NSRDS-NBS 16

Thermal Conductivity of Selected Materials

Part 2

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UNITED STATES DEPARTMENT OF COMMERCE
Alexander B. Trowbridge, *Secretary*
NATIONAL BUREAU OF STANDARDS • A. V. ASTIN, *Director*

Thermal Conductivity of Selected Materials

Part 2

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Foreword

The National Standard Reference Data System is a government-wide effort to give to the technical community of the United States optimum access to the quantitative data of physical science, critically evaluated and compiled for convenience. This program was established in 1963 by the President's Office of Science and Technology, acting upon the recommendation of the Federal Council for Science and Technology. The National Bureau of Standards has been assigned responsibility for administering the effort. The general objective of the System is to coordinate and integrate existing data evaluation and compilation activities into a systematic, comprehensive program, supplementing and expanding technical coverage when necessary, establishing and maintaining standards for the output of the participating groups, and providing mechanisms for the dissemination of the output as required.

The NSRDS is conducted as a decentralized operation of nation-wide scope with central coordination by NBS. It comprises a complex of data centers and other activities, carried on in government agencies, academic institutions, and nongovernmental laboratories. The independent operational status of existing critical data projects is maintained and encouraged. Data centers that are components of the NSRDS produce compilations of critically evaluated data, critical reviews of the state of quantitative knowledge in specialized areas, and computations of useful functions derived from standard reference data.

For operational purposes, NSRDS compilation activities are organized into seven categories as listed below. The data publications of the NSRDS, which may consist of monographs, looseleaf sheets, computer tapes, or any other useful product, will be classified as belonging to one or another of these categories. An additional "General" category of NSRDS publications will include reports on detailed classification schemes, lists of compilations considered to be Standard Reference Data, status reports, and similar material. Thus, NSRDS publications will appear in the following eight categories:

Category	*Title*
1	General
2	Nuclear Properties
3	Atomic and Molecular Properties
4	Solid State Properties
5	Thermodynamic and Transport Properties
6	Chemical Kinetics
7	Colloid and Surface Properties
8	Mechanical Properties of Materials

The present compilation is in category 5 of the above list. It constitutes the sixteenth publication in a new NBS series known as the National Standard Reference Data Series.

A. V. Astin, *Director.*

PREFACE

This report was prepared under contract by the Thermophysical Properties Research Center (TPRC) of Purdue University and forms a continuation of the work described in the first report NSRDS-NBS-8.

The work presented in this report comprises the critical evaluation, analysis, and synthesis of the available thermal conductivity data and the generation of recommended values for twelve metallic elements, mainly for the solid state, for a range of graphites, and for three fluids in the gaseous state. These are cadmium, chromium, lead, magnesium, molybdenum, nickel, niobium, tantalum, tin, titanium, zinc, zirconium, Acheson graphite, ATJ graphite, pyrolytic graphite, 875S graphite, 890S graphite, acetone, ammonia, and methane. For each of the materials recommended values are given over a wide range of temperature.

The senior staff engaged in this program consisted of the same personnel as for the first report. Dr. C. Y. Ho and Dr. R. W. Powell collaborated on the sections comprising the metallic elements and graphites and Dr. P. E. Liley was responsible for the section on fluids. Dr. Y. S. Touloukian has served as adviser to the program. The cooperation and assistance received from other TPRC staff is gratefully acknowledged.

This effort will continue into the third year, when it is hoped to complete the assessment of the data that are available for the thermal conductivity for all elements and to include recommended values wherever possible.

In order to give a greater degree of confidence to the recommendations set forth in this work, following the same procedure as that for the first report, a preliminary version of the present report has been submitted internationally to some sixty expert workers in this field for their comments and criticisms. The authors wish to express their appreciation and gratitude to all who responded so generously. Particular acknowledgment is made for the valuable contributions of the following individuals:

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Prof. N. B. Vargaftik, Moskovskii Aviatsionnyi Institut, Moscow, U. S. S. R.

It goes without saying that while the individuals mentioned above have read selected parts of the preliminary version of this report and given helpful comments and criticisms, this in no way commits them to the views expressed in this report for which the authors assume complete responsibility.

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By

C. Y. Ho, R. W. Powell, and P. E. Liley

ABSTRACT

The work presented in this report comprises the critical evaluation, analysis, and synthesis of the available thermal conductivity data and the generation of recommended values for twelve metallic elements, mainly for the solid state, for a range of graphites, and for three fluids in the gaseous state. These are cadmium, chromium, lead, magnesium, molybdenum, nickel, niobium, tantalum, tin, titanium, zinc, zirconium, Acheson graphite, ATJ graphite, pyrolytic graphite, 875S graphite, 890S graphite, acetone, ammonia, and methane. For each of the materials recommended values are given over a wide range of temperature.

KEY WORDS

Thermal Conductivity
Metallic Elements
Metals
Graphites
Gases
Critical Evaluation
Recommended Values
Standard Reference Data

PART I

THERMAL CONDUCTIVITY OF METALLIC ELEMENTS

PART I - THERMAL CONDUCTIVITY OF METALLIC ELEMENTS

A. Introduction

The metallic elements studied in this report consist of cadmium (solid and liquid states), chromium, lead (solid and liquid states), magnesium (solid and liquid states), molybdenum, nickel, niobium, tantalum, tin (solid and liquid states), titanium, zinc (solid and liquid states), and zirconium. Whereas the seven metallic elements of the first report that were studied in the solid state have cubic crystal structures, of those now considered, only chromium, lead, molybdenum, nickel, niobium, and tantalum have this symmetrical structure. The others can be expected to yield thermal conductivity values that are dependent on the crystal orientation and which may differ for polycrystalline and single crystal samples. For non-cubic metals the recommended values are mainly for randomly oriented polycrystalline samples of each metal, but whenever sufficient data are available for the main crystal directions of single crystals, the thermal conductivities for these directions will also be given.

The general method of procedure has followed closely that adopted in the first report [1].* The Thermophysical Properties Research Center (TPRC) data sheets for each material have been thoroughly updated, the original papers have been critically re-examined and more complete specification tables have been prepared.

The method previously adopted for dealing with the thermal conductivity data for metallic elements at low temperatures has again been followed [2-4]. For each metallic element the experimental curve yielding the highest thermal conductivity values in the region of the maximum has been accepted as representative of the values for the sample of the highest purity so far examined. From these data a value of β, the impurity-imperfection parameter, has been derived, as indicated previously, and this has been used to calculate thermal conductivity values from 1 K to about 1.5 T_m, where T_m is the temperature corresponding to the thermal conductivity maximum, by using the equation

$$k = [\alpha' T^n + \beta/T]^{-1} \tag{1}$$

where

$$\alpha' = \alpha''(\beta/n\alpha'')^{a/(m+1)} \tag{2}$$

Here a, m, n, and α'' are constants for a metal whereas α' and β are dependent on the purity and perfection. Theoretically,

$$\beta = \rho_0/L_0 \tag{3}$$

where ρ_0 is the residual electrical resistivity and L_0 is the theoretical value of the Lorenz function and equal to 2.443×10^{-8} Volt^2 T^{-2}. Using the theoretical relationship as given by Equation (3), Equations (1) and (2) can be written as

$$k = [\alpha' T^n + \rho_0/L_0 T]^{-1} \tag{4}$$

$$\alpha' = \alpha''(\rho_0/n\alpha'' L_0)^{a/(m+1)} \tag{5}$$

Equations (4) and (5) give explicitly the relationship between the thermal conductivity and the residual electrical resistivity of a metallic element, though their application is more limited than Equations (1) and (2) due to the limited applicability of Equation (3).

As explained before, the thermal conductivity in this range of temperature is particularly sensitive to the degree of purity and perfection of the sample, since β decreases as the purity and perfection increase. The values that have been used for β in each instance are given in Table 1 together with the associated constants and parameters. Due to the insufficiency of available low-temperature thermal conductivity data for these metallic

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*References appear under the heading REFERENCES.

elements it is hardly possible to determine the constants a, m, and α'' of Equation (2), and therefore only the values of n and α' of Equation (1) are determined from the available data. Here the values for α' are the average values, and actually α' varies from sample to sample and is a function of β depending upon sample purity and perfection. It can be seen in Table 1 that the values of β of column 9, derived from thermal conductivity data and used for subsequent calculations of the recommended values, are comparable with those of column 8 derived for the same sample from residual electrical resistivity measurements whenever available using Equation (3). For the latter $\rho_{4.2K}$ has been used as approximating to ρ_0. The values of the electrical resistivity ratio $\rho_{295K}/\rho_{4.2K}$ of column 6 relate to the purest samples for which low-temperature thermal conductivity measurements have been reported, whereas the values of this ratio given in the last column of Table 1 are the highest that have been reported so far. Comparison of the values in these two columns reveals large differences for most of the metallic elements. This indicates that the much purer samples now becoming available will possess correspondingly lower values of β and higher thermal conductivities. It is clear that in the low temperature region most of the thermal conductivity values now given will need to be increased subsequently.

The recommended thermal conductivity values are reported collectively in Tables 2a, 2b, and 2c and plotted in Figures 1 and 2. These recommended values are for fully annealed high-purity metals with purity and residual electrical resistivity indicated in the Tables. The residual electrical resistivity characterization is very important only at low temperatures below 100 K and is therefore not given in Tables 2b and 2c. Table 2a contains the recommended values at temperatures below 100 K and Tables 2b and 2c contain those above 100 K. The temperatures given in Tables 2a and 2b are in degree K and those in Table 2c are in degree C. In the tables the third significant figure is given only for internal comparison and for smoothness and is not indicative of the degree of accuracy.

In Figure 1 the thermal conductivity curves that are reproduced for those metallic elements that become superconducting above 1 K include values that have been obtained for both normal and superconducting states. The recommended values are, however, limited at present to the normal state of each metallic element. With lead and tin, since T_m is below the transition temperature at which the metal normally becomes superconducting, it is possible to determine T_m by using measurements made in the presence of a magnetic field of sufficient strength for the sample to remain in the normal state.

In order to make recommendations at higher temperatures the available experimental information for the thermal conductivity of each metallic element has been plotted on a linear temperature scale as shown in Figures 3 to 14. These curves have been carefully examined in the light of the information given in the accompanying specification tables and from other considerations. In the specification tables, the code designations used for the experimental methods are as follows:

C Comparative method
E Electrical 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

An attempt has been made in each figure to include a curve that seems likely to prove the most probable for each metallic element and this is drawn to form a smooth continuation of the above mentioned low-temperature curve. Use is made of electrical resistivity (or conductivity) data whenever possible and this information and other pertinent comments regarding the treatment of the data for each metallic element are given in the following section.

B. Thermal Conductivity of a Group of Selected Metallic Elements

Cadmium

Four curves are available for the thermal conductivity of cadmium at low temperatures. That giving the highest thermal conductivity is by Rosenberg [5] for a single crystal of 99.995 percent Cd with the direction of heat flow inclined at 79 degrees to the hexagonal axis of the crystal. Only this one crystal direction appears to have been investigated, but Mendelssohn and Rosenberg [6] obtained values for a cast polycrystalline sample that was stated to be of 99.9999 percent purity. These values are so very much lower, that, if the purity is as stated either the thermal conductivity of cadmium in the region of the maximum and below is very strongly dependent on the crystal orientation, or the purer of these samples must be unannealed and in a highly strained condition; alternatively this sample is less pure than stated.

The two curves published by Zavaritskii [7] relate mainly to the superconducting state,* but do include a few values for the normal state. These are for two single crystals that appear to be of the same material but with the heat flow direction respectively perpendicular and parallel to the hexagonal axis. At the transition temperature (0.53 K given by Zavaritskii) these results indicate the thermal conductivity ratio $k_\perp / k_{/\!/}$ to be 1.31. Zavaritskii's paper contains a thermal conductivity value at this temperature for one other sample. This was also for the perpendicular direction and the value is about three times that of the plotted curve and is comparable with the higher curve of Rosenberg. This last value has been used for the derivation of β and the calculation of the low-temperature curve for cadmium in the normal state and to about 1.5 T_m. Since this is for a sample that tends to approximate to the higher perpendicular direction, corresponding values have also been derived for the parallel direction and for polycrystalline cadmium, assuming $k_\perp / k_{/\!/} = 1.31$ at 0.53 K.

Further measurements are required in this temperature range, and the present values can only be regarded as tentative.

At higher temperatures, Goens and Grüneisen [8] give values in fair agreement for two single crystals (curves 13 and 14) approximating to the perpendicular direction and for one (curve 12) approximating to the parallel direction. These results indicate that over the range 21 to 293 K $k_\perp / k_{/\!/}$ increases from about 1.12 to about 1.25. It seems reasonable to raise the $k_\perp$ value at 21 K to give the same ratio of 1.25, particularly as it then lies close to Rosenberg's curve.

The recommended low temperature curves have been smoothly extended to higher temperatures. That for the perpendicular direction at first approximates to curve 8, and then follows Goens and Grüneisen's derived values for k to about 300 K. The curve for the parallel direction is derived from this on the basis of $k_{/\!/} = k_\perp / 1.25$ and for polycrystalline cadmium by assuming $k = 1/3\,(2k_\perp + k_{/\!/})$. It is noted that on account of the effect of anisotropy the thermal conductivity of cadmium single crystals (and other single crystals of non-cubic crystal structure) with different impurities will form many families of curves (instead of one single family of curves). Each family of curves corresponds to each crystal orientation. Within one family of curves (with the same orientation but with different impurity) the curves are non-crossing whilst curves of different families might cross one another at temperatures above T_m.

Further extrapolation of these curves to the melting point is believed to be justified. Most of the available data in this temperature range conform with these recommendations to within 5 percent. Only determinations by Mikryukov and Rabotnov [9] for a single crystal and by Mikryukov, Tyapunina, and Cherpakov [10] for a polycrystalline sample at temperatures below 400 K seem noticeably high.

It is of interest that several workers who had included electrical resistivity measurements had obtained Lorenz functions that agree to within a few percent with the theoretical value at temperatures near normal.

For liquid cadmium the only available thermal conductivity data are those of Brown [11]. Unfortunately Brown's values for the solid state are seen to differ from most others in having a positive rather than a slight negative coefficient. He made no electrical resistivity measurements, but when his data for the liquid phase are used with the electrical resistivity values of Matuyama [12] for temperatures near the melting point and 100 K above, the resulting Lorenz functions are 2.50×10^{-8} and $2.34 \times 10^{-8} V^2 K^{-2}$, which seem reasonably acceptable. Furthermore, use of these resistivity values in the equation proposed by Powell [13] for liquid metals

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[*] Cadmium becomes electrically superconducting at and below 0.53 K (more recent value given as 0.56 K). The thermal conductivity of the superconducting state is not treated here.

$$k = 2.32 \times 10^{-8} T\rho^{-1} + 0.012 \quad (6)$$

yields values for k that are only some 4 percent greater than those obtained by Brown. The recommended curve has been drawn through the mean of his data. At the melting point the ratio of the recommended thermal conductivity values for the solid state $k_{\perp}$, $k_{\text{polycrys.}}$, $k_{//}$ to that for the liquid state are, respectively, 2.26, 2.1, and 1.8.

The recommended values are thought to be accurate to within ±4 percent of the true values at moderate temperatures, ±6 percent at high temperatures, ±10 percent for molten cadmium, and ±15 percent at low temperatures.

Chromium

Only two groups of workers, Lucks and Deem [14] and Powell and Tye [15] have measured the thermal conductivity of chromium to temperatures appreciably above normal. The investigation of Powell and Tye was of interest in that they commenced with an electrolytically deposited tube of the metal and followed the changes brought about by heating to successively higher temperatures. After their final heating to 1410 C the thermal conductivity at 50 C was 3.66 times the initial value, and the density had increased from 6.975 to 7.15 g cm^{-3}. At 470 K the value of Lucks and Deem for a chemically pure ductile chromium is greater by 1.7 percent, at 1000 K, the region of greatest difference, by 11 percent, and at 1270 K by 5 percent. In view of this good agreement for two quite independent determinations, the most probable curve from 470 to 720 K has been drawn as a smooth curve through the points of Lucks and Deem and from 720 to 1270 K through the mean values of Lucks and Deem and Powell and Tye. This curve has been extended to both higher and lower temperatures and at temperatures of 320 and 345 K it passes two of the points obtained by McElroy et al. [16]. Just below, at 311 K, is the Néel temperature, where these workers found signs of an upward turn and promised further confirmatory measurements in this region.

The foregoing completes the information available for relatively pure chromium above the Néel temperature. Whilst at the moment the agreement appears very good, this is for only two samples, so may be somewhat fortuitous, particularly as large values of the Lorenz function are indicated. The Lorenz function of Powell and Tye fell from 3.75×10^{-8} to $3.15 \times 10^{-8} V^2K^{-2}$ over the range 323 to 1273 K, indicating about one third of the heat conduction at the lower temperature to be by phonons. With two different conducting mechanisms present in fairly comparable proportions and with a Néel temperature included it is conceivable that the thermal conductivity may not be a simple function of chemical purity or temperature and that the curve for a high-purity chromium may differ from that now proposed.

At low temperatures, β has been derived from the experimental data of Harper, Kemp, Klemens, Tainsh, and White [17] for a 99.998 percent chromium with a residual electrical resistivity $\rho_0 = 0.55 \times 10^{-7}$ ohm cm. This yields a T_m of 23 K and the calculated curve in this instance agrees reasonably well with the experimental one up to about 55 K. From 55 K to 311 K the curve has been continued smoothly through the uppermost values of Harper et al. to 150 K and on for another 150 K or so for which no measurements have yet been made. The slope of the recommended curve changes abruptly at the Néel point.

The properties of chromium in the normal temperature region could also be influenced under some conditions by a change of phase. At temperatures below 299 K it has been found possible to electrolytically deposited chromium having the close-packed hexagonal structure [18, 19]. The stable cubic form, to which the above thermal conductivity curve applies, is obtained on heating. Chromium is certainly a metal for which measurements on a further range of specimens would be of interest from about 100 K and upwards.

With the forgoing reservations, the recommended values are thought to be accurate to within ±3 percent of the true values at moderate temperatures, ±5 percent at temperatures below 40 K, and ±10 percent in the ranges 40 to 200 K and above 700 K.

Lead

There are 142 curves available for the thermal conductivity of lead.

In the low temperature region, curve 56 of Wolff [20] for an annealed pure single crystal enriched with lead isotopes is the highest. The recommended values below 3 K were obtained by calculation using a value of β derived from this curve. From 3 to 7 K the recommended curve follows closely curve 56 and from 7 to 35 K lies close to curves 17 and 6. The former is by Mendelssohn and Rosenberg [6] for a 99.998 percent pure single crystal and the latter by DeHaas and Rademakers [21] for a high-purity single crystal.

At normal and higher temperatures the thermal conductivity of lead is of particular interest owing to its early use by Shelton and Swanger [22] (the same results were later published by Van Dusen and Shelton [23]). The sample used was the NBS melting-point lead as available in the 1930's, having a freezing point of 327.4 C.*

The most recent publication on the thermal conductivity of lead is by Lucks [24]. He used a similar comparative method to that just mentioned but with Armco iron as the standard material. It was Lucks who had organized a round-robin investigation of the thermal conductivity of this same stock of Armco iron and he used the mean values as reported by four other measuring laboratories. He has studied two NBS Pyrometric Standard lead samples, one of their most recent, with a freezing point of 327.417 C and an earlier grade with a freezing point of 327.31 C. The tabulated smooth values of Lucks and those of Van Dusen and Shelton agreed exactly over the common range of 50 to 150 C for their two samples, and extrapolation leads to complete agreement from 0 to 300 C. For the purer sample, Lucks' value at 50 C is greater by about 1.8 percent, and at 150 C by about 4.3 percent, whilst at 300 C the extrapolated difference is nearly 9 percent.

Lucks concludes "These data are believed significant and indicate the data of Van Dusen and Shelton should not be used for NBS Pyrometric Standard lead having a freezing point 0.1 C difference".

Support for Lucks' higher set of values is forthcoming from the recently published values of Dauphinee, Armstrong, and Woods [25]. These workers had carried out their measurements several years previously by an absolute longitudinal heat flow method on a very pure lead that was stated to be of 99.999 percent or better purity. Their temperature range was about -50 to 300 C. Two independent sets of measurements gave results that agreed to within 1 percent but fitted straight lines of differing slope. Lucks' values at 50 C for the higher freezing point sample are in close agreement and his extrapolated value at 300 C is greater than the mean value of Dauphinee et al. by only 1.5 percent. Thus both of Lucks' curves receive independent support from other workers and the recommended curve has been drawn to fit closely with these two recent determinations. The derived Lorenz function is of the order of $2.5 \times 10^{-8} V^2 K^{-2}$ and is thus in fairly good agreement with the earlier values of Lees [26] and of Jaeger and Diesselhorst [27]. Nevertheless the divergence of the thermal conductivity curves with increase in temperature for these two grades of lead is sufficiently unusual to warrent further independent investigation. The 3 to 4 percent higher thermal conductivity values of Powell and Tye [28] were made on smaller and less suitable samples and these values which were thought to have an uncertainty of ±3 percent, have been ignored as likely to be too high. The many earlier determinations are considered low, probably due to use of less pure lead.

The two sections of the recommended curve below 35 K and above room temperature were extrapolated to join smoothly together and the resulting curve in the subnormal temperature region lies above the curve of Lees [26] by about 2 percent.

For molten lead there are eight curves available and the values differ by about 60 percent and in the sign of the temperature coefficient. The recommended values are derived from electrical resistivity and the theoretical value of the Lorenz function and are seen to agree most closely with the data of Dutchak and Panasyuk [29] and of Powell and Tye [30], whose specimen in the molten state was from the same supply as the specimen measured in the solid state. At the melting point the ratio of the recommended thermal conductivity for the solid lead to that for the molten lead is 2.01, which is close to the value of 1.94 obtained by Roll and Motz [31] for the corresponding electrical conductivity ratio.

The curve for superconducting lead from 1 to 7.19 K (the transition temperature) is also shown in Figure 1,

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*The freezing point of this lead was quoted as 327.3 C by Lucks [24].

but the values are not considered sufficiently well established to be recommended.

The recommended values are thought to be accurate to within ±3 percent of the true values at moderate temperatures, ±5 percent at high temperatures, and ±10 percent at low temperatures and for molten lead.

Magnesium

There are 24 curves available for the thermal conductivity of magnesium. At low temperatures the purest magnesium studied seems to be the annealed Johnson Matthey sample of 99.98^+ percent magnesium content used by Kemp, Sreedhar, and White [32]. The recommended values below 25 K were calculated using a β value derived from their data for this specimen, and the continuation of the recommended curve from 25 to 150 K closely follows their data. From 150 to 273 K and above 729 K no determinations appear to have been made for the thermal conductivity of magnesium.

The majority of the workers that have made thermal conductivity determinations on magnesium in the range 273 to 729 K have included electrical resistivity values for the same samples. The resultant values of the Lorenz function at about 373 K range from 2.16×10^{-8} to $2.48 \times 10^{-8} V^2 K^{-2}$ and it seems significant that in only one work is the theoretical value exceeded. These highest values are due to Mannchen [33], a worker whose data have been criticized and are thought to be uncertain (see Kempf, Smith, and Taylor [34] and Powell [35]). The values for the Lorenz function obtained by Schofield [36], Powell [35], and Powell et al. [37] are in fair accord and indicate that this quantity probably increases slowly with increase in temperature and has values of 2.27, 2.31, 2.33, 2.35, 2.36, 2.37, and $2.38 \times 10^{-8} V^2 K^{-2}$ at temperatures of 273, 373, 473, 573, 673, 773, and 923 K, respectively.

From these values and the electrical resistivity of pure magnesium the most probable thermal conductivity curve has been derived. The electrical resistivity at 273 K has been taken as 3.95×10^{-6} ohm cm with values of 5.61, 7.28, 9.00, 10.76, 12.51, and 15.2×10^{-6} ohm cm at 373, 473, 573, 673, 773, and 923 K. Increasing uncertainty arises as the melting point, 923 K, is approached. The above value at 923 K is based on that of Roll and Motz [31] of 15.4×10^{-6} ohm cm for magnesium of 99.8 percent purity, but it should be noted that measurements by Horn [38] indicate a strong upturn as the melting point is approached, his value being greater by about ten percent.

Since no thermal conductivity determinations have been made on molten magnesium, a provisional value can be evaluated from Equation (6) proposed by Powell [13]. Roll and Motz [31] have reported values for ρ which, used with Equation (6), lead to thermal conductivity values at 923 K and 1173 K respectively of 0.79 and 0.96 Watt $cm^{-1}K^{-1}$.

The recommended values are considered accurate to within ±3 percent of the true values at moderate temperatures, ±10 percent for low temperatures and as the melting point is approached, and ±15 percent for the liquid state.

Molybdenum

But few thermal conductivity values have been reported for molybdenum at low temperatures and β has been derived from the data of Rosenberg [5] for a 99.95 percent sample of this metal. The maximum is about 35 K and the calculated curve has been extended to about 50 K where the agreement with Rosenberg's data is still good. This most probable curve approximately follows Rosenberg's to its upper limit (96 K) where it is some 4 percent above a very recent curve due to Bäcklund [39]. A smoothly falling curve can be drawn through Bäcklund's experimental values and this tends to disprove the shallow minimum at about 200 K which had been indicated by Kannuluik [40, 41]. The recommended curve has accordingly been drawn some 2 percent above Bäcklund's curve to merge into that due to Tye [42] for the range 323 to 473 K. This curve is continued smoothly to the melting point. It falls at a steadily decreasing rate and in the high temperature range lies up to 10 percent below the values of Rasor and McClelland [43], Timrot, Peletskii, and Voskresenskii [44], and those derived from the thermal diffusivity data of Kraev and Stel'makh [45], and exceeds the derived values of Wheeler [46] by about 10 percent and the thermal conductivity measurements of Lebedev [47] and of several other workers by still greater amounts.

The recommended curve gives a value of 0.94 W $cm^{-1}K^{-1}$ at 1723 K, which with Tye's electrical resistivity of 44.7 μohm cm leads to a Lorenz function at 1723 K of $2.44 \times 10^{-8}V^2K^{-2}$.

Further measurements are required to confirm the exact form of the thermal conductivity curve, particularly at high temperatures. The low temperature curve is for a sample with the high ρ_0 of 0.167 μohm cm and data are certainly required for a purer sample. The present values should be within some ±4 percent of that of high-purity molybdenum near normal temperatures, ±10 percent at low temperatures, and within ±15 percent as the melting point is approached.

Nickel

In view of the technological importance of nickel, it appears that insufficient attention has been given to the thermal conductivity of this metal. This examination of the available data indicates both the need for further work and the interest likely to be found in attempting to more fully understand the conducting processes involved. No very firm recommendations can be made at present.

Only three curves are available at cryogenic temperatures, there is the customary dearth of values at temperatures just below normal, whilst at high temperatures the tendency, found for iron, for values to converge with increase of temperature seems completely lacking.

The β value used to calculate the low temperature values for the range 1 to 30 K has been derived from the highest available thermal conductivity values in this region, those of Kemp, Klemens, and White [48] for an annealed sample of 99.99^+ percent nickel. In attempting to fit these results with the form of curve usually adopted and considered satisfactory, the first difficulty arises, and suggests the need for further measurements on nickel at low temperatures. As the present results do not fit the curve of Equation (1), a compromise has been adopted and a value used for β to give a curve that is some 6 percent too high in the region of the maximum and about the same amount low near 2 K.

At temperatures above normal the available values cover a wide band. Whilst those of Angell [49] and Sager [50] can be discounted as of low accuracy, much of the spread is no doubt due to a strong dependence of the thermal conductivity of nickel on purity. The sharp decrease in conductivity with increase in temperature that was found with iron is again evident and again persists to the Curie temperature. With nickel, however, there is hardly any tendency for the values to converge as the Curie temperature is approached, possibly because this temperature is much lower than that with iron. Above the Curie temperature the thermal conductivity increases with temperature, and here again, the well separated individual curves remain roughly parallel to each other. A strong increase in the electronic component of thermal conductivity, k_e, can be expected from consideration of the Lorenz equation, and the unusually high value of the constant term in the linear equation that approximates to the temperature variation of electrical resistivity, ρ.

Assuming that

$$\rho = mT + c \tag{7}$$

the Lorenz relationship gives

$$k_e = L_0T(mT + c)^{-1} \tag{8}$$

from which it follows that

$$\frac{dk_e}{dT} = L_0c(mT + c)^{-2} \tag{9}$$

For most metals c is close to zero and k_e relatively constant, but for nickel and iron above their Curie temperatures, c has large positive values and k_e increases strongly with T.

It has been usual to assume that $L_0 = 2.443 \times 10^{-8} V^2 K^{-2}$ and then to derive the lattice thermal conductivity component, k_g, from

$$k_g = k - k_e = k - 2.443 \times 10^{-8} T\rho^{-1} \tag{10}$$

For nickel in this high-temperature region the recent work of Powell, Tye, and Hickman [51] indicates k_g as found in this way to be relatively large, to vary from sample to sample, and to increase with increase in temperature whereas this quantity is usually expected to decrease according to T^{-1}. Thus it seems probable that the conducting mechanisms of nickel are not fully understood. Further support for this is suggested by the relatively high temperature to which a Lorenz function persists that is less than the theoretical value. This even seems to be the case with nickel at the Debye temperature ($\theta = 375$ K), where the above procedure would yield a quite unacceptable negative value for k_g.

Such considerations as the above indicate that the thermal conductivity of a sample of nickel cannot be predicted with any degree of certainty from an electrical resistivity determination and that further work is required for nickel in both the experimental and theoretical fields.

A reasonably good link for the immediate sub-normal temperature range has been provided by the recent measurements of Bäcklund and Langemar [39] over the range 87 to 374 K, and the curve at present regarded as most probable for the thermal conductivity of pure nickel follows their curve fairly closely to a location between the curves of Shelton and Swanger [22] and the highest due to Powell et al. [51]. The mean course of these last mentioned curves is followed to the Curie temperature, where a sharp minimum is shown and the curve to about 1400 K is drawn as a straight line again fitting the highest values of Powell et al. The uncertainty of much of this curve is probably of the order of ±10 percent.

Niobium

Niobium becomes superconducting at a higher temperature than any other metal. This no doubt helps to account for the high proportion of thermal conductivity determinations on niobium that relate to the superconducting state. From the point of view of the present analysis, the highest values so far obtained in the superconducting region are due to Kuhn [52] for a single crystal of about 99.9 percent purity. By applying an appropriate magnetic field he has obtained thermal conductivity values for the normal state over the temperature range of 1.3 to 9.4 K. His values are much higher than those of Mendelssohn [53, 54] for a zone-refined 99.999^+ percent pure single crystal. The last-mentioned purity of the sample seems questionable. From Kuhn's data a β value has been derived and calculated values have been obtained to about $1.5\ T_m \approx 23$ K. This is the curve for $\beta = 3.991$, and is at present assumed to represent the thermal conductivity of niobium at low temperatures. It is realized that this can scarcely be regarded as satisfactory. Furthermore, niobium is a metal that readily takes up gaseous impurities at high temperature, even from a relatively good vacuum, and improved preparation techniques will probably yield samples for which this curve is too low.

Nor is the situation much better at higher temperatures, except that above room temperature all measurements show a steady increase in thermal conductivity.

From 94 to 273 K there are no values at all. Indeed, since the two sets of measurements of White and Woods [55] and of Mendelssohn and Rosenberg [5, 6] made to about 90 K gave lower values than that used for deriving the low temperature curve and since the 99.99 percent Nb sample of the latter yielded values much lower than those of the 99.9^+ percent Nb sample of the former, there is need for experimental data for pure niobium to be provided for the range from 1 to 273 K. A probable curve has been drawn in this region, but it is a very tentative line drawn to link on smoothly with another curve fitted to the available high temperature data. Until recently the values in the range of approximately 323 to 873 K were limited to five sets of measurements that differed by about 20 percent, with the lowest of these measurements continuing to 1910 K. Now, however, a sixth set of values has been reported by Raag and Kowger [56] that tends to support the highest of those previously given. These workers determined the thermal diffusivity of a 99.95 percent rod of niobium over the range 345 to 1195 K. They claimed an accuracy of ±2 percent and to derive thermal conductivity, made use of the specific heat data of Jaeger and Veenstra [57]. This is certainly regarded as the most acceptable of the available specific heat data. Raag and Kowger also measured the electrical resistivity and obtained values of the Lorenz function that increase from $2.73 \times 10^{-8} V^2 K^{-2}$ at 300 K to $2.77 \times 10^{-8} V^2 K^{-2}$ at 1200 K, and for the lower two thirds of this range are in reasonable agreement with the data of Bell and Tottle [58, 59]. The recommended curve has been drawn as a straight line through the thermal conductivity data so derived by Raag and Kowger.

At still higher temperatures, three sets of information are available. All are lower than the normal extension of the present curve, but this difference is probably associated with the reduced purity of the samples studied. The radial heat flow thermal conductivity determinations of Fieldhouse, Hedge, and Lang [60] lie on a linear curve which is about 14 percent below the recommended curve at 1200 K. Those of Voskresenskii, Peletskii, and Timrot [61] are within 2 percent of the curve of Fieldhouse et al., whilst the thermal conductivity values deduced from the thermal diffusivity data of Kraev and Stel'makh [45] are lower than those of Fieldhouse et al. by 6 percent at 1800 K. These no longer increase linearly with temperature but rise to a small maximum at about 1900 K. In view of these results it seems reasonable to allow the curve at present recommended to continue its linear increase to about 1500 K and then to gradually decrease its slope. In this high temperature region there is clearly need for more experimental work on pure material that remains pure under the test conditions.

The recommended values are thought to be accurate to within ±5 to ±10 percent at moderate temperatures and ±15 percent at low and high temperatures. The curve for superconducting niobium from 1 to 9.13 K is also shown in Figure 1, but the values are not considered sufficiently well established to be recommended.

Tantalum

At low temperatures the highest curve at present available is that of White and Woods [62] for a 99.9 percent tantalum that had been annealed at 2500 C. The value of β derived from these measurements has been used to give calculated values up to about 30 K. White and Woods' experimental curve has been followed up to about 65 K. From here to about 300 K is a region of uncertainty and lacking in experimental evidence.

Rosenberg [5] had obtained considerably lower values for a purer but unannealed sample, and had indicated a minimum in the region of 65 K but this occurred towards the upper limit of his method and appears unlikely. In the approximate temperature range of 323 to 400 K, however, thermal conductivity values due to Deverall [63], Tye [42], and Denman [64] agree to within about ±4 percent and all have small positive temperature coefficients. Hence, from about 65 K, the tentative recommended curve has been smoothly extrapolated to give a shallow minimum at about 250 K and then to pass through a point at 373 K which is the mean value obtained from these three sets of data. This curve has been continued through the upper portion of Denman's curve approximately linearly to about 1300 K and then with gradually decreasing slope as the melting point is approached. In this upper temperature range the proposed curve lies some 9 percent above the mean values of Rasor and McClelland [43] and of Peletskii and Voskresenskii [65], and from 5 to 10 percent below the values derived by Wheeler [46] from thermal diffusivity determinations. There are however, uncertainties associated with the density and specific heat data required for deriving thermal conductivity values from thermal diffusivity measurements, and other available values of density and specific heat could bring Wheeler's data into close agreement at the highest temperature. For similar reasons, it seems possible that the thermal diffusivity determinations of Kraev and Stel'makh [45] could yield thermal conductivities having a negative temperature coefficient at these high temperatures. This would support some of the measurements of Jun and Hoch [66], but, these seem low, since, if the recent electrical resistivity data of Peletskii and Voskresenskii [65] of 108.8 μohm cm at 2900 K represents the value for pure tantalum, any thermal conductivity at this temperature that is lower than the recommended value by more than 2 percent would bring the Lorenz function below the theoretical value.

It is of interest to note that the 1914 measurements of Worthing [67] which must have been the first reported measurements for temperatures of the order of 2000 K are only from 16 to 29 percent above the proposed curve.

The uncertainty of the proposed curve is probably of the order of ±5 percent at room temperature, rising to ±10 percent at the highest temperature. The curve for superconducting tantalum from 1 to 4.48 K is also shown in Figure 1, but the values are not considered sufficiently well established to be recommended.

Tin

In this section it is only proposed to consider white tin. No thermal conductivity values are available for the gray cubic form of tin to which the white tetragonal form transforms under certain conditions at about 13 C. The majority of the thermal conductivity determinations on tin relate to the supperconducting state, and thus 114 of the available 133 curves are at temperatures below 5 K.

In this low-temperature region the highest thermal conductivity curve is that of Zavaritskii [68] for a high-purity single crystal in the normal state measured with heat flow perpendicular to the tetragonal axis. The residual electrical resistivity of this sample was reported to be $(1 \pm 0.5) \times 10^{-10}$ ohm cm. He also reported data from 2.6 to 4.6 K for two other single crystals measured with heat flow parallel to the tetragonal axis. All these three crystals are apparently of the same material. These data indicate the thermal conductivity anisotropy ratio $k_\perp / k_{/\!/}$ to be 1.44.

An attempt was made to derive values of β from Zavaritskii's data so as to complete his curves down to 0 K. However, preliminary calculations indicate that the values of T_m for his curves are below 1.5 K. His data are therefore at temperatures above 1.5 T_m and Equation (1) cannot be used to fit his thermal conductivity data. Furthermore, β values cannot be accurately derived from his residual electrical resistivity data either, since the latter have 50 percent uncertainty. Consequently no values below 3 K are given for tin.

