Remarks
1	61	Grüneisen, E. and Reddemann, H.	1934	L	21-93	10	75.2	24.8	Calculated composition; polycrystalline; form factor 1.53×10^3; residual electrical resistivity 6.54 $\mu\Omega$ cm; electrical resistivity 5.09 and 4.71 $\mu\Omega$ cm at -190 and -251 C, respectively.
2	61	Grüneisen, E. and Reddemann, H.	1934	L	21-91	9	87.4	12.6	Calculated composition; polycrystalline; form factor 2.61×10^3; residual electrical resistivity 3.83 $\mu\Omega$ cm; electrical resistivity 2.487 and 2.172 $\mu\Omega$ cm at -190 and -251 C, respectively.
3	65	Zolotukhin, G.E.	1957	L	422.7		56.33	43.67	Calculated composition; cylindrical specimen 1.43 cm long and 0.63 cm^2 in cross-section; cast; density 14.30 g cm^{-3}.
4	65	Zolotukhin, G.E.	1957	L	448.2				The above specimen; annealed for 10 hr.
5	65	Zolotukhin, G.E.	1957	L	411.2				The above specimen; annealed for 20 hr.
6	65	Zolotukhin, G.E.	1957	L	467.2				The above specimen; annealed for 30 hr.
7	65	Zolotukhin, G.E.	1957	L	422.2				The above specimen; annealed for 40 hr.
8	62	Kemp, W.R.G., Klemens, P.G., and Tainsh, R.J.	1957	L	1.9-124			20.09	8 cm long and 0.5 cm in diameter; annealed at 750 C for 1 hr; electrical resistivity reported as 3.53, 3.91, and 5.37 $\mu\Omega$ cm at 0, 90, and 293 K, respectively.
9	62	Kemp, W.R.G., et al.	1957	L	1.9-91			37.99	Similar to the above specimen except electrical resistivity reported as 7.04, 7.38, and 8.89 $\mu\Omega$ cm at 0, 90, and 293 K, respectively.
10	63	Sedström, E.	1919	T	273, 373		55.24	44.76	Calculated composition; specimen rolled and drawn to wire 1 mm diameter; heated to near melting point for 0.5 hr; electrical conductivity 5.7×10^4 and 5.5×10^4 Ω^{-1} cm^{-1} at 0 and 100 C, respectively.
11	63	Sedström, E.	1919	T	273, 373		73.52	26.48	Similar to the above specimen except electrical conductivity 10.7×10^4 and 9.1×10^4 Ω^{-1} cm^{-1} at 0 and 100 C, respectively.
12	63	Sedström, E.	1924	T	273.2		94.6	5.4	Calculated composition; specimen rolled and drawn to a wire of 3 cm in length and 1 mm^2 in cross-section, then heated to the melting point; electrical resistivity 8.2 $\mu\Omega$ cm at 0 C.
13	63	Sedström, E.	1924	T	273.2		87.6	12.4	Similar to the above specimen except electrical resistivity 4.7 $\mu\Omega$ cm at 0 C.
14	63	Sedström, E.	1924	T	273.2		72.7	27.3	Similar to the above specimen except electrical resistivity 7.3 $\mu\Omega$ cm at 0 C.
15	63	Sedström, E.	1924	T	273.2		55.0	45.0	Similar to the above specimen except electrical resistivity 10.4 $\mu\Omega$ cm at 0 C.
16	120	Leaver, A.D.W. and Charsley, P.	1971	L	2.6-4.2	10 Au		25.4	Polycrystalline; obtained from the International Research and Development Co., Ltd.; annealed; residual electrical resistivity 4.386 $\mu\Omega$cm.
17	120	Leaver, A.D.W. and Charsley, P.	1971	L	2.1-4.1	10 Au			The above specimen tensile strained 13.4% under a stress of 36.68 kg mm^{-2}; residual electrical resistivity 4.444 $\mu\Omega$cm.