The recommended curves for $k_\perp$ and $k_{/\!/}$ from 3 to 5 K follow Zavaritskii's data. The values for polycrystalline tin are calculated assuming $k_{\text{polycrys.}} = 1/3\,(2\,k_\perp + k_{/\!/})$. From 5 to 36 K the curves have been drawn approximately parallel to that of Rosenberg [5] for a 99.997 percent tin single crystal sample. There are no measurements from 36 to 99 K and only those of Lees [26] obtained from a rod of Kahlbaum pure polycrystalline tin, from 99 K to normal temperature. Lees appears from general evidence to have been a careful worker, but the purity of his sample may have been rather low, hence for polycrystalline tin a smooth curve has been drawn from 36 K to lie some 2 percent above that of Lees. The continuation of this curve to the melting point conforms reasonably well with most of the higher experimental values for polycrystalline tin in this temperature range. The values of $k_\perp$ and $k_{/\!/}$ from 36 K to the melting point are derived from values of $k_{\text{polycrys.}}$ based on the assumption that $k_\perp / k_{/\!/} = 1.44$ is valid also in this temperature range. This anisotropy ratio is further supported by the electrical resistivity measurements of Bridgman [69]. He obtained room-temperature values for $\rho_{/\!/}$ and $\rho_\perp$ of 14.3 and 9.9 μohm cm, respectively, which gives $\rho_{/\!/} / \rho_\perp = 1.44$.

The curve of Mikryukov and Rabotnov [9] is displaced to much higher values, about 10 percent higher than the recommended curve for $k_\perp$. Their measurements are reported as being made on a single crystal of tin. The crystal direction in which the measurements were made is not stated, but from the reported electrical resistivity, which ranges from 14.45 μohm cm at 117.2 C to 18.94 μohm cm at 187.1 C, it seems likely that this was the high conductivity direction. It is further noticed that over this temperature range their Lorenz function ranges from 2.94×10^{-8} to $2.98 \times 10^{-8}\,V^2K^{-2}$ and are probably some 15 to 20 percent too high, since those of Lees [26] and of Jaeger and Diesselhorst [27] are in fair agreement at 291 K with values of 2.47×10^{-8} and $2.53 \times 10^{-8}\,V^2K^{-2}$, respectively. Thus the high values of Mikryukov and Rabotnov appear to be capable of a reasonable explanation.

The seven sets of data available for the thermal conductivity of molten tin show closer agreement than for many other metals. The proposed straight line for the thermal conductivity of tin in the liquid state has been drawn through a mean value ($0.317\ W\,cm^{-1}K^{-1}$) at 573 K and a derived value at 973 K obtained from the equation

$$k = 2.443 \times 10^{-8}\,T\rho^{-1} \tag{11}$$

when using the value of Roll and Motz [31] of 59.6 μohm cm for the value of ρ. It is interesting to note that at 1473 K this line also conforms closely with the value derived from the ρ-value of 72.0 μohm cm which Roll and

Motz obtained. Also that the thermal conductivity values of Nikol'skii et al. [70] fit this line well up to 833 K. At 1300 K, however, the recommended thermal conductivity value is some 55 percent greater than the almost temperature independent value which Filippov [71] and Yurchak and Filippov [72] have given in separate papers as derived from thermal diffusivity measurements.

At the melting point the ratio of the values proposed for the solid state $k_{\perp}$, $k_{\text{polycrys.}}$, $k_{/\!/}$ to that for the liquid state are, respectively, 2.18, 1.96, and 1.52.

The recommended values for polycrystalline tin are thought to be accurate to within ±3 percent of the true values at moderate temperatures, ±5 percent at high temperatures, and ±15 percent at low temperatures. The values for $k_{\perp}$ and $k_{/\!/}$ of tin single crystal should be accurate to within ±6 percent at moderate temperatures, ±10 percent at high temperatures, and ±15 percent at low temperatures. For molten tin the values are probably good to ±5 percent near the melting point, but an increasing uncertainty remains to be resolved at higher temperatures. The curves for superconducting tin from 1 to 3.72 K are also shown in Figure 1, but the values are not considered sufficiently well established to be recommended.

Titanium

The calculated curve for polycrystalline titanium at low temperatures has been based on the experimental curve of White and Woods [62] for a 99.99 percent titanium sample that had been annealed at 800 C for 60 hours. The experimental and calculated curves agree closely over the range 7.3 to 20 K. Beyond 20 K the calculated values are higher, and at the maximum, which occurs at about 41 K, the difference has risen to the order of 10 percent. Well before 1.5 T_m is reached, however, the curves cross. Titanium has a relatively shallow maximum for the samples so far studied and it seems clear that the normal form of Equation (1), which is more applicable to the thermal conductivity of high-purity samples, does not apply well to this case.

From just above T_m to the 293 K value of Powell and Tye [73] for a sample of very high purity with ρ_{293K} = 42.7 μohm cm, a smooth curve with a gradually decreasing slope has been drawn.

Over the temperature range from about 300 to 900 K the 11 sets of thermal conductivity values that are available cover a wide range, with the highest values some 50 percent greater than the lowest. With most metals, the purer the sample, the higher is the thermal conductivity. In the present instance, however, the two highest curves are those of Loewen [74] for a commercially pure titanium, for which no analysis is given, and of Mikryukov [75] for a sample of 99.6 percent purity. The situation is further complicated by the fact that Mikryukov reported at the same time values for a sample of 99.9 percent purity which are mainly some 6 to 12 percent lower. For the less pure sample Mikryukov's data indicate a higher Lorenz function and one that is increasing with increase in temperature, whereas the results for the purer sample are more in accord with the Lorenz function found by Powell and Tye [73] and Deem, Wood, and Lucks [76] which gives mean values decreasing from 3.24×10^{-8} at 323 K to $3.06 \times 10^{-8} V^2 K^{-2}$ at 773 K. Whilst admitting that complications might well be associated with the high phonon conductivity component of this metal, a tentative curve from room temperature upwards has been derived by assuming values of the Lorenz function of the order found by these three groups of workers. The Lorenz function has been assumed to continue to fall steadily to $2.4 \times 10^{-8} V^2 K^{-2}$ at 1673 K, and in the uppermost range use has been made of the electrical resistivity data compiled in [77]. A minimum thermal conductivity is indicated at about 650 K. Over the range 750 to 1400 K the suggested curve shows no step at the phase transition (1155 K) and lies some 30 to 3 percent above a curve deduced from the thermal diffusivity measurements made by Rudkin, Parker, and Jenkins [78] on a sample of titanium for which no details were given. From 1417 to 1606 K similarly derived values lie on a reasonable continuation of the proposed curve.

The close-packed hexagonal crystalline form of this metal transforms into body-centered cubic form at about 1155 K. Any associated change in the thermal conductivity has yet to be experimentally investigated. The curve derived from the measurements of Rudkin, Parker, and Jenkins has a gradual drop of about 8 percent in this region, whereas according to the previously quoted electrical resistivity data [77], the electrical conductivity increases by about 10 percent. Since these changes are about equal and opposite, no break has been introduced at this stage in the proposed curve.

Quite apart from the importance of titanium in modern technology, facts such as the foregoing should encourage further investigation to be undertaken of the thermal and electrical conductivities of titanium in the transformation region and above.

The values given by the proposed curve are thought to be accurate to within ±10 percent of the true values at moderate temperatures, and ±15 percent at low and high temperatures.

Zinc

The low-temperature thermal conductivity measurements on zinc single crystals are found to involve a difficulty that has not been met with the earlier metals treated. The curves for $k_\perp$ and $k_\parallel$ appear to cross both above and below the temperature where the thermal conductivity is a maximum.

This behavior occurs with curves 22 and 23 of Table 13. Both relate to measurements made by Mendelssohn and Rosenberg [6] on samples prepared from the same batch of 99.997 percent purity zinc. Sample No. 3 (curve 23) has the higher maximum, but lower values are shown for this below about 7 K and above 27 K. This sample was a single crystal with the hexagonal axis at 13 degrees to the rod axis, and thus gave values approximating to $k_\parallel$. Sample No. 2 (curve 22), with the lower maximum was a single crystal with the hexagonal axis at 80 degrees to the rod axis and so gave values that approximated to $k_\perp$. The data for another sample No. 4 (curve 34) with the hexagonal axis at 13 degrees to the rod axis measured by Rosenberg [5] agree well with those for sample No. 3.

Goens and Grüneisen [8] had previously made measurements on four single crystals of zinc at temperatures of 21.2, 83.2, and 293.2 K. From these measurements they derived values for $k_\parallel$ and $k_\perp$ at these temperatures. Their values are given in the following table:

Values for Ideal Undeformed Zinc Crystals Parallel and Perpendicular
to the Hexagonal Axis as Extrapolated by Goens and Grüneisen

T, K	$k_\perp$, $Wcm^{-1}K^{-1}$	$k_\parallel$, $Wcm^{-1}K^{-1}$	$k_\perp/k_\parallel$	$\rho_\perp$, μohm cm	$\rho_\parallel$, μohm cm	$\rho_\parallel/\rho_\perp$
21.2	5.65	7.09	0.797	0.0366	0.0440	1.202
83.2	1.372	1.316	1.043	1.155	1.293	1.119
293.2	1.242	1.242	1.00	5.83	6.05	1.038

These thermal conductivity values seem to be consistent with those of Mendelssohn and Rosenberg at temperatures above T_m. Whereas $k_\parallel > k_\perp$ at 21.2 K, $k_\parallel < k_\perp$ at 83.2 K and the two thermal conductivity values agree at 293.2 K. The electrical resistivity values on the other hand show no similar cross-over. The electrical conductivity for the perpendicular direction exceeds that for the parallel direction at all three temperatures.

Zavaritskii [7] has made thermal conductivity determinations on zinc single crystals at lower temperatures. Zinc becomes superconducting at $T_c = 0.825$ K[*] and he was mainly interested in the thermal conductivity of the superconducting state. He found $k_\perp > k_\parallel$ for the normal state at temperatures close to T_c as well as for the superconducting state. These findings are also in accord with Mendelssohn and Rosenberg's measurements.

The three sets of available measurements of the low temperature thermal conductivities of zinc crystals are therefore self-consistent. They show a type of behaviour, however, that is quite incompatible with the treatment of Cezairliyan and Touloukian [2-4] which has formed the basis of the evaluation of thermal conductivity values in this low-temperature region. The use of different values for β yields a family of curves which never intersect at temperatures below T_m.

Whilst this unusual behaviour appears to be reasonably well established, it clearly requires explanation and therefore calls for further experimental investigation. Since the resistivity data of Goens and Grüneisen show no

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[*] Given by Zavaritskii; recent information suggesting $T_c = 0.875$ K.

cross-over it seems likely that the explanation might be associated with a marked difference in the anisotropy of the electronic and lattice components of the heat conduction. There seems no reason why other non-cubic metals should not show similar departures from what has come to be regarded as normal behaviour.

Pending further information, it is considered ill-advisable to present any recommended curves for the thermal conductivity of single crystals that cross one another, and, for the time being the recommendations for zinc will relate only to the polycrystalline form. These will be derived at low temperature in the same manner that has been used throughout this work.

The highest low-temperature value is a single observation at 0.825 K reported by Zavaritskii [7] for a single crystal of zinc having the hexagonal axis perpendicular to the direction of measurement. From this value the corresponding thermal conductivity of a polycrystalline sample has been derived, using the ratio of $k_\perp$ to $k_{/\!/}$ obtained by Zavaritskii at this temperature for two other samples. This has been used to evaluate β and to derive the curve for polycrystalline zinc in the normal state and up to about 8 K. Beyond the maximum the curve continues to reach the value derived for polycrystalline zinc from the single crystal data of Goens and Grüneisen around 83 K. It then continues with steadily falling conductivity and passes some 2 percent below the polycrystalline value derived in the same way at 293 K. From here to the melting point the proposed curve has about the mean slope of the earlier values but is drawn in a rather higher position to compensate for the reduced purity of these specimens. It is located about mid-way between the early measurements of Shelton and Swanger [22] and the most recent values which are due to Mikryukov and Rabotnov [9].

A need clearly exists for new measurements on polycrystalline zinc of the high purity now available. A more complete examination of the conducting properties of single crystals of zinc is also most desirable.

There is also a very strong case for a redetermination of the thermal conductivity of molten zinc, although the position has been somewhat improved whilst this report was in progress by the recently reported measurements of Dutchak and Panasyuk [29]. Theirs is the third determination to be made of the thermal conductivity of molten zinc. The earlier measurements of Konno [79] and Bidwell [80] had agreed closely with each other but posed problems when considered in the light of the electrical resistivity. Both workers obtained a negative temperature coefficient, whereas the thermal conductivity as derived by use of the theoretical value of the Lorenz function should have a strong positive coefficient. Also, the ratio of the two conductivities, thermal and electrical, for the solid and liquid states are far from comparable. The present recommended curve gives a thermal conductivity of 1.0 W $cm^{-1}K^{-1}$ for solid zinc at the melting point. In the liquid state, if a mean line is fitted to the data of Konno and Bidwell, it yields a value at the same temperature of 0.6 W $cm^{-1}K^{-1}$. Hence the ratio k_S/k_L = 1.67 and this may be compared with a value of 2.2 as obtained by Roll and Motz [31] for the ratio ρ_L/ρ_S.

The recent values of Dutchak and Panasyuk [29] for the thermal conductivity of molten zinc in the range 713 to 873 K do show about the expected increase with increase in temperature, but are considered too high since they give a ratio k_S/k_L of 1.72.

The broken line shown in Figure 13 yields a ratio k_S/k_L of about 2.0 and is regarded as being a more likely representation of the thermal conductivity of molten zinc. It is tentatively proposed, but clearly further experimental investigation is required.

The recommended values are thought to be accurate to within ±3 percent of the true values at moderate temperatures, ±5 percent at high temperatures, and ±15 percent at low temperatures and for molten zinc.

Zirconium

The β-value has again been calculated from experimental data due to White and Woods [62], and, using this β-value, the low-temperature section of the proposed curve has been derived to about 20 K. An extension of this curve passes through the data of White and Woods near 90 K, but at higher temperatures considerable uncertainties arise. In the temperature range 94 to 297 K the only determination available is at 121 K. This is the uppermost point due to White and Woods where radiation corrections could lead to some uncertainty. From 298 to about 900 K several sets of values are available; these are consistent in indicating the thermal conductivity versus temperature curve to have a minimum within this range, but this is about the limit of their consistency. The minimum value ranges from about 0.170 to 0.245 W cm^{-1} K^{-1}. Mikryukov [75] obtained this highest value for a 99.9 percent sample of iodide zirconium which is seen to have an unusually low electrical resistivity. Indeed, the quoted value of 36.1 μohm cm at 331 K (which extrapolates to about 26 μohm cm at 273 K) has to be compared with Treco's 273 K value of 38.8 μohm cm [81], which is the next lowest value reported for zirconium. Treco obtained his value for an oxygen-free high-purity zirconium and found the 273 K resistivity to increase to 57.7 μohm cm at 2.5 atomic percent of oxygen. As zirconium is a metal that readily combines with oxygen, this seems a factor which could help in explaining some of the conductivity differences. Since zirconium has a hexagonal crystal structure below about 1135 K, another contributing factor could be the varying degrees of preferred orientation. No information appears to be available, however, regarding the anisotropy of the conductivity of zirconium.

At high temperatures the two sets of data available for the thermal conductivity again differ considerably. That of Timrot and Peletskii [82] appears to be much too low in its lower temperature range, for, at 1200 K, use of the electrical resistivity value of 117 μohm cm selected by Touloukian [77] leads to a Lorenz function of only $2.0 \times 10^{-8} V^2 K^{-2}$.

Over the range 331 to 898 K the mean Lorenz function reported by Mikryukov [75] from his measurements on two samples decreases from 3.42×10^{-8} to $3.11 \times 10^{-8} V^2 K^{-2}$ whilst that of Powell and Tye [83] for three samples at 323 K is $3.10 \times 10^{-8} V^2 K^{-2}$, decreasing to $2.73 \times 10^{-8} V^2 K^{-2}$ at 823 K for two samples. Bing et al. [84] for three samples reported mean values of $3.14 \times 10^{-8} V^2 K^{-2}$ at 323 K and $2.84 \times 10^{-8} V^2 K^{-2}$ at 523 K.

Zirconium is clearly a metal that requires considerably more experimental investigation before any very firm recommendation about its thermal conductivity is possible.

For the present a smooth curve showing a steadily decreasing rate of fall of thermal conductivity has been drawn from the value of 0.35 W cm^{-1} K^{-1} at 90 K to 0.232 W cm^{-1} K^{-1} at 273 K, the latter value having been derived from Treco's electrical resistivity and a Lorenz function close to the mean value indicated by the three sets of measurements last mentioned. This value lies 4 percent above the lowest-temperature value of the smooth curve obtained by Moss [85] for nominally high-purity zirconium, and the curve now proposed follows about this amount above Moss' curve until it commences to cross the curve of Fieldhouse and Lang [86] and to lie some 3 percent below this curve to the highest temperature.

As with titanium at about 1155 K, the true curve of thermal conductivity of zirconium versus temperature could be expected to have a discontinuous change at about 1135 K where a phase transformation occurs. The electrical resistivity has been found to undergo a drop of about 14 percent in this region, but the only thermal conductivity measurements which extend above and below this region, those of Fieldhouse and Lang, shown no comparable increase in thermal conductivity, but possibly a decrease in slope. Hence the proposed curve has been drawn with no discontinuity, but this is clearly another aspect of the thermal conductivity of zirconium that requires further investigation.

The proposed curve may represent the thermal conductivity of very high-purity polycrystalline zirconium to about ±10 percent at temperatures below 800 K, the uncertainty increasing to ±20 to ±25 percent as the melting point is approached.

Predictions could be made with more certainty at high temperatures if the electrical resistivity determinations were extended to temperatures above the present upper limit of about 1280 K.

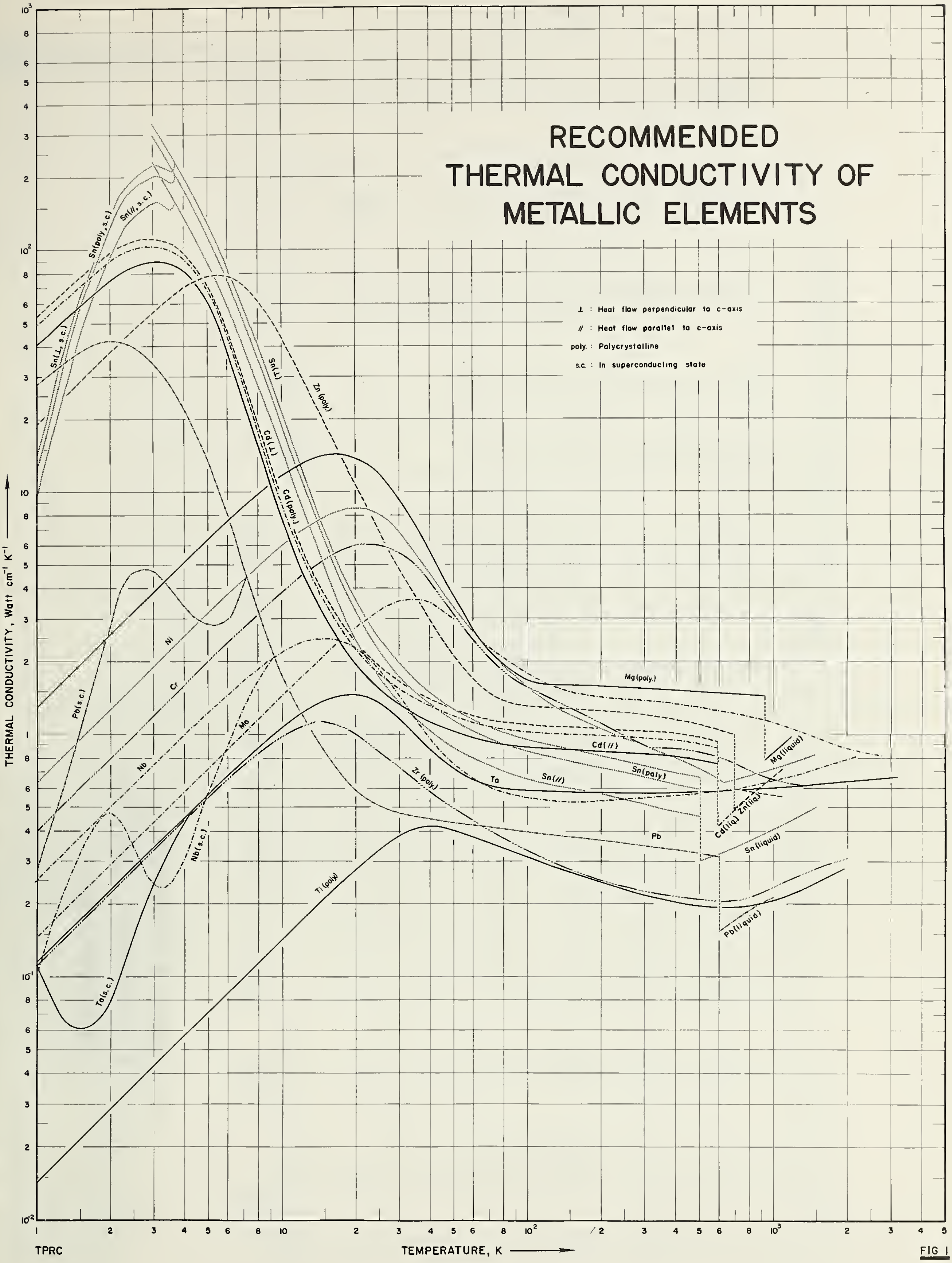
TABLE 1. DERIVED VALUES OF β AND ASSOCIATED CONSTANTS AND PARAMETERS FOR HIGH-PURITY METALLIC ELEMENTS

Element	Cur.* No.	Author(s)	Year	Purity (%)	$\frac{\rho_{295K}}{\rho_{4.2K}}$	ρ_0** (μohm cm)	β(calculated from ρ_0) (cm K^2 Watt^{-1})	β(derived from k data) (cm K^2 Watt^{-1})	ρ_0(derived from recommended k values) (μohm cm)	n	$\alpha' \times 10^4$ (cm K^{1-n} Watt^{-1})	1966 "highest" $\rho_{295K}/\rho_{4.2K}$
(⊥ to c-axis)	24							0. 0188	0. 000463	2. 5	1. 77	‡
Cadmium (∥ to c-axis)		Zavaritskii, N. V.	1960					0. 0246	0. 000606	2. 5	1. 90	‡
(polycrystalline)								0. 0204	0. 000502	2. 5	1. 80	‡
Chromium	13	Harper, A. F. A., Kemp, W. R. G., Klemens, P. G., Tainsh, R. J., White, G. K.	1957	99. 998	217 $(=\frac{\rho_{273K}}{\rho_{4.2K}})$	0. 055	2. 25	2. 49	0. 0609	2. 0	1. 04	‡
Lead	56	Wolff, C. L.	1961	99.9^+				0. 0353	0. 00088	3. 0	7. 40	‡
Magnesium	9	Kemp, W. R. G., Sreedhar, A. K., and White, G. K.	1953	99.98^+				0. 772	0. 0189	2. 0	0. 83	‡
Molybdenum	13	Rosenberg, H. M.	1955	99. 95				6. 85	0. 167	2. 6	0. 0776	14, 000 [87]
Nickel	5	Kemp, W. R. G., Klemens, P. G., and White, G. K.	1956	99.99^+	208 $(=\frac{\rho_{293K}}{\rho_{4.2K}})$	0. 0347	1. 42	1. 57	0. 0384	2. 0	0. 957	3, 500 [88, 89]
Niobium	44	Kuhn, G.	1966	99. 9		0. 09	3. 68	3. 99	0. 0975	2. 0	5. 92	4, 000 [90]
Tantalum	18	White, G. K. and Woods, S. B.	1959	99. 9	62. 1	0. 212	8. 68	8. 69	0. 212	2. 1	4. 52	10, 000 [91]
(⊥ to c-axis)	94					$(1.2 \pm 0.5) \times 10^{-4}$	$(4.9 \pm 2) \times 10^{-3}$				1. 13	
Tin (∥ to c-axis)	90	Zavaritskii, N. V.	1961			$(1.65 \pm 0.2) \times 10^{-4}$	$(6.8 \pm 0.8) \times 10^{-3}$			2. 6	1. 54	80, 000 [92]
(polycrystalline)											1. 28	
Titanium	12	White, G. K. and Woods, S. B.	1959	99. 99	21. 9	1. 92	78. 6	69. 5	1. 70	2. 6	0. 432	‡
Zinc								0. 0525	0. 00128	3. 0	0. 188	35, 000 [93]
Zirconium	14	White, G. K. and Woods, S. B.	1959	99. 95	168	0. 251	10. 3	8. 98	0. 219	2. 2	7. 45	850 [94]

* This is the curve number in the respective figure and table of the metallic element.

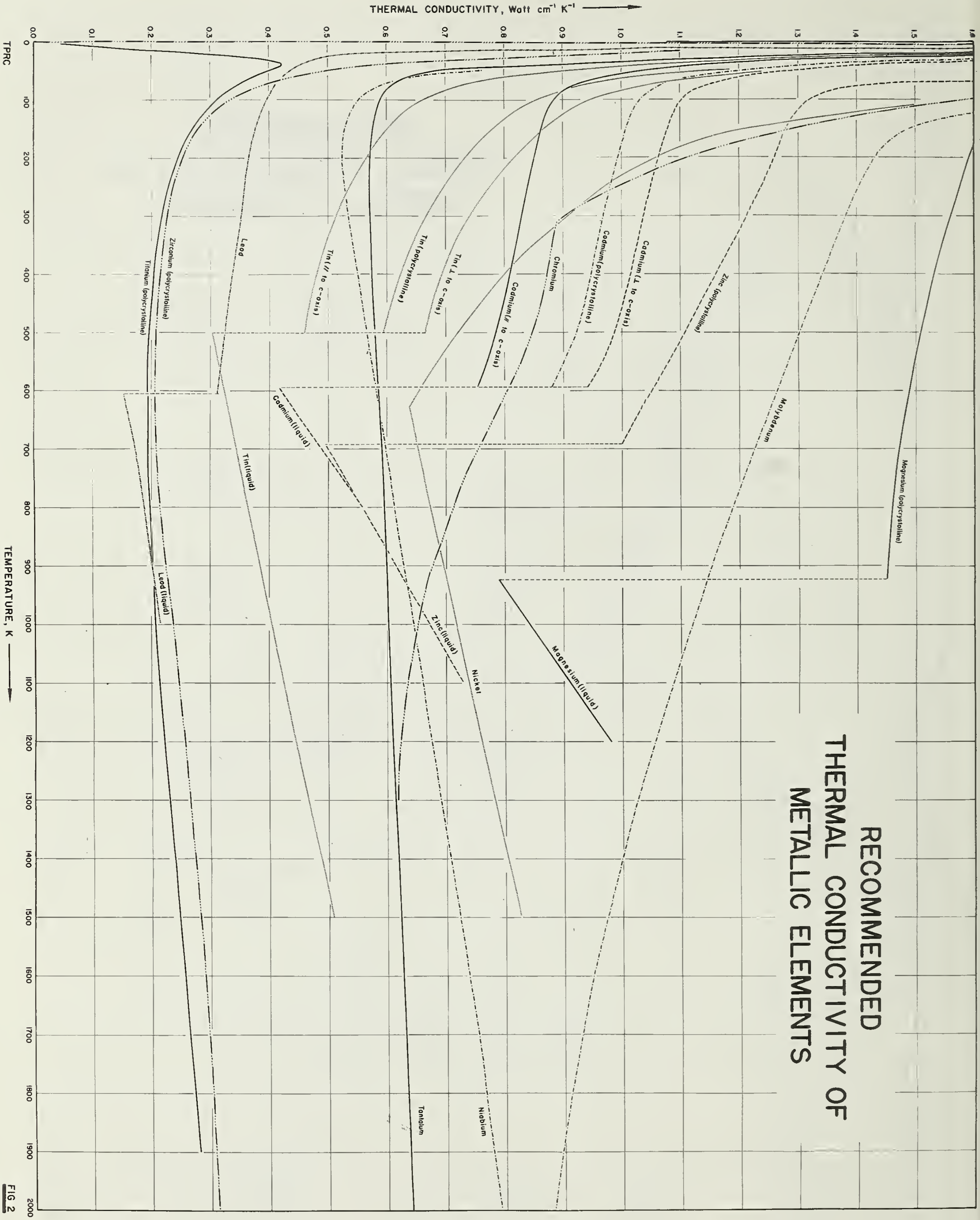
** The value of ρ at 4. 2K is used approximately as ρ_0.

‡ Information not available.



RECOMMENDED THERMAL CONDUCTIVITY OF METALLIC ELEMENTS

FIG I



RECOMMENDED THERMAL CONDUCTIVITY OF METALLIC ELEMENTS

FIG 2

TABLE 2a. RECOMMENDED THERMAL CONDUCTIVITY OF METALLIC ELEMENTS AT LOW TEMPERATURES*

Thermal Conductivity, k, Watt cm^{-1} K^{-1}

T, K	Cadmium 99.999+% 0.000463‡ (Single Crystal) ⊥ to c-axis	 0.000606‡ // to c-axis	Cadmium 99.999+% 0.000502‡ (Polycrystalline)	Chromium 99.998 % 0.0609‡	Lead 99.99+% 0.00088‡	Magnesium 99.98+% 0.0189‡ (Polycrystalline)	Molybdenum 99.95 % 0.167‡	Nickel 99.99+% 0.0384‡	Niobium 99.9+% 0.0975‡	Tantalum 99.9 % 0.212‡	Tin 99.999+% 0.000115‡ (Single Crystal) ⊥ to c-axis	 0.000165‡ // to c-axis	Tin 99.999+% 0.000132‡ (Polycrystalline)	Titanium 99.99 % 1.70‡	Zinc 99.999+% 0.00128‡ (Polycrystalline)	Zirconium 99.95 % 0.219‡	T, K
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	52.8	40.3	48.7	0.401	27.7	1.30	0.146	0.64	0.251	0.115				0.0144	19.0	0.111	1
2	96.3	74.7	89.3	0.802	42.4	2.59	0.292	1.27	0.501	0.230				0.0288	37.9	0.223	2
3	111	89.5	104	1.20	34.0	3.88	0.438	1.91	0.749	0.345	331	230	297	0.0432	55.5	0.333	3
4	96.6	81.8	92.0	1.60	22.4	5.15	0.584	2.54	0.993	0.459	202	140	181	0.0576	69.7	0.442	4
5	71.9	61.3	69.0	1.99	13.8	6.39	0.730	3.16	1.23	0.571	130	90	117	0.0719	77.8	0.549	5
6	47.3	37.8	44.2	2.38	8.2	7.60	0.876	3.77	1.46	0.681	85	59	76	0.0863	78.0	0.652	6
7	30.0	24.0	28.0	2.77	4.9	8.75	1.02	4.36	1.67	0.788	58	40	52	0.101	71.7	0.748	7
8	19.3	15.4	18.0	3.14	3.2	9.83	1.17	4.94	1.86	0.891	40	28	36	0.115	61.8	0.837	8
9	13.1	10.5	12.2	3.50	2.3	10.8	1.31	5.49	2.04	0.989	29	20.1	26	0.129	51.9	0.916	9
10	9.5	7.6	8.87	3.85	1.78	11.7	1.45	6.00	2.18	1.08	21.5	14.9	19.3	0.144	43.2	0.984	10
11	7.4	5.92	6.91	4.18	1.46	12.5	1.60	6.48	2.30	1.16	16.5	11.4	14.8	0.158	36.4	1.04	11
12	6.0	4.76	5.56	4.49	1.23	13.1	1.74	6.91	2.39	1.24	12.9	9.0	11.6	0.172	30.8	1.08	12
13	5.0	4.00	4.67	4.78	1.07	13.6	1.88	7.30	2.46	1.30	10.4	7.2	9.3	0.186	26.1	1.11	13
14	4.3	3.44	4.01	5.04	0.94	14.0	2.01	7.64	2.49	1.36	8.5	5.9	7.6	0.200	22.4	1.13	14
15	3.8	3.04	3.55	5.27	0.84	14.3	2.15	7.92	2.50	1.40	7.0	4.9	6.3	0.214	19.4	1.13	15
16	3.38	2.70	3.16	5.48	0.77	14.4	2.28	8.15	2.49	1.44	5.9	4.1	5.3	0.227	16.9	1.12	16
18	2.81	2.24	2.62	5.81	0.66	14.3	2.53	8.45	2.42	1.47	4.5	3.1	4.0	0.254	13.3	1.08	18
20	2.42	1.94	2.26	6.01	0.59	13.9	2.77	8.56	2.29	1.47	3.6	2.5	3.2	0.279	10.7	1.01	20
25	1.92	1.54	1.79	6.07	0.507	12.0	3.25	8.15	1.87	1.36	2.5	1.72	2.22	0.337	6.9	0.85	25
30	1.67	1.34	1.56	5.58	0.477	9.5	3.55	6.95	1.45	1.16	2.0	1.36	1.76	0.382	4.9	0.74	30
35	1.51	1.21	1.41	5.03	0.462	7.4	3.62	5.62	1.16	0.99	1.67	1.16	1.50	0.411	3.72	0.65	35
40	1.41	1.13	1.32	4.30	0.451	5.7	3.51	4.63	0.97	0.87	1.50	1.04	1.35	0.422	2.97	0.58	40
45	1.34	1.07	1.25	3.67	0.442	4.57	3.26	3.91	0.84	0.78	1.37	0.95	1.23	0.416	2.48	0.535	45
50	1.28	1.03	1.20	3.17	0.435	3.75	3.00	3.36	0.76	0.72	1.28	0.89	1.15	0.401	2.13	0.497	50
60	1.21	0.97	1.13	2.48	0.424	2.74	2.60	2.63	0.66	0.651	1.16	0.80	1.04	0.377	1.71	0.442	60
70	1.16	0.93	1.08	2.08	0.415	2.23	2.30	2.21	0.61	0.616	1.07	0.74	0.96	0.356	1.48	0.403	70
80	1.13	0.905	1.06	1.82	0.407	1.95	2.09	1.93	0.58	0.603	1.02	0.71	0.91	0.339	1.38	0.373	80
90	1.11	0.892	1.04	1.68	0.401	1.78	1.92	1.72	0.563	0.596	0.98	0.68	0.88	0.324	1.34	0.350	90
100	1.10	0.883	1.03	1.58	0.396	1.69	1.79	1.58	0.552	0.592	0.95	0.66	0.85	0.312	1.32	0.332	100

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[*] In the table the third significant figure is given only for internal comparison and for smoothness and is not indicative of the degree of accuracy.

[‡] Residual electrical resistivity in microhm cm.

TABLE 2b. RECOMMENDED THERMAL CONDUCTIVITY OF METALLIC ELEMENTS AT MODERATE AND HIGH TEMPERATURES*

Thermal Conductivity, k, Watt cm^{-1} K^{-1}

T, K	Cadmium 99.999^{+}% (Single Crystal) ⊥ to c-axis	Cadmium 99.999^{+}% (Single Crystal) // to c-axis	Cadmium 99.999^{+}% (Polycrystalline)	Chromium 99.998 %	Lead 99.99 %	Magnesium 99.98^{+}%	Molybdenum 99.95 %	Nickel 99.99^{+}%	Niobium 99.9^{+}%	Tantalum 99.9 %	Tin 99.999^{+}% (Single Crystal) ⊥ to c-axis	Tin 99.999^{+}% (Single Crystal) // to c-axis	Tin 99.999^{+}% (Polycrystalline)	Titanium 99.99 % (Polycrystalline)	Zinc 99.999^{+}% (Polycrystalline)	Zirconium 99.95 % (Polycrystalline)	T, K
100	1.10	0.883	1.03	1.58	0.396	1.69	1.79	1.58	0.552	0.592	0.95	0.66	0.85	0.312	1.32	0.332	100
150	1.08	0.864	1.01	1.29	0.377	1.61	1.49	1.21	0.530	0.580	0.867	0.602	0.779	0.270	1.28	0.278	150
200	1.06	0.851	0.993	1.11	0.366	1.59	1.43	1.06	0.526	0.575	0.816	0.567	0.733	0.245	1.26	0.252	200
250	1.05	0.840	0.980	0.992	0.358	1.57	1.40	0.97	0.530	0.574	0.775	0.538	0.696	0.229	1.24	0.237	250
273	1.04	0.835	0.975	0.948	0.355	1.57	1.39	0.94	0.533	0.574	0.759	0.527	0.682	0.224	1.22	0.232	273
300	1.04	0.830	0.968	0.903	0.352	1.56	1.38	0.905	0.537	0.575	0.742	0.515	0.666	0.219	1.21	0.227	300
350	1.03	0.821	0.958	0.881	0.348	1.55	1.36	0.850	0.544	0.576	0.715	0.496	0.642	0.210	1.18	0.221	350
400	1.01	0.811	0.947	0.873	0.338	1.53	1.34	0.801	0.552	0.578	0.693	0.481	0.622	0.204	1.16	0.216	400
500	0.985	0.788	0.920	0.848	0.325	1.51	1.30	0.721	0.567	0.582	0.664	0.461	0.596	0.197	1.11	0.210	500
600	[(0.420)]	[(0.420)]	[(0.420)]	0.805	0.312	1.49	1.26	0.655	0.582	0.586	[0.323]	[0.323]	[0.323]	0.194	1.05	0.207	600
700	[0.490]	[0.490]	[0.490]	0.757	[0.174]	1.47	1.22	0.653	0.598	0.590	[0.343]	[0.343]	[0.343]	0.194	[(0.499)]	0.209	700
800	[(0.559)]	[(0.559)]	[(0.559)]	0.713	[0.190]	(1.46)	1.18	0.674	0.613	0.594	[0.364]	[0.364]	[0.364]	0.197	[0.557]	0.216	800
900				0.678	[0.203]	(1.45)	1.15	0.696	0.629	0.598	[0.384]	[0.384]	[0.384]	0.202	[0.615]	0.226	900
1000				0.653	[0.215]	[0.84]**	1.12	0.718	0.644	0.602	[0.405]	[0.405]	[0.405]	(0.207)	[0.673]	0.237	1000
1100				0.636		[0.91]**	1.08	0.739	0.659	0.606	[0.425]	[0.425]	[0.425]	(0.213)	[(0.730)]	0.248	1100
1200				0.624		[0.98]**	1.05	0.761	0.675	0.610	[0.446]	[0.446]	[0.446]	(0.220)		0.257	1200
1300				(0.616)			1.02	0.782	0.690	0.614	[0.466]	[0.466]	[0.466]	(0.228)		0.266	1300
1400				(0.611)			0.996	0.804	0.705	0.618	[(0.487)]	[(0.487)]	[(0.487)]	(0.236)		0.275	1400
1500							0.970	0.825	0.721	0.622	[(0.507)]	[(0.507)]	[(0.507)]	(0.245)		0.282	1500
1600							0.946		0.735	0.626				(0.253)		0.290	1600
1700							0.925		0.750	0.630				(0.262)		0.297	1700
1800							0.907		0.764	0.634				(0.271)		0.302	1800
1900							0.893		0.778	0.637				(0.280)		0.308	1900
2000							0.880		0.791	0.640						(0.313)	2000
2200							0.858		0.815	0.647							2200
2400							0.840			0.653							2400
2600							0.825			0.658							2600
2800							0.813			0.663							2800
3000										0.665							3000
3200										(0.666)							3200
311				0.886													311
505.04											0.662 [0.303]	0.460 [0.303]	0.595 [0.303]				505.04
594.1	(0.942) [(0.416)]	(0.754) [(0.416)]	(0.880) [(0.416)]														594.1
600.6					0.312 [(0.155)]												600.6
631								0.638									631
692.7															1.00 [(0.495)]		692.7
923						(1.45) [0.79]**											923

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*Values in parentheses are extrapolated and in square brackets are for liquid state. In the table the third significant figure is given only for internal comparison and for smoothness and is not indicative of the degree of accuracy.

**Estimated.

TABLE 2c. RECOMMENDED THERMAL CONDUCTIVITY OF METALLIC ELEMENTS AT MODERATE AND HIGH TEMPERATURES*

Thermal Conductivity, k, Watt $cm^{-1} C^{-1}$

T, C	Cadmium		Cadmium	Chromium	Lead	Magnesium	Molybdenum	Nickel	Niobium	Tantalum	Tin		Tin	Titanium	Zinc	Zirconium	T, C
	99.999+%		99.999+%	99.998 %	99.99 %	99.98+%	99.95 %	99.99+%	99.9+%	99.9 %	99.999+%		99.999+%	99.99 %	99.999+%	99.95 %	
	(Single Crystal)		(Polycrystalline)			(Polycrystalline)					(Single Crystal)		(Polycrystalline)	(Polycrystalline)			
	⊥to c-axis	//to c-axis									⊥to c-axis	//to c-axis					
-150	1.09	0.873	1.02	1.42	0.386	1.63	1.60	1.37	0.538	0.585	0.905	0.629	0.812	0.290	1.30	0.301	-150
-100	1.07	0.858	1.00	1.20	0.371	1.60	1.45	1.13	0.527	0.577	0.842	0.585	0.756	0.257	1.27	0.265	-100
- 50	1.06	0.846	0.987	1.05	0.362	1.58	1.42	1.02	0.527	0.574	0.796	0.553	0.715	0.237	1.25	0.244	- 50
0	1.04	0.835	0.975	0.948	0.355	1.57	1.39	0.94	0.533	0.574	0.759	0.527	0.682	0.224	1.22	0.232	0
25	1.04	0.831	0.969	0.906	0.352	1.56	1.38	0.908	0.536	0.575	0.743	0.516	0.667	0.219	1.21	0.227	25
50	1.03	0.826	0.964	0.885	0.348	1.55	1.37	0.879	0.540	0.575	0.728	0.505	0.654	0.215	1.20	0.224	50
100	1.02	0.816	0.953	0.878	0.342	1.54	1.35	0.827	0.548	0.577	0.704	0.489	0.632	0.207	1.17	0.218	100
200	0.994	0.795	0.928	0.856	0.329	1.52	1.31	0.741	0.563	0.581	0.670	0.466	0.601	0.198	1.12	0.211	200
300	(0.953)	(0.764)	(0.890)	0.817	0.316	1.50	1.27	0.672	0.578	0.585	[0.318]	[0.318]	[0.318]	0.195	1.07	0.207	300
400	[0.471]	[0.471]	[0.471]	0.770	[0.169]	1.48	1.23	0.646	0.594	0.589	[0.338]	[0.338]	[0.338]	0.194	1.01	0.208	400
500	[(0.540)]	[(0.540)]	[(0.540)]	0.725	[0.186]	(1.47)	1.19	0.668	0.609	0.593	[0.358]	[0.358]	[0.358]	0.196	[0.541]	0.213	500
600				0.687	[0.200]	(1.45)	1.16	0.690	0.624	0.597	[0.379]	[0.379]	[0.379]	0.200	[0.599]	0.223	600
700				0.659	[0.212]	[0.83]**	1.12	0.712	0.640	0.601	[0.399]	[0.399]	[0.399]	0.205	[0.657]	0.234	700
800				0.640		[0.89]**	1.09	0.733	0.655	0.605	[0.420]	[0.420]	[0.420]	0.211	[(0.715)]	0.245	800
900				0.627		[0.96]**	1.06	0.755	0.670	0.609	[0.440]	[0.440]	[0.440]	0.218		0.255	900
1000				0.618			1.03	0.776	0.686	0.613	[0.461]	[0.461]	[0.461]	0.226		0.264	1000
1100				(0.612)			1.00	0.798	0.701	0.617	[(0.481)]	[(0.481)]	[(0.481)]	0.234		0.272	1100
1200							0.976	0.820	0.716	0.621	[(0.502)]	[(0.502)]	[(0.502)]	0.242		0.280	1200
1300							0.952		0.731	0.625				0.251		0.288	1300
1400							0.930		0.746	0.629				(0.260)		0.295	1400
1500							0.912		0.760	0.633				(0.269)		0.301	1500
1600							0.896		0.774	0.636				(0.277)		0.307	1600
1700							0.883		0.787	0.639						(0.311)	1700
1800							0.871		0.800	0.643						(0.315)	1800
1900							0.860		0.812	0.646							1900
2000							0.850			0.649							2000
2200							0.834			0.655							2200
2400							0.820			0.660							2400
2600							(0.810)			0.664							2600
2800										0.665							2800
37.8				0.886													37.8
231.89											0.662 [0.303]	0.460 [0.303]	0.595 [0.303]				231.89
320.9	(0.942) [(0.416)]	(0.754) [(0.416)]	(0.880) [(0.416)]														320.9
327.4					0.312 [(0.155)]												327.4
357.8								0.638									357.8
419.5															1.00 [(0.495)]		419.5
649.8						(1.45) [0.79]**											649.8

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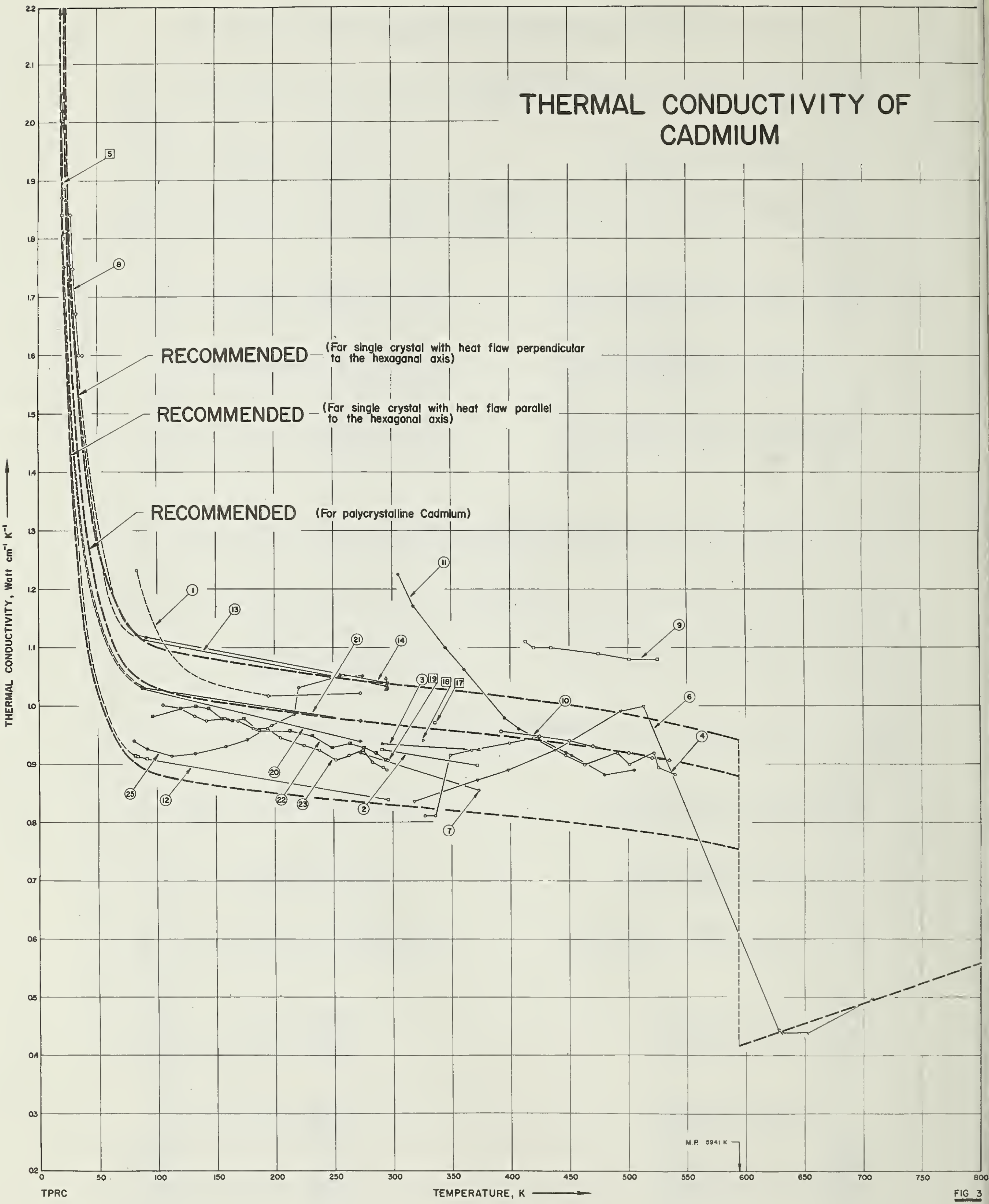
* Values in parentheses are extrapolated and in square brackets are for liquid state. In the table the third significant figure is given only for internal comparison and for smoothness and is not indicative of the degree of accuracy.

** Estimated.



THERMAL CONDUCTIVITY OF CADMIUM

FIG 3

TABLE 3. SPECIFICATIONS OF THE SPECIMENS OF CADMIUM

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	35	Eucken, A. and Gehlhoff, G.	1912	L	83-273		Specimen 2 - 3 cm in dia.; electrical conductivity at -190, -79, and 0 C being, respectively, 5.05, 1.835, and 1.289 x 10^5 ohm^{-1} cm^{-1}.
2	77	Jaeger, W. and Diesselhorst, H.	1900	E	291, 373		Less than 0.05 each of Pb, Zn, and Fe; density 8.63 g cm^{-3} at 18 C; electrical conductivity at 18 and 100 C being, respectively, 13.13 and 9.89 x 10^4 ohm^{-1} cm^{-1}.
3	77	Jaeger, W. and Diesselhorst, H.	1900	E	291, 373		Similar to the above specimen but drawn into a wire; electrical conductivity at 18 and 100 C being, respectively, 13.25 and 10.18 x 10^4 ohm^{-1} cm^{-1}.
4	6	Bailey, L. C.	1931	L	327-540		Pure; redistilled; density = 8.64 g cm^{-3} at 21 C; same specimen as used by Lees (curves 22 & 23).
5	97	Mendelssohn, K. and Rosenberg, H. M.	1952	L	2.3-21	Cd 1	99.9999 pure; cast in glass.
6	19	Brown, W. B.	1923	L	318-708		Cylindrical rod 1.5 cm in dia. and 12 cm long; melting point 320 C.
7	706	Lorenz, L.	1881	L	273, 373		Density 8.62 g cm^{-3}; electrical conductivity at 0 and 100 C being, respectively, 14.41, and 10.18 x 10^4 ohm^{-1} cm^{-1}. (The paper reported 14.41 and 10.18 x 10^5 ohm^{-1} cm^{-1}, obviously, a typographical error.)
8	122	Rosenberg, H. M.	1955	L	1.7-37	Cd 2	99.995 pure; single crystal; with heat flow at 79 degrees to the hexagonal axis.
9	431	Mikryukov, V. E. and Rabotnov, S. N.	1944	E	414-526		Single crystal; electrical resistivity at 140.6, 146.9, 162.4, 202.0, 228.6, and 252.4 C being, respectively, 10.08, 10.33, 10.90, 12.23, 13.20, and 14.10 μohm cm.
10	431	Mikryukov, V. E. and Rabotnov, S. N.	1944	E	393-536		Polycrystal; electrical resistivity at 119.6, 152.8, 177.2, 196.9, 228.2, 248.8, and 262.6 C being, respectively, 11.84, 13.22, 14.34, 15.22, 16.65, 17.59, and 18.30 μohm cm.
11	383	Mikryukov, V. E., Tyapunina, N. A., and Cherpakov, V. P.	1956	E	306-506		Pure; electrical conductivity at 32.5, 72.2, 122.2, 174.3, 207.5, and 232.6 C being, respectively, 12.89, 11.11, 9.51, 8.38, 7.60, and 7.32 x 10^4 ohm^{-1} cm^{-1}.
12	294	Goens, E. and Gruneisen, E.	1932	L	21-297	Cd 53	Single crystal; the angle between rod axis and hexagonal axis $\phi = 14^\circ$, length L = 6.70 cm, and cross-sectional area A = 0.1475 cm^2; electrical resistivity at -252, -190, 0, and 20 C being, respectively, 0.185, 2.001, 7.65, and 8.27 μohm cm.
13	294	Goens, E. and Gruneisen, E.	1932	L	22-295	Cd 47a	Single crystal; $\phi = 84^\circ$, L = 4.48 cm, and A = 0.1009 cm^2; electrical resistivity at -252, -190, 0, and 20 C being, respectively, 0.1352, 1.63, 6.38, and 6.89 μohm cm.
14	294	Goens, E. and Gruneisen, E.	1932	L	21-297	Cd 47b	Similar to the above specimen but L = 6.65 cm, and A = 0.0914 cm^2.
15	727	Zavaritskii, N. V.	1960	L	0.10-0.60	Cd 1	Pure; single crystal; heat flow along the hexagonal axis; includes superconducting state.
16	727	Zavaritskii, N. V.	1960	L	0.10-0.75	Cd 3	Pure; single crystal; heat flow perpendicular to the hexagonal axis; includes superconducting state.
17	230	Smith, A. W.	1925	L	336.2		Impurities less than 0.03; rod 5 to 6 cm long, cross-sectional area 0.3 cm^2; electrical conductivity 13.76 x 10^4 ohm^{-1} cm^{-1} at 23 C.
18	230	Smith, A. W.	1925	L	326.2		Similar to the above specimen but 10 cm long and 1.9 cm in dia.
19	511	Lussana, S.	1918	L	296.9		Radius 0.550 cm; specimen from Erba.
20	619	Schott, R.	1916	L	20-273		Purified; specimen ~0.5 cm in dia. and 5 cm long; electrical conductivity at 20.4, 87.0, and 273 K being, respectively, 622.0, 52.5, and 14.5 x 10^4 ohm^{-1} cm^{-1}.

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*See TPRC Data Book Vol. 1, Chapter 1, References [95]

TABLE 3. SPECIFICATIONS OF THE SPECIMENS OF CADMIUM (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
21	619	Schott, R.	1916	L	20-273		Chemically pure (Kahlbaum); specimen ~0. 5 cm in dia. and 5 cm long; electrical conductivity at 20. 4, 87. 0, and 273 K being, respectively, 67. 89, 53. 58, and 14. 6 x 10^4 ohm^{-1} cm^{-1}.
22	88	Lees, C.H.	1908	L	96-297		Turned from a cast stick of "Pure Redistilled Cadmium" as used in Cadmium-Cell; specimen 7 - 8 cm long, 0. 585 cm in dia. ; density 8. 64 g cm^{-3} at 21 C; electrical resistivity at -178. 1, -165. 9, -105. 8, -75. 1, -59. 9, -25. 2, -5. 7, and 22. 8 C being, respectively, 2. 22, 2. 56, 4. 18, 5. 05, 5. 46, 6. 38, 6. 96, and 7. 78 μohm cm; first experiment.
23	88	Lees, C.H.	1908	L	105-295		The above specimen, second experiment.
24	727	Zavaritskii, N. V.	1960	L	0. 53	Cd-2	Pure; single crystal; heat flow perpendicular to the hexagonal axis; at the transition point.
25	851	Wright, W. H.	1960	L	82-276		99. 95 pure; specimen 0. 1877 in. in dia and 2. 255 in. long turned from a cast stick obtained from A. D. Mackay; data corrected for rise in temperature during measurement.

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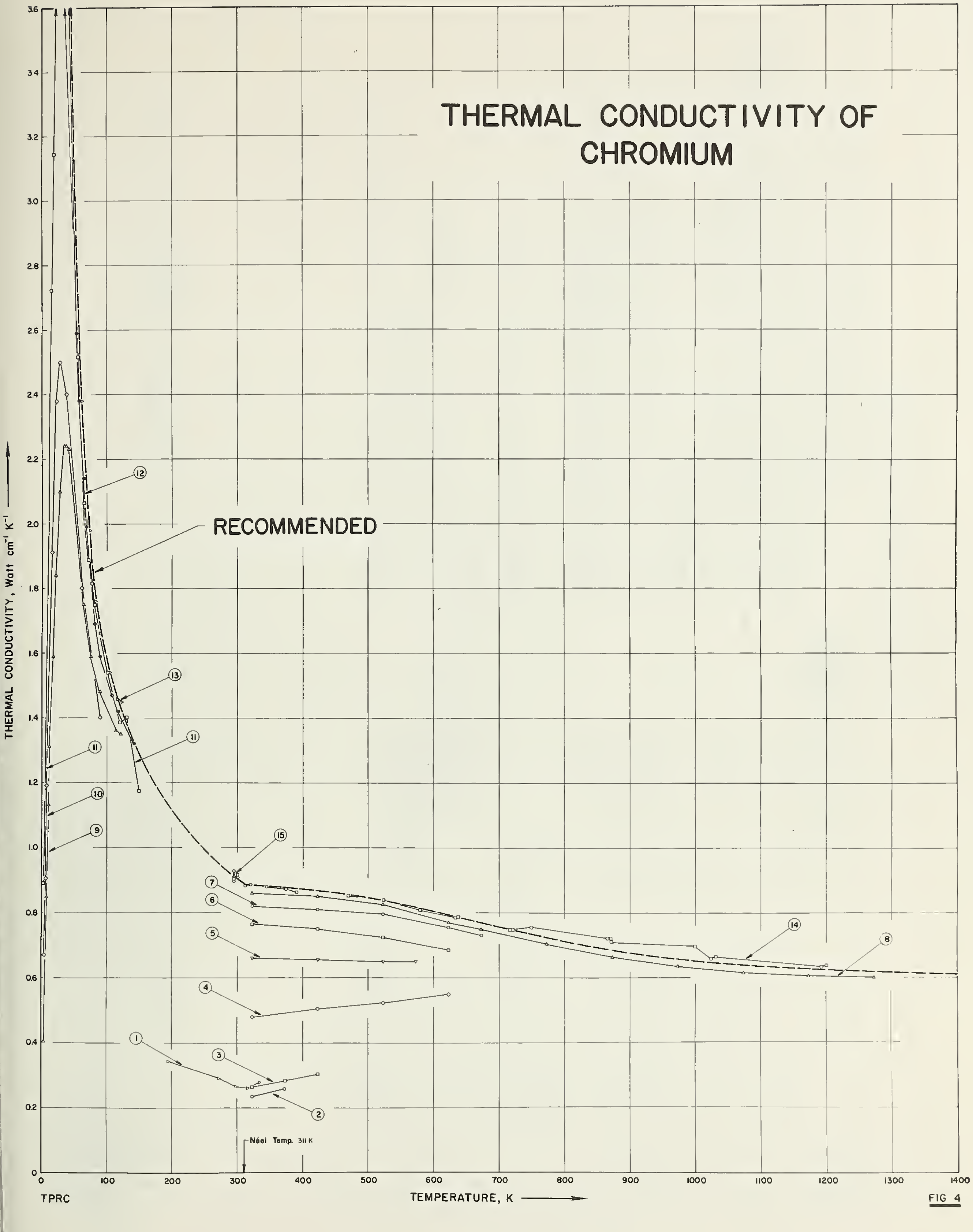
*See TPRC Data Book Vol. 1, Chapter 1, References


THERMAL CONDUCTIVITY OF CHROMIUM
RECOMMENDED
THERMAL CONDUCTIVITY, Watt cm⁻¹ K⁻¹
TEMPERATURE, K
Néel Temp. 311 K
0
0.2
0.4
0.6
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1.2
1.4
1.6
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2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
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FIG 4

TABLE 4. SPECIFICATIONS OF THE SPECIMENS OF CHROMIUM

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	136	Sochtig, H.	1940	L	196-334	Cr II	Electrolytic; specimen dimensions 0.7 x 0.23 x 0.21 cm; annealed at 1000 C for 30 min.
2	112	Powell, R.W. and Tye, R.P.	1957	L, C	323, 373		0.43 O; electrodeposited chromium tube, 1.28 cm O.D., 0.63 cm I.D., and 18.05 cm long; as deposited; density 6.975 g cm^{-3}; electrical resistivity ρ_{293} = 48.5 μohm cm.
3	112	Powell, R.W. and Tye, R.P.	1957	L, C	323-423		The above specimen heat treated at 486 K; ρ_{293} = 39.7 μohm cm.
4	112	Powell, R.W. and Tye, R.P.	1957	L, C	323-623		The above specimen heat treated at 478 K; density increased to 7.08 g cm^{-3}; ρ_{293} = 25.5 μohm cm.
5	112	Powell, R.W. and Tye, R.P.	1957	L, C	327-573		The above specimen heat treated at 818 K; ρ_{293} = 19.3 μohm cm.
6	112	Powell, R.W. and Tye, R.P.	1957	L, C	323-623		The above specimen heat treated at 1133 K; ρ_{293} = 16.0 μohm cm.
7	112	Powell, R.W. and Tye, R.P.	1957	L, C	323-673		The above specimen heat treated at 1327 K; ρ_{293} = 15.0 μohm cm.
8	112	Powell, R.W. and Tye, R.P.	1957	L, C	323-1273		The above specimen heat treated at 1683 K; density increased to 7.15 g cm^{-3}; ρ_{293} = 13.6 μohm cm; ρ_4 = 0.05 μohm cm; ρ_{293}/ρ_4 = 272.
9	68	Harper, A.F.A., Kemp, W.R.G., Klemens, P.G., Tainsh, R.J., and White, G.K.	1957	L	4.5-123	1	99.998 pure; cold worked; residual resistivity ρ_0 = 0.255 μohm cm.
10	68	Harper, A.F.A., Kemp, W.R.G., Klemens, P.G., Tainsh, R.J., and White, G.K.	1957	L	5.1-91	2	The above specimen annealed at 1050 C; ρ_0 = 0.181 μohm cm.
11	68	Harper, A.F.A. et al.	1957	L	4.6-151	3	99.998 pure; partially recrystallized; ρ_0 = 0.125 μohm cm.
12	68	Harper, A.F.A. et al.	1957	L	2.9-142	4	The above specimen annealed at 1050 C; ρ_0 = 0.090 μohm cm.
13	68	Harper, A.F.A. et al.	1957	L	2.4-123	5	99.998 pure; fully recrystallized; ρ_0 = 0.055 μohm cm; ρ_{293}/ρ_0 = 217.
14	89	Lucks, C.F. and Deem, H.W.	1956	C	470-1201		Chemically pure; ductile; density 7.16 g cm^{-3}.
15	‡	McElroy, D.L., Kollie, T.G., Fulkerson, W., Moore, J.P., and Graves, R.S.	1965	C	295-391		No details given for the specimen characterization; Néel temperature 37.8 C.

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* See TPRC Data Book Vol. 1, Chapter 1, References

‡ Private communication, 1965

THERMAL CONDUCTIVITY OF LEAD

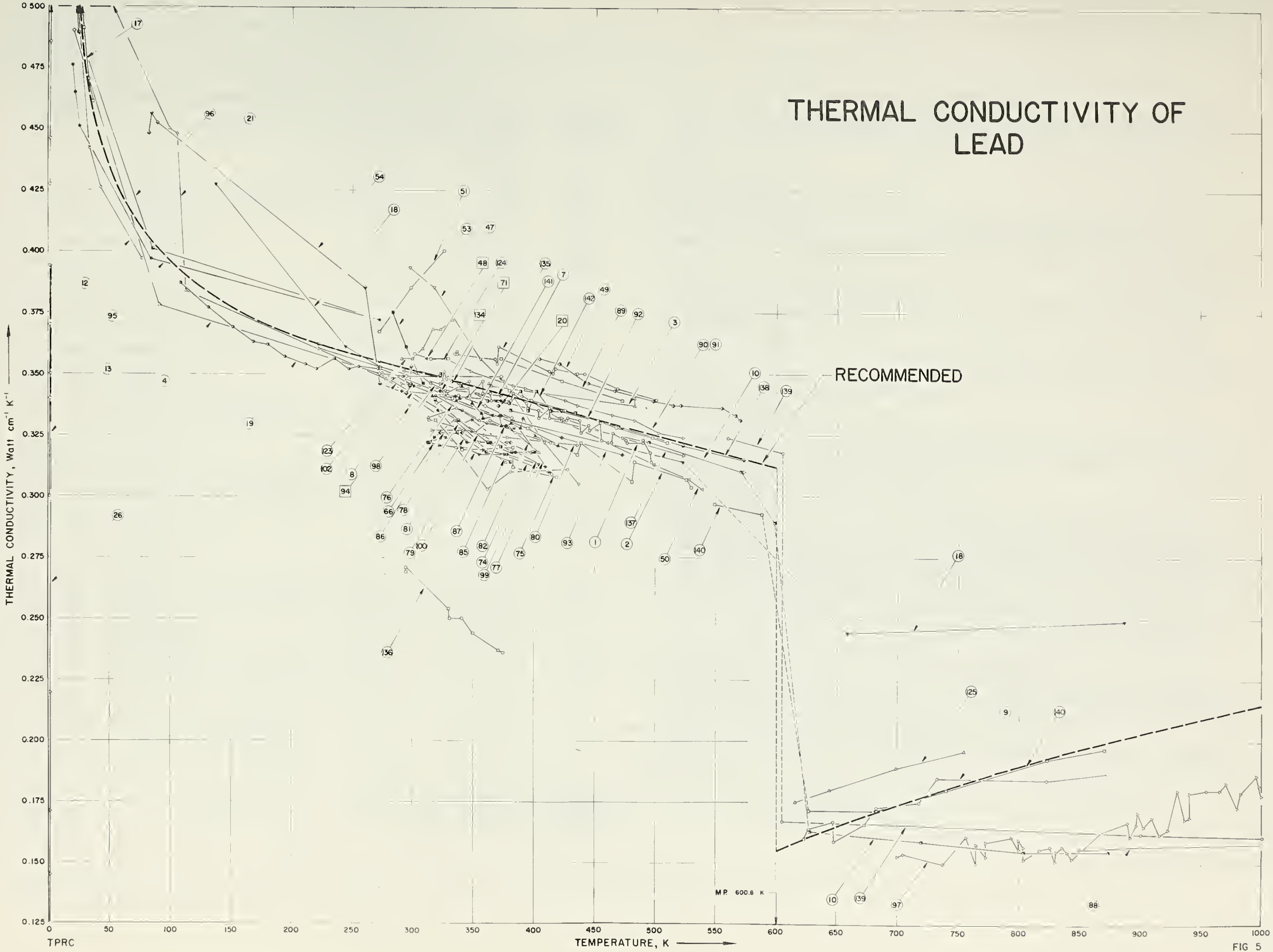

FIG 5

TABLE 5. SPECIFICATIONS OF THE SPECIMENS OF LEAD

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	48	Francl, J. and Kingery, W.D.	1954	L	326-497		Specimen of 1 in. cube, cut and machined from a bar of melting-point lead supplied by NBS (sample No. 49c); all surfaces carefully lapped.
2	129 852	Shelton, S.M. and Swanger, W.H.	1933	C	273-530	L. S.	Bureau of Standards melting point standard lead; purity indicated by freezing point of 327.4 C; specimen 15 cm long, 2 cm in dia. melted in graphite and cast in bottom-feed cast-iron mold; all data referred to the value 0.352 Watt $cm^{-1}K^{-1}$ at 0 C taken from International Critical Tables, Volume II, p. 218.
3	84	King, R.W.	1918	P	363-483		Pure; "squirted" wire, 3.1 mm in dia.
4	95	Meissner, W.	1915	E	22-374		99.998 pure; specimen 6.24 cm long, 0.2996 cm in dia.; electrical resistivity at 0 and 18 C being, respectively, 19.26 and 20.68 μohm cm.
5	63	DeHaas, W.J. and Rademakers, A.	1940	L	2.6-23		Single crystal; pure lead obtained from Adam Hilger Ltd. (H.S. brand); melted under high vacuum; the molten lead filtered through a narrow glass opening, pressed under nitrogen into a glass tube of the desired shape then cooled slowly to make a specimen of 15 cm long, 2.5 mm in dia.; transition point ~7.13 K; k data in normal state below transition point obtained by applying a transverse magnetic field of 472-810 gauss.
6	63	DeHaas, W.J. and Rademakers, A.	1940	L	2.0-7.1		The above specimen in superconducting state.
7	77	Jaeger, W. and Diesselhorst, H.	1900	L	291, 273		99.95 Pb (by difference); <0.05 total Cu, Bi, Fe, and Ni; density 11.32 g cm^{-3} at 18 C; electrical conductivity at 18 and 100 C being, respectively, 4.84 and 3.64 x 10^4 ohm^{-1} cm^{-1}.
8	77	Jaeger, W. and Diesselhorst, H.	1900	L	291, 273		The above specimen drawn into a wire.
9	113	Powell, R.W. and Tye, R.P.	1957	C	623-873	Lab. No. 5873	99.995^+ pure; specimen 7 mm in dia.; in liquid state.
10	85	Konno, S.	1919	L	381-874		No details reported.
11	18	Bremmer, H. and DeHaas, W.J.	1936	L	2.6-7.1		In superconducting state.
12	18	Bremmer, H. and DeHaas, W.J.	1936	L	7.9-77		No details reported.
13	117	Rademakers, A.	1949	L	1.4-3.8	Pb II	High purity; single crystal; specimen 3.8 mm in dia. obtained from Adam Hilger Ltd. (H.S. brand); in superconducting state.
14	117	Rademakers, A.	1949	L	1.4-3.9	Pb II	The above specimen in normal state with a longitudinal magnetic field of 850 oersteds.
15	117	Rademakers, A.	1949	L	1.4-2.5	Pb III	Similar to the above specimen but 4.0 mm in dia.; in superconducting state.
16	98	Mendelssohn, K. and Rosenberg, H.M.	1952	L	1.8-6.7	Pb I	99.998 pure; Tadanac lead; single crystal; in superconducting state.
17	98	Mendelssohn, K. and Rosenberg, H.M.	1952	L	1.7-38	Pb I	The above specimen in normal state.
18	14	Bidwell, C.C.	1940	L	138-887		No details reported.
19	88	Lees, C.H.	1908	L	109-299		Turned from a bar of pure lead supplied by Messrs. Baxendale, Manchester; density 11.29 g cm^{-3} at 25 C; electrical resistivity at -170, -129.4, -89.2, -51.8, -14.0, and 17.4 C being, respectively, 6.71, 9.71, 12.9, 15.7, 18.5, and 20.9 μohm cm.
20	144	Weeks, J. L. and Seifert, R. L.	1952	L	317.2		Specimen from melting point standard lead supplied by NBS.

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*See TPRC Data Book, Vol. 1, Chapter 1, References

TABLE 5. SPECIFICATIONS OF THE SPECIMENS OF LEAD (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
21	16	Bidwell, C. C. and Lewis, E. J.	1929	F	37-378		No details reported.
22	257, 379	Montgomery, H.	1958	L	1. 1-4. 6	Pb 1	99. 99 pure; obtained from Johnson and Matthey Co., Ltd. (No. 560); monocrystal; specimen $\sim$7 cm long; 3 mm in dia.; annealed in vacuo for several days at a few degrees below the melting point; in superconducting state.
23	257, 379	Montgomery, H.	1958	L	1. 2-4. 8	Pb 1	The above specimen in normal state with a transverse magnetic field of 1000 gauss.
24	257	Montgomery, H.	1958	L	1. 0-4. 6	Pb 2	99. 99 pure; obtained from Johnson and Matthey Co., Ltd. (No. 560); polycrystal; grain size 0. 5 mm; specimen $\sim$7 cm long, 3 mm in dia.; annealed in vacuo for several hrs at a few degrees below the melting point; in superconducting state.
25	257	Montgomery, H.	1958	L	1. 1-3. 9	Pb 2	The above specimen in normal state with a transverse magnetic field of 1000 gauss.
26	257	Montgomery, H.	1958	L	1. 1-4. 6	Scroll	Pure; hollow cylindrical specimen 3 cm in dia. made from lead foil 0. 070 mm thick; annealed in vacuo for 5 days at a few degrees below the melting point; in superconducting state.
27	257	Montgomery, H.	1958	L	1. 6-4. 6	Scroll	The above specimen in normal state at 1000 gauss.
28	257	Montgomery, H.	1958	L	0. 98-4. 2	PbBi 0. 02	99. 98 Pb, 0. 02 Bi, polycrystal with long crystals; specimen $\sim$7 cm long, 3 mm in dia.; annealed in vacuo for several hrs at a few degrees below the melting point; in superconducting state.
29	257	Montgomery, H.	1958	L	0. 98-4. 3	PbBi 0. 02	The above specimen in normal state at 1000 gauss.
30	257	Montgomery, H.	1958	L	1. 1-4. 8	PbBi 0. 1	99. 899 Pb (by difference), 0. 101 Bi; polycrystal; grain size 0. 3 mm; specimen $\sim$7 cm long, 3 mm in dia.; annealed in vacuo for several hrs at a few degrees below the melting point; in superconducting state.
31	257	Montgomery, H.	1958	L	1. 0-4. 4	PbBi 0. 1	The above specimen in normal state at 1000 gauss.
32	342	Mendelssohn, K. and Rosenberg, H. M.	1953	L	2. 7	Pb 1	99. 998 pure; single crystal; measured in a transverse magnetic field ranging from 0. 70 to 3. 90 kilooersteds.
33	342	Mendelssohn, K. and Rosenberg, H. M.	1953	L	2. 7	Pb 1	The above specimen measured in a longitudinal field of 0. 87 to 3. 94 kilooersteds.
34	342	Mendelssohn, K. and Rosenberg, H. M.	1953	L	5. 3	Pb 1	The above specimen measured in a transverse field of 1. 86 to 3. 94 kilooersteds.
35	342	Mendelssohn, K. and Rosenberg, H. M.	1953	L	6. 4	Pb 1	The above specimen measured in a transverse field of 0. 52 to 3. 94 kilooersteds.
36	18	Bremmer, H. and DeHaas, W. J.	1936	L	3. 8-8. 6		In a magnetic field of 764 gauss.
37	18	Bremmer, H. and DeHaas, W. J.	1936	L	6. 39		The above specimen in a field of 765 gauss.
38	461	Webber, R. T. and Spohr, D. A.	1951	L	2. 5		99. 998 pure; measured in an increasing transverse magnetic field of 0 to 921 gauss.
39	461	Webber, R. T. and Spohr, D. A.	1951	L	2. 5		The above specimen measured in a decreasing transverse magnetic field from 685 to 0 gauss.
40	462	Olsen, J. L. and Renton, C. A.	1952	L	0. 40-1. 2		Single crystal; in superconducting state.

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*See TPRC Data Book Vol. 1, Chapter 1, References

TABLE 5. SPECIFICATIONS OF THE SPECIMENS OF LEAD (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
41	462	Olsen, J. L. and Renton, C. A.	1952	L	0. 43		The above specimen measured in an increasing magnetic field with strength ranging from 0 to 100% of the critical magnetic field.
42	462	Olsen, J. L. and Renton, C. A.	1952	L	0. 43		The above specimen measured in a decreasing magnetic field with strength ranging from 82 to 0% of the critical magnetic field.
43	462	Olsen, J. L. and Renton, C. A.	1952	L	0. 59		The above specimen measured in an increasing field with strength ranging from 0 to 100% of the critical magnetic field.
44	462	Olsen, J. L. and Renton, C. A.	1952	L	0. 59		The above specimen measured in a decreasing magnetic field with strength ranging from 72 to 37% of the critical field.
45	462	Olsen, J. L. and Renton, C. A.	1952	L	1. 5		The above specimen measured in an increasing magnetic field with strength ranging from 0 to 86% of the critical field.
46	462	Olsen, J. L. and Renton, C. A.	1952	L	1. 5		The above specimen measured in a decreasing magnetic field with strength ranging from 69 to 0% of the critical field.
47	248	Mikryukov, V. E. and Tyapunia, N. A.	1956	E	298-437		Nominally pure; electrical conductivity at 37, 50, 100, 150, 200, and 230 C being, respectively, 4. 4, 4. 25, 3. 6, 3. 05, 2. 65, and 2. 45 x 10^4 ohm^{-1} cm^{-1}.
48	406	Van Dusen, M. S.	1922	C	313. 2		Pure lead specimen 3 cm long and 3 cm in dia.; zinc used as a comparative standard.
49	431	Mikryukov, V. E. and Rabotnov, S. N.	1944	E	405-570		Pure; single crystal; electrical resistivity at 405. 1, 445. 1, 499. 1, 521. 1, and 570. 1 K being, respectively, 29. 67, 34. 01, 39. 68, 42. 01, and 47. 16 μohm cm.
50	431	Mikryukov, V. E. and Rabotnov, S. N.	1944	E	390-540		Pure; polycrystal; electrical resistivity at 390. 1, 461. 8, 499. 0, and 539. 9 K being, respectively, 30. 1, 38. 16, 42. 44, and 46. 88 μohm cm.
51	463	O'Day, M. D.	1924	E	273-326		Pure (supposed to be Kahlbaum's); 25 cm long, cross sectional area 0. 439 cm^2.
52	682	Zavaritskii, N. V.	1960	L	0. 16-1. 2	1	99. 999 pure; specimen 0. 13 cm in dia., ~5. 0 cm long; in superconducting state.
53	464	Peczalski, T.	1917	R	285-310		Commercially pure (major impurity was probably tin); specimen composed of 2 hollow hemispheres of 3. 65 cm internal radius and 7 cm external radius.
54	465	Macchia, P.	1907	C	83-300		Pure specimen (Kahlbaum lead) 32. 85 mm in dia. and 7 cm long; copper used as the comparative standard.
55	466	Wolff, C. L.	1961	L	1. 4-7. 5	E	99.9^+ Pb (by difference); <0. 1 metallic impurities; single crystal; enriched in isotopes of lead; specimen 1. 54 cm long, 0. 186 cm in dia.; cast under high vacuum (10^{-5}mm Hg); annealed in vacuum for 5 hrs at 260 C; in superconducting state.
56	466	Wolff, C. L.	1961	L	2. 9-7. 3	E	The above specimen measured in a longitudinal magnetic field of 900 gauss; in normal state.
57	466	Wolff, C. L.	1961	L	1. 5-7. 7	D	Similar to the above specimen but 99. 95 pure (by difference); 0. 05 metallic impurities; specimen 2. 40 cm long, 0. 123 cm in dia.; in superconducting state.
58	466	Wolff, C. L.	1961	L	2. 0-7. 6	D	The above specimen measured in a longitudinal magnetic field of 900 gauss; in normal state.
59	466	Wolff, C. L.	1961	L	2. 4-7. 6	B	Similar to the above specimen but 2. 26 cm long and 0. 123 cm in dia.; in superconducting state.