TABLE 10. THERMAL CONDUCTIVITY OF GOLD + COPPER ALLOYS -- SPECIMEN CHARACTERIZATION AND MEASUREMENT INFORMATION

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) Au	Cu	Composition (continued), Specifications, and Remarks
1	65	Zolotukhin, G. E.	1957	L	488.7	IV	75.61	24.39	Calculated composition; cast; 1.30 cm long and 0.63 cm^2 in cross-section; density 18.34 g cm^{-3}.
2	65	Zolotukhin, G. E.	1957	L	483.2	IV			The above specimen annealed 10 hr at 200 C.
3	65	Zolotukhin, G. E.	1957	L	420.7	IV			The above specimen annealed 20 hr at 200 C.
4	65	Zolotukhin, G. E.	1957	L	473.7	IV			The above specimen annealed 30 hr at 200 C.
5	65	Zolotukhin, G. E.	1957	L	395.2	IV			The above specimen annealed 40 hr at 200 C.
6	65	Zolotukhin, G. E.	1957	L	466.2	V	85.20	14.80	Calculated composition; cast; 1.30 cm long and 0.63 cm^2 in cross-section; density 19.40 g cm^{-3}.
7	65	Zolotukhin, G. E.	1957	L	504.7	V			The above specimen annealed 10 hr at 200 C.
8	65	Zolotukhin, G. E.	1957	L	426.2	V			The above specimen annealed 20 hr at 200 C.
9	65	Zolotukhin, G. E.	1957	L	481.7	V			The above specimen annealed 30 hr at 200 C.
10	65	Zolotukhin, G. E.	1957	L	460.7	V			The above specimen annealed 40 hr at 200 C.
11	65	Zolotukhin, G. E.	1957	L	445.7	II	50.82	49.18	Calculated composition; cast; 1.49 cm long and 0.63 cm^2 in cross-section; density 15.05 g cm^{-3}.
12	65	Zolotukhin, G. E.	1957	L	493.2	II			The above specimen annealed 10 hr at 200 C.
13	65	Zolotukhin, G. E.	1957	L	401.7	II			The above specimen annealed 20 hr at 200 C.
14	65	Zolotukhin, G. E.	1957	L	470.2	II			The above specimen annealed 30 hr at 200 C.
15	65	Zolotukhin, G. E.	1957	L	403.7	II			The above specimen annealed 40 hr at 200 C.
16	65	Zolotukhin, G. E.	1957	L	497.7	III	62.54	37.46	Calculated composition; cast; 1.45 cm long and 0.63 cm^2 in cross-section; density 16.70 g cm^{-3}.
17	65	Zolotukhin, G. E.	1957	L	455.7	III			The above specimen annealed 10 hr at 200 C.
18	65	Zolotukhin, G. E.	1957	L	437.7	III			The above specimen annealed 20 hr at 200 C.
19	65	Zolotukhin, G. E.	1957	L	457.7	III			The above specimen annealed 30 hr at 200 C.
20	65	Zolotukhin, G. E.	1957	L	444.7	III			The above specimen annealed 40 hr at 200 C.
21	63	Sedström, E.	1919	T	273, 373		96.73	3.27	Calculated composition; rolled and drawn to 1 mm diameter wire; annealed close to melting point for 0.5 hr; electrical conductivity 14.3 and 13.4 x $10^4\ \Omega^{-1}\ cm^{-1}$ at 0 and 100 C, respectively.
22	63	Sedström, E.	1919	T	273, 373		92.55	7.45	Similar to the above specimen except electrical conductivity 8.5 and 8.2 x $10^4\ \Omega^{-1}\ cm^{-1}$ at 0 and 100 C, respectively.
23	63	Sedström, E.	1919	T	273, 373		87.77	12.23	Similar to the above specimen except electrical conductivity 6.3 and 5.9 x $10^4\ \Omega^{-1}\ cm^{-1}$ at 0 and 100 C, respectively.
24	63	Sedström, E.	1919	T	273, 373		59.25	40.75	Similar to the above specimen except electrical conductivity 5.0 and 4.6 x $10^4\ \Omega^{-1}\ cm^{-1}$ at 0 and 100 C, respectively.
25	64	Sedström, E.	1924	T	273.2		50.8	49.2	Rolled and drawn to 1 mm^2 in cross-sectional area and 3 cm long; annealed close to melting point for 0.5 hr; electrical resistivity 10.8 $\mu\Omega$ cm at 273 K.
26	64	Sedström, E.	1924	T	273.2		54.0	46.0	Similar to the above specimen except electrical resistivity 11.4 $\mu\Omega$ cm at 273 K.