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*See TPRC Data Book Vol. 1, Chapter 1, References

TABLE 5. SPECIFICATIONS OF THE SPECIMENS OF LEAD (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
60	466	Wolff, C. L.	1961	L	2.4-7.3	B	The above specimen measured in a longitudinal magnetic field of 900 gauss; in normal state.
61	466	Wolff, C. L.	1961	L	2.4-7.7	C	Similar to the above specimen but 2.05 cm long and 0.123 cm in dia.; in superconducting state.
62	466	Wolff, C. L.	1961	L	2.4-7.3	C	The above specimen measured in a longitudinal magnetic field of 900 gauss; in normal state.
63	389, 676	Mendelssohn, K. and Rowell, P. M.	1958	L	1.0-4.4		99.99 pure; single crystal; straight thin bar; annealed at 270 C for 3 days; in superconducting state.
64	389, 676	Mendelssohn, K. and Rowell, P. M.	1958	L	1.0-4.0		The above specimen bent at 4.2 K and annealed at 90 K; in superconducting state.
65	389, 676	Mendelssohn, K. and Rowell, P. M.	1958	L	1.1-4.4		The above specimen annealed at 290 K; in superconducting state.
66	467	Koenig, J. H.	1953	C	313-429	55 Ni-1	NBS melting point standard lead; inconel used as the comparative standard.
67	412	Mendelssohn, K. and Renton, C. A.	1955	L	0.41-1.2		99.998 pure Tadanac lead; single crystal; measured without magnetic shielding; in superconducting state.
68	412	Mendelssohn, K. and Renton, C. A.	1955	L	0.30-0.87		The above specimen measured with magnetic shielding; in superconducting state.
69	508, 468	Mendelssohn, K.	1952	L	2.7-7.2		99.98 Pb (by difference), 0.02 Bi; in superconducting state.
70	508, 468	Mendelssohn, K.	1952	L	2.5-11		The above specimen in normal state.
71	230	Smith, A. W.	1925	L	333.2		Total impurities <0.03; rod 1.9 cm in dia. and 10 cm long.
72	18	Bremmer, H. and DeHaas, W. J.	1936	L	3.47		Measured in a magnetic field of 1006 gauss.
73	18	Bremmer, H. and DeHaas, W. J.	1936	L	4.4, 4.6		The above specimen in a magnetic field of 956 gauss.
74	506	Koenig, J. H.	1953	C	322-414	55 M-1	NBS melting point standard lead; specimen 0.350 in. in dia. and 0.510 in. long; copper used as the comparative standard.
75	506	Koenig, J. H.	1953	C	319-419	55 P-1	Similar to the above specimen but 0.450 in. in dia. and 0.509 in. long.
76	506	Koenig, J. H.	1953	C	319-385	55 J-1	Similar to the above specimen but 0.250 in. in dia. and 0.265 in. long.
77	506	Koenig, J. H.	1953	C	321-416	55 K-1	Similar to the above specimen but 0.25 in. in dia. and 0.528 in. long.
78	506	Koenig, J. H.	1953	C	316-398	55 L-1	Similar to the above specimen but 0.300 in. in dia. and 0.502 in. long.
79	506	Koenig, J. H.	1953	C	319-400	55 N-1	Similar to the above specimen but 0.410 in. in dia. and 0.489 in. long.
80	506	Koenig, J. H.	1953	C	316-436	55 N-2	Similar to the above specimen but 0.410 in. in dia. and 0.487 in. long.
81	506	Koenig, J. H.	1953	C	322-401	55 Q-1	Similar to the above specimen but 0.500 in. in dia. and 0.500 in. long.
82	506	Koenig, J. H.	1953	C	314-405	55 Q-2	Similar to the above specimen but 0.500 in. in dia. and 0.476 in. long.
83	507, 468	Mendelssohn, K. and Olsen, J. L.	1950	L	2.6-9.4		99.9 Pb, 0.1 Bi; in normal state.

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*See TPRC Data Book Vol. 1, Chapter 1, References

TABLE 5. SPECIFICATIONS OF THE SPECIMENS OF LEAD (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
84	507, 468	Mendelssohn, K. and Olsen, J. L.	1950	L	2. 7-6. 4		The above specimen in superconducting state.
85	509	Ruh, E.	1954	C	314-381		Accurately ground specimen 0. 500 ±0. 001 in. in dia. and 0. 500 ±0. 005 in. long; electrolytic deposited pure copper used as a comparative material; reference data of copper taken from International Critical Tables 1929.
86	509	Ruh, E.	1954	C	324-401	55 B-2	Second run of the above specimen.
87	509	Ruh, E.	1954	C	314-414	55 B-3	Third run of the above specimen.
88	735, 839	Yurchak, R. P. and Filippov, L. P.	1965	P	850-1250		Molten specimen in a tantalum crucible made from 2 coaxial tubes with diameters of 23. 8 and 8 mm, each tube 0. 12 mm thick; data calculated from measurements of thermal diffusivity and specific heat data; data of density taken from M. P. Slavinskii, Physicochemical Properties of Elements (in Russian), 1952.
89	510	Suzuki, H., Kuwayama, N., and Yamauchi, T.	1956	L	373-473		99. 997$^+$ pure electrolytic lead; specimen 20 mm in dia. and 40 mm long; mean temperature difference between the specimen and the guard ring was -12. 3 C, leading to high values.
90	510	Suzuki, H., Kuwayama, N., and Yamauchi, T.	1956	L	328-523		The above specimen with a difference in temperature from its guard ring of -0. 55 C.
91	510	Suzuki, H., Kuwayama, N., and Yamauchi, T.	1956	L	328-523		Rectangular specimen of the same purity as the above specimen; size 22 x 22 x 40 mm; mean temperature difference between the specimen and the guard ring was 0.15 C.
92	510	Suzuki, H., Kuwayama, N., and Yamauchi, T.	1956	L	380-510		Similar to the above specimen but 20 mm in dia. and 50 mm long; mean temperature difference between the specimen and the guard ring was 0. 15 C.
93	510	Suzuki, H., Kuwayama, N., and Yamauchi, T.	1956	L	373-473		Similar to the above specimen but only 40 mm long and the mean temperature difference between the specimen and the guard ring was 10. 35 C, leading to low values.
94	511	Lussana, S.	1918	L	298. 0		Specimen radius 0. 675 cm; furnished by "Erba".
95	619	Schott, R.	1916	L	20-273		Lead (technical) specimen 0. 5 cm in dia. and 5 cm long; electrical conductivity at 20. 4 and 273 K being, respectively, 173. 57 and 5. 09 x 10^4 ohm^{-1} cm^{-1}.
96	619	Schott, R.	1916	L	21-273		Pure Kahlbaum lead specimen 0. 5 cm in dia. and 5 cm long.
97	592	Nikol'skii, N. A., Kalakutskaya, N. A., Pchelkin, I. M., Klassen, T. V., and Vel'tishcheva, V. A.	1959	L	700-1130		Melting point 327. 4 C; in liquid state.
98	702	Tewfik, O. E., Eckert, E. R. G., and Jurewicz, L. S.	1961	L	293-347		99. 99 Pb; size 0. 184 x 2 x 6 in.; specimen cut from a prefabricated sheet.
99	703	Smoke, E. J., Illyn, A. V., Eichbaum, B. R., Snyder, N. H., Lass, G., and Nussbaum, T.	1955	C	319-411		NBS melting point standard lead; data obtained by using 28 gauge iron-constantan thermocouples.
100	703	Smoke, E. J., et al.	1955	C	328-405		The above specimen measured by using 30 gauge copper-constantan thermocouples.
101	703	Smoke, E. J., et al.	1955	C	317-376		The above specimen measured by using 24 gauge copper-constantan thermocouples.
102	706	Lorenz, L.	1881	L	273, 373		Electrical conductivity at 0 and 100 C being, respectively, 5. 141 and 3. 602 x 10^4 ohm^{-1}cm^{-1}. (The author reported as 5. 141 and 3. 602 x 10^5 ohm^{-1} cm obviously a typographical error.)

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*See TPRC Data Book Vol. 1, Chapter 1, References

TABLE 5. SPECIFICATIONS OF THE SPECIMENS OF LEAD (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
103	237	Mendelssohn, K. and Olsen, J. L.	1950	L	2.7		99.998$^+$ pure (by difference), impurity <0.002; cylindrical specimen prepared from Johnson Matthey H. S. lead; temperature gradient along the rod ~ 0.1 C cm^{-1}; measured in an increasing longitudinal magnetic field.
104	237	Mendelssohn, K. and Olsen, J. L.	1950	L	2.7		The above specimen measured in a decreasing magnetic field.
105	237	Mendelssohn, K. and Olsen, J. L.	1950	L	4.6		The above specimen measured in an increasing magnetic field and at a different fixed temperature.
106	237	Mendelssohn, K. and Olsen, J. L.	1950	L	4.6		The above specimen measured in a decreasing magnetic field.
107	237	Mendelssohn, K. and Olsen, J. L.	1950	L	5.29		About 99.98 Pb (by difference), 0.02 Bi; cylindrical specimen prepared from Johnson Matthey H. S. lead (impurity $<0.002\%$); temperature gradient along the rod ~ 0.1 C cm^{-1}; measured in an increasing longitudinal magnetic field.
108	237	Mendelssohn, K. and Olsen, J. L.	1950	L	5.29		The above specimen measured in a decreasing longitudinal field.
109	237	Mendelssohn, K. and Olsen, J. L.	1950	L	5.40		The above specimen measured in an increasing transverse magnetic field at a different fixed temperature.
110	237	Mendelssohn, K. and Olsen, J. L.	1950	L	5.40		The above specimen measured in a decreasing transverse field.
111	237	Mendelssohn, K. and Olsen, J. L.	1950	L	2.89		The above specimen measured in an increasing transverse field at a different fixed temperature.
112	237	Mendelssohn, K. and Olsen, J. L.	1950	L	2.89		The above specimen measured in a decreasing transverse field.
113	237	Mendelssohn, K. and Olsen, J. L.	1950	L	2.92		The above specimen measured in an increasing longitudinal magnetic field and at a different fixed temperature.
114	237	Mendelssohn, K. and Olsen, J. L.	1950	L	2.92		The above specimen measured in a decreasing longitudinal field.
115	237	Mendelssohn, K. and Olsen, J. L.	1950	L	2.6-21		The above specimen measured in a magnetic field greater than the critical field; in normal state.
116	237	Mendelssohn, K. and Olsen, J. L.	1950	L	2.8-72		The above specimen measured in zero field; in superconducting state.
117	237	Mendelssohn, K. and Olsen, J. L.	1950	L	2.7-3.9		The above specimen in a "frozen in" field.
118	693, 729	Watson, J. H. P. and Graham, G. M.	1963	L	7.2-8.3		Lead specimen grade 69 of the Consolidated Mining and Smelting Co.; single crystal; zone refined; 0.25 in. in dia. and 3 in. long; measured in zero field; in normal state.
119	693, 729	Watson, J. H. P. and Graham, G. M.	1963	L	6.4-8.3		The above specimen in a magnetic field of 600 gauss; in normal state.
120	693, 729	Watson, J. H. P. and Graham, G. M.	1963	L	6.3-8.3		The above specimen in a magnetic field of 680 gauss; in normal state.
121	693, 729	Watson, J. H. P. and Graham, G. M.	1963	L	6.2-7.3		The above specimen in a magnetic field of 800 guass; in normal state.

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*See TPRC Data Book Vol. 1, Chapter 1, References

TABLE 5. SPECIFICATIONS OF THE SPECIMENS OF LEAD (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
122	693, 729	Watson, J. H. P. and Graham, G. M.	1963	L	5. 5-7. 2		The above specimen in superconducting state.
123	730	Plott, R. F. and Raeth, C. H.	1945	L	291-333	NBS sample 49b	Calibration specimen for freezing point determination.
124	730	Plott, R. F. and Raeth, C. H.	1945	L	302-330	NBS sample 49b	The above specimen remeasured with a slightly different method of balancing thermocouples to avoid radial heat losses.
125	707	Rosenthal, M. W.	1953	C	617-755		Foreign non-volatile matter 0. 10 (max), Ag 0. 001 (max), other foreign metals 0. 001 (max); produced by Mallinckrodt Chemical Works; measured in molten state; test cylinder 3 in. in dia. ; Armco iron used as reference material.
126	731	Nicol, J.	1953	L	0. 13-0. 29		99. 998$^+$ pure; provided by Johnson Matthey and Co. Ltd. , London, (Batch No. 3620); specimen size 8 x 2. 1 x 25 mm; warm up number 1; in superconducting state.
127	731	Nicol, J.	1952	L	0. 18-0. 36		The above specimen, warm up number 2.
128	731	Nicol, J.	1952	L	0. 19-0. 38		The above specimen, warm up number 3.
129	732	March, R. H. and Symko, O. G.	1965	L	0. 015-0. 23		99. 999 pure (nominal); supplied by Koch-Light Laboratories Ltd. (Colnbrook, England); wire 5 cm long and 0. 5 mm in dia. ; measured in a longitudinal magnetic field of 1000 gauss; in normal state.
130	733	Reese, W. and Steyert, W. A. , Jr.	1962	L	0. 11-0. 41		99. 999 pure; polycrystalline; material obtained from Central Research Laboratories, American Smelting and Refining Co. ; ratio of cross sectional area of the specimen to the length being 3. 47 x 10^{-3} cm; cut and rolled from a lead bar of the mentioned purity; annealed at room temperature for many weeks; measured in a longitudinal magnetic field of 900 gauss; in normal state.
131	733	Reese, W. and Steyert, W. A. , Jr.	1962	L	0. 20-0. 38		The above specimen measured in a transverse field of 3000 gauss.
132	733	Reese, W. and Steyert, W. A. , Jr.	1962	L	0. 42		The above specimen measured in a transverse field of 2000 gauss.
133	733	Reese, W. and Steyert, W. A. , Jr.	1962	L	0. 14-0. 44		The above specimen measured in a transverse field of 1000 gauss.
134	734	Angell, M. F.	1926	R	323. 2		Specimen in the form of a long hollow cylinder.
135	841	Powell, R. W. and Tye, R. P.	1966	L, C	335-501		99. 995$^+$ Pb, 0. 001 Cd, 0. 0005 Cu, 0. 0005 Ag, and 0. 0003 Bi; spectrographically standardized sample from Johnson, Matthey and Co. Ltd. , Laboratory No. 5873; dia. 7 mm and length 15 mm; electrical resistivity at 273, 323, 373, 423, 473, 523, and 573 K being, respectively, 19. 3, 23. 4, 27. 5, 31. 8, 36. 3, 40. 8, and 45. 7 μohm cm; Lorenz function at 323, 373, 423, 473, and 523 K being, respectively, 2. 61, 2. 625, 2. 64, 2. 64, and 2. 62 x $10^{-8}V^2K^{-2}$.
136	714	Bishop, F. L.	1906	R	295-376		99. 16 pure; impurities being Fe and Al; specimen in the form of a hollow sphere of cast lead, divided into two hemispheres by a plane passing through a great circle of the sphere; external radius 8. 742 ± 0. 00055 cm, internal radius 3. 695 cm, thickness 5. 045 cm; density 11. 313 ± 0. 018 g cm^{-3} at 22 C.

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* See TPRC Data Book Vol. 1, Chapter 1, References

TABLE 5. SPECIFICATIONS OF THE SPECIMENS OF LEAD (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
137	840	Dauphinee, T. M., Armstrong, L. D., and Woods, S. B.	1966	L	223-573		99.999 pure; obtained from the Dept. of Mines and Technical Surveys (Ottawa); smoothed values given (experimental point deviations less than 1.5%).
138	840	Dauphinee, T. M., Armstrong, L. D., and Woods, S. B.	1966	L	223-573		Specimen cut from the same bar as the above specimen and measured by another apparatus with modifications in the thermal shielding.
139	838	Filippov, L. P.	1966	P	560-1355		Measured with an apparatus capable of giving simultaneously thermal conductivity, thermal diffusivity, and specific heat.
140	838	Dutchak, Ya. I. and Panasyuk, P. V.	1967	C	474-870		Molten specimen placed in a hole 21 mm in diameter drilled in an asbestos cement cylinder 30 mm in height; 1Kh18N9T steel used as reference material.
141	842	Lucks, C. F.	1967	C	316-420		0.03 Bi, 0.002 Ag, 0.002 Cd, 0.001 Fe, 0.001 Ni, 0.001 Si, 0.001 Te, 0.0005 Cu, 0.0005 Sn, and 0.0001 Mg; electrical resistivity reported 0.394, 0.735, 4.84 and 21.31 μohm cm at 20, 25, 77, and 298 K, respectively; M. P. 327.3 C; Armco iron used as standard.
142	842	Lucks, C. F.	1967	C	323-434		0.001 Fe, 0.001 Ni, 0.001 Si, <0.001 Te, 0.0005 Ag, 0.0005 Bi, 0.0005 Cu, <0.0005 Cd, <0.0005 Sn, and 0.0001 Mg; electrical resistivity reported 0.366, 0.685, 4.83 and 21.25 μohm cm at 20, 25, 77, and 298 K, respectively; M. P. 327.417 C; Armco iron used as standard.

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* See TPRC Data Book Vol. 1, Chapter 1, References

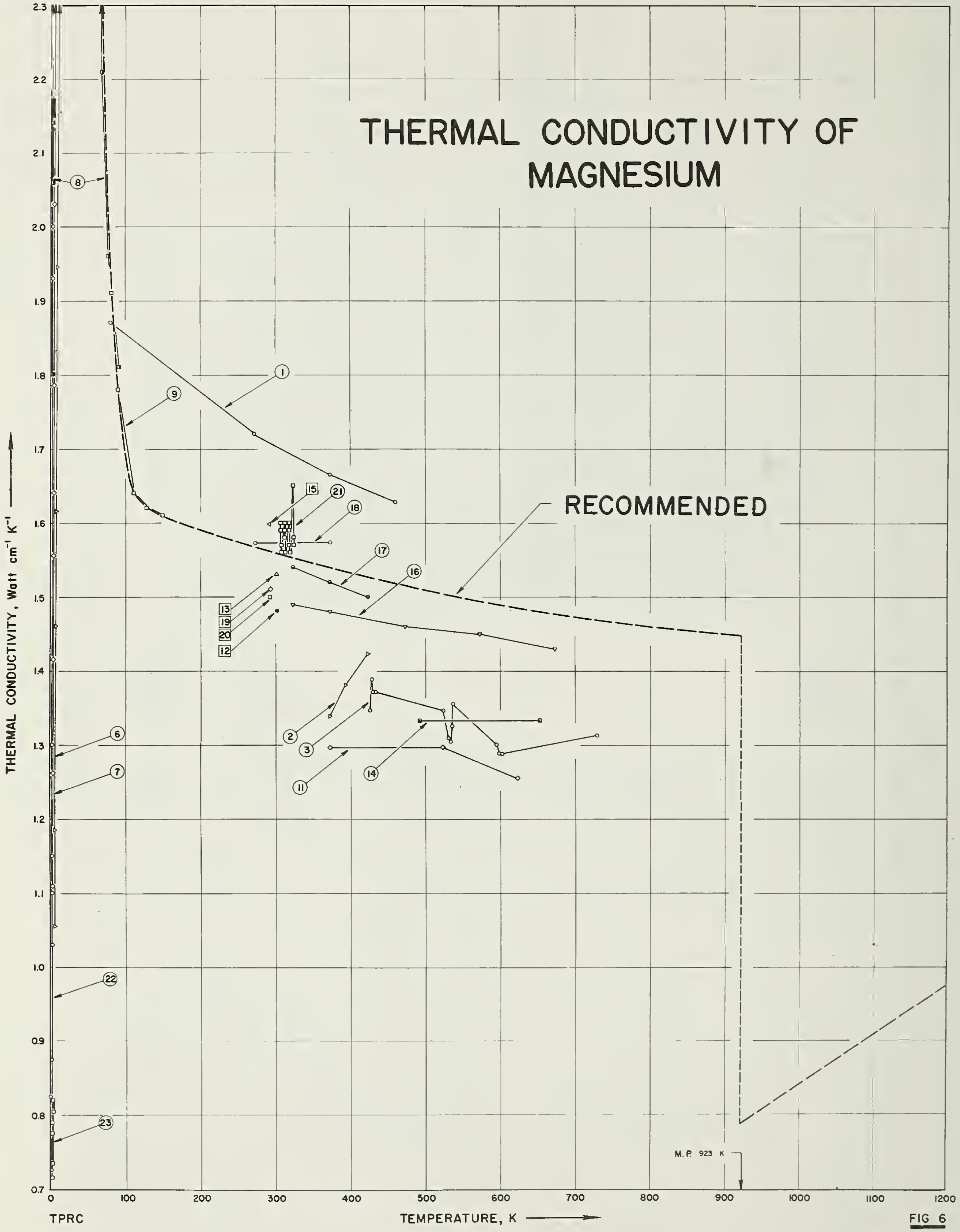
THERMAL CONDUCTIVITY OF MAGNESIUM
RECOMMENDED
THERMAL CONDUCTIVITY, Watt cm^{-1} K^{-1}
TEMPERATURE, K
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FIG 6

TABLE 6. SPECIFICATIONS OF THE SPECIMENS OF MAGNESIUM

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	93	Mannchen, W.	1931	L	80-460		Extremely pure; electrical resistivity at 80, 273, 373, and 460 K being, respectively, 0. 82, 3. 91, 5. 56, and 7. 27 μohm cm.
2	53	Grard, C. and Villey, J.	1927	E	373-423		Commerically pure.
3	127	Schofield, F. H.	1925	L	430-729		99. 6 pure; density (at 21 C), 1. 75 g cm^{-3}; extruded and then annealed for 6 hrs at 360 C.
4	97	Mendelssohn, K. and Rosenberg, H. M.	1952	L	2. 6-47		99. 95 pure; polycrystalline.
5	121	Rosenberg, H. M.	1954	L	2. 5-35	Mg 2	99. 95$^+$ pure; 0. 03 Mn, 0. 0075 Fe, 0. 004 Al, annealed in vacuo at 500 C.
6	137	Spohr, D. A. and Webber, R. T.	1957	L	1. 5-24	Mg (Mn)	99. 95$^+$ pure; 0. 043 Mn, 0. 001 Fe, 0. 0048 Zn, traces of Cu, Pb, Sb, and Ca; polycrystalline; cold-worked.
7	137	Spohr, D. A. and Webber, R. T.	1957	L	1. 6-22	Mg (Fe)	99. 98$^+$ pure; 0. 0023 Mn, 0. 013 Fe, 0. 0013 Pb; polycrystalline; annealed.
8	275	Kemp, W. R. G., Sreedhar, A. K., and White, G. K.	1953	L	2. 5-91	JM1848; Mg1	99. 98$^+$ pure; 0. 0023 Mn, 0. 013 Fe, 0. 0013 Pb, and faintly visible spectral lines of Si, Cu, Ag, Ca, and Na; as drawn.
9	275	Kemp, W. R. G., Sreedhar, A. K., and White, G. K.	1953	L	2. 5-149	JM1848; Mg2	The above specimen after annealing in vacuo for 3 hrs at 350 C.
10	275	Kemp, W. R. G., Sreedhar, A. K., and White, G. K.	1953	L	2. 2-27	JM1848; Mg3	Similar to specimen Mg2.
11	225	Maybrey, H. J.	1928	L	373-623		0. 031 Si, 0. 012 Cu, 0. 014 total Fe and Al; annealed for 5 hrs at 530 C before machining.
12	408	Masumoto, H.	1925	E	302. 2	Mg	0. 175 Si, 0. 052 Al, 0. 014 Fe; chill-cast.
13	408	Masumoto, H.	1925	E	301. 2	Mg	The above specimen annealed for 30 min at 450 C.
14	295	McCreight, L. R.	1952		493, 653		Extruded powder specimen; 98~100 pure.
15	673	Kikuchi, R.	1932	E	291. 3		Pure.
16	674	Powell, R. W., Hickman, M. J., and Tye, R. P.	1964	L, C	323-673	Mg1	99. 95 pure; $\approx$0. 033 Al, $\approx$0. 012 Zn, forged and stabilizing heat treated; 1. 9 cm in dia. and 30 cm long; supplied by the Metallurgy Division of the National Physical Laboratory; electrical resistivity at 293, 323, 373, 473, 573, and 673 K being respectively, 4. 5, 5. 01, 5. 85, 7. 57, 9. 30, and 11. 04 μohm cm.
17	674	Powell, R. W., Hickman, M. J., and Tye, R. P.	1964	L, C	323-423	MgII	99. 98 pure; $\approx$0. 016 Al, $\approx$0. 004 Zn; 0. 635 cm in dia. and 10 cm long; supplied by Messrs. Johnson, Matthey and Co., Ltd.; electrical resistivity at 293, 323, 373, and 423 K being, respectively, 4. 34, 485, 5. 70, and 6. 51 μohm cm.
18	706	Lorenz, L.	1881	L	273, 373		Electrical conductivity at 0 and 100 C being, respectively, 24. 47 and 17. 50 x 10^4 ohm^{-1} cm^{-1}.
19	719	Taylor, R.	1965	P	293. 2		Spectroscopically pure; specimen 1. 27 cm long; k calculated from thermal diffusivity data.
20	719	Taylor, R.	1965	P	293. 2		Similar to the above specimen but 0. 635 cm long.
21	722	Stephenson, A. E.	1963	L	307-324		4. 025 in. in dia and 1. 015 in. thick; large corrections made in determining thermal conductivity.
22	721	Sharkoff, E. G.	1953	L	1. 0-4. 7	Sample 765	99. 98$^+$ Mg, 0. 01 Mn, 0. 0002 Al, <0. 0001 Cu, 0. 0008 Fe, <0. 0001 Ni, 0. 0012 Pb, <0. 001 Si, <0. 001 Sn, 0. 003 Zn, and 0. 001 Ca; specimen 9. 03 cm long and 0. 310 cm in dia.; electrical resistivity at 1. 0, 3. 0, 5. 0, 10. 0, 15. 0, 20. 0, 25. 0, and 30 K, being, respectively, 0. 048, 0. 042, 0. 04, 0. 037, 0. 04, 0. 042, 0. 047, and 0. 058 μohm cm.

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*See TPRC Data Book Vol. 1, Chapter, 1, References

TABLE 6. SPECIFICATIONS OF THE SPECIMENS OF MAGNESIUM (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
23	721	Sharkoff, E.G.	1953	L	1.1–4.4	Sample 767	99.95 Mg, 0.043 Mn, 0.0002 Al, <0.0001 Cu, 0.001 Fe, <0.0001 Ni, 0.0011 Pb, <0.001 Si, 0.0011 Sn, 0.0048 Zn, and 0.0012 Ca; specimen 8.93 cm long and 0.307 cm in dia.; electrical resistivity at 1.0, 3.0, 5.0, 10, 15, 20, and 25 K, being, respectively 0.153, 0.144, 0.136, 0.123, 0.120, 0.127, and 0.137 μohm cm.
24	721	Sharkoff, E.G.	1953	L	1.0–4.5	Sample 370	99.87^+ Mg, 0.12 Mn, 0.0002 Al, 0.0001 Cu, 0.0011 Fe, <0.0002 Ni, 0.0014 Pb, <0.001 Si, <0.001 Sn, 0.0036 Zn, and 0.0006 Ca; specimen 9.35 cm long and 0.305 cm in dia.; electrical resistivity at 1.0, 3.0, 5.0, 10, 20, 30, and 40, being, respectively 0.365, 0.34, 0.32, 0.29, 0.275, 0.30, and 0.37 μohm cm.

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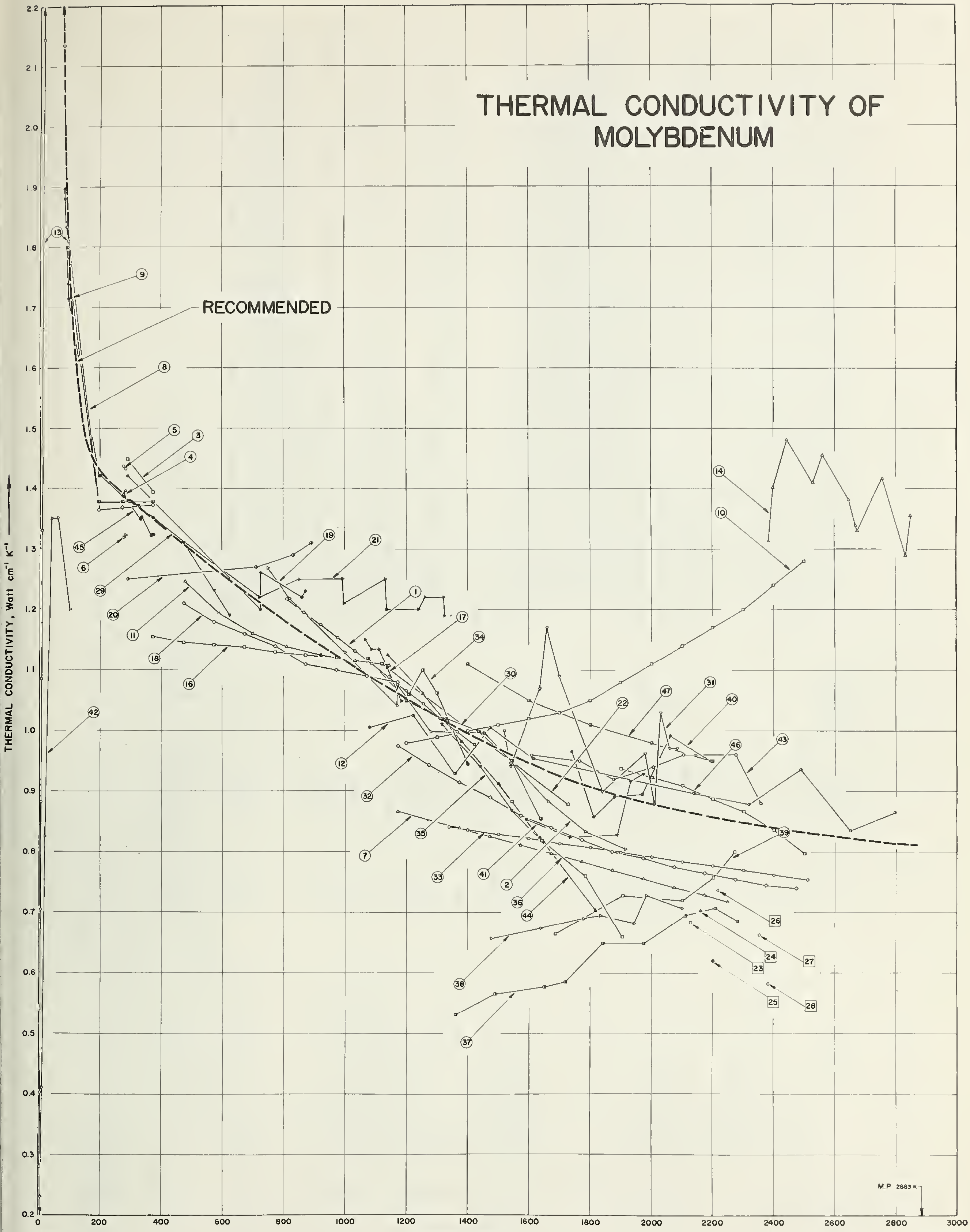
*See TPRC Data Book Vol. 1, Chapter 1, References



THERMAL CONDUCTIVITY OF MOLYBDENUM

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FIG 7

TABLE 7. SPECIFICATIONS OF THE SPECIMENS OF MOLYBDENUM

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	100	Mikol, E. P.	1952	R	811-1422		99.9 pure; less than 0.005 Fe, less than 0.003 C; wrought just below the recrystalline temperature.
2	40	Fieldhouse, I. B., Hedge, J. C., Lang, J. L., Takata, A. N., and Waterman, T. E.	1956	L	749-1915		Pure; arc-melted.
3	8	Barratt, T.	1914	L	290, 373		Pure.
4	78	Kannuluik, W. G.	1931	E	277, 283	Mo I	Pure; annealed at 220 C.
5	78	Kannuluik, W. G.	1931	E	278, 283	Mo I	Pure; annealed at 900 C.
6	78	Kannuluik, W. G.	1931	E	277, 282	Mo II	Less pure than the above sample; annealed at 220 C.
7	723	Feith, A. D.	1965	R	1173-2248		0.0269 C, $<$0.01 Si, $<$0.01 Fe, $<$0.01 Ca, $<$0.01 Mg, $<$0.01 Cu, 0.0006 H, O, and 0.00019 N; as received; specimen 1.985±0.015 in. in dia; made from arc-cast molybdenum of the above purity; electrical resistivity at 0, 500, 1000, 1500, 2000, and 2300 C being, respectively, 5.6, 17.8, 32.2, 48.0, 63.2 and 73.3 μohm cm; density 99% of theoretical value; considerable changes in thermal conductivity with heating had been found; these are mean values as obtained from the 4th to 7th heating cycles.
8	79	Kannuluik, W. G.	1933	E	90-373	Mo I	99.836$^+$ pure; 0.05 Bi, 0.05 Cd, traces of Ti, Sn, Ge, V and W.
9	79	Kannuluik, W. G.	1933	E	90-373	Mo 2	Approx. same as the above sample.
10	156	Zwikker, C.	1927	E	1200-2500		Pure.
11	89	Lucks, C. F. and Deem, H. W.	1956	C	478-1144		Pure.
12	118	Rasor, N. S. and McClelland, J. D.	1957	R	1080-2795		0.0025 Fe, 0.00073 Si, 0.00021 Ti, 0.00013 Cu, and 0.00007 C.
13	122	Rosenberg, H. M.	1955	L	2.1-95		99.95 pure.
14	255	Allen, R. D., Glasier, L. F., Jr., and Jordan, P. L.	1960	E	2384-2849		Commercially pure; 0.18 Fe, 0.036 Mn, 0.073 Si, 0.04 C, 0.005 O_2, 0.01 others; cast under inert gas, hot-worked, and hot-rolled.
15	98	Mendelssohn, K., Rosenberg, H. M.	1952	L	2.1-21	Mo I	99.95 pure.
16	414	Bell, I. P. and Makin, S. M.	1954	L	373-973		Coarse grain structure on the outside and fine grain structure in the interior; with a large number of inclusions; forged and machined.
17	503	Bode, K. H.	1961	E	1068-1183		99.98 pure; wire; dia 1 mm; polished; annealed in vacuo for 12 hrs at about 1000 C; metal obtained from Radium-Elektrizitätsgesellsch Wipperfürth.
18	543	Semchyshen, M. and Barr, R. Q.	1955	C	473-1173	Heat No. 990	Recrystallized at 2250 F; measured in a vacuum of 2 x 10^{-5} mm Hg.
19	599	Cutler, M., Snodgrass, H. R., Cheney, G. T., Appel, J., Mallon, C. E., and Meyer, C. H., Jr.	1961	E	290-871		99.9 pure; electrical resistivity 5.98 μohm cm at 23 C; received from Fansteel Metallurgical Corp.
20	599	Cutler, M., et al.	1961	E	290-890		Second run of the above specimen.
21	599	Cutler, M., et al.	1961	E	290-1325		Third run of the above specimen.