TABLE 10. THERMAL CONDUCTIVITY OF GOLD + COPPER ALLOYS -- SPECIMEN CHARACTERIZATION AND MEASUREMENT INFORMATION (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) Au	Cu	Composition (continued), Specifications, and Remarks
27	64	Sedström, E.	1924	T	273.2		57.0	43.0	Similar to the above specimen except electrical resistivity 11.8 $\mu\Omega$ cm at 273 K.
28	64	Sedström, E.	1924	T	273.2		62.6	37.4	Similar to the above specimen except electrical resistivity 13.0 $\mu\Omega$ cm at 273 K.
29	64	Sedström, E.	1924	T	273.2		67.2	32.8	Similar to the above specimen except electrical resistivity 13.6 $\mu\Omega$ cm at 273 K.
30	64	Sedström, E.	1924	T	273.2		71.9	28.1	Similar to the above specimen except electrical resistivity 10.5 $\mu\Omega$ cm at 273 K.
31	64	Sedström, E.	1924	T	273.2		78.1	21.9	Similar to the above specimen except electrical resistivity 7.6 $\mu\Omega$ cm at 273 K.
32	64	Sedström, E	1924	T	273.2		78.2	21.8	Similar to the above specimen except electrical resistivity 7.6 $\mu\Omega$ cm at 273 K.
33	64	Sedström, E.	1924	T	273.2		78.9	21.1	Similar to the above specimen except electrical resistivity 8.4 $\mu\Omega$ cm at 273 K.
34	64	Sedström, E.	1924	T	273.2		82.1	17.9	Similar to the above specimen except electrical resistivity 11.6 $\mu\Omega$ cm at 273 K.
35	64	Sedström, E.	1924	T	273.2		82.4	17.6	Similar to the above specimen except electrical resistivity 11.6 $\mu\Omega$ cm at 273 K.
36	64	Sedström, E.	1924	T	273.2		87.5	12.5	Similar to the above specimen except electrical resistivity 11.6 $\mu\Omega$ cm at 273 K.
37	64	Sedström, E.	1924	T	273.2		94.1	5.9	Similar to the above specimen except electrical resistivity 8.0 $\mu\Omega$ cm at 273 K.
38	61	Grüneisen, E. and Reddemann, H.	1934	L	80, 92	11	89.6	10.4	Calculated composition; polycrystalline; cast; electrical resistivity 9.27 $\mu\Omega$ cm at 83 K.
39	61	Grüneisen, E. and Reddemann, H.	1934	L	22-80	11a			The above specimen annealed in vacuo for 40 hr at 365 C; electrical resistivity 10.88 $\mu\Omega$ cm at 273 K.
40	61	Grüneisen, E. and Reddemann, H.	1934	L	22-91	12	96.9	3.10	Calculated composition; polycrystalline; cast; electrical resistivity 3.828, 4.345, and 5.94 $\mu\Omega$ cm at 22, 83, and 273 K, respectively.
41	61	Grüneisen, E. and Reddemann, H.	1934	L	21-91	13	98.43	1.57	Calculated composition; polycrystalline; cast; electrical resistivity 1.841, 2.353, and 3.93 $\mu\Omega$ cm at 22, 83, and 273 K, respectively.
42	61	Grüneisen, E. and Reddemann, H.	1934	L	79-91	14a	50.1	49.9	Calculated composition; polycrystalline; cast; quenched from 800 C; electrical resistivity 6.64 $\mu\Omega$ cm at 83 K.
43	61	Grüneisen, E. and Reddemann, H.	1934	L	87.4	14b			The above specimen annealed at ~400 C for 20 hr; electrical resistivity 3.23 and 5.80 $\mu\Omega$ cm at 83 and 273 K, respectively.
44	61	Grüneisen, E. and Reddemann, H.	1934	L	79, 92	14c			The above specimen annealed at ~360 C for 32 hr; electrical resistivity 3.126 and 5.42 $\mu\Omega$ cm at 83 and 273 K, respectively.
45	61	Grüneisen, E. and Reddemann, H.	1934	L	80, 92	14d			The above specimen annealed at ~820 C for 2 hr and then quenched; electrical resistivity 11.49 $\mu\Omega$ cm at 273 K.
46	61	Grüneisen, E. and Reddemann, H.	1934	L	22-80	14e			The above specimen measured after 5 months; electrical resistivity 9.88 and 11.48 $\mu\Omega$ cm at 83 and 273 K, respectively.

TABLE 10. THERMAL CONDUCTIVITY OF GOLD + COPPER ALLOYS -- SPECIMEN CHARACTERIZATION AND MEASUREMENT INFORMATION (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) Au	Cu	Composition (continued), Specifications, and Remarks
47	61	Grüneisen, E. and Reddemann, H.	1934	L	21-81	14f			The above specimen annealed at ~325 C for 30 hr; electrical resistivity 2.70 and 3.41 μΩ cm at 22 and 83 K, respectively.
48	61	Grüneisen, E. and Reddemann, H.	1934	L	86.9	15a	75.6	24.4	Calculated composition; polycrystalline; cast; quenched from 800 C; electrical resistivity 11.57, 13.2, and 13.41 μΩ cm at 33, 273, and 292 K, respectively.
49	61	Grüneisen, E. and Reddemann, H.	1934	L	85, 85	15b			The above specimen annealed at 360 C for 22 hr; electrical resistivity 1.753, 3.974, and 4.82 μΩ cm at 83, 273, and 293 K, respectively.
50	61	Grüneisen, E. and Reddemann, H.	1934	L	81, 92	15c			The above specimen annealed at 345 C for 30 hr; electrical resistivity 2.228 and 4.48 μΩ cm at 83 and 273 K, respectively.
51	61	Grüneisen, E. and Reddemann, H.	1934	L	79-91	15d			The above specimen annealed at 325 C for 30 hr; electrical resistivity 1.797 and 4.07 μΩ cm at 83 and 273 K, respectively.
52	61	Grüneisen, E. and Reddemann, H.	1934	L	79, 91	15e			The above specimen annealed at 800 C for 2 hr and then quenched; electrica resistivity 9.17 μΩ cm at 83 K.
53	61	Grüneisen, E. and Reddemann, H.	1934	L	22-79	15f			The above specimen measured after 4 months; electrical resistivity 7.90 μΩ cm at 83 K.
54	61	Grüneisen, E. and Reddemann, H.	1934	L	21-80	15g			The above specimen annealed at ~325 C for 30 hr; electrical resistivity 1.826 and 4.09 μΩ cm at 83 and 273 K, respectively.
55	126, 174, 175	Lindenbaum, S.D. and Quimby, S.L.	1962	L	407-680	Cu_3Au		49.18	Intermetallic compound; 0.1858 in. diameter and 2.41 in. long; successively annealed at 360 C for 90 hr, 240 C for 110 hr, and 220 C for 600 hr; critical temperature lies between 387.5 and 358.2 C; electrical resistivity reported as 4.2582, 4.3864, 4.8367, 5.2834, 5.6889, 6.2509, 6.6710, 7.2362, 8.2142, 9.3038, 10.6252, 10.8993, 11.3171, 12.1987, 13.6671, 14.0257, 14.0355, 14.0752, 14.1084, and 14.2959 μΩ cm at 33.30, 43.74, 83.38, 124.04, 160.92, 211.71, 248.80, 278.71, 311.98, 345.78, 373.61, 377.93, 382.60, 385.80, 387.54, 388.19, 390.97, 395.25, 404.20, and 419.77 C, respectively (selected from 76 points reported by the authors).
56	66	Goff, J.F., Verbalis, A.C., Rhyne, J.J., and Klemens, P.G.	1968	L	1.7-275	Cu_3Au		49.18	0.1 Fe; intermetallic compound; specimen 60 mm x 3.2 mm x 3.2 mm; prepared from ASARCO five-9 Cu and Au material; the melt was first homogenized by rocking for about 10 min then cast in a constricted end of the same tube; annealed for 2 hr at 850 C and quenched from 700 C by breaking the capsule in water (all melting and annealing the specimen and specimen materials were done in quartz tubes had been evacuated to less than 10^{-6} torr at close-off); residual electrical resistivity 0.092 μΩ cm; electrical resistivity ratio $\rho(300K)/\rho(4.2K) = 1.23$; electrical resistivity reported as 9.1, 9.1, 9.2, 9.3, 9.3, 9.2, 9.4, 9.4, 9.5, 9.7, 9.8, 9.9, 10.2, 10.5, 10.8, 11.0, 10.9, and 11.3 μΩ cm at 1.8, 5.6, 13.0, 16.4, 19.6, 30.0, 41.3, 63.2, 86.6, 101, 114, 131, 163, 191, 227, 254, 261, and 299 K respectively.