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*See TPRC Data Book Vol. 1, Chapter 1, References

TABLE 7. SPECIFICATIONS OF THE SPECIMENS OF MOLYBDENUM (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
22	834	Martinet, J.	1961	E	1122, 1727		Tubular specimen 8 mm O.D., 5 mm I.D., and 100 mm long.
23	601	Hoch, M. and Nitti, D.A.	1962	R	2129		Heated in high vacuum (10^{-5} mm Hg) by high frequency induction to 1000 to 3000 C; localized heating within 0.003 in. of the surface at current frequencies of 500,000 cps; specimen 0.4923 in. in dia and 0.863 in. in length; measured with the cylindrical axis parallel to the magnetic field; run G-2.
24	601	Hoch, M. and Nitti, D.A.	1962	R	2161		The above specimen; run G-3.
25	601	Hoch, M. and Nitti, D.A.	1962	R	2200		The above specimen; run G-5.
26	601	Hoch, M. and Nitti, D.A.	1962	R	2216.5		The above specimen; run G-4.
27	601	Hoch, M. and Nitti, D.A.	1962	R	2351.5		The above specimen; run M-1.
28	601	Hoch, M. and Nitti, D.A.	1962	R	2382		The above specimen; run M-3.
29	652	Tye, R.P.	1961	L, C	323-623		Spectrographically standardized molybdenum; JM 720 of Johnson, Matthey and Co.; rod of about 5 mm in dia and 15 cm in length; electrical resistivity reported as 5.65, 6.25, 7.4, 9.9, 12.45, and 13.75 μohm cm at 293, 323, 373, 473, 573, and 623 K, respectively.
30	653	Cutler, M. and Cheney, G.T.	1963	E	1075-1640		Single crystal.
31	667	Rudkin, R.L., Parker, W.J., and Jenkins, R.J.	1962	E	1520-2085		Spectrographically pure wire of 0.010 in. in dia; suspended vertically in a vacuum of better than 10^{-5} mm Hg; electrical resistivity at 1550, 1830, 2040, and 2110 K being, respectively, 41.3, 50.6, 58.1, and 59.1 μohm cm.
32	600, 709	Lebedev, V.V.	1960	E	1173-2473		Wire; 1 mm in dia, 30 mm long, used to determine the constant "a" in the assumed temperature distribution curve and another wire 1 mm in dia, 150 mm long, to measure other unknowns in the derived formula $k = \rho(I_1^2 - I_2^2)/2s^2a$; where ρ is the electrical resistivity; s, wire cross sectional area; I_1, I_2, current in the first and second wire, respectively; electrical resistivity reported as 27.8, 35.6, 45.2, 56.4, and 74.8 μohm cm at 1173, 1473, 1773, 2073, and 2473 K, respectively.
33	654	Wheeler, M.J.	1965	P	1340-2510		99.99 Mo (by difference); <0.01 Fe, traces of other elements; 0.04 in. thick sheet; sintered and hot rolled; obtained from Murex Co.; average grain size after test 110 μ; density 10.3 g cm^{-3}; data calculated from thermal diffusivity measurements using the specific heat data of Kubaschewski, O., and Evans, L. Ll., Metallurgical Thermochemistry, Pergamon, London, 1956.
34	710	Osborn, R.H.	1938	E	1207-1400		Very pure; spectrographic analysis showed very small traces of impurities; 20-mil wire; polished; aged at about 2200 K for 15 mins; k values calculated from data of the specimen of which the temperature was kept below 1405 K.
35	710	Osborn, R.H.	1938	E	1315-1647		Similar to the above specimen but for temperature <1709 K.
36	710	Osborn, R.H.	1938	E	1545-1905		Similar to the above specimen but for temperature <1947 K; electrical resistivity at 1115, 1325, 1515, 1685, and 1840 K being, respectively, 26.4, 32.4, 37.8, 42.8, and 47.4 μohm cm.

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*See TPRC Data Book Vol. 1, Chapter 1, References

TABLE 7. SPECIFICATIONS OF THE SPECIMENS OF MOLYBDENUM (continued)

Cur. No.	Ref.[*] No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
37	711	Jun, C.K. and Hoch, M.	1965	R	1362-2282	Sample 1	99.98$^+$ Mo, 0.005 Fe, 0.004 Si, 0.003 Ni, 0.0023 O, 0.0021 C, 0.001 V, <0.0005 N, and 0.00023 H; specimen 2.118 cm in dia. and 0.225 cm thick; prepared by powder metallurgy techniques; polished with No. 4/0 emery paper; average grain dia. 34 μ; density 9.104 g cm^{-3}; experiment performed in high vacuum (10^{-5} mm Hg); specimen heated by high frequency induction current; specimen axis parallel to the axis of magnetic field; data calculated from total emittance measurements using specific heat data from an empirical formula whose agreement with those of Kirilin, V.A., et al. was within 2%; run No. 1.
38	711	Jun, C.K. and Hoch, M.	1965	R	1476-2100	Sample 2	Similar to the above specimen but with 99.964$^+$ Mo, 0.028 C, 0.0021 O, 0.002 Si, 0.001 Fe, 0.001 Cu, 0.001 V, <0.0005 N, and 0.00015 H; specimen 1.905 cm in dia., 0.206 cm thick; prepared by arc melting technique; average grain dia. 706 μ; density 10.119 g cm^{-3}; run No. 1.
39	711	Jun, C.K. and Hoch, M.	1965	R	1687-2272	Sample 2	The above specimen; run No. 2.
40	711	Jun, C.K. and Hoch, M.	1965	R	1740-2194	Sample 3	Similar to the above specimen but with 99.948$^+$ Mo, 0.011 C, <0.01 Si, <0.01 Fe, <0.01 Ti, <0.01 Zr, 0.003 O, 0.0006 N, and 0.0002 H; specimen 1.910 cm in dia.; 0.195 cm thick; prepared by arc melting and heated to 2500 K for very long times in hydrogen such that it underwent grain growth; average grain dia. 4850 μ; density 10.163 g cm^{-3}; run No. 1.
41	711	Jun, C.K. and Hoch, M.	1965	R	1686-2271	Sample 3	The above specimen; run No. 2.
42	494	Powell, R.L., Harden, J.L., and Gibson, E.F.	1960	L	4.0-100		1-2% (by volume) ThO_2 with the following impurities in mole percent, 0.01-0.1 Fe, Si; 0.001-0.01 Al, Nb, and Cu; <0.001 Ca, Cr, and Mg; cylindrical rod 3.67 mm in dia., 13 cm long; furnished by LASL; electrical resistivity at 4, 6, 10, 20, 40, 60, and 100 K being, respectively, 0.57, 0.57, 0.57, 0.57, 0.60, 0.80, and 1.50 μohm cm.
43	744	Filippov, L.P.	1966	P	1609-2355		Measured with an apparatus capable of giving simultaneously thermal conductivity, thermal diffusivity, and specific heat.
44	845, 844	Pigalskaya, L.A., Yurchak, R.P., Makarenko, I.N., and Filippov, L.P.	1966	P	1140-1816	Specimen 1	99.9 Mo, 0.01 Mo_2O_3, 0.001 Ni, 0.001 SiO, traces Mg and CaO; cylindrical specimen 10 mm in dia and 70 mm long; density 10.2 g cm^{-3} at room temperature; electrical resistivity 5.78 μohm cm at 23 C; thermal conductivity data obtained from the smooth curve calculated from measurements of thermal diffusivity, specific heat, and density.
45	**	Bäcklund, N.G.	1967	L	86-377		Bar-shaped specimen 0.5 cm in dia and 10 cm long, from Johnson, Matthey & Co.; electrical resistivity 5.58 μohm cm at 296.8 K.
46	‡	Kraev, O.A. and Stel'makh, A.A.	1964	P	1900-2500		8~9 mm in dia and 0.3 mm thick; thermal conductivity values were not given in the paper but were calculated by TPRC using the authors' thermal diffusivity data and using the TPRC selected density and specific heat values from Thermophysical Properties of High Temperature Solid Materials, Vol. 1, MacMillan, 1967, and the density was further calculated as a function of temperature from the thermal expansion data.
47	‡‡	Timrot, D.L., Peletskii, V.E., and Voskresenskii, V.Yu.	1966		1400-2200		99.95 pure; single crystal.

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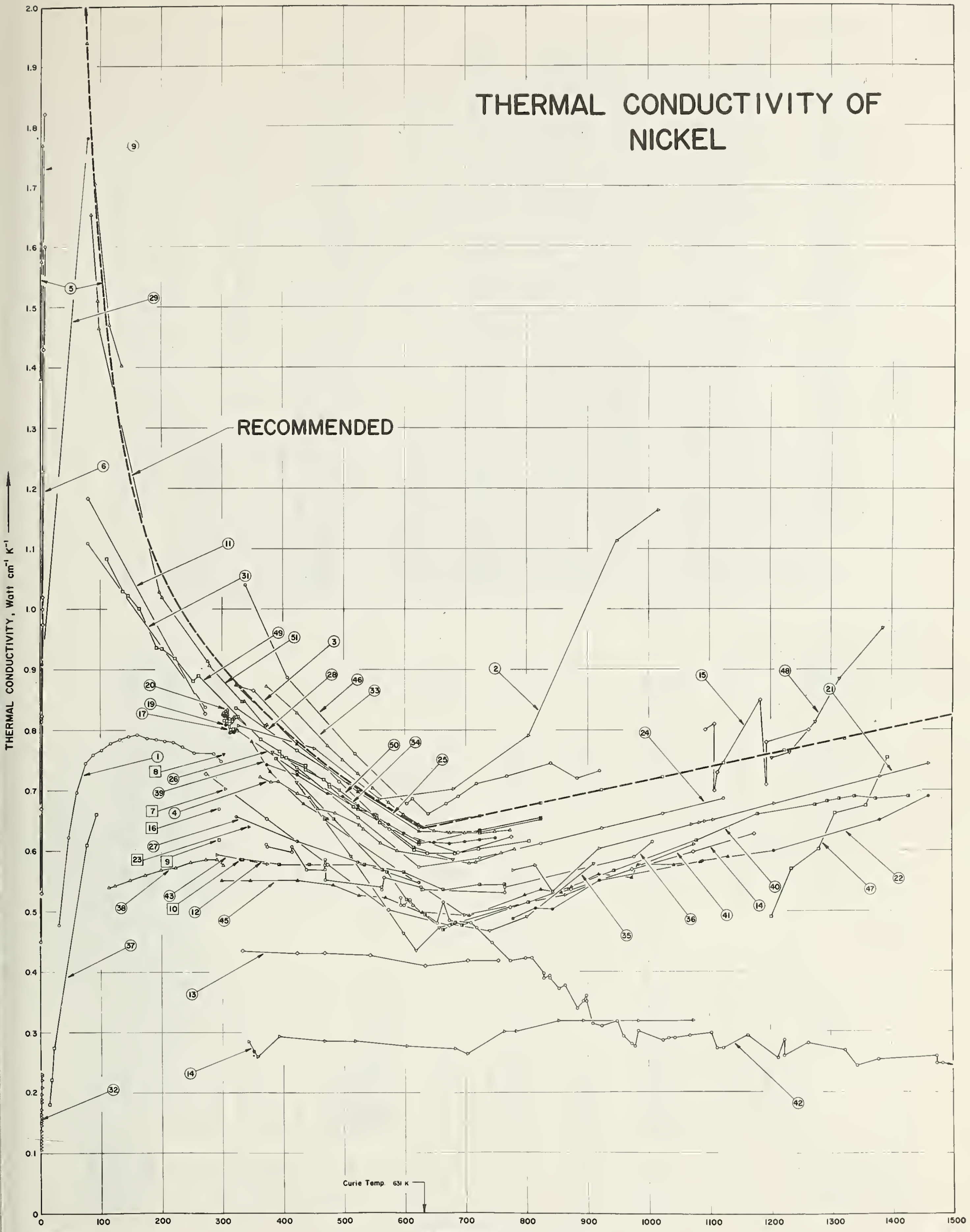
[*] See TPRC Data Book Vol. 1, Chapter 1, References

[**] Private communication, January 24, 1967

[‡] Teplofiz. Vysokikh Temp., 2 (2), 302, 1964

[‡‡] Private communication from Prof. A.E. Sheindlin, February 13, 1967



THERMAL CONDUCTIVITY OF NICKEL

FIG 8

TABLE 8. SPECIFICATIONS OF THE SPECIMENS OF NICKEL

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	114	Powers, R. W., Schwartz, D., and Johnston, H. L.	1950	L	32-300	"L" nickel	Commercially pure.
2	124	Sager, G. F.	1930	P	327-1016		Pure nickel, electrolyzed from Mond anodes; wire, about 0.2 cm in dia; vacuum melted under a pressure of 0.3 mm Hg using an Arsen furnace and an alundum crucible; chill cast, forged, and cold drawn to the above dimension; annealed twice at about 750 C for several hrs; electrical conductivity at 54, 179, 285, 407, 530, 676, and 743 C being, respectively, 9.60, 5.95, 4.10, 3.03, 2.74, 2.47, and 2.32 x 10^4 ohm^{-1} cm^{-1}.
3	129	Shelton, S. M. and Swanger, W. H.	1933	C	330-775		99.94 Ni, 0.03 Fe, 0.016 Co, 0.006 Cu, 0.006 Si, 0.005 C, and 0.004 S; specimen 2 cm in dia and 15 cm long; melted in Arsen furnace and furnace cooled; the value of thermal conductivity of lead at 0 C (0.352 watt cm^{-1} K^{-1}) from International Critical Tables Vol. II was used as the reference value.
4	101	Moss, M.	1955	L	363-780		99.65 pure (by difference), 0.082 Cu, 0.094 Si, 0.056 Fe, 0.027 C, 0.025 Co, traces of S and Al; specimen 7.938 in. long and 0.787 in. in dia; prepared in a zircon crucible from high purity electrolytic nickel shot, hot rolled at 1000 C to a bar 1 in. square, machined and ground to size; annealed for 45 min. at 1000 C in hydrogen atmosphere.
5	83	Kemp, W. R. G., Klemens, P. G., and White, G. K.	1956	L	2.0-136		99.99^+ pure; traces of Si, Ca, Al, Ag, and Cu; material obtained from Johnson Matthey Co. (JM 4497); specimen 2 mm in dia; annealed for 4 hrs in vacuo at 750 C; electrical resistivity at 293 and 4.2 K being, respectively, 7.22 and 0.0347 μohm cm; $\rho(293K)/\rho(4.2K) = 208$.
6	122	Rosenberg, H. M.	1955	L	2.0-44	Ni 1	99.997 pure; obtained from Johnson and Matthey Co. (JM 4884); polycrystalline; specimen 2.92 cm long, 0.305 cm in dia; annealed; electrical resistivity ratio $\rho(293K)/\rho(20K) = 80.9$.
7	186	Ellis, W. C., Morgan, F. L., and Sager, G. F.	1928	P	305.2	R-12	Wire about 35 cm long, 0.25 cm in dia; specific heat 0.102 cal g^{-1} C^{-1}, electrical conductivity 9.66 x 10^4 ohm^{-1} cm^{-1} at approximately 32 C.
8	238	Masumoto, H.	1927	E	303.2		0.10 Fe, 0.037 C, 0.019 S, 0.006 Si, 0.013 Cu, traces of Al, Co, Mn, and P; cast and machined to a specimen 20 cm long, 5 mm in dia; annealed for 40 min. at 800 C; electrical resistivity 8.58 μohm cm at 30 C.
9	499	Starr, C.	1937	P	295.2		99.98 pure; annealed in hydrogen at 870 C; density 8.79 g cm^{-3}; electrical resistivity 7.21 μohm cm at 22 C.
10	230	Smith, A. W.	1925	L	329.2		99.97^+ pure.
11	496	Aoyama, S. and Ito, T.	1940	C	80, 273		Specimen 60 mm long, 4 mm in dia; copper used as a comparative material.
12	500	Francl, J. and Kingery, W. D.	1954	C	333-763	NIVAC	Extremely pure and homogeneous; vacuum cast; supplied by the Vacuum Metal Corp.; specimen 1 in. cube.
13	500	Francl, J. and Kingery, W. D.	1954	C	333-753		Similar to the above specimen but with cylindrical pores of 0.146 cm in dia; porosity 9.8%.
14	500	Francl, J. and Kingery, W. D.	1954	C	343-1073		Similar to the above specimen but the porosity 19.6%.
15	503	Bode, K. H.	1961	E	1093-1263	Nickel O	99.95 pure; vacuum-melted and cast; wire 1 mm in dia; polished; annealed for 12 hrs at ~1000 C.

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*See TPRC Data Book Vol. 1, Chapter 1, References

TABLE 8. SPECIFICATIONS OF THE SPECIMENS OF NICKEL (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
16	504	Parker, W.J., Jenkins, R.J., Butler, C.P., and Abbott, G.L.	1961	P	295.2		Pure; density 8.90 g cm^{-3} at 20 C.
17	618	Fritz, W. and Bode, K.H.	1960	C	305-323		Specimen 20 mm in dia. and 18 mm long; steel used as comparative material.
18	618	Fritz, W. and Bode, K.H.	1960	C	303-317		The above specimen using pure Ni as comparative material.
19	618	Fritz, W. and Bode, K.H.	1960	C	302-320		The above specimen using yellow brass as a comparative material.
20	618	Fritz, W. and Bode, K.H.	1960	C	305-321		The above specimen using Al as comparative material.
21	594	Booker, J., Paine, R.M., and Stonehouse, A.J.	1961	R	778-1462	"L" nickel	Specimen consisted of 5 vertically stacked hollow cylinders, each 2-5/8 in. O.D. and 1 in. high, and having a 1/4 in. bore concentric with the axis.
22	40	Fieldhouse, I.B., Hedge, J.C., Lang, J.L., Takata, A.N., and Waterman, T.E.	1956	L	778-1616	"A" nickel	Disk, 7 in. in dia. and 1-1/2 in. thick; density 8.844 g cm^{-3}.
23	276	Weeks, J.L. and Seifert, R.L.	1953	C	343.2	"A" nickel	Cylinder 1.75 in. long and 0.22 in. in dia; density 8.8 g cm^{-3}; Armco iron used as a comparative material.
24	675	Powell, R.W., Tye, R.P., and Hickman, M.J.	1965	L, C	323-1023	Sample 1	Electrolytic nickel; <0.01 each of Cr, Co, Mo, Ti, Al, Si, Mn, Zr, Mg, Cu, Sn, and Zn, <0.005 Pb, <0.002 B, and <0.03 Fe; supplied by The Castner Kellner Alkali Co.; tube of 1.272 cm I.D., 1.908 cm O.D. and 20 cm long; density 8.61 g cm^{-3}; Armco iron used as a reference material.
25	675	Powell, R.W., Tye, R.P., and Hickman, M.J.	1965	L, C	323-823	Sample 2	Electrolytic nickel; very high purity; supplied by the National Engineering Lab.; tube with 0.634 I.D., 2.801 O.D., and 19 cm long; density 8.90 g cm^{-3}; Armco iron used as reference material.
26	675	Powell, R.W., Tye, R.P., and Hickman, M.J.	1965	L, C	323-823	Sample 3	99.5 ± 0.1 Ni, 0.1-0.2 Co, 0.1-0.2 Si, 0.04 Fe, 0.03 Mg, and 0.01 Cr; supplied by the Atomic Energy Research Establishment in the form of 3 tubes of 1.589 cm O.D., 1.538 cm I.D. and about 43 cm long, 32 strips each 0.95 cm wide and 14 cm long were cut from the tubes and pressed together to form a compact specimen; density 8.9 g cm^{-3}; Armco iron used as reference material.
27	675	Powell, R.W., Tye, R.P., and Hickman, M.J.	1965	L, C	323-623	Sample 4	Commercial nickel; rod 2.54 cm in dia., about 20 cm long; supplied by the Explosives Research and Development Establishment; Armco iron used as reference material.
28	675	Powell, R.W., Tye, R.P., and Hickman, M.J.	1965	L, C	323-1323	Sample 5	High spectrogaphic purity; very small impurities of Si, Ca, Al, Ag, Cu, Mg, Na, and Li; supplied by Messrs. Johnson, Matthey Co. Ltd. (Lab. No. 4497); rod 0.5 cm in dia. and 15 cm long; density 8.91 g cm^{-3}.
29	716	Berger, L. and Rivier, D.	1962	L	4.2, 81	Ni 5011(I)	Specimen 0.15 cm in dia. turned from a cylindrical sample 5.2 cm long; supplied by Messrs. Johnson, Matthey Co. Ltd.; annealed for 4 hrs at 1273 K in vacuum of 10^{-5} mm of Hg; the furnace cooled at a rate of 150 K per hr; electrical resistivity at 4.18, 80.5 and 292 K reported respectively as 0.11, 0.676, and 7.16 μohm cm; electrical resistivity ratio $\rho_{(273K)}/\rho_{(4.2K)} = 60$.
30	716	Berger, L. and Rivier, D.	1962	L	4.18	Ni 5011(II)	Specimen 0.19 cm in dia. drawn from a cylindrical sample 5.0 cm long; supplied by Messrs. Johnson, Matthey Co. Ltd.; annealed for 10 hrs at 1573 K in hydrogen and left at 1573 K in a vacuum of 10^{-2} mm Hg for 2 hrs; electrical resistivity at 4.18, 80.5, and 273.15 K reported respectively as 0.0213, 0.60, and 6.35 μohm cm; $\rho_{(273K)}/\rho_{(4.2K)} = 298$.

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*See TPRC Data Book Vol. 1, Chapter 1, References

TABLE 8. SPECIFICATIONS OF THE SPECIMENS OF NICKEL (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
31	34	Eucken, A. and Dittrich, K.	1927	L	80, 273		Electrolytic nickel; electrical conductivity at 80 and 273 K being, respectively, 90.2 and 13.05 x 10^4 ohm^{-1} cm^{-1}.
32	736	Mendelssohn, K., Sharma, J. K. N., and Yoshida, I.	1965	L	0.42-0.95		Pure.
33	737	Neimark, B. E. and Bykova, T. I.	1965	E	373-773	No. 1	99.87 Ni + Co; tube 8.51 mm O. D. and 8.025 mm I. D.; electrical resistivity at 100, 200, 300, 400, and 500 C being, respectively, 11.50, 17.24, 24.70, 31.84, and 35.36 μohm cm.
34	737	Neimark, B. E. and Bykova, T. I.	1965	E	373-748	No. 2	Tube 12.96 mm O. D. and 11.025 mm I. D.; electrical resistivity at 100, 200, 300, 400, and 475 C being, respectively, 11.60, 17.29, 24.74, 32.01, and 33.98 μohm cm.
35	26	Davey, P. O., Danielson, G. C., and Pearson, G. C.	1954	C	423-910		99.542 Ni, 0.030 Si, 0.034 Co, 0.068 Fe, 0.034 Mg, 0.250 Mn, 0.020 Ti, 0.014 Cu, and traces of Al, B, Ca, and Cr; cylindrical bar ~15.25 cm long and 2 cm in dia; Armco iron used as a reference material.
36	127	Schofield, F. H.	1925	L	372-1006		99.2 Ni; cast in 3 in. mould, hot-rolled to 1.5 in. in dia; reheated and rolled to 7/8 in. in dia, close-annealed at 800 C, cold drawn to 13/16 in. in dia, reannealed and drawn to 3/4 in. in dia, finally annealed between 750 C and 800 C; density 8.79 g cm^{-3} at 21 C; electrical resistivity reported as 10.04, 14.60, 16.17, 19.73, 25.90, 32.35, 36.85, and 47.60 μohm cm at 14, 111, 142.4, 200.5, 280.0, 349.5, 465.2, and 820.7 C, respectively.
37	104	DeNobel, J.	1951	L	15-93		99.4 Ni; as forged.
38	88	Lees, C. H.	1908	L	114-301		99.0 Ni; specimen 8 cm long, 0.585 cm in dia; turned from a bar supplied by Messrs. Johnson and Matthey Co.; density 8.8 g cm^{-3} at 21 C; electrical resistivity at -181.7, -117.5, -94.3, -50, -24.1, and 22.1 C being, respectively, 5.29, 7.22, 8.24, 9.92, 11.02, and 13.07 μohm cm.
39	163	Maurer, E.	1936	L	348-473		99.23 Ni; data determined by using D. Hattori's method.
40	163	Maurer, E.	1936	L	388-1428		The above specimen using the method of K. Honda and T. Simidu; measured while increasing temperature.
41	163	Maurer, E.	1936	L	468-1073		The above specimen measured while reducing temperature.
42	4	Angell, M. F.	1911	R	593-1508		Unknown impurity, (the author estimated 2-3% Co); obtained from H. Boker, New York; hollow cylindrical rod 6 in. long, 1.2 cm O. D. and 0.168 cm I. D.
43	77	Jaeger, W. and Diesselhorst, H.	1900	L	291, 373		97.0 Ni, 1.4 Co, 0.4 Fe, 1.0 Mn, 0.1 Cu, and 0.1 Si; specimen 27.0 cm long, 1.605 cm in dia; density 8.81 g cm^{-3} at 18 C; electrical conductivity at 18 and 100 C being, respectively, 8.50 and 6.37 x 10^4 ohm^{-1} cm^{-1}.
44	490, 310	Hogan, C. L.	1950	F	273-1173	"A" nickel	99.48 Ni, 0.22 Mn, 0.14 Fe, 0.06 C, 0.05 Cu, 0.02 Si, and 0.005 S; specimen 30 cm long, 0.75 cm in dia; electrical conductivity at 0, 200, 400, 600, 800, and 900 C being, respectively, 11.3, 5.12, 2.87, 2.40, 2.10, and 2.02 x 10^4 ohm^{-1} cm^{-1}.
45	71	Honda, K. and Simidu, T.	1917	R	299-1130		96.8 pure; specimen 8 cm long and 1 cm in dia; electrical resistivity at 26, 81, 143, 197, 264, 310, 346, 375, 401, 469, 531, 609, 762, and 836 C being, respectively, 11.9, 14.8, 18.3, 21.6, 26.5, 31.2, 34.6, 36.4, 37.4, 39.8, 42.0, 44.3, 48.5, and 51.0 μohm cm.

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* See TPRC Data Book Vol. 1, Chapter 1, References

TABLE 8. SPECIFICATIONS OF THE SPECIMENS OF NICKEL (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
46	743	Kirichenko, P.I. and Mikryukov, V.E.	1964	E	340-920		99.999 pure; specimen 30 cm long and 0.3 cm in dia; annealed in vacuum for 48 hrs at 1173 K; electrical resitivity at 40, 105, 210, 305, 375, 485, 590, 720, 780, and 900 C being, respectively, 8.0, 11.5, 17.0, 24.5, 29.0, 35.0, 38.5, 42.0, 44.0, and 46.0 μohm cm.
47	846	Jain, S.C., Goel, T.C., and Chandra, I.	1967	E	1201-1393		99.95 pure; 0.05 cm x 1 cm x 14 cm, obtained from Johnson, Matthey and Co.; data obtained without heating the ends of the specimen.
48	846	Jain, S.C., Goel, T.C., and Chandra, I.	1967	E	1202-1386		99.95 pure; 0.05 cm x 1 cm x 14 cm, obtained from Johnson, Matthey and Co.; measuring technique improved by heating the ends of the specimen.
49	**	Watson, T.W. and Robinson, H.E.	1964	L	111-804		99.85 Ni (by difference), 0.11 Co, 0.026 Cu, 0.006 Fe, 0.004 Si, <0.002 Ti, 0.001 Al, <0.001 Mg, <0.001 Cr, and <0.0005 Mn; electroformed nickel radially deposited on a nickel wire submitted by the International Nickel Co.; specimen 2.54 cm in dia and 37.0 cm long; electrical resistivity at 111, 123, 173, 223, 273, 323, 373, 423, 473, 523, 573, 623, 673, 723, 773, and 813 K being, respectively, 2.08, 2.42, 3.88, 5.47, 7.24, 9.24, 11.50, 14.09, 17.05, 20.43, 24.27, 28.64, 32.34, 34.10, 35.86, and 37.26 μohm cm; measured at increasing temperatures.
50	**	Watson, T.W. and Robinson, H.E.	1964	L	383-679		The above specimen; data obtained on cooling from the maximum temperature attained.
51	‡	Bäcklund, N.G. and Langemar, K.T.	1967	L	87-374		Bar-shaped specimen 0.5 cm in dia and 10 cm long, received from Johnson, Matthey and Co.; electrical resistivity 7.26 μohm cm at 295.3 K; density 8.92 g cm^{-3}.

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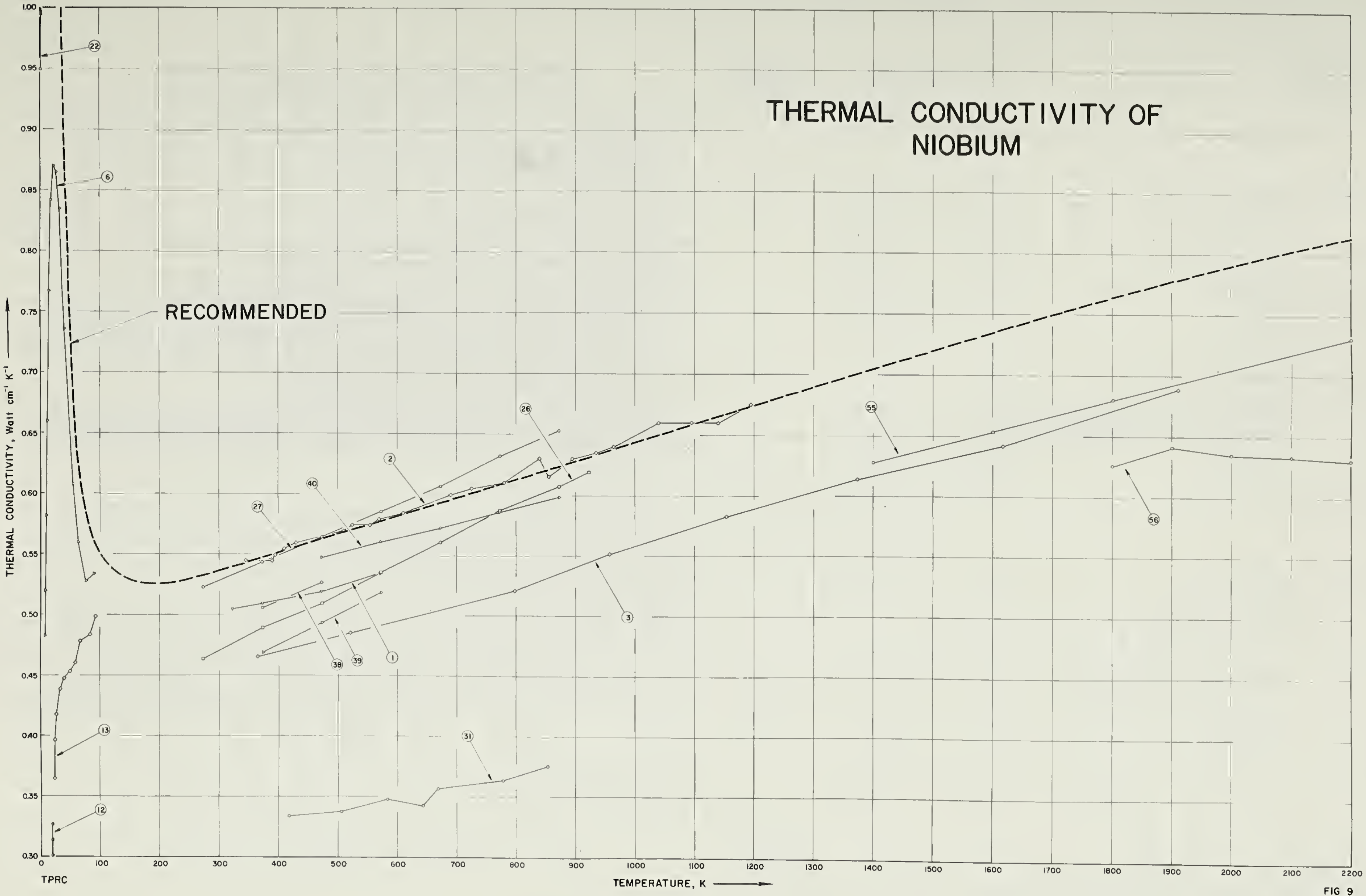
[*] See TPRC Data Book Vol. 1, Chapter 1, References

[**] "Thermal Conductivity of a Specimen of Electroformed Nickel", NBS unpublished report, April 30, 1964

[‡] Private communication, January, 24, 1967



THERMAL CONDUCTIVITY OF NIOBIUM

FIG 9

TABLE 9. SPECIFICATIONS OF THE SPECIMENS OF NIOBIUM

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	652	Tye, R. P.	1961	L, C	323-573		<0.1 Ta, <0.01 C, <0.01 Si, <0.01 N_2, <0.01 Fe, <0.015 Ti, and <0.01 O_2; sintered above 2000 C and cold swaged; manufactured by Murex Ltd.; rod about 6 mm in dia and 10 cm in length; electrical resistivity reported as 15.0, 16.5, 18.7, 23.2, and 27.7 μohm cm at 293, 323, 373, 473, and 573 K, respectively; Armco iron used as comparative standard; energy flow also measured by water flow calorimeter.
2	728	Raag, V. and Kowger, H.V.	1965	P	345-1195		99.95^+ pure; 0.011 O_2, 0.005 C, 0.0027 N_2, and 0.0006 H_2; specimen 1/4 in. in dia and 2 in. long; machined from a 0.5 in. rod purchased from Kawecki Chemical Co.; refined by electron beam melting and annealed; density 8.61 g cm^{-3}; specific heat data taken from Jaeger, F.M. and Veenstra, W.A.; electrical resistivity at 300, 600, 900, and 1200 K was, respectively, 15.2, 28.2, 39.1, and 49.3 μohm cm; data of thermal diffusivity and electrical resistivity corrected for the effects of thermal expansion.
3	39	Fieldhouse, I.B., Hedge, J.C., and Lang, J.I.	1958	R	365-1911		High purity.
4	96	Mendelssohn, K. and Olsen, J. L.	1950	L	2.2-10		High purity; in normal state.
5	96	Mendelssohn, K. and Olsen, J. L.	1950	L	2.3-7.3		High purity; in superconducting state.
6	151	White, G.K. and Woods, S.B.	1957	L	8.9-90	Nb 5	99.9^+ pure; drawn and annealed wire; in normal state.
7	151	White, G.K. and Woods, S.B.	1957	L	4.4-7.5	Nb 5	99.9^+ pure; drawn and annealed wire; in superconducting state.
8	98	Mendelssohn, K. and Rosenberg, H.M.	1952	L	2.3-3.1	Nb 1	99.99 pure; polycrystalline; magnetic field "frozen in"; in superconducting state.
9	98	Mendelssohn, K. and Rosenberg, H.M.	1952	L	2.0-9.2	Nb 1	The above specimen in superconducting state at zero gauss.
10	98	Mendelssohn, K. and Rosenberg, H.M.	1952	L	3.1-7.8	Nb 1	The above specimen measured in a field of 2300 gauss; assumed in superconducting state below 6 K and in normal state above 6 K.
11	98	Mendelssohn, K. and Rosenberg, H.M.	1952	L	2.3-7.9	Nb 1	The above specimen measured in a field of 3300 gauss; assumed in superconducting state below 5 K and in normal state above 5 K.
12	98	Mendelssohn, K. and Rosenberg, H.M.	1952	L	9.5-21	Nb 1	The above specimen in normal state.
13	122	Rosenberg, H.M.	1955	L	24-94		The above measurement extended to 94 K.
14	400	Mendelssohn, K. and Renton, C.A.	1953	L	0.54-0.75	Nb 1	99.99 pure; polycrystalline; magnetic field "frozen in"; in superconducting state.
15	400	Mendelssohn, K. and Renton, C.A.	1953	L	0.55-0.97	Nb 1	99.99 pure; polycrystalline; in superconducting state.
16	389	Mendelssohn, K.	1958	L	1.0-3.7		Unstrained; in normal state.
17	389	Mendelssohn, K.	1958	L	1.0-4.2		5-13.4% strained; in normal state.
18	389	Mendelssohn, K.	1958	L	1.0-3.7		19.5% strained; in normal state.
19	389, 676	Mendelssohn, K.	1958	L	0.97-4.2		Single crystal; zone refined; not intentionally annealed; 5.1% strained; in superconducting state.
20	389, 676	Mendelssohn, K.	1958	L	1.0-4.4		Similar to the above specimen but 13.4% strained.
21	389, 676	Mendelssohn, K.	1958	L	0.87-4.1		Similar to the above specimen but 19.5% strained.

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*See TPRC Data Book Vol. 1, Chapter 1, References

TABLE 9. SPECIFICATIONS OF THE SPECIMENS OF NIOBIUM (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
22	389, 501	Mendelssohn, K.	1958	L	1.0-2.4	Nb II	0.0003 Cu, 0.0003 Mg; single crystal; specimen made by the floating zone melting of polycrystalline rod; in normal state.
23	389, 501	Mendelssohn, K.	1958	L	1.0-4.3	Nb II	The above specimen in superconducting state.
24	389, 501	Mendelssohn, K.	1958	L	1.0-3.0	Nb I	Similar to the above specimen; not intentionally annealed; in normal state.
25	389, 501, 676	Mendelssohn, K.	1958	L	1.0-4.3	Nb I	The above specimen in superconducting state.
26	413, 138	Bell, I. P.; Tottle, C. R.	1955	L	353-888		99.95 pure; <0.05 O; rectangular specimen; density 8.38 g cm^{-3}.
27	413, 138	Bell, I. P.; Tottle, C. R.	1955	L	323-856		99.95 pure; <0.05 O; cylindrical specimen; density 8.65 g cm^{-3}.
28	412	Mendelssohn, K. and Renton, C. A.	1955	L	0.39-0.72		99.99 pure; polycrystalline; measured with magnetic shielding; in superconducting state.
29	412	Mendelssohn, K. and Renton, C. A.	1955	L	0.54-0.76		99.99 pure; polycrystalline; measured without magnetic shielding; in superconducting state.
30	412	Mendelssohn, K. and Renton, C. A.	1955	L	0.54-0.99		99.99 pure; polycrystalline; measured without magnetic shielding; in superconducting state.
31	606	Bell, I. P.	1954		417-853		Density 7.73 g cm^{-3}.
32	677	Chaudhuri, K. D., Mendelssohn, K., and Thompson, M. W.	1960	L	1.1-4.2		Single crystal; rod 4 mm in dia. and 50 mm long; prepared by the "floating zone" technique in an electron bombardment furnace; before irradiation; in superconducting state.
33	677	Chaudhuri, K. D., Mendelssohn, K., and Thompson, M. W.	1960	L	1.2-4.4		The above specimen after irradiation by a dose of 10^{18} fast neutrons cm^{-2} at $30 \pm 5^{\circ}$ C and then allowing a few weeks for radioactivity to decay; in superconducting state.
34	677	Chaudhuri, K. D., Mendelssohn, K., and Thompson, M. W.	1960	L	1.3-2.3		The above specimen before irradiation; in normal state.
35	677	Chaudhuri, K. D., Mendelssohn, K., and Thompson, M. W.	1960	L	1.7-2.6		The above specimen after irradiation by a dose of 10^{18} fast neutrons cm^{-2} at $30 \pm 5^{\circ}$ C and then allowing a few weeks for radioactivity to decay; in normal state.
36	705	Connolly, A. and Mendelssohn, K.	1962	L	0.26-1.2	Nb II	Very pure specimen; 0.0003 Cu, 0.0003 Mg; single crystal obtained by the floating zone melting of polycrystalline rod of niobium in a vacuum; dia. 4.0 mm; ratio of length to cross sectional area 25.7 cm^{-1}; residual resistance ratio 60.5; in superconducting state.
37	705	Connolly, A. and Mendelssohn, K.	1962	L	0.25-4.2	Nb III	Similar to the above specimen but no impurities reported; dia. 2.2 mm; ratio of length to cross sectional area 89.6 cm^{-1}; residual resistance ratio 120.0; in superconducting state.
38	724	Powell, R. W.	1957	L, C	373, 473	Sample B	Pure specimen; 0.1 Ta; electrical resistivity at 20, 100, and 200 C was, respectively, 16.2, 19.5, and 23.5 μohm cm; energy flow measured calorimetrically and also by use of Armco iron as comparative standard.