TABLE 10. THERMAL CONDUCTIVITY OF GOLD + COPPER ALLOYS -- SPECIMEN CHARACTERIZATION AND MEASUREMENT INFORMATION (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) Au	Composition (weight percent) Cu	Composition (continued), Specifications, and Remarks
57	66	Goff, J. F., Verbalis, A. C., Rhyne, J. J., and Klemens, P. G.	1968	L	117-269	Cu_3Au		49.18	Intermetallic compound; similar to the above except electrical resistivity reported as 9.7, 9.9. 10.1, 10.3, 10.4, 10.6, 10.8, 10.7, 10.9, and 11.3 $\mu\Omega$ cm at 88, 115, 148, 159, 180, 194, 224, 232, 247, and 293 K, respectively; measurement was made with an insulating packing inside the radiation shield.
58	66	Goff, J. F., et al.	1968	L	154-276	Cu_3Au		49.18	Similar to the above except electrical resistivity reported as 9.1, 9.9, 9.8, 9.9, 10.1, 10.5, 11.0, 10.7, 10.9, 11.0, and 11.4 $\mu\Omega$ cm at 9.0, 112, 129, 143, 171, 211, 235, 240, 260, 265, and 287 K, respectively; measurement was made in the original condition but with a measured radiation loss correction.

4.4. Copper-Nickel Alloy System

The copper-nickel alloy system forms a continuous series of solid solutions and is free of all tranformations except that of ferromagnetism. As shown in figure 2, the electrical resistivity versus temperature curves for Ni+Cu alloys change slope abruptly at the Curie temperature of the alloys. The Curie temperature decreases as the concentration of copper in the alloys increases. The ferromagnetism disappears and the Curie temperature drops to zero as the concentration of copper reaches 61.88% (60 At.%).

Mott [3] has given an explanation of the ferromagnetic behavior of these alloys based on the filling of holes in the *d* band of nickel by the *s* electrons of copper. The *d*-shell in a copper atom is completely occupied and there is a single *s* electron outside, whereas the $3d\uparrow$ band of a nickel atom is full but there are 0.54 holes in the $3d\downarrow$ band; these *d*-band holes are the elementary magnets in nickel. The Curie temperature is proportional to the number of elementary magnets per unit volume, which in nickel is thus 0.54 times the number of atoms per unit volume. The density of states in the *d* band of the nickel atom at the Fermi surface is approximately ten times greater than the density of states in the *s* band, so that as copper is added to nickel about 90 percent of the extra *s* electrons go to fill up the *d* band, and thus decrease the number of elementary magnets per unit volume, until at 60 % Cu the *d* band of nickel is full, at which point the ferromagnetism disappears and the Curie temperature drops to K. The insert in figure 2 shows the Curie temperature as a function of percent copper in nickel, which is linear for the atomic percent of copper. This straight-line relationship was determined from the electrical resistivity data shown in figure 2. The behavior of the electrical resistivity of these alloys has a direct bearing on the behavior of the thermal conductivity (see figure 29), and therefore the knowledge of the former is prerequisite to the understanding of the latter.

There are 153 sets of experimental data available for the thermal conductivity of this alloy system. However, of the 104 data sets available for Cu+Ai alloys listed in table 12 and shown in figure 30, 27 sets are merely single data points and 5 sets cover only a narrow temperature range from around room temperature to about 500 K. Of the 49 data sets for Ni+Cu alloys listed in table 13 and shown in figure 31, 23 sets are single data points. Furthermore, many sets of data show large discrepancies.

For the Cu+Ni alloys, the most reliable measurements at room temperature were made by Smith and Palmer [49] (Cu+Ni curves 1-7), surprisingly in 1935, for a set of well-annealed alloys. Electrical resistivity data were also reported for the same specimens used for the thermal conductivity measurements. These provided the basis for the easy separation of the lattice component from the measured thermal conductivity.

Hulm [69] measured the thermal conductivity of an alloy with 20% Ni below 25 K (Cu+Ni curve 15). Berman [70] measured thermal conductivity of a sample of Constantan (40% Ni) below 100 K (Cu+Ni curve 21). Wilkinson and Wilks [71] measured the thermal conductivity of an alloy with 30% Ni below 20 K (Cu+Ni curve 14). These three sets of low-temperature data appear to be reliable and consistent in view of the cold-work condition of the 30% Ni specimen of Wilkinson and Wilks (curve 14).

In the temperature range below 70 K, Erdmann and Jahoda have measured the thermal conductivity of the Cu-Ni alloy system several times [72-74] (Cu+Ni curves 52-55, 62-66, 68, and 84; Ni+Cu curves 13-19 and 21-23). One set of their measurements [74] (Cu+Ni curves 52-55 and Ni+Cu curves 13-19) is the only one that covers a wide range of composition at low temperature. However, it was very difficult to evaluate the reliability of their results. For copper-rich alloys, the lattice thermal conductivities derived from their measured total thermal conductivities are about 40% higher than those derived from other authors' results. Since their samples seemed to be the best annealed (at 930° C) among the alloy samples, it had been thought that the lattice thermal conductivities of their samples might be higher than those of the others because annealing could eliminate dislocations. However, after the effect of annealing on the electrical resistivity and lattice thermal conductivity of binary alloys had been reviewed carefully, it was concluded that the differences are too large to be accounted for by annealing. Furthermore, around liquid helium temperature, the difference between the lattice thermal conductivities of their own dilute and concentrated alloys are too large compared with those of other measurmements. If their measured total thermal conductivities are connected to the total thermal conductivities above 300 K measured by other authors, the slopes of the conductivity-temperature curves become negative between 100 and 300 K for concentrated alloys. This seems unlikely for it does not occur in the conductivity-temperature curves of the analogous silver-palladium alloys. Recent private communication from Klemens [76] provided useful thermal conductivity data for a copper alloy with 4 At.% Ni at temperatures below 40 K (Cu+Ni curve 103). The sample was annealed at 1075° C for 72 hours and slowly cooled. The results also indicate that the lattice thermal conductivities of Erdmann and Jahoda are too high at temperatures above that of the maximum of the lattice component although they are in agreement with the results of others at lower temperatures. Consequently, the results of Erdmann and Jahoda were not used in the present data synthesis at temperatures above that of the lattice component maximum.

For Ni+Cu alloys, Sager [77] (Ni+Cu curves 1 and 2), Smith [45] (Ni+Cu curves 3-6), and Sedström [63] (Ni+Cu curves 7 and 8) have measured the thermal conductivity around room temperature. There is some doubt about the reported compositions of their specimens as the electrical resistivity data reported for the same specimens differ from those obtained by other authors for alloys with the same nominal compositions.

Greig and Harrison [78] measured the thermal conductivities of nickel alloys with 0.32, 0.6, 1.5, and 4.2 At% Cu below 100 K (Ni+Cu curves 9-12). More recently Farrell and Greig [79] studied the electrical resistivity and thermal conductivity of a ncikel alloy with 0.31 At.% Cu below 100 K (Ni+Cu curve 34). They concluded that the lattice thermal conductivity of pure nickel is quite high and close to those of dilute copper alloys.

Chari [80] has suggested a method to separate the lattice thermal conductivity from total thermal conductivity of pure nickel and dilute nickel-rhenium alloys above 400 K. There is, however, doubt concerning his method of graphical separation of electrical resistivity into the instrinsic and magnetic components, because the anomaly of the temperature dependence of the electrical resistivity of the ferromagnetic metals can be explained by the ferromagnetic ordering of metals below the Curie point. Many authors have tried to express the resistivities of the ferromagnetic alloys in the form of $\varrho=\varrho^*(1+\mu)$, where μ, the ferromagnetic ordering parameter, is negative and vanishes above the Curie point [167], and ϱ^* represents the resistivity of ferromagnetic metal in the absence of ferromagnetic ordering. In other words, ϱ^* represents the resistivity of the "normal" non-ferromagnetic metal. Farrell and Greig [81] indicated that deviations from Matthiessen's rule due to spin mixing must be taken into account when analyzing the electronic transport properties of nickel alloys.