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*See TPRC Data Book Vol. 1, Chapter 1, References

TABLE 9. SPECIFICATIONS OF THE SPECIMENS OF NIOBIUM (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
39	724	Powell, R.W.	1957	L, C	373-573	Sample A	Pure specimen; 0.3 Ta; electrical resistivity at 20, 100, 200, 300 C was, respectively, 16.9, 21.2, 25.5, and 29.6 μohm cm; energy flow measured calorimetrically and also by use of Armco iron as comparative standard.
40	720	Heal, T.J.	1958		473-873		99.5$^+$ Nb; 0.3 Ta.
41	725	Radhakrishana, P. and Nielsen, M.	1963	L	1.8-8.0		99.8 Nb (by difference), 0.2 Zr; vacuum-annealed wire of 1 mm in dia; measured in superconducting state.
42	725	Radhakrishana, P. and Nielsen, M.	1963	L	1.7-8.0		The above specimen in normal state.
43	847	Kuhn, G.	1966	L	1.2-9.4	Mb I	0.03 Al, 0.03 Fe, 0.02 Si, 0.01 C, < 0.01 Cr, < 0.01 Cl, < 0.01 Mn, < 0.01 Pb; single crystal, 2.34 mm in dia and 20 mm long, obtained by fusion in a floating zone by electronic bombardment, supplied by Johnson, Matthey and Co.; residual electrical resistivity (ρ_0) 0.09 μohm cm; virgin specimen in superconducting state; transition temperature 9.5 K.
44	847	Kuhn, G.	1966	L	1.3-9.4	Nb I	The above specimen in normal state.
45	847	Kuhn, G.	1966	L	1.1-9.9	Nb I	The above specimen irradiated by 5.6 x 10^{17} fast neutrons cm^{-2}; ρ_0 = 0.11 μohm cm; in superconducting state.
46	847	Kuhn, G.	1966	L	1.2-5.0	Nb I	The above specimen in normal state.
47	847	Kuhn, G.	1966	L	1.4-9.0	Nb I	The above specimen annealed at 1870 C under 5 x 10^{-5} torr for 63 hrs; residual electrical resistivity 2.48 μohm cm; specimen in superconducting state.
48	847	Kuhn, G.	1966	L	1.4-9.2	Nb I	The above specimen in normal state.
49	847	Kuhn, G.	1966	L	1.3-9.0	Nb III DA	0.1 Ta, 0.01 Ti, 0.007 Fe, 0.005 Cu, 0.005 N, 0.005 O, 0.003 Na, 0.002 Al, 0.002 C, 0.002 Si, and 0.001 H; single crystal, 5.10 mm in dia and 21 mm long, made from polycrystalline sample of Pechiney; annealed at 1350 C under < 10^{-5} torr for 3 min; residual electrical resistivity ρ_0 = 0.21 μohm cm; specimen in superconducting state; transition temperature 9.25 K.
50	847	Kuhn, G.	1966	L	1.3-9.0	Nb III DA	The above specimen in normal state.
51	847	Kuhn, G.	1966	L	1.3-8.8	Nb IV AA	Single crystal, 2.96 mm in dia and 21 mm long supplied by Kuhlmann; annealed at 1320 C by electron bombardment for 15 min under a vacuum of < 10^{-5} torr; residual electrical resistivity ρ_0 = 0.38 μohm cm; specimen in superconducting state; transition temperature 9.25 K.
52	847	Kuhn, G.	1966	L	1.4-9.2	Nb IV AA	The above specimen in normal state.
53	847	Kuhn, G.	1966	L	1.3-9.6	Nb IV B	Single crystal, 2.96 mm in dia and 21 mm long, obtained by fusion in a floating zone, supplied by Kuhlmann; residual electrical resistivity ρ_0 = 0.22 μohm cm; specimen in superconducting state; transition temperature 9.25 K.
54	847	Kuhn, G.	1966	L	1.5-9.9	Nb IV B	The above specimen in normal state.
55	848	Voskresenskii, V.Y., Peletskii, V.E., and Timrot, D.L.	1966	E	1400-2300		99.7 (Nb + Ta), 0.17 Ta, 0.06 Si, 0.03 Fe, 0.025 Ti; cylindrical specimen 14 mm in dia and 65 mm long finished to an "eighth-class" surface (max. height of asperities 2.2 μ); specimen preheated at 2000 to 2200 K for 4 hrs; density 8.56 g cm^{-3}; measured in vacuum of 5 x 10^{-5} mm Hg.

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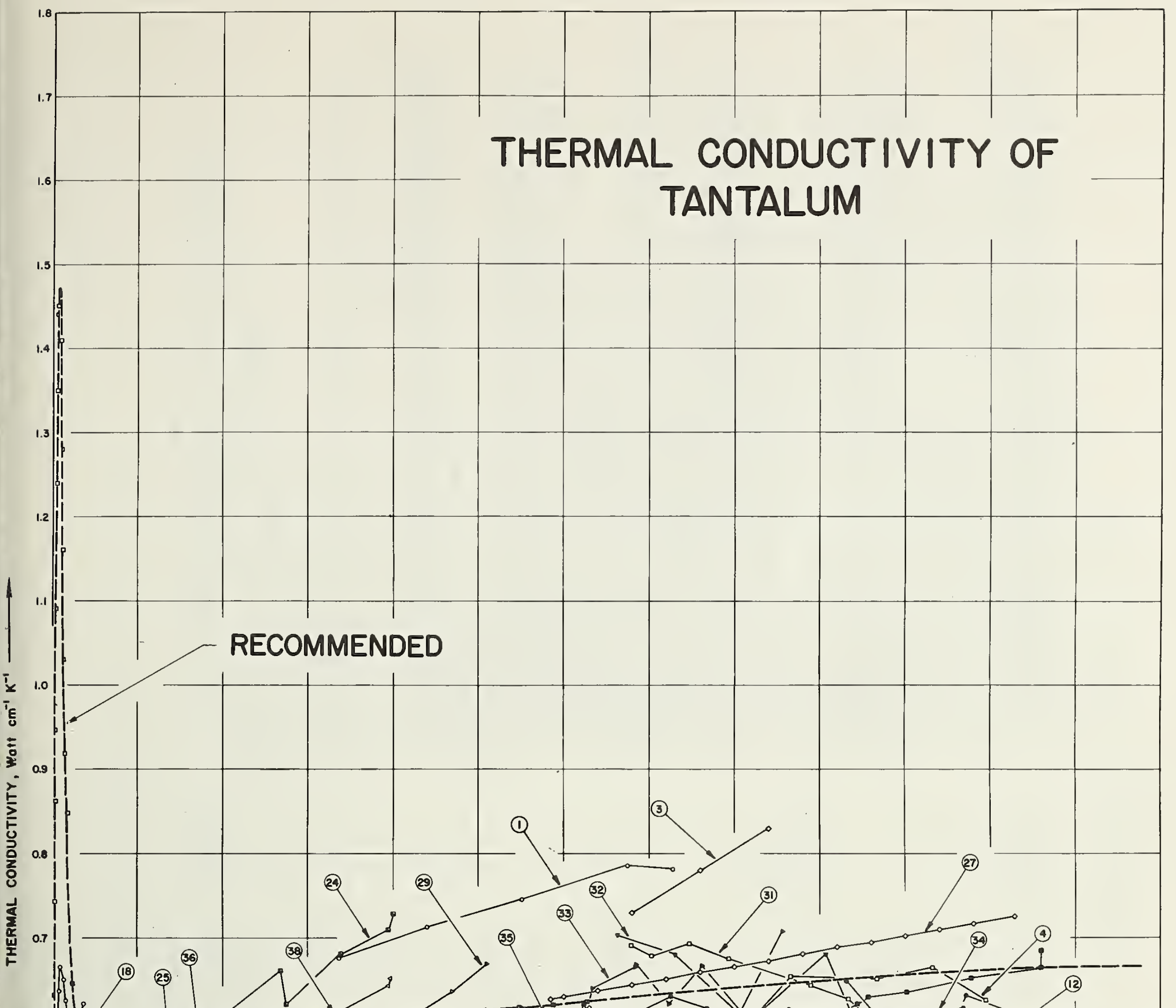
*See TPRC Data Book Vol. 1, Chapter 1, References

TABLE 9. SPECIFICATIONS OF THE SPECIMENS OF NIOBIUM (continued)

Cur. No.	Ref. No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
56	‡	Kraev, O.A. and Stel'makh, A.A.	1964	P	1800-2600		8~9 mm in dia and 0.3 mm thick; thermal conductivity values were not given in the paper but were calculated by TPRC using the authors' thermal diffusivity data and using the TPRC selected density and specific heat values from TPRC Report 16, 1966.

[‡] Teplofiz. Vysokikh Temp., 2 (2), 302, 1964



THERMAL CONDUCTIVITY OF TANTALUM

TPRC

FIG 10

TABLE 10. SPECIFICATIONS OF THE SPECIMENS OF TANTALUM

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	42	Fieldhouse, I. B., Hedge, J. C., and Waterman, T. E.	1956	L	840-1820		0.052 N, traces of Ca, Cu, and Mg; sintered; density 16.48 g cm^{-3}.
2	8	Barratt, T.	1914	L	290, 373		Pure; specific gravity 16.67.
3	153	Worthing, A. G.	1914	E	1700-2100		Pure; filament.
4	118	Rasor, N. S. and McClelland, J. D.	1957	R	1316-2736		Pure; 0.0073 Zr, 0.0073 Cu, 0.0021 Fe, 0.0008 C, 0.0009 Ni, 0.0007 Co, 0.0003 Mn, 0.0002 Si, 0.00017 Al.
5	74	Hulm, J. K.	1950	L	1.7-4.2	Hilger 8017, Ta 1	99.9 pure; polycrystalline; in normal state.
6	74	Hulm, J. K.	1950	L	1.7-3.9	Hilger 8017, Ta 1	The above specimen in superconducting state.
7	122	Rosenberg, H. M.	1955	L	2.0-92	Ta 1	99.98 pure; specimen 0.225 cm in dia., 3 cm long; Johnson-Matthey's unannealed rod JM 3804; electrical resistivity ratio, $\rho(293\ K)/\rho(20\ K)$, 9.7; in normal state.
8	96	Mendelssohn, K. and Olsen, J. L.	1950	L	2.6-4.2		Very pure; in normal state.
9	96	Mendelssohn, K. and Olsen, J. L.	1950	L	2.6-7.9		Very pure; in superconducting state.
10	182	Deverall, J. E.	1959	L	373-773		99.896 pure; 0.014 O, 0.01 Zn, 0.03 Nb, 0.01 W, 0.006 N, 0.0025 C, 0.0025 H, and 0.003 each of Zr, Sn, and Pb, trace of V.
11	255	Allen, R. D., Glasier, L. F., Jr., and Jordan, P. L.	1960	E	2343-3148	1	Commercially pure; 0.005 Fe, 0.02^{+} Si, 0.0008 C, 0.003 Mo, and 0.052 others; pressed and sintered tantalum powder; heated and cold rolled.
12	255	Allen, R. D., Glasier, L. F., Jr., and Jordan, P. L.	1960	E	2326-3071	2	Commercially pure; 0.0028 Fe, 0.0035 Nb, 0.0016 C, 0.0032 - 0.005 O, >0.001 N, and 0.0175 others; cast in vacuum, cold rolled, swaged, and cold drawn.
13	98	Mendelssohn, K. and Rosenberg, H. M.	1952	L	2.3-21	Ta 1	99.98 pure; obtained from Johnson-Matthey Co. (JM 3804); unannealed; in normal state.
14	98	Mendelssohn, K. and Rosenberg, H. M.	1952	L	2.3-3.9	Ta 1	The above specimen in superconducting state.
15	705	Connolly, A. and Mendelssohn, K.	1962	L	0.23-1.2	Ta II	Single crystal obtained by floating-zone melting of polycrystalline rod in a vacuum; specimen dia. 6.1 mm; ratio of length to cross sectional area 16.6 cm^{-1}; ratio of room temperature resistance to residual resistance 47.0.
16	400	Mendelssohn, K. and Renton, C. A.	1953	L	0.60-0.86	Ta 1	99.98 pure; polycrystalline; effected by "frozen in" magnetic field; in superconducting state.
17	400	Mendelssohn, K. and Renton, C. A.	1953	L	0.79-1.0	Ta 1	Separate run of the above specimen; also effected by "frozen in" magnetic field; in superconducting state.
18	401	White, G. K. and Woods, S. B.	1959	L	4.4-114	Ta 3	99.9 pure; annealed in vacuum at 2500 C; $\rho(295K)/\rho_0 = 62.1$.
19	412	Mendelssohn, K. and Renton, C. A.	1955	L	0.42-1.2		99.98 pure; polycrystalline; in superconducting state.
20	501	Calverley, A., Mendelssohn, K., and Rowell, P. M.	1961		0.95-4.3		0.005 Fe, 0.003 Si, 0.0003 O, and 0.00025 H, N not detected; single crystal; specimen obtained by floating-zone melting of polycrystalline rod; in normal state.
21	501	Calverley, A., et al.	1961		0.95-4.4		The above specimen in superconducting state.

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*See TPRC Data Book Vol. 1, Chapter 1, References

TABLE 10. SPECIFICATIONS OF THE SPECIMENS OF TANTALUM (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
22	501	Calverley, A., et al.	1961		0.92-4.0		0.1 Nb, 0.01 C, 0.01 Fe, 0.01 W, 0.01 Mo, 0.001 O, 0.00075 N, and 0.00045 H; polycrystalline; in normal state.
23	501	Calverley, A., et al.	1961		1.0-4.3		The above specimen in superconducting state.
24	599	Cutler, M., Snodgrass, H.R., Cheney, G.T., Appel, J., Mallon, C.E., and Meyer, C.H., Jr.	1961	E	299-1000		99.9 pure; density 16.4 g cm^{-3}; electrical resistivity 15.1 μohm cm at 24 C; obtained from Fansteel Metallurgical Corp.
25	652	Tye, R.P.	1961	L, C	323-523		Spectrographically standardized tantalum; JM615 of John Matthey and Co.; rod of about 4.5 mm in dia and 10 cm long; energy flow measured calorimetrically and also by use of Armco iron as comparative standard; electrical resistivity reported as 14.5, 15.45, 17.72, 22.25, and 24.4 μohm cm at 293, 323, 373, 473, and 523 K, respectively.
26	709	Gumenyuk, V.S., Ivanov, V.E., and Lebedev, V.V.	1962	E	1233-2793		Wire, 1 mm in dia, 30 mm long, used to determine the constant "a" in the assumed temperature distribution curve and another wire, 1 mm in dia and 150 mm long, to measure other unknowns in the derived formula $k = \rho (I_1^2 - I_2^2)/2 S^2 a$; where ρ is the electrical resistivity; S, the wire cross-sectional area; I_1, I_2, the current in the first and second specimen respectively; electrical resistivity at 900, 1500, 2000, and 2500 C was respectively 50, 73, 89, and 109 μohm cm.
27	654	Wheeler, M.J.	1965	P	1460-2820		About 99.89 Ta (by difference); < 0.1 Nb, < 0.01 C, and traces of other elements; 0.040 in. thick sheet; vacuum beam melted; obtained from Murex Co.; average grain size after testing 140 μ; density 16.6 g cm^{-3}; data calculated from thermal diffusivity measurements using the specific heat data of Kubaschewski, O., and Evans, L. Ll., (Metallurgical Thermochemistry; London; Pergamon; 1956).
28	24	Cox, M.	1943	E	273-373		99.9 pure; wire 0.01 in. in dia and ~15.7 in. long (40 cm); obtained from Fansteel Corp.; measured in high vacuum (10^{-6} mm of Hg); electrical resistivity at 77.33, 273.2 and 373.4 K was respectively 2.46, 12.41, and 17.18 μohm cm; the author stated that the data were very unreliable due to poor emissivity data used in the calculation.
29	726	Pozdnyak, N.Z. and Akhmetzyanov, K.G.	1963	E	273-1273		99.4$^+$ Ta, 0.5 Nb, 0.06 Fe, 0.008 Ti, 0.005 W, 0.003 Si, 0.002 C, and 0.001 Mo; cylindrical specimen 4 mm in dia and 100 mm long; sintered from electrolytic powder of tantalum; rectangular sample from tantalum powder was compressed under a pressure of 2.5 ton cm^{-2}; sintered in vacuum (residual pressure 10^{-3} mm of Hg) for 5 hrs at 1723 K, resintered in a vacuum of 10^{-5} mm Hg for 5 hrs at 2873 K, then forged to the desired dia, refined twice by the method of zone-melting; electrical conductivity at 273, 473, 673, 873, 1073, and 1273 K was respectively 8.0, 4.35, 2.86, 2.26, 2.0, and 1.66 x 10^4 ohm^{-1} cm^{-1}.
30	849	Jun, C.K. and Hoch, M.	1966		1578-2007	No. 1	0.0019 C, 0.0017 H, 0.0017 N, and 0.0017 O; specimen 2.4892 cm in dia and 0.3927 cm thick; average grain size 0.26 mm in dia; density 16.65 g cm^{-3}; thermal conductivity was derived from the temperature distribution on the flat surface of the cylindrical disc specimen heated in high vacuum (10^{-5} mm Hg) by high frequency induction generating localized heating within 0.003 in. of the surface at current frequency of 500,000 cps with heat lost only by radiation from the flat surfaces.

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*See TPRC Data Book Vol. 1, Chapter 1, References

TABLE 10. SPECIFICATIONS OF THE SPECIMENS OF TANTALUM (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
31	849	Jun, C.K. and Hoch, M.	1966		1700-2398	No. 2	0.0655 O, 0.0137 C, 0.0016 N, and 0.0027 H; cut from the same bar as the above specimen; specimen 2.2232 cm in dia and 0.2125 cm thick; average grain size not given; density 16.63 g cm^{-3}; measuring method same as that for the above specimen.
32	849	Jun, C.K. and Hoch, M.	1966		1660-2490	No. 3	0.0114 O, 0.0030 C, 0.0016 N, and 0.00027 H; cut from the same bar as the above specimen; specimen 2.2232 cm in dia and 0.2018 cm thick; average grain size 1.04 mm in dia; density 16.62 g cm^{-3}; measuring method same as that for the above specimen.
33	849	Jun, C.K. and Hoch, M.	1966		1563-2142	No. 4	0.0036 O, 0.0018 N, 0.00009 H, and 0.00005 C; cut from the same bar as the above specimen; specimen 1.9075 cm in dia and 0.2316 cm thick; average grain size 1.23 mm in dia; density 16.63 g cm^{-3}; measuring method same as that for the above specimen.
34	849	Jun, C.K. and Hoch, M.	1966		1665-2671	No. 5	0.0036 O, 0.0018 N, 0.00009 H, and 0.00005 C; cut from the same bar as the above specimen; specimen 1.9062 cm in dia and 0.2273 cm thick; average grain size 1.86 mm in dia; density 16.60 g cm^{-3}; measuring method same as that for the above specimen.
35	308	Peletskii, V.E. and Voskresenskii, V.Yu.	1966	L	1208-2900		99.61 Ta, 0.33 Nb, 0.02 Mo, 0.014 W, <0.01 Fe, <0.01 Si, and <0.01 Ti; 7.28 mm in dia and 65.8 mm long; prepared from a bar produced by electron-beam melting in vacuum; density 16.57 g cm^{-3} at 20 C; electrical resistivity reported as 54.8, 63.3, 64.5, 72.4, 80.7, 90.5, 100.4, and 105.2 μohm cm at 1243, 1488, 1512, 1750, 2010, 2350, 2623, and 2782 K, respectively.
36	**	Denman, G. L.	1966	P	323-1573		0.02 Nb, 0.1 Fe, <0.1 Zr, 0.002 Cr, 0.008 O, 0.0021 N, 0.0017 C, 0.00005 H; specimen 0.686 cm in dia and 0.152 cm thick, supplied by Fansteel Met. Corp.; manufactured by powder metallurgy; density 16.50 g cm^{-3}; electrical resistivity reported as 14.0, 14.2, 16.7, 21.5, 25.6, 26.6, 29.8, 31.4, 34.1, and 35.8 μohm cm at 24, 31, 88, 189, 282, 306, 372, 422, 480, and 521 C, respectively; thermal conductivity values calculated from measured thermal diffusivity data; specific heat values taken from Hultgren, R., Orr, R. L., Anderson, P. D., and Kelley, K. K., "Selected Values of Thermodynamic Properties of Metals and Alloys", Wiley, 271-5, 1963; density values obtained by using literature values for thermal expansion of tantalum.
37	‡	Kraev, O.A. and Stel'makh, A.A.	1964	P	1900-3150		8~9 mm in dia and 0.2 mm thick; thermal conductivity values were not given in the paper but were calculated by TPRC using the authors' thermal diffusivity data and using the TPRC selected density and specific heat values from Thermophysical Properties of High Temperature Solid Materials, Vol. 1, MacMillan, 1967, and the density was further calculated as a function of temperature from the thermal expansion data.
38	313	Cutler, M.	1962	T	300-995		No details given for the specimen; thermal conductivity measured by the "small area contact method".

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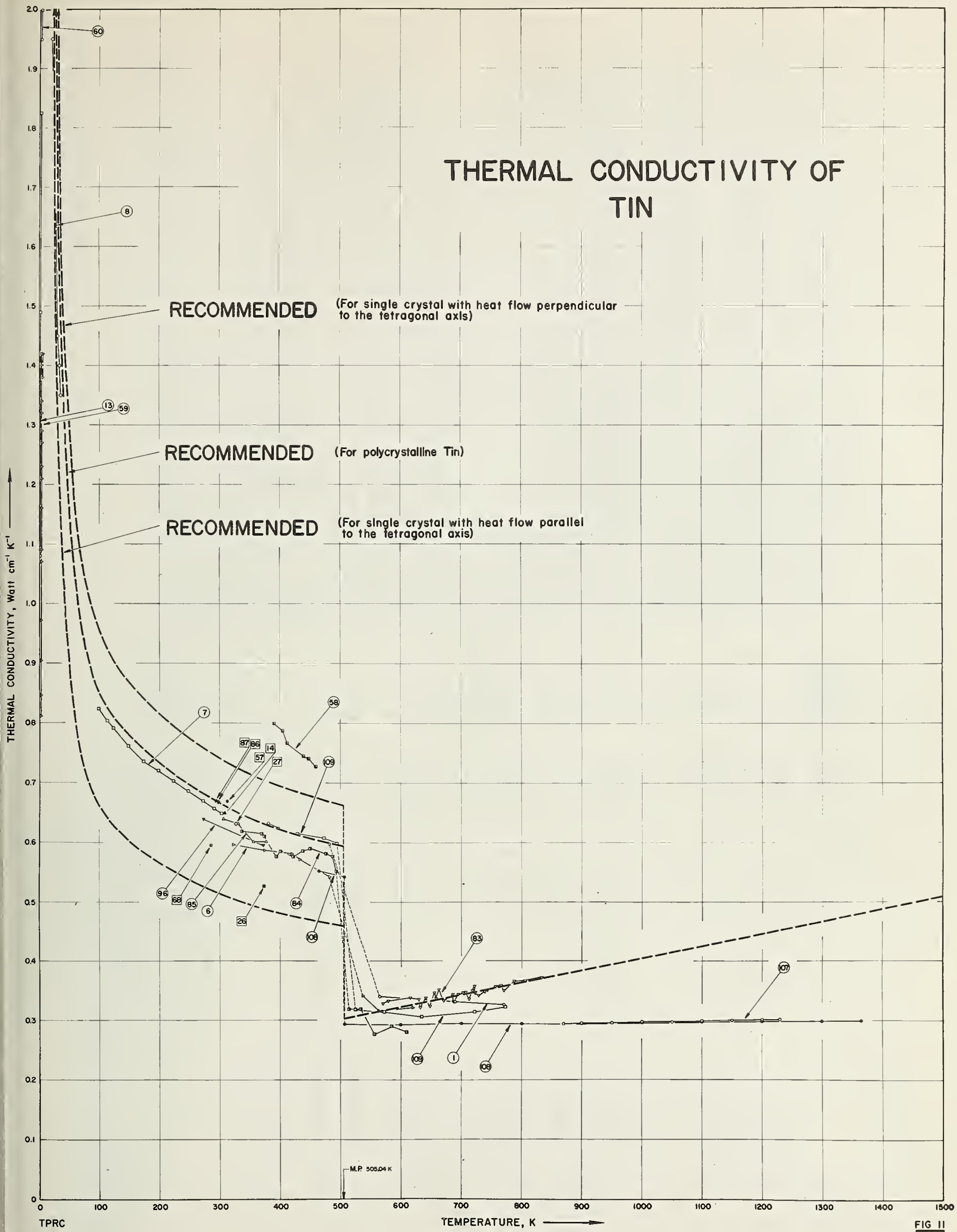
[*] See TPRC Data Book Vol. 1, Chapter 1, References

[**] Unpublished data, 1966

[‡] Teplofiz. Vysokikh Temp., 2 (2), 302, 1964



THERMAL CONDUCTIVITY OF TIN

RECOMMENDED (For single crystal with heat flow perpendicular to the tetragonal axis)

RECOMMENDED (For polycrystalline Tin)

RECOMMENDED (For single crystal with heat flow parallel to the tetragonal axis)

TPRC

FIG 11

TABLE 11. SPECIFICATIONS OF THE SPECIMENS OF TIN

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	85	Konno, S.	1919	L	381-771		Pure; in both solid and liquid states.
2	117	Rademakers, A.	1949	L	1. 4-3. 7	Sn I	Single crystal made of further purified Chempur tin (initial purity 99. 992); measured in superconducting state with heat flow at 85 degrees to the tetragonal axis.
3	117	Rademakers, A.	1949	L	3. 8-4. 1	Sn I	The above specimen in normal state.
4	117	Rademakers, A.	1949	L	1. 3-3. 6	Sn II	Single crystal made of further purified Chempur tin (initial purity 99. 992); specimen 0. 8 mm dia. and 70 mm long; $R_{4.2K} = 8 \times 10^{-7}$ ohm (equivalent to $\rho_{4.2K} = 5.7 \times 10^{-10}$ ohm cm); $R_{273K}/R_{4.2K} = 16700$; measured in superconducting state with heat flow at 85 degrees to the tetragonal axis.
5	117	Rademakers, A.	1949	L	1. 5-3. 7	Sn II	The above specimen in normal state.
6	19	Brown, W. B.	1923	L	323-620		Specimen 12 cm long and 1. 5 cm in dia. ; M. P. 232 C; part of measurements for liquid state.
7	88	Lees, C. H.	1908	L	99-303		Pure; from Kahlbaum; density (21 C) = 7. 28 g cm^{-3} $\rho_{11.6C} = 10.65$ μohm cm; $\rho_{-170.4C} = 3.00$ μohm cm.
8	122	Rosenberg, H. M.	1955	L	2. 3-36	Sn I	99. 997 pure; single crystal; supplied by Johnson, Matthey Co. Ltd. ; specimen 2. 95 cm long, 0. 389 cm in dia. ; in normal state.
9	122	Rosenberg, H. M.	1955	L	2. 3-3. 6	Sn 1	The above specimen in superconducting state.
10	457	Hulm, J. K.	1949	L	1. 8-4. 4	Sn 2	99. 997 Sn (by difference), 0. 003 impurities; polycrystalline; in normal state.
11	457	Hulm, J. K.	1949	L	1. 8-3. 5	Sn 2	The above specimen in superconducting state.
12	457	Hulm, J. K.	1949	L	1. 8-4. 4	Sn 3	99. 967 Sn (by difference), 0. 033 Hg; polycrystalline; in normal state.
13	457	Hulm, J. K.	1949	L	1. 8-3. 4	Sn 3	The above specimen in superconducting state.
14	270	King, R. W.	1915	P	308. 2		Specimen 25 cm long, 0. 25 cm in dia. ; specific heat 0. 0547 cal $g^{-1} C^{-1}$; density 7. 28 g cm^{-3}.
15	342	Mendelssohn, K. and Rosenberg, H. M.	1953	C	4. 4	Sn 1	99. 997 pure; single crystal; supplied by Johnson, Matthey Co. , Ltd. ; measured in a transverse magnetic field with strength H ranging from 0. 19 to 3. 57 kilooersteds.
16	342	Mendelssohn, K. and Rosenberg, H. M.	1953	C	3. 0	Sn 1	The above specimen measured in a transverse magnetic field with strength H ranging from 0. 29 to 3. 57 kilooersteds.
17	342	Mendelssohn, K. and Rosenberg, H. M.	1953	C	2. 4	Sn 1	The above specimen measured in a transverse magnetic field with strength H ranging from 0. 35 to 3. 75 kilooersteds.
18	342	Mendelssohn, K. and Rosenberg, H. M.	1953	C	2. 4	Sn 1	The above specimen measured in a longitudinal magnetic field with strength H ranging from 0. 29 to 3. 75 kilooersteds.
19	342	Mendelssohn, K. and Rosenberg, H. M.	1953	C	3. 0	Sn 1	The above specimen measured in a longitudinal magnetic field with strength H ranging from 0. 35 to 3. 66 kilooersteds.
20	342	Mendelssohn, K. and Rosenberg, H. M.	1953	C	4. 4	Sn 1	The above specimen measured in a longitudinal magnetic field with strength H ranging from 0. 35 to 3. 75 kilooersteds.
21	74	Hulm, J. K.	1950	L	2. 21	Sn 2	99. 996 pure; homogeneous solid solution with few large crystals; measured in a magnetic field with strength H ranging from 62 to 1453 gauss.

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*See TPRC Data Book Vol. 1, Chapter 1, References

TABLE 11. SPECIFICATIONS OF THE SPECIMENS OF TIN (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
22	74	Hulm, J.K.	1950	L	4.29	Sn 2	The above specimen measured in a magnetic field with strength H ranging from 62 to 1453 gauss.
23	74	Hulm, J.K.	1950	L	2.42	Sn 3	99.967 pure; homogeneous solid solution with few large crystals; measured in a magnetic field with strength H ranging from 123 to 1213 gauss.
24	412	Mendelssohn, K. and Renton, C.A.	1955	L	0.39-0.65		99.997 pure; single crystal; supplied by Johnson, Matthey Co., Ltd.; in superconducting state (same specimen as used for curve No. 8).
25	412	Mendelssohn, K. and Renton, C.A.	1955	L	0.25-0.80		99.997 pure; polycrystalline; supplied by Johnson, Matthey Co., Ltd.; in superconducting state.
26	460	Cherpakov, V.P.	1957		373.2		No details reported.
27	230	Smith, A.W.	1925	L	327		0.03 total impurities; specimen 10 cm long and 1.9 cm in dia.; electrical conductivity 8.96 x 10^4 ohm^{-1} cm^{-1} at 22 C.
28	452	Laredo, S.J.	1955	L	0.2-4.2	Sn 2 JM 4600	Spectroscopically pure; cast and recrystallized; single crystal with tetragonal axis parallel to rod axis; supplied by Johnson, Matthey Co., Ltd.; negligible strain; specimen 2.530 mm in dia.; in superconducting state.
29	452	Laredo, S.J.	1955	L	1.7-3.5	Sn 2 JM 4600	The above specimen measured in a longitudinal field of 400 gauss; in normal state.
30	452	Laredo, S.J.	1955	L	0.40-0.64	Sn 3 JM 4600	Similar to the above specimen but the dia. of the rod was 5.11 mm; in superconducting state.
31	452	Laredo, S.J.	1955	L	0.34-0.71	Sn 4 JM 4600	Similar to the above specimen but with tetragonal axis 88 degrees to the rod axis; rod dia. 2.135 mm; in superconducting state.
32	452	Laredo, S.J.	1955	L	0.24-1.2	Sn 5 JM 4600	Pure; cast, recrystallized, and strained; polycrystalline with grain size 0.50 mm; specimen dia. 2.315 mm; in superconducting state.
33	290	Detwiler, D.P. and Fairbank, H.A.	1952	L	1.59	Sn II	99.996 pure; polycrystal with several large crystals; prepared from Johnson-Matthey tin, J.M. Lab. No. 2356; specimen 4.1 mm in dia.; $\rho(273K)/\rho(4.2K) = 8000$; measured in an increasing transverse magnetic field with strength H ranging from zero to 303 gauss.
34	290	Detwiler, D.P. and Fairbank, H.A.	1952	L	1.59	Sn II	The above specimen measured in a decreasing transverse magnetic field with strength H ranging from 246 to 120 gauss.
35	290	Detwiler, D.P. and Fairbank, H.A.	1952	L	2.21	Sn II	The above specimen measured in a increasing transverse magnetic field with strength H ranging from zero to 273 gauss.
36	290	Detwiler, D.P. and Fairbank, H.A.	1952	L	2.21	Sn II	The above specimen measured in a decreasing transverse magnetic field with strength H ranging from 255 to zero gauss.
37	290	Detwiler, D.P. and Fairbank, H.A.	1952	L	2.53	Sn II	The above specimen measured in an increasing transverse magnetic field with strength H ranging from zero to 240 gauss.
38	290	Detwiler, D.P. and Fairbank, H.A.	1952	L	2.53	Sn II	The above specimen measured in a decreasing transverse magnetic field with strength H ranging from 149 to zero gauss.

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*See TPRC Data Book Vol. 1, Chapter 1, References

TABLE 11. SPECIFICATIONS OF THE SPECIMENS OF TIN (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
39	290	Detwiler, D. P. and Fairbank, H. A.	1952	L	2. 18	Sn IV	99. 996 pure; single crystal with its tetragonal axis at about 70 degrees from the geometric axis; prepared from Johnson-Matthey tin, J. M. Lab. No. 2356; specimen 4. 3 mm in dia.; $\rho_{(273K)}/\rho_{(4.2K)} = 11000$; measured in an increasing transverse magnetic field with strength H ranging from zero to 272 gauss and field direction nearly parallel to the tetragonal axis.
40	290	Detwiler, D. P. and Fairbank, H. A.	1952	L	2. 18	Sn IV	The above specimen measured in a decreasing transverse magnetic field nearly parallel to the tetragonal axis with strength H ranging from 181 to zero gauss.
41	290	Detwiler, D. P. and Fairbank, H. A.	1952	L	2. 86	Sn IV	The above specimen measured in an increasing transverse magnetic field with strength H ranging from zero to 204 gauss and field direction at about 20 degrees with the tetragonal axis.
42	290	Detwiler, D. P. and Fairbank, H. A.	1952	L	2. 86	Sn IV	The above specimen measured in a decreasing transverse magnetic field with strength H ranging from 115 to zero gauss and field direction at about 20 degrees with the tetragonal axis.
43	290	Detwiler, D. P. and Fairbank, H. A.	1952	L	3. 62	Sn IV	The above specimen measured in a transverse magnetic field with strength H ranging from zero to 2620 gauss and field direction at about 20 degrees with the tetragonal axis.
44	290	Detwiler, D. P. and Fairbank, H. A.	1952	L	1. 27		99. 866 pure; 0. 134 Bi; polycrystalline; prepared from Johnson-Matthey materials; specimen 5. 0 mm in dia.; measured in an increasing transverse magnetic field with strength H ranging from zero to 304 gauss.
45	290	Detwiler, D. P. and Fairbank, H. A.	1952	L	1. 27		The above specimen measured in a decreasing transverse magnetic field with strength H ranging from 237 to zero gauss.
46	285	Detwiler, D. P. and Fairbank, H. A.	1952	L	2. 5		Spectroscopically pure; polycrystal with a few large crystals; prepared from Johnson-Matthey tin; measured in an increasing transverse magnetic field with strength H ranging from zero to 238. 2 gauss.
47	285	Detwiler, D. P. and Fairbank, H. A.	1952	L	2. 5		The above specimen measured in a decreasing transverse magnetic field with strength H ranging from 149. 7 to zero gauss.
48	404, 738	Andrews, F. A., Webber, R. T., and Spohr, D. A.	1950	L	2. 7-5. 6	Sn 1	99. 996^{+} pure; single crystal; supplied by Johnson-Matthey Co., Ltd.; specimen 8 cm long, 4 mm in dia.; measured without magnetic field; in superconducting state below transition temperature.
49	404, 738	Andrews, F. A., Webber, R. T., and Spohr, D. A.	1950	L	2. 1-4. 7	Sn II	Similar to the above specimen but with a dia. of 2 mm; in superconducting state below transition temperature.
50	404, 738	Andrews, F. A., Webber, R. T., and Spohr, D. A.	1950	L	2. 18	Sn II	The above specimen measured in a longitudinal magnetic field with strength H ranging from zero to 455. 2 gauss.
51	404, 738	Andrews, F. A., Webber, R. T., and Spohr, D. A.	1950	L	3. 19	Sn II	The above specimen measured in a longitudinal magnetic field with strength H ranging from zero to 258. 7 gauss.
52	404, 738	Andrews, F. A., Webber, R. T., and Spohr, D. A.	1950	L	3. 32	Sn II	The above specimen measured in a longitudinal magnetic field with strength H ranging from zero to 376. 1 gauss.

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[*] See TPRC Data Book Vol. 1, Chapter 1, References

TABLE 11. SPECIFICATIONS OF THE SPECIMENS OF TIN (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
53	404, 738	Andrews, F.A., Webber, R.T., and Spohr, D.A.	1950	L	3.77	Sn II	The above specimen measured in a longitudinal magnetic field with strength H ranging from zero to 375.2 gauss.
54	404, 738	Andrews, F.A., Webber, R.T., and Spohr, D.A.	1950	L	4.38	Sn II	The above specimen measured in a longitudinal magnetic field with strength H ranging from zero to 532 gauss.
55	404, 738	Andrews, F.A., Webber, R.T., and Spohr, D.A.	1950	L	5.02	Sn II	The above specimen measured in a longitudinal magnetic field with strength H ranging from zero to 434.5 gauss.
56	404, 738	Andrews, F.A., Webber, R.T., and Spohr, D.A.	1950	L	2.2-3.7	Sn II	The above specimen in normal state.
57	406	Van Dusen, M.S.	1922	C	313.2		Pure; specimen 3 cm long and 3 cm in dia.; thermal conductivity of zinc (assumed to be 0.265 cal sec^{-1} cm^{-1} C^{-1}) used as comparative standard.
58	431	Mikryukov, V.E. and Rabotnov, S.N.	1944	E	390-460		Single crystal; electrical resistivity at 390.2, 404.4, 412.0, 439.5, 447.6, and 460.2 K being, respectively, 14.45, 15.30, 15.80, 17.55, 18.03, and 18.94 μohm cm.
59	456	Garfinkel, M. and Lindenfeld, P.	1958	L	2.4-4.3	1	0.197 Bi; annealed for several months; electrical resistivity at 4.2 and 300 K being, respectively, 0.0721 and 11.69 μohm cm.
60	458	Zavaritskii, N.V.	1958	L	2.1-4.0	Sn 1	99.9 pure; monocrystalline rod with polished surface, 1.89 mm in dia.; in superconducting state.
61	458	Zavaritskii, N.V.	1958	L	0.14-4.2	Sn 2	99.998 pure; monocrystalline rod with rough surface 1.72 mm in dia.; angle between specimen axis and [001] direction = 30°; in superconducting state.
62	458	Zavaritskii, N.V.	1958	L	2.3-3.7	Sn 2	The above specimen in normal state.
63	458	Zavaritskii, N.V.	1958	L	0.12-1.4	Sn 3	99.998 pure; monocrystalline rod with rough surface, 1.40 mm in dia.; angle between specimen axis and [001] direction = 70°; in superconducting state.
64	458	Zavaritskii, N.V.	1958	L	0.11-0.92	Sn 4	99.998 pure; monocrystalline rod with polished surface, 1.81 mm in dia.; angle between specimen axis and [001] direction = 45°; in superconducting state.
65	400	Mendelssohn, K. and Renton, C.A.	1953	L	0.47-0.64	Sn 2	99.997 pure; polycrystalline; effected by "frozen in" magnetic field; in superconducting state.
66	400	Mendelssohn, K. and Renton, C.A.	1953	L	0.57-0.71	Sn 2	99.997 pure; polycrystalline; in superconducting state.
67	400	Mendelssohn, K. and Renton, C.A.	1953	L	0.33-0.80	Sn 1	99.997 pure; single crystal; in superconducting state.
68	459	Grossman, G.	1905	P	286.7		Chemically pure; cast and turned; specimen in ring form; density 7.31 g cm^{-3} at 14 C; specific heat 0.0529 cal g^{-1} C^{-1}; electrical resistivity 11.82 μohm cm at 13.5 C.
69	454	Graham, G.M.	1958	L	0.21-0.52	E0	Spectroscopically pure; single crystal; provided by Johnson, Matthey Co., Ltd.; orientation Θ(the angle between tetragonal axis and specimen axis) = 85°; electropolished; surface roughness 0.05 μ; residual resistivity 0.00377 μohm cm; in superconducting state.
70	454	Graham, G.M.	1958	L	0.21-0.52	E1	Above specimen but 50% clouding etch by exposure to HCl fumes; surface roughness 0.3 μ; in superconducting state.
71	454	Graham, G.M.	1958	L	0.26-0.51	E2	Above specimen but light etch; surface roughness 0.7 μ; in superconducting state.

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*See TPRC Data Book Vol. 1, Chapter 1, References

TABLE 11. SPECIFICATIONS OF THE SPECIMENS OF TIN (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
72	454	Graham, G. M.	1958	L	0. 25-0. 53	E3	Above specimen but etched to surface roughness 1. 1 μ; in superconducting state.
73	454	Graham, G. M.	1958	L	0. 21-0. 47	E4	Above specimen but electro-polished; surface roughness 0. 05 μ; in superconducting state.
74	454	Graham, G. M.	1958	L	0. 21-0. 47	E5	Above specimen but 25% clouding etch by exposure to HCl fumes; surface roughness 0. 12 μ; in superconducting state.
75	454	Graham, G. M.	1958	L	0. 25-0. 52	E6	Above specimen but electro-polished; surface roughness 0. 10 μ; in superconducting state.
76	454	Graham, G. M.	1958	L	0. 24-0. 53	E7	Above specimen but etched to surface roughness 1. 0 μ; in superconducting state.
77	454	Graham, G. M.	1958	L	0. 27-0. 65	E10	Above specimen but annealed at 220 C to remove strain associated with previous etching; surface roughness 1. 0 μ; in superconducting state.
78	454	Graham, G. M.	1958	L	0. 24-0. 66	D0	Spectroscopically pure; with 3 large crystals; as cast; surface roughness 0. 10 μ; in superconducting state.
79	454	Graham, G. M.	1958	L	0. 26-0. 63	D1	Above specimen but etched; surface roughness 0. 7 μ; in superconducting state.
80	455	Goodman, B. B.	1953	L	0. 18-0. 67	Sn II	Spectroscopically pure; cast in tube; polycrystal with $\rho_0/L_0 = 0.217\ W^{-1}\ cm\ K^2$; dia = 1. 3 mm, and size of crystals of the order of the dia; in superconducting state.
81	455	Goodman, B. B.	1953	L	0. 23-0. 90	Sn III	Similar to the above specimen but with $\rho_0/L_0 = 0.133\ W^{-1}\ cm\ K^2$, and dia = 0. 7 mm; in superconducting state.
82	682	Zavaritskii, N. V.	1960	L	0. 13-4. 0		0. 002 impurity; single crystal; 0. 175 cm in dia and ~50 mm long; cast in vacuo in thin-walled glass capillary in which crystallization took place immediately after casting; $\rho_{(0K)}/\rho_{(293K)} = 0.00016$; in superconducting state below transition point.
83	592	Nikolskii, N. A., Kalakutskaya, N. A., Pchelkin, I. M., Klassen, T. V., and Veltishcheva, V. A.	1959	L	570-833		In molten state (melting point 231. 9 C).
84	597, 708	Pashaev, B. P.	1961	L	337-610		Solid state; 99. 94 pure. Liquid state: molten tin (from the same source) 3 mm in dia, 64 mm long; data determined by a different apparatus.
85	509	Ruh, E.	1954	C	306-378	56 B-1	Specimen made from NBS freezing-point tin No. 42b (freezing point 231. 9 C); electrolytically deposited pure copper used as comparative material; thermal conductivity of copper taken from International Critical Tables, 1929.
86	511	Lussana, S.	1918	L	298. 0		Specimen with radius of 0. 7 cm furnished by Erba.
87	504	Parker, W. J., Jenkins, R. J., Butler, C. P., and Abbott, G. L.	1961	P	295. 2		Rectangular plate 1. 9 x 1. 9 x 0. 306 cm; density 7. 30 g cm^{-3} (from Smithsonian Physical Tables by Forsythe, W. E., 1954); specific heat 0. 057 cal g^{-1} K^{-1} at 295 K; data calculated from thermal diffusivity measurements.

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*See TPRC Data Book Vol. 1, Chapter 1, References

TABLE 11. SPECIFICATIONS OF THE SPECIMENS OF TIN (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
88	712	Zavaritskii, N. V.	1961	L	2. 9-4. 6	Sn 1	High purity; single crystal; specimen 2. 6 mm in dia. ; orientation [001]; residual resistivity $\rho_0(1 \pm 0.5) \times 10^{-4}$ μohm cm; measured in normal state.
89	712	Zavaritskii, N. V.	1961	L	1. 9-3. 7	Sn 1	The above specimen measured in superconducting state; data corrected to zero field at temperatures below T_c of 3. 72 K.
90	712	Zavaritskii, N. V.	1961	L	2. 6-4. 4	Sn 2	Similar to the above specimen but only 1. 1 mm in dia. ; residual resistivity $\rho_0(1.65 \pm 0.2) \times 10^{-4}$ μohm cm; measured in normal state.
91	712	Zavaritskii, N. V.	1961	L	0. 6-3. 7	Sn 2	The above specimen measured in superconducting state; data corrected to zero field at temperature below T_c of 3. 72 K.
92	712	Zavaritskii, N. V.	1961	L	2. 3-4. 7	Sn 3	Similar to the above specimen but 1. 5 mm in dia. ; residual resistivity ρ_0 6. 1 x 10^{-4} μohm cm; measured in normal state.
93	712	Zavaritskii, N. V.	1961	L	2. 0-3. 7	Sn 3	The above specimen measured in superconducting state; data corrected to zero field at temperatures below T_c of 3. 72 K.
94	712	Zavaritskii, N. V.	1961	L	2. 8-4. 5	Sn 4	Similar to the above specimen but with a dia. of 2. 1 mm; residual resistivity $\rho_0(1.2 \pm 0.5) \times 10^{-4}$ μohm cm; orientation [110]; measured in normal state.
95	712	Zavaritskii, N. V.	1961	L	2. 5-3. 7	Sn 4	The above specimen measured in superconducting state; data corrected to zero field at temperature below T_c of 3. 72 K.
96	706	Lorenz, L.	1881	L	273, 373		Density 7. 27 g cm^{-3}; electrical conductivity at 0 and 100 C being, respectively, 9. 346 and 6. 524 x 10^4 ohm^{-1} cm^{-1} (the paper reported the conductivity of 9. 346 and 6. 524 x 10^5, evidently a typographical error).
97	739	Guénault, A. M.	1961	L	2. 7-4. 3	Sn 1	High purity tin from Vulcan De-tinning Co. ; single crystal; specimen about 14 cm long made from 2 mm dia. extruded wire; etched in concentrated HCl; cut with a sharp razor blade to get a precise [001] orientation and the tetrad axis along the tin rod; $R_{(20C)}/R_0$, ratio of electrical resistance at 20 C to the residual resistance (resistance at 1. 2 K extrapolated to zero field) is 80, 000; in normal state.
98	739	Guénault, A. M.	1961	L	2. 8-4. 2	Sn 2	Similar to the above specimen but the specimen made from 5 parts of Johnson Matthey Specpure and 8 parts of high purity tin from Vulcan De-tinning Co. ; $R_{(20C)}/R_0 = 23000$; in normal state.
99	739	Guénault, A. M.	1961	L	2. 7-4. 2	Sn 4	Similar to the above specimen but the specimen made from equal parts of Johnson Matthey Specpure and Vulcan De-tinning Co. high purity tin; $R_{(20C)}/R_0 = 4500$; in normal state.
100	740	Peshkov, V. P. and Parshin, A. Ya.	1965	L	0. 34-1. 3		99. 99^+ pure; single crystal; specimen 2. 2 mm in dia. and 100 mm long; residual resistivity $\rho_{(4.2K)} = 1.7 \times 10^{-10}$ ohm cm (this corresponds to a purity of about 99. 9998%); in superconducting state.
101	740	Peshkov, V. P. and Parshin, A. Ya.	1965	L	0. 48-1. 3		The above specimen measured in a longitudinal magnetic field of 500 oersteds; in normal state.
102	740	Peshkov, V. P. and Parshin, A. Ya.	1965	L	0. 45-1. 2		The above specimen measured in a transverse magnetic field of 500 oersteds; in normal state.

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*See TPRC Data Book Vol. 1, Chapter 1, References

TABLE 11. SPECIFICATIONS OF THE SPECIMENS OF TIN (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
103	740	Peshkov, V. P. and Parshin, A. Ya.	1965	L	0.39-1.5		0.05 mm tin foil produced by rolling tin having the same purity as the above specimen; in superconducting state.
104	740	Peshkov, V. P. and Parshin, A. Ya.	1965	L	0.42-2.0		The above specimen measured in a longitudinal magnetic field of 330 oersteds; in normal state.
105	740	Peshkov, V. P. and Parshin, A. Ya.	1965	L	0.36-1.7		Similar to the above specimen but the foil had been preliminarily etched; in superconducting state.
106	740	Peshkov, V. P. and Parshin, A. Ya.	1965	L	0.43-1.4		The above specimen measured in a longitudinal magnetic field of 330 oersteds; in normal state.
107	735, 839	Yurchak, R. P. and Filippov, L. P.	1965	P	870-1230		Molten specimen in a tantalum crucible made from 2 coaxial tubes with diameters of 23.8 and 8 mm, each tube 0.12 mm thick; data calculated from measurements of thermal diffusivity and specific heat data; data of density taken from M. P. Slavinskii, Physicochemical Properties of Elements (Russian), 1952.
108	744	Filippov, L. P.	1966	P	465-1365		Measured with an improved apparatus capable of giving simultaneously thermal conductivity, thermal diffusivity, and specific heat.
109	838	Dutchak, Ya. I. and Panasyuk, P. V.	1967	C	429-773		Molten specimen placed in a hole of 21 mm in dia drilled in an asbestos cement cylinder 30 mm in height; 1Kh18N9T steel used as reference material.
110	837	Pearson, G. J., Ulbrich, C. W., Gueths, J. E., Mitchell, M. A., and Reynolds, C. A.	1967	L	1.6-4.5	Sn 1	99.999 pure; supplied by Johnson-Matthey; extruded into 1.5 mm dia wire; electrical resistivity 0.00213, and 13.06 μohm cm at 4.2 and 273°K, respectively; T_c (superconducting transition temperature) 3.720°K, below the transition temperature, a longitudinal magnetic field was applied to the specimen as the normal-state data were taken.
111	837	Pearson, G. J., Ulbrich, C. W., Gueths, J. E., Mitchell, M. A., and Reynolds, C. A.	1967	L	1.6-3.6	Sn 1	Same as the above specimen, except the magnetic field was removed so the superconducting-state data were taken.
112	837	Pearson, G. J., Ulbrich, C. W., Gueths, J. E., Mitchell, M. A., and Reynolds, C. A.	1967	L	1.6-4.5	Pb 1	0.019 Pb; prepared by vacuum-melting appropriate amounts of Johnson-Matthey 99.999 pure Sn and Pb, extruding into 1.5 mm dia wire, annealed at ~200°C for several days; electrical resistance 0.00564 and 12.71 μohm cm at 4.2 and 273°K, respectively; T_c 3.716°K; normal-state data were taken at temperatures below T_c with a longitudinal magnetic field applied to the specimen.
113	837	Pearson, G. J., Ulbrich, C. W., Gueths, J. E., Mitchell, M. A., and Reynolds, C. A.	1967	L	2.2-3.6	Pb 1	The above specimen measured without the magnetic field as the superconducting-state data were taken.
114	837	Pearson, G. J., Ulbrich, C. W., Gueths, J. E., Mitchell, M. A., and Reynolds, C. A.	1967	L	1.6-4.6	Pb 2	0.174 Pb; prepared by vacuum-melting appropriate amounts of Johnson-Matthey 99.999 pure Sn and Pb, extruding into 1.5 mm dia wire, annealed at ~200°C for several days; electrical resistivity 0.0500 and 13.19 μohm cm at 4.2 and 273°K, respectively; T_c 3.713°K; normal-state data were taken at temperatures below T_c with a longitudinal magnetic field applied to the specimen.
115	837	Pearson, G. J., Ulbrich, C. W., Gueths, J. E., Mitchell, M. A., and Reynolds, C. A.	1967	L	1.4-3.7	Pb 2	The above specimen measured without the magnetic field as the superconducting-state data were taken.

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*See TPRC Data Book Vol. 1, Chapter 1, References

TABLE 11. SPECIFICATIONS OF THE SPECIMENS OF TIN (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks*
116	837	Pearson, G.J., Ulbrich, C.W., Gueths, J.E., Mitchell, M.A., and Reynolds, C.A.	1967	L	1.3-4.5	Bi 1	0.012 Bi; prepared by vacuum-melting appropriate amounts of Johnson-Matthey 99.999 pure Sn and Bi, extruding into 1.5 mm dia wire, annealed at ~200°C for several days; electrical resistivity 0.00578 and 12.61 μohm cm at 4.2 and 273°K, respectively; T_c 3.725°K; normal-state data were taken at temperatures below T_c with a longitudinal magnetic field applied to the specimen.
117	837	Pearson, G.J., Ulbrich, C.W., Gueths, J.E., Mitchell, M.A., and Reynolds, C.A.	1967	L	1.4-3.7	Bi 1	The above specimen measured without the magnetic field as the superconducting-state data were taken.
118	837	Pearson, G.J., Ulbrich, C.W., Gueths, J.E., Mitchell, M.A., and Reynolds, C.A.	1967	L	1.4-4.4	Bi 2	0.140 Bi; prepared by vacuum-melting appropriate amounts of Johnson-Matthey 99.999 pure Sn and Bi, extruding into 1.5 mm dia wire, annealed at ~200°C for several days; electrical resistivity 0.0721 and 11.91 μohm cm at 4.2 and 273°K, respectively; T_c 3.709°K; normal-state data were taken at temperatures below T_c with a longitudinal magnetic field applied to the specimen.
119	837	Pearson, G.J., Ulbrich, C.W., Gueths, J.E., Mitchell, M.A., and Reynolds, C.A.	1967	L	2.2-3.7	Bi 2	The above specimen measured without the magnetic field as the superconducting-state data were taken.
120	837	Pearson, G.J., Ulbrich, C.W., Gueths, J.E., Mitchell, M.A., and Reynolds, C.A.	1967	L	1.6-4.7	Hg 1	0.018 Hg; prepared by vacuum-melting appropriate amounts of Johnson-Matthey 99.999 pure Sn and Hg, extruding into 1.5 mm dia wire, annealed at ~200°C for several days; electrical resistivity 0.0203 and 12.87 μohm cm at 4.2 and 273°K, respectively; T_c 3.718°K; normal-state data were taken at temperatures below T_c with a longitudinal magnetic field applied to the specimen.
121	837	Pearson, G.J., Ulbrich, C.W., Gueths, J.E., Mitchell, M.A., and Reynolds, C.A.	1967	L	1.7-3.7	Hg 1	The above specimen measured without the magnetic field as the superconducting-state data were taken.
122	837	Pearson, G.J., Ulbrich, C.W., Gueths, J.E., Mitchell, M.A., and Reynolds, C.A.	1967	L	1.4-4.0	Hg 2	0.168 Hg; prepared by vacuum-melting appropriate amounts of Johnson-Matthey 99.999 pure Sn and Hg, extruding into 1.5 mm dia wire, annealed at ~200°C for several days; electrical resistivity 0.113 and 11.28 μohm cm at 4.2 and 273°K, respectively; T_c 3.686°K; normal-state data were taken at temperatures below T_c with a longitudinal magnetic field applied to the specimen.
123	837	Pearson, G.J., Ulbrich, C.W., Gueths, J.E., Mitchell, M.A., and Reynolds, C.A.	1967	L	1.4-3.6	Hg 2	The above specimen measured without the magnetic field as the superconducting-state data were taken.
124	836	Boxer, A.S.	1958	L	1.6-4.6	2	0.047 Hg; prepared by vacuum-melting appropriate amounts of Johnson-Matthey 99.999 pure Sn and Hg, casting into 1 mm dia x 12 cm long wire with pyrex capillary; electrical resistivity 0.014 μohm cm; a magnetic field was applied when taking normal-state data at temperatures below T_c.
125	836	Boxer, A.S.	1958	L	1.6-4.2	2	The above specimen measured without the magnetic field as the superconducting-state data were taken.

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*See TPRC Data Book Vol. 1, Chapter 1, References

TABLE 11. SPECIFICATIONS OF THE SPECIMENS OF TIN (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
126	836	Boxer, A.S.	1958	L	1.6-4.8	5	0.049 Bi; prepared by vacuum-melting appropriate amounts of Johnson-Matthey 99.999 pure Sn and Bi, casting into 1 mm dia x 12 cm long wire with pyrex capillary; electrical resistivity 0.020 μohm cm; a magnetic field was applied when taking normal-state data at temperatures below T_c.
127	836	Boxer, A.S.	1958	L	1.5-2.8	5	The above specimen measured without the magnetic field as the superconducting-state data were taken.
128	836	Boxer, A.S.	1958	L	1.6-4.9	8	0.040 Pb; prepared by vacuum-melting appropriate amounts of Johnson-Matthey 99.999 pure Sn and Pb, casting into 1 mm dia x 12 cm long wire with pyrex capillary; electrical resistivity 0.010 μohm cm; a magnetic field was applied when taking normal-state data at temperatures below T_c.
129	836	Boxer, A.S.	1958	L	1.6-2.8	8	The above specimen measured without the magnetic field as the superconducting-state data were taken.
130	835	Walton, A.J.	1966	L	1.65	Sn 5.0	Polycrystalline; 2.25 mm dia x 10 cm long; supplied by Johnson-Matthey and Co; specimen was recrystallized in an alumina packing, annealed at a temperature just below the melting point for several hours; $\rho_{290\,K}/\rho_{4.2K}$ 5000; measured in a transverse static magnetic field with strength ranging from 72 to 277 gauss.
131	835	Walton, A.J.	1966	L	1.65	Sn 5.0	The above specimen measured with the field rotated about the specimen axis 10 times at 5 sec rev^{-1} between points of measurement.
132	835	Walton, A.J.	1966	L	1.80	Sn 47	Single crystal with tetrad axis at 3° to the specimen axis; w. 15 mm dia x 10 cm long; same preparation procedure as the above specimen; $\rho_{290K}/\rho_{4.2K}$ 47000; measured in a transverse static magnetic field with strength ranging from 76 to 227 gauss.
133	835	Walton, A.J.	1966	L	1.80	Sn 47	The above specimen measured with the field rotated about the specimen axis 5 times at 8 sec rev^{-1} between points of measurement.

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[*] See TPRC Data Book Vol. 1, Chapter 1, References

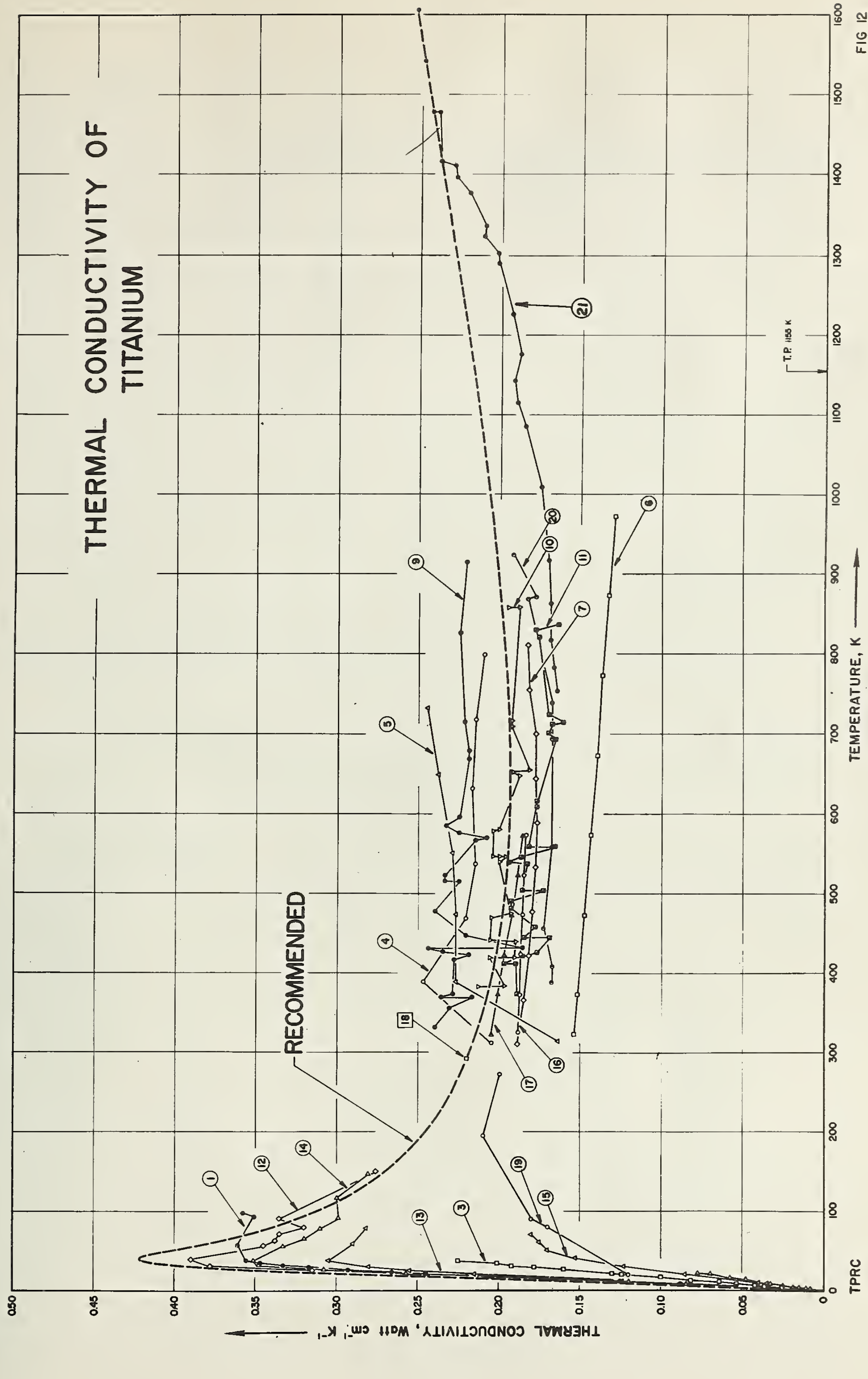
THERMAL CONDUCTIVITY OF TITANIUM
RECOMMENDED
THERMAL CONDUCTIVITY, Watt cm⁻¹ K⁻¹
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
TEMPERATURE, K
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
T.P. 1155 K
TPRC
1
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FIG 12

TABLE 12. SPECIFICATIONS OF THE SPECIMENS OF TITANIUM

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	122	Rosenberg, H. M.	1955	L	2.6-99	Ti3	99.99 pure; single crystal.
2	98	Mendelssohn, K. and Rosenberg, H. M.	1952	L	2.3-22	Ti1	99.9 pure; polycrystalline.
3	98	Mendelssohn, K. and Rosenberg, H. M.	1952	L	2.3-38	Ti2	99.99 pure; polycrystalline; annealed.
4	441	Mikryukov, V. E.	1957		312-799	Iodide titanium	99.9 pure; annealed in vacuum for 5 hrs at 700 C.
5	441	Mikryukov, V. E.	1957		315-732		Forged titanium specimen 99.6 pure; annealed in vacuum for 5 hrs at 700 C.
6	131	Silverman, L.	1953	C	323-973		0.04Fe, 0.1 Mn, 0.035 C, 0.01 Mg; annealed at 700 C.
7	231, 304	Deem, H.W., Wood, W.D., and Lucks, C.F.	1958	C	311-811	A-55 (RC-55)	Commercially pure; in a mill-annealed condition.
8	683	Davey, G. and Mendelssohn, K.	1963		0.3-0.9		Single crystal.
9	340	Loewen, E. G.	1956	L	332-915	Ti 75 A(1)	Commercially pure.
10	340	Loewen, E. G	1956	L	383-858	Ti 75 A(2)	99.75 Ti, 0.0068 H, 0.06 C, 0.048 N, 0.131 O, and 0.07 Fe.
11	340	Loewen, E. G.	1956	L	375-838	RC-55	99.64 Ti, 0.0073 H, 0.08 C, 0.028 N, 0.123 O, and 0.12 Fe.
12	401	White, G. K. and Woods, S. B.	1959	L	7.3-150	Ti3	99.99 pure; annealed in vacuum for 60 hrs at 800 C; $\rho(295K)/\rho_0 = 21.9$.
13	401	White, G. K. and Woods, S. B.	1959	L	11-78	Ti4	99.99 pure; rolled; $\rho(295K)/\rho_0 = 16.4$.
14	401	White, G. K. and Woods, S. B.	1959	L	7.0-147	Ti5	99.99 pure; annealed in vacuum for 60 hrs at 800 C; $\rho(295K)/\rho_0 = 18.3$.
15	672	Gladun, D. and Holzhäuser, W.	1964	L	9-70		99.9 pure.
16	698	Powell, R.W. and Tye, R.P.	1961	L, C	323-573	Sample A	Normal commercial grade; electrical resistivity at 50, 100, 150, 200, 250, and 300 C was respectively 56.0, 65.0, 73.5, 82.5, 90.5, and 98.5 μohm cm; energy flow measured both calorimetrically and by using Armco iron as a comparative standard.
17	698	Powell, R.W. and Tye, R.P.	1961	L, C	323-573	Sample B	High purity grade; electrical resistivity at 50, 100, 150, 200, 250, and 300 C was respectively 51.8, 60.8, 70.0, 79.2, 88.4, and 97.5 μohm cm; energy flow measured both calorimetrically and by using Armco iron as a comparative standard.
18	698	Powell, R.W. and Tye, R.P.	1961	L, C	293.2	Sample C	Very high purity grade; DPN (Diamond Pyramid Hardness Number) 58-62; electrical resistivity 42.7 μohm cm at 20 C; energy flow measured both calorimetrically and by using Armco iron as a comparative standard.
19	718, 119	Rigney, C. J. and Bockstahler, L. I.	1951	L	27-277		Average purity from 3 commercially pure specimens ~99.0; 0.005-0.015 H, 0.01 - 0.03 N, 0.03-0.25 O, 0.04-0.12 Si, 0.08-0.22 Fe, 0.06-0.25 Cr, 0.05-0.1 Ni, 0.01-0.2 Mg, and <0.02 Zn, Al, Mn, and other elements; specimen ~8 mm in dia and 72 mm long.
20	742	Krzhizhanovskii, R. E.	1964	T	388-923		99.6 pure (Russian commercial titanium); obtained from the Central Boiler and Turbine Institute; specimen 5 mm in dia and 100 mm long; experiment carried out in vacuum (10^{-4} - 10^{-5} mm Hg); electrical resistivity at 0, 100, 200, 300, 400, 500, 600, and 650 C being, respectively, 47, 64, 82, 99, 117, 133, 143, and 145 μohm cm.
21	‡	Rudkin, R. L., Parker, W. J., and Jenkins, R. J.	1963	P	753-1606		No details reported for the specimen; thermal conductivity values were not given in the paper but were calculated by TPRC using the reported thermal diffusivity data (measured by the flash method) and selected density and specific heat values from TPRC Report 16, 1966.

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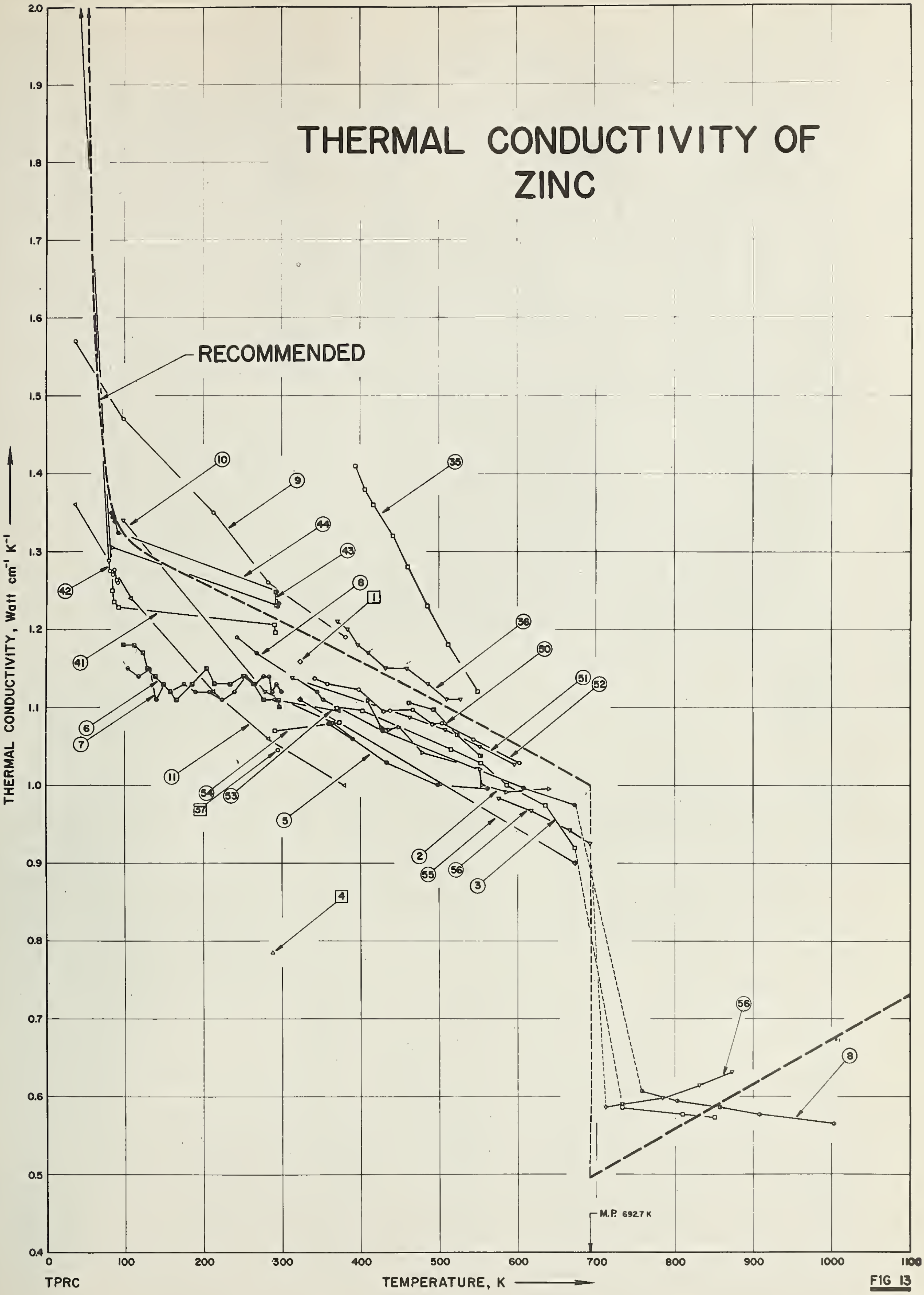
[*] See TPRC Data Book Vol. 1, Chapter 1, References

[‡] ASD-TDR-62-24, 1-20, 1963.


THERMAL CONDUCTIVITY OF ZINC
RECOMMENDED
THERMAL CONDUCTIVITY, Watt cm⁻¹ K⁻¹
TEMPERATURE, K
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0
100
200
300
400
500
600
700
800
900
1000
1100
M.P. 692.7 K
10
9
35
44
43
8
1
36
50
51
52
42
41
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11
54
37
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56
8

TPRC

FIG 13

TABLE 13. SPECIFICATIONS OF THE SPECIMENS OF ZINC

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	230	Smith, A.W.	1925	L	323		Pure; <0. 03 total impurity; cylindrical rod 10 cm long, 1. 9 cm in dia. ; electrical conductivity at 22 C being 17. 0 x 10^4 ohm^{-1} cm^{-1}.
2	6	Bailey, L.C.	1931	L	409-640		"Pure redistilled zinc"; fracture crystalline with crystals radiating from axis of rod; density 7. 10 g cm^{-3} at 21 C; the same specimen used by Lees in 1908 (curve 6).
3	85	Konno, S.	1919	L	370-851		Part of the measurements for molten zinc.
4	511	Lussana, S.	1918	L	288. 4		Specimen radius 0. 685 cm; furnished by the manufacturer Erba.
5	127	Schofield, F.H.	1925	L	361-562		99. 8 pure; obtained from London Zinc Mills; cast from billets, rolled at 200 C, sawn into strips and drawn cold; density 7. 13 g cm^{-3}; electrical resistivity at 35, 105, 200, and 350. 2 being, respectively, 6. 08, 8. 09, 10. 48, and 14. 50 μohm cm.
6	88	Lees, C.H.	1908	L	99-297		Pure; turned from a cast stick of "pure redistilled zinc"; fracture crystalline with crystals radiating from the axis of rod; cylinder about 7 cm long, 0. 585 cm in dia. ; density 7. 1 g cm^{-3} at 21 C; electrical resistivity at -180. 3, -168. 4, -116. 3, -99. 7, -70. 1, -24. 7, 16. 7, 47. 8, 54. 3, and 90. 3 being, respectively, 1. 699, 1. 96, 3. 26, 3. 69, 4. 32, 5. 36, 6. 30, 6. 99, 7. 14, and 8. 01 μohm cm; first experiment.
7	88	Lees, C.H.	1908	L	104-300		Second experiment of the above specimen.
8	13, 14	Bidwell, C.C.	1939	F	241-1003		Specimens 4-5 cm in dia. ; 20-25 cm long used to find data in the solid state; for the liquid state molten zinc contained in a graphite cylinder to form a specimen 25 cm long and 4 cm in dia.
9	16	Bidwell, C.C. and Lewis, E.J.	1929	F	37-381		99. 993 Zn, 0. 005 Fe, and 0. 0018 Cd; single crystal; obtained from the Bureau of Standards; melted in an evacuated glass tube; heat flow parallel to the basal plane.
10	16	Bidwell, C.C. and Lewis, E.J.	1929	F	98-434	No. 2	Similar to the above specimen but polycrystalline; cast in vacuo in a graphite mold.
11	16	Bidwell, C.C. and Lewis, E.J.	1929	F	38-380	No. 1	Similar to the above specimen but cast in air.
12	342	Mendelssohn, K. and Rosenberg, H. M.	1953	L	2. 5	Zn 2	99. 997 pure; single crystal; obtained from Imperial Smelting Corp. ; rod axis at 80 degrees with the hexagonal axis; measured in a transverse magnetic field with strength H ranging from 0. 17 to 3. 73 kilooersteds.
13	342	Mendelssohn, K. and Rosenberg, H. M.	1953	L	4. 6	Zn 2	The above specimen measured in a transverse magnetic field with strength H ranging from 0. 17 to 3. 73 kilooersteds.
14	342	Mendelssohn, K. and Rosenberg, H. M.	1953	L	4. 6	Zn 2	The above specimen measured in a longitudinal magnetic field with strength H ranging from 0. 17 to 3. 73 kilooersteds.
15	342	Mendelssohn, K. and Rosenberg, H. M.	1953	L	2. 5	Zn 4	Similar to the above specimen but rod axis at 13 degrees with the hexagonal axis; measured in a transverse magnetic field with strength ranging from 0. 36 to 3. 59 kilooersteds.
16	342	Mendelssohn, K. and Rosenberg, H. M.	1953	L	2. 5	Zn 4	The above specimen measured in a longitudinal magnetic field with strength ranging from 0. 36 to 3. 50 kilooersteds.

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*See TPRC Data Book Vol. 1, Chapter 1, References

TABLE 13. SPECIFICATIONS OF THE SPECIMENS OF ZINC (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
17	342	Mendelssohn, K. and Rosenberg, H. M.	1953	L	3.4	Zn 4	The above specimen measured in a transverse magnetic field with strength ranging from 0.36 to 3.59 kilooersteds.
18	342	Mendelssohn, K. and Rosenberg, H. M.	1953	L	3.4	Zn 4	The above specimen measured in a longitudinal magnetic field with strength ranging from 0.36 to 3.75 kilooersteds.
19	342	Mendelssohn, K. and Rosenberg, H. M.	1953	L	4.5	Zn 4	The above specimen measured in a transverse magnetic field with strength ranging from 0.36 to 3.90 kilooersteds.
20	342	Mendelssohn, K. and Rosenberg, H. M.	1953	L	4.5	Zn 4	The above specimen measured in a longitudinal magnetic field with strength ranging from 0.36 to 3.85 kilooersteds.
21	97	Mendelssohn, K. and Rosenberg, H. M.	1952	L	3.0-23	Zn 1	99.9995 pure; polycrystalline; provided by Hilger H. S. brand (H S 8392); annealed in evacuated quartz tube for several hrs at two-thirds the melting point.
22	97	Mendelssohn, K. and Rosenberg, H. M.	1952	L	1.8-41	Zn 2	99.997 pure; single crystal; provided by Imperial Smelting Corp.; hexagonal axis at 80 degrees to the rod axis; annealed as the above specimen.
23	97	Mendelssohn, K. and Rosenberg, H. M.	1952	L	3.0-40	Zn 3	Similar to the above specimen but hexagonal axis at 13 degrees to the rod axis.
24	280	Cinnamon, C. A.	1934	L	330.2		99.99^+ pure; 0.0047 Pb, 0.0008 Cd, 0.0004 Fe, and 0.0002 Cu; unstrained single crystals grown from a single 50 lb slab of "Evanwall" zinc; specimens 30 cm long; area of cross section 1.24 cm^2; 11 specimens having various orientations with values of $\cos^2\theta$ ranging from zero to 0.990 where θ is the angle between the normal to the basal cleavage plane and the axis of the rod.
25	280	Cinnamon, C. A.	1934	L	330.2		Similar to the above specimens but strained; three specimens with $\cos^2\theta$ ranging from zero to 0.51.
26	280	Cinnamon, C. A.	1934	L	330.2		Similar to the above specimens but strained and annealed.
27	280	Cinnamon, C. A.	1934	L	330.2		Similar to the above specimens but in the form of unstrained "optically mosiac" crystals; four specimens with $\cos^2\theta$ ranging from 0.13 to 0.935.
28	280	Cinnamon, C. A.	1934	L	330.2		Similar to the above specimens but strained; $\cos^2\theta$ = 0.91.
29	280	Cinnamon, C. A.	1934	L	330.2		Similar to the above specimen but strained and annealed; $\cos^2\theta$ = 0.13 and 0.91.
30	279	Girton, W. Z. and Potter, J. H.	1951	R	331.4		Powdered; apparent density 2.454 g cm^{-3}.
31	279	Girton, W. Z. and Potter, J. H.	1951	R	330.8		Powdered; apparent density 2.443 g cm^{-3}.
32	279	Girton, W. Z. and Potter, J. H.	1951	R	331.0		Powdered; apparent density 2.465 g cm^{-3}.
33	279	Girton, W. Z. and Potter, J. H.	1951	R	331.1		Powdered; apparent density 2.456 g cm^{-3}.
34	122	Rosenberg, H. M.	1955	L	2.7-21	Zn 4	99.997 pure; obtained from Imperial Smelting Corp.; single crystal with hexagonal axis at 13 degrees to rod axis; specimen made from the same material as used for curve 22.
35	431	Mikryukov, V. E. and Rabotnov, S. N.	1944	E	394-550		Single crystal; electrical resistivity at 121.1, 143.9, 169.6, 188.4, 213.8, 238.9, and 277.1 C being, respectively, 8.32, 8.88, 9.59, 10.10, 10.85, 11.53 and 12.66 μohm cm.
36	431	Mikryukov, V. E. and Rabotnov, S. N.	1944	E	371-529		Polycrystal; electrical resistivity at 97.9, 111.2, 137.6, 159.4, 186.4, 213.6, 247.1, and 255.8 C being, respectively, 8.22, 9.09, 9.45, 10.19, 11.04, 11.85, 12.70, and 13.19 μohm cm.
37	504	Parker, W. J., Jenkins, R. J., Butler, C. P. and Abbott, G. L.	1961	P	295.2		Pure; specimen size 1.9 x 1.16 x 0.282 cm; density (20 C) 7.14 g cm^{-3} taken from Smithsonian Physical Table, 1954; measured specific heat (22 C) 0.088 cal g^{-1}K^{-1}.

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*See TPRC Data Book Vol. 1, Chapter 1, References

TABLE 13. SPECIFICATIONS OF THE SPECIMENS OF ZINC (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
38	409	Zavaritskii, N. V.	1958	L	0.14-0.87	Zn 1	0.0001 impurity; single crystal; ~1.5 mm in dia. and 100 mm long; with an angle of 30 degrees between the [001] direction and the specimen axis; measured in a magnetic field of 0.2 oersted; in superconducting state.
39	409	Zavaritskii, N. V.	1958	L	0.18-0.91	Zn 1	The above specimen measured in a longitudinal magnetic field of 60 oersteds; in normal state.
40	409	Zavaritskii, N. V.	1958	L	0.22-1.3	Zn 2	Similar to the above specimen but measured in a magnetic field of 0.2 oersted; in superconducting state.
41	294	Goens, E. and Grüneisen, E.	1932	L	22-293	Zn 61	Single crystal; specimen 5.27 cm long, area of cross section 0.0552 cm^2; angle between rod axis and hexagonal axis $\theta = 3.6^\circ$; electrical resistivity at -252, -190, 0, and 20 C being respectively, 0.0674, 1.331, 5.69, and 6.16 μohm cm.
42	294	Goens, E. and Grüneisen, E.	1932	L	21-92	Zn 100	Single crystal; $\theta = 4.9^\circ$; electrical resistivity at -252, -190, 0, and 20 C being, respectively, 0.056, 1.333, 5.72, and 6.20 μohm cm.
43	294	Goens, E. and Grüneisen, E.	1932	L	21-293	Zn 72	Single crystal; specimen 6.13 cm long, area of cross section 0.0634 cm^2; $\theta = 8.7^\circ$; electrical resistivity at -252, -190, 0, and 20 C being, respectively, 0.0522, 1.3, 5.58, and 6.05 μohm cm.
44	294	Goens, E. and Grüneisen, E.	1932	L	21-296	Zn 101	Single crystal; specimen 4.94 cm long, area of cross section 0.0623 cm^2; $\theta = 79.7^\circ$; electrical resistivity at -252, -190, 0, and 20 C being, respectively, 0.0524, 1.179, 5.43, and 5.88 μohm cm.
45	291, 727	Zavaritskii, N. V.	1960	L	0.10-0.94	Zn 4	Single crystal; grown along the principal crystallographic direction by Kapitza's method; heat flow parallel to the hexagonal axis; in superconducting state.
46	291, 727	Zavaritskii, N. V.	1960	L	0.10-1.03	Zn 7	Similar to the above specimen ; heat flow perpendicular to the hexagonal axis; in superconducting state.
47	291, 727	Zavaritskii, N. V.	1960	L	0.825	Zn 1	Similar to the above specimen, value given at the transition point.
48	291, 727	Zavaritskii, N. V.	1960	L	0.825	Zn 2	Similar to the above specimen, value given at the transition point.
49	291, 727	Zavaritskii, N. V.	1960	L	0.825	Zn 5	Similar to the above specimen; heat flow parallel to the hexagonal axis; value given at the transition point.
50	129	Shelton, S. M. and Swanger, W. H.	1933	C	462-553	Z. S.	99.9$^+$ pure; 0.04 Pb, 0.02 Fe; specimen prepared by remelting commercially pure zinc and casting in graphite; lead used as the comparative standard (value taken from International Critical Table Vol. II: 0.352 Watt cm^{-1} C^{-1} at 0 C).
51	129	Shelton, S. M. and Swanger, W. H.	1933	C	313-596	Z. S.	Similar to that of the above specimen except commercial malleable nickel used as the indirect comparative standard (also based on the data for lead).

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*See TPRC Data Book Vol. 1, Chapter 1, References

TABLE 13. SPECIFICATIONS OF THE SPECIMENS OF ZINC (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
52	129	Shelton, S.M. and Swanger, W.H.	1933	C	342-602	Z. S.	Similar to that of the above specimen except zinc used as the indirect comparative standard (also based on the data of lead).
53	77	Jaeger, W. and Diesselhorst, H.	1900	L	291, 373	Zinc II	99.97 pure (by difference); 0.01 Pb, 0.01 Cd, and 0.01 Fe; specimen 27 cm long and 1.805 cm in dia.; density 7.11 g cm^{-3}; electrical conductivity at 18 and 100 C being 16.51 and 12.59 x 10^4 ohm^{-1} cm^{-1} respectively.
54	77	Jaeger, W. and Diesselhorst, H.	1900	L	291, 373	Zinc II, wire	Wire of similar specifications as above, electrical conductivity at 18 and 100 being 15.98 and 12.42 x 10^4 ohm^{-1} cm^{-1}.
55	734	Angell, M. F.	1926	R	323-673		Specimen in the form of a hollow cylinder.
56	838	Dutchak, Ya.I. and Panasyuk, P. V.	1967	C	576-874		Molten specimen placed in a hole 21 mm in dia drilled in an asbestos cement cylinder 30 mm in height; 1Kh18N9T steel used as reference material.

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*See TPRC Data Book Vol. 1, Chapter 1, References

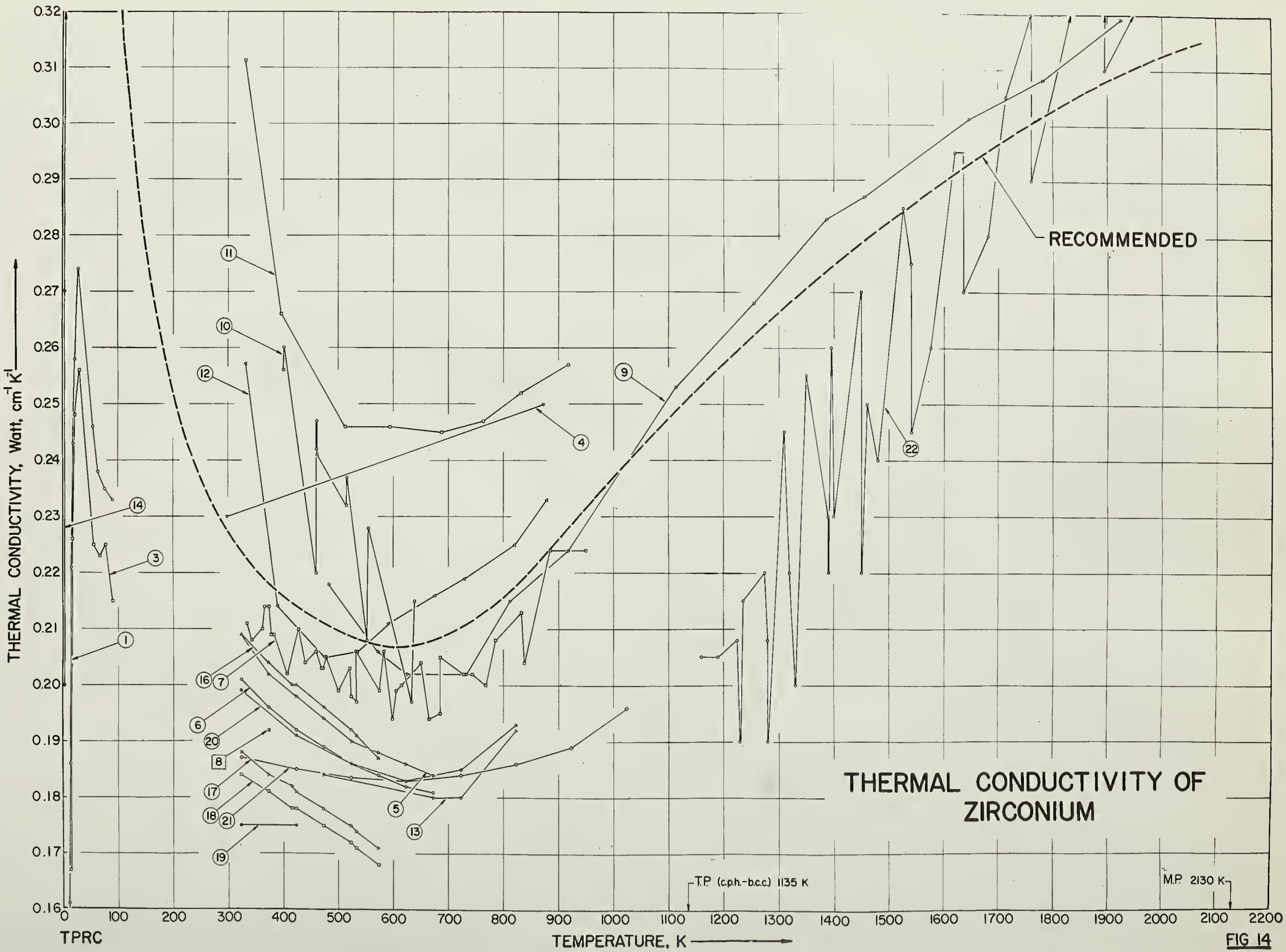
THERMAL CONDUCTIVITY OF ZIRCONIUM
RECOMMENDED
THERMAL CONDUCTIVITY, Watt, cm⁻¹K⁻¹
0.16
0.17
0.18
0.19
0.20
0.21
0.22
0.23
0.24
0.25
0.26
0.27
0.28
0.29
0.30
0.31
0.32
TEMPERATURE, K
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
T.P. (c.p.h.-b.c.c.) 1135 K
M.P. 2130 K
TPRC
1
3
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FIG 14

TABLE 14. SPECIFICATIONS OF THE SPECIMENS OF ZIRCONIUM

Cur. No.	Ref.* No.	Author(s)	Year	Met'd Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	83	Kemp, W.R.G., Klemens, P.G., and White, G.K.	1956	L	2.2-91	Zr 1a	99.99 Zr; spectroanalysis shows Fe (all sensitive lines), Hf and Ni (all sensitive lines faintly), Si and Ti (some sensitive lines), and Al, Cr, Cu, and Mg (faintly visible); JM5000 from Johnson, Matthey and Co.; 3 mm dia rod annealed at 950 C for 5 hrs in vacuum; electrical resistivity 48 μohm cm at 293 K, residual electrical resistivity 1.98 μohm cm; mounted in the cryostat with a push fit into copper fitting; measured with the current lead (for the measurements of electrical resistivity) attached.
2	83	Kemp, W.R.G., Klemens, P.G., and White, G.K.	1956	L	3.3-90	Zr 1b	The above specimen measured with the current lead removed.
3	83	Kemp, W.R.G., Klemens, P.G., and White, G.K.	1956	L	14-90	Zr 1c	The above specimen unintentionally strained by drilling and tapping to insert the connectors for re-mounting.
4	292	Danielson, G.C.	1954	P	298, 873		Preliminary results.
5	27	Deem, H.W.	1953	C	323-673	2682 A	Pure; low Hf; arc-melted from WAPD grade 1 crystal bar.
6	27	Deem, H.W.	1953	C	323-673	498	Pure; low Hf; arc-melted from Bureau of Mines sponge Zr.
7	101	Moss, M.	1955	L	336-950		Nominally pure; cylindrical specimen 7.938 in. long, 0.787 in. in dia; obtained from Westinghouse; prepared from Foote Grade I crystal-bar ingot; the ingot being melted in tungsten arc furnace; forged in Argon to size 10 x 1 x 1 in. at 845 C; annealed in vacuum for 0.5 hr at 1000 C; machined to final shape.
8	555	Smith, K.F. and Chiswik, H.H.	1956	C	373.2		Hafnium-containing crystal bar.
9	614	Fieldhouse, I.B. and Lang, J.I.	1961	R	484-1925		99.95 Zr; 0.029 Fe, 0.017 C, 0.0045 Hf and all other elements <0.031; specimen composed of 5 one-in. disks.
10	194	Vianey, L.R.	1951	L	402-639	D-151	Assumed to be pure; crystal bar; lot No. D-151.
11	441	Mikryukov, V.E.	1957		331-917	Iodide Zirconium	99.9 pure; annealed in vacuum for 8 hrs at 700 C; electrical resistivity at 58.0, 124.1, 239.8, 321.0, 415.6, 490.6, 558.8, and 644.0 C being respectively, 36.1, 47.6, 66.6, 75.8, 87.0, 94.4, 100.0, and 106 μohm cm; Lorenz numbers reported at these temperatures were 3.38, 3.33, 3.18, 3.11, 3.08, 3.04, 3.03, and 2.92 x 10^{-8} V^2K^{-2}, respectively.
12	441	Mikryukov, V.E.	1957		332-879		99.78 Zr; 0.14 Hf, 0.08 C; electrical resistivity reported as 53.76, 64.93, 78.74, 87.71, 95.23, 105.26, 111.11, 120.48, and 125.00 μohm cm at 59.0, 117.0, 202.0, 262.0, 318.0, 402.0, 456.0, 548.0, and 606.0 C, respectively; Lorenz numbers reported at these temperatures were 3.46, 3.44, 3.54, 3.36, 3.37, 3.34, 3.37, 3.28 and 3.29 x 10^{-8} V^2K^{-2}, respectively.
13	295	McCreight, L.R.	1952	R	473-823		Pure; 98-100% of theoretical density.
14	401	White, G.K. and Woods, S.B.	1959	L	2.0-121	Zr 4	99.95 pure; annealed in vacuum.
15	401	White, G.K. and Woods, S.B.	1959	L	4.4-89	Zr 4a	99.95 pure; annealed in vacuum.
16	442	Bing, G., Fink, F.W., and Thompson, H.B.	1951	C	323-573	Zr 1	0.001 Sn, 0.007 Ti, 0.04 Hf, 0.001 Al, 0.04 Fe, 0.02 Ni, Westinghouse ingot D-216 forged at 1250 F, and machined; electrical resistivity reported as 44.1 and 81.3 μohm cm at 298 and 533 K, respectively.

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* See TPRC Data Book Vol. 1, Chapter 1, References

TABLE 14. SPECIFICATIONS OF THE SPECIMENS OF ZIRCONIUM (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
17	442	Bing, G., Fink, F.W., and Thompson, H.B.	1951	C	323-573	Zr 7	0.07 Ta, 0.07 C, 0.0055 N, 0.007 Ti, 0.02 Al, 0.1 Fe; obtained from ANL, identified as SA 1568; annealed; electrical resistivity reported as 50.5, 68.2, and 85.1 μohm cm at 298, 415, and 533 K, respectively.
18	442	Bing, G., Fink, F.W., and Thompson, H.B.	1951	C	323-573	Zr 8	0.16 Ta, 0.002 C, 0.015 N, 0.005 Ti, 0.06 Al, 0.1 Fe; obtained from ANL, identified as SA 1576; annealed; electrical resistivity reported as 52.4, 70.1, and 86.6 μohm cm at 298, 415, and 533 K, respectively.
19	715	Powell, R.W. and Tye, R.P.	1961	L, C	323, 423	050	99.827 Zr (by difference), 0.11 O, 0.045 Fe, 0.01 C, 0.008 N; as-extruded rod 10 cm long, 1.27 cm in dia; arc-melted; electrical resistivity reported as 59.5 and 75 μohm cm at 323 and 423 K, respectively; Armco iron used as a reference standard, energy flow also measured calorimetrically.
20	715	Powell, R.W. and Tye, R.P.	1961	L, C	323-823		0.3-0.6 O (analysis made after completion of tests), 0.016 C, 0.016 H, 0.012 Fe, and 0.0025 N; specimen 0.435 cm in dia and 9.7 cm long, cold swaged from a bar of about 0.5 cm dia that had been prepared by the Van Arkel method; the bar was polycrystalline and consisted almost entirely of hexagonal crystals with their c-axis parallel to the axis of the bar, and considerable preferred orientation present in the specimen; density of the bar 6.57 g cm^{-3}; electrical resistivity reported as 49.2, 65.6, 82.1, 97.8, 111.2, and 119.7 μohm cm at 323, 423, 523, 623, 723, and 823 K, respectively, at these temperatures the Lorenz function being, respectively, 3.03, 2.96, 2.92, 2.87, 2.85, and 2.80 x 10^{-8} V^2 K^{-2}; Armco iron used as a reference standard; energy flow also measured calorimetrically.
21	715	Powell, R.W. and Tye, R.P.	1962	L, C	323-1023	Sample 715	0.1-0.6 O (analysis made after completion of tests), 0.043 C, 0.018 Fe, 0.0075 N, 0.007 Al, 0.007 Nb, and 0.0025 H; specimen 1.27 cm in dia and 10 cm long; in the as-extruded condition, melted in graphite before extrusion; electrical resistivity reported as 53.5, 70.0, 85.0, 98, 110, 119, 127, and 133 μohm cm at 323, 423, 523, 623, 723, 823, 923, and 1023 K, respectively, at these temperatures the Lorenz function being, respectively, 3.10, 3.06, 2.98, 2.88, 2.80, 2.69, 2.60, and 2.55 x 10^{-8} V^{2}K^{-2}; Armco iron used as a reference standard; energy flow also measured calorimetrically.
22	741	Timrot, D. L. and Peletskii, V.E.	1965	L	1160-2000	Iodide Zirconium	99.5$^+$ pure; 14 mm dia x 65 mm long; vacuum annealed; density 6.45 g cm^{-3} at room temperature.

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* See TPRC Data Book Vol. 1, Chapter 1, References

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PART II

THERMAL CONDUCTIVITY OF GRAPHITES

A. Introduction

Since graphite is not a specific material but a large family of materials and since graphite crystal is highly anisotropic due to its two-dimensional layer structure, the thermal conductivity of graphite covers a very wide range. The available thermal conductivity data for graphite are shown in Figure 15 and the information on the test specimens corresponding to the respective curves in the figure is given in Table 15. For the sake of clarity, only three-tenth of the 580 curves listed in Table 15 are plotted in the figure. For those curves not shown in the figure, one is referred to the TPRC Data Book, Volume 3, Chapter 1 [1]*, in which complete numerical data tables are also given.

Graphite falls into two categories: Natural graphite and artificial graphite. Of the latter category pyrolytic graphite distinguishes itself from pitch-bonded artificial graphite for its well-oriented crystal structure such that the thermal conductivity of treated pyrolytic graphite measured both parallel and perpendicular to the layer planes approaches the values for ideal graphite single crystal [2]. Due to the lack of sufficiently large single crystals of graphite and the difficulty in handling them, information on graphite single crystals can best be obtained through the study of pyrolytic graphite. Experimental evidences indicate that the anisotropy of the thermal conductivity of pyrolytic graphite is far greater than that of natural graphite. In Figure 15 the highest thermal conductivity curves are for pyrolytic graphite in the direction parallel to the layer planes. At temperatures above 100 K they are higher than the thermal conductivity of all known solids except diamond. In contrast, the thermal conductivity of pyrolytic graphite in the direction perpendicular to the layer planes is comparable with that of the insulators. In between these two extremes lie the whole family of curves of pitch-bonded graphite varieties and natural graphites, the location of the curves depending upon the combined effect of various parameters such as impurity, imperfection (defects), the orientation and the size and the degree of ordering of the grains and of the crystallites, the degree of graphitization, i.e., the ratio of the amount of the crystalline graphite to that of the cross-linking intercrystalline carbon, the nature of the raw material, porosity and the size, shape, number, and distribution of the pores, and so forth.

In graphite at temperatures below about 2000 K, heat is conducted primarily by lattice vibrations (phonons). This is evidenced by the fact that the Lorenz function of graphite is highly dependent on temperature and on the type of graphite and at room temperature it is two hundred to several hundred times the value for good metallic conductors, that the thermal conductivity of graphite above room temperature varies approximately as T^{-1}, which is typical for a nonmetallic crystal in which the phonon-phonon (Umklapp) scattering is predominant**, and that the low temperature dependence of the thermal conductivity of graphite is different from that of metals. At very high temperatures (above 2000 K), however, the thermal conductivity of graphite varies much more slowly than T^{-1}, and becomes nearly temperature independent at least up to 3000 K. This behavior has been explained by Kaspar[4] in terms of ambipolar (electrons and holes) thermal conduction in graphite at very high temperatures. He showed that, in this high temperature region, the Wiedemann-Franz law holds for graphite with a Lorenz number of about $9(K/e)^2$, in consequence of the established ambipolar electrical conduction in graphite.

At low temperatures the phonons are scattered mainly by the boundaries of crystallites, and, according to Casimir's theory [5], the thermal conductivity should be proportional to the average size of the crystallites and to the specific heat. It has been experimentally verified that at low temperatures the thermal conductivity of graphite is indeed roughly proportional to the crystallite size [see, for example, 6 and 7]. However, the thermal conductivity of graphite at low temperatures does not have the same temperature dependence as the specific heat (T^2 dependence above 10 K), but rather varies more rapidly with temperature (as great as $T^{2.7}$) [see, for example, 6, 8-10].

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* References appear under the heading REFERENCES.

**The general feature of the thermal conductivity of nonmetallic crystals has been briefly discussed in the INTRODUCTION to Part II of the first report [3].

The specific heat of graphite was treated by Komatsu and Nagamiya [11] and Gurney [12] assuming that in the layer-type structure of graphite each layer can be treated separately as a two-dimensional crystal, thus yielding a T^2 dependence of the specific heat of graphite at low temperatures instead of the familiar T^3 law for most solids. From another approach, by employing a semirigorous analysis of the normal mode problem for the transverse vibrations, Krumhansl and Brooks [13] showed the T^2 dependence of the specific heat to be a consequence of the elastic anisotropy of graphite. Experimentally this T^2 dependence has been confirmed by the measurements of DeSorbo and Tyler [14] in the temperature range from 13 to 54 K. Measurements by Keesom and Pearlman [15] also confirmed this T^2 dependence for temperatures between 10 and 20 K, though both theory [16] and experiment [15,17-19] showed that the T^2 law does not hold below 10 K and that eventually the T^3 law predominates.

This anomaly of the thermal conductivity of graphite, which increases with temperature faster than does the specific heat at low temperatures (above 10 K), has been explained by Klemens [20] in terms of a mean free path for waves in the hexagonal plane, which, as a consequence of the crystallite geometry, is considerably larger for longitudinal than for transverse waves, resulting in an increased contribution of the former to the thermal conductivity. Another explanation for this anomaly was proposed by Hove and Smith [21] in terms of a two-medium theory, which is based on their assumption that the pitch-bonded artificial graphite is comprised of two media: the graphite particles (each of which is made up of many single crystallites) and the intergranular ungraphitized carbon (pitch residue). They considered the thermal conductivity of graphite particles as having a T^2 dependence while that of the ungraphitized carbon, which is assumed to be an isotropic thermal conductor, is considered to have a T^3 dependence, and the latter can be taken in series with the former to obtain the total conductivity. In this way, as they claimed, the anomalous temperature dependence of the artificial graphite can be immediately explained.

This two-medium theory has, however, been criticized by Klein and Holland and their co-workers [22, 23] on the ground that, while magnetic susceptibility results [24] imply that there is little if any nongraphitic carbon in pyrolytic graphite, experimental results indicate that the thermal conductivity of pyrolytic graphite at low temperatures is not proportional to T^2, but rather varies more rapidly than T^2 also.

Klein and Holland [22] found that across the layer planes the thermal conductivity of turbostratic* pyrolytic graphite below 20 K is nearly proportional to $T^{2.3}$. Slack [25] also reported a similar temperature variation for a sample of pyrolytic graphite deposited at 2250 C. It was concluded that heat transfer across the layer planes proceeds entirely through the lattice vibrations.

Along the layer planes, Klein and Holland's results [22] indicate that the thermal conductivity of turbostratic pyrolytic graphite varies as $T^{2.5}$ from about 10 to 80 K. On another sample of pyrolytic graphite that had been heat-treated at 3250 C [23], their thermal conductivity data above 10 K exhibit a $T^{2.7}$ dependence that accords with Berman's measurements on a natural graphite crystal [6].

At temperatures below 10 K the thermal conductivity of pyrolytic graphite along the layer plane falls much less rapidly than it does above 10 K**, leading to the conclusion that electrons are involved in the layer-plane heat transport at very low temperatures [27]. Thus the thermal conductivity along the layer planes of pyrolytic graphite below 10 K can be expressed [22] as a sum of two terms: $aT + bT^n$, where aT represents the electronic contribution, bT^n the phonon contribution, and $n \approx 2.6$ as predicted from a long-wave-length treatment of the "effective" phonon velocity, which shows that the in-plane modes of lattice vibrations are seriously enhanced relative to the part they play in the lattice specific heat.

Because of the large anisotropy of graphite crystals, the over-all thermal conduction of conventional graphite will be mainly determined by the basal-plane behavior. Therefore, to sum up the discussions on the low temperature region, the thermal conductivity of graphite should vary as $T^{2.5 \pm 0.2}$ above 10 K and as $aT + bT^{2.5 \pm 0.2}$ below 10 K.

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* Pyrolytic graphite whose adjacent basal planes are randomly rotated with respect to one another and thus do not display evidence of three-dimensional ordering.

** The thermal conductivity of pitch-bonded artificial graphite behaves also in the same manner, see, for example, Deegan's curves [26] in Figure 15.

In Figure 15 it can be seen that in the low temperature region there seems to be a trend for the thermal conductivity of pitch-bonded graphite that the higher the curve the steeper is its slope. Probably this can be explained as the direct result of the aforementioned fact that the thermal conductivity of graphite crystal along the basal plane varies with temperature more rapidly than that across the basal plane, in addition to the difference in magnitude due to anisotropy.

In manufacturing the pitch-bonded artificial graphite [28, 29], when the calcined petroleum coke is crushed or milled to obtain the dry aggregate, the individual particles, although irregular in shape, tend to have one dimension larger than the other two. This results from the fact that, in the coking process, the aromatic molecules tend to be oriented with the planes of the benzene rings parallel to the cellular walls of the coke. These walls usually fracture so that the length of coke particles is in the direction of the layer planes of the ultimate graphite crystalline structure. In the process of forming, the long axes of the particles tend to take a preferred orientation: either parallel to the direction of extrusion or perpendicular to the direction of molding pressure. The final graphite product retains the same pattern of grain orientation. The with-the-grain direction is parallel to the direction of extrusion in extruded graphite and perpendicular to the direction of molding pressure in the molded piece. The across-the-grain direction is perpendicular to this. Therefore, it is apparent that the low-temperature thermal conductivity of pitch-bonded graphite measured in the with-the-grain direction is not only higher (due to inherent anisotrophy) than that measured in the across-the-grain direction but also varying more rapidly with temperature (due to inherent difference in temperature dependence).

For a group of different graphite samples measured in the same direction, say, in the direction with-the-grain, it is also apparent that the higher the curve the steeper is its slope. Since, other things being equal, higher thermal conductivity implies higher degree of ordering and better alignment of the axes, and therefore the contribution to the total heat flow from conduction in the basal-plane direction is higher.

In Figure 15 it is also observed that many of the maxima of the thermal conductivity curves seem to fall approximately on a straight line (in the logarithmic plot). There are, however, many exceptions, notably the curves for samples of Canadian natural graphite [10, 30] and many of the lower curves. The information available for this correlation of thermal conductivity maxima is extremely sparse due to the termination near room temperature of almost all the low temperature curves of pitch-bonded graphite before reaching their maxima. It is therefore highly desirable to have systematic measurements extending from low to high temperatures for a set of selected graphite samples with thermal conductivity covering a wide range. While knowing that the thermal conductivity maxima falling on a straight line in logarithmic plot is a characteristic feature of the thermal conductivity of a metallic element* and therefore can hardly be true for graphite, the following tentative equation has been derived for this line:

$$k_m = 4.64 \times 10^{10} T_m^{-4.35} \qquad (1)$$

where T_m is the temperature corresponding to the thermal conductivity maximum k_m. This line (a curve in linear plot) is intended mainly for the pitch-bonded graphite varieties.

Pitch-bonded artificial graphite is a mixture of crystalline graphite and cross-linking intercrystalline carbon which may have also been graphitized or partially graphitized, and is usually of high purity but low density, with numerous pores distributed throughout. Its thermal conductivity (or thermal resistivity) is the result of contributions from all sources and is therefore affected by many factors. In order to understand some of the factors affecting its thermal conductivity, the production process is here briefly reviewed [28, 29]. In manufacturing the pitch-bonded graphite, the raw material such as calcined petroleum coke is first crushed or milled to obtain fine particles, which are then combined with coal tar pitch to make the plastic mix. This mixture is heated to assure homogeneity and is then formed into pieces by extrusion or molding. The formed pieces are then heated by gas to a temperature of 750 to 900 C in a kiln to coke the pitch binder in the pieces to develop an infusible carbon bond

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*See References [2-4] of Part I of this report.

(the so-called first bake). In order to improve the density and other properties of the final product, the baked pieces are pitch-impregnated at this stage. Finally the impregnated pieces are heated in an electric furnace to a temperature in the 2600-3000 C range to convert carbon into graphite, known as graphitizing.

First of all, the thermal conductivity of pitch-bonded artificial graphite is affected by the nature of the starting raw material. Cokes from different sources behave differently with respect to the shapes of the crushed particles. Some yield longer and more splintery particles than others and each coke source tends to have a different particle eccentricity, which affects the degree of alignment on molding or extrusion. The other major difference among petroleum cokes is the graphiticity, or perfection attained by the graphite crystals after heating to 2600 to 3000 C, which affects greatly the properties of the final products. Besides the difference in the attainable perfection of graphitization, some petroleum cokes are also graphitized more easily than the others and require lower graphitizing temperature. Thus the sensitivity of thermal conductivity to thermal history can vary considerably with graphites of different coke sources. Therefore, graphite samples of the same composition and manufactured under identical process conditions but from different coke sources might have different anisotropy ratios and different thermal conductivities.

Purity of the sample is an important factor affecting thermal conductivity. The purity of artificial graphite is usually high, higher than that of the natural graphite [31]. This is partly because, during the graphitization process, a large fraction of the impurities, which are present in the original materials to the extent of about 1 percent, distill away, since the temperatures involved are higher than the boiling points of most of the impurity compounds.

Density (or porosity) is another important factor. Results on the variation of thermal conductivity of graphite with bulk density obtained by workers at Battelle Memorial Institute and reported by Caecciotti [32] showed that the thermal conductivities of a series of samples of graphite measured parallel to the direction of extrusion with densities 1.41, 1.55, 1.65, 1.70, and 1.75 g cm^{-3} are, respectively, 0.795, 1.21, 1.46, 1.88, and 2.34 Watt $cm^{-1}K^{-1}$. The conductivity versus density curve is nearly linear in the density range from 1.41 to 1.65 g cm^{-3} and also in the range from 1.65 to 1.75 g cm^{-3} with a gradual change of slope around 1.65 g cm^{-3}. Thus, in the density range from 1.41 to 1.65 g cm^{-3}, samples with 1 percent difference in density would have about 5 percent difference in thermal conductivity, while in the range 1.65 to 1.75 g cm^{-3}, 1 percent difference in density would cause about 10 percent difference in thermal conductivity. It should be noted that besides the bulk density (or total porosity), the size, shape, number, and the way of distribution of the pores also have effect on thermal conductivity. In the same graphite stock, thermal conductivity and density can vary not only from piece to piece but also within a piece of graphite. In many cases in a large piece of graphite thermal conductivity and density are the highest near the surface and are the lowest at the center of the piece, with intermediate values gradually decreasing from the surface to the central region. Consequently, specimens cut out of the same piece of graphite may not have the same thermal conductivity and density.

As mentioned before, the thermal conductivity of graphite is roughly proportional to the size of the crystallites, which make up the grains (graphitic particles). Thus the crystallite size is a very important factor influencing thermal conductivity. Due to the large anisotropy of graphite crystals, thermal conductivity is affected also by the degree of ordering of the crystallites. Another important factor is the crystal imperfection; the type and the concentration of defects are of important influence. The effect of lattice defects on the thermal conductivity of graphite has been extensively studied [see, for example, 10, 26, 33-40] by investigating the effects of irradiation damage on thermal conductivity. The thermal conductivity of graphite is drastically reduced by irradiation, which produces lattice defects, and it can be recovered by annealing. Smith and Rasor [10] found that neutron irradiation causes the thermal conductivity of graphite to decrease markedly at a rate that decreased with exposure time and also the exponent of the temperature dependence decreases with exposure. Mason and Knibbs [37] found that when the crystallite size of graphite is so small (<100 Å) that the number of crystal layers per unit volume is greater than the number of displaced atoms, clusters cannot form and the thermal resistivity is directly proportional