In the present data synthesis, the electronic thermal conductivities of the alloys were calculated directly from eq (12) using the recommended electrical resistivity values from ref. [7] and the recommended thermoelectric power values from ref. [40]. This analysis does not include spin-disorder scattering in agreement with the treatment by Coles [189]. For those alloys for which both the thermal conductivity and electrical resistivity had been measured the electronic thermal conductivities were also calculated from eq (12) in order to separate the lattice component from the measured total thermal conductivity. The resulting "experimental" lattice thermal conductivity data at low temperatures were used directly to generate the low-temperature lattice conductivity values, and those at moderate and high temperatures were used for the adjustment of the lattice thermal conductivities of the virtual crystals so that the calculated lattice conductivities are in agreement with the experimental data.

At moderate and high temperatures, lattice conductivities were calculated from eq (35). As stated previously in section 2.2, experimental data for k_u, which are necessary as input for eq (35), are available for copper but not for nickel. For copper, White [91] reported an experimental value for k_uT at temperatures above 60 K as 35.0 W cm^{-1} and this value was used in eq (35) for the calculations. The value of k_uT for nickel estimated from the modified Leibfried-Schlömann equation (37) varies considerably depending upon the selected value of the Debye temperature used in the calculation, and the initial estimates of the value of k_uT range from 21 to 31 W cm^{-1}. A final value of 30.8 W cm^{-1} was determined by using the various values for the calculations of the lattice conductivities and comparing the calculated values with the experimental data as shown in figure 6 and discussed previously in section 3. From the two k_uT values for copper and nickel the k_u values of the virtual crystals were estimated and used in eq (35) to generate lattice conductivities for all the alloys at temperatures above the region of the maximum in k_g.

A graphical comparison of the recommended total thermal conductivity values with selected experimental data is given in figures 26 and 27. The smooth solid curves in these figures were obtained by interpolating the recommended values of table 11 in order to obtain thermal conductivities for the desired alloy compositions. For copper-rich alloys shown in figure 26, the recommended values are in agreement with the data of Smith and Palmer [49] (Cu+Ni curves 1-7), of Bouley et al. [76] (Cu+Ni curve 103), of Zimmerman [130] (Cu+Ni curves 17 and 20), and of Willett [146] (Cu+Ni curve 99) to within 5%, and with the data of Kierspe [83] (Cu+Ni curve 67), of Berman [70] (Cu+Ni curve 21), and with some of the data of Mikryukov [144] (Cu+Ni curves 44 and 72) to within 12%. For nickel-rich alloys shown in figure 27, at high temperatures the recommended values agree with the data of Smith [45] (Ni+Cu curves 3-6) and of Jackson and Saunders [147] (Ni+Cu curve 20) to within 12%. At low temperatures there is conflict between different sets of experimental data and the agreement of the recommendations with the data is less satisfactory. The large difference between the data of Erdmann and Jahoda [74] (Ni+Cu curve 19) and those of Greig and Harrison [78] (Ni+Cu curve 9) for an alloy of the same composition, for example, illustrates the large discrepancies in the results of different investigators. For alloys with about 4% copper, the data of Erdmann and Jahoda [74] (Ni+Cu curve 18) and of Greig and Harrison [78] (Ni+Cu curve 11) both agree with the recommendations to within 10%, but at other solute concentrations, the recommendations receive little direct experimental support. The thermal conductivity values in this range are consequently provisional.

The resulting recommended values for k, k_e, and k_g are tabulated in table 11 for 25 alloy compositions covering the temperatures from 4 to 1200 K. These values are for alloys which have not been severely cold worked or quenched. The values for k are also presented in figures 28 and 29. The values of residual electrical resistivity for the alloys are also given in table 11. The uncertainties of the thermal conductivity values are stated in a footnote to table 11, while the uncertainties of the k_e and k_g values are indicated by their being designated as recommended, provisional, or typical values. The ranges of uncertainties of recommended, provisional, and typical values are less than ±15%, between ±15 and ±30%, and greater than ±30%, respectively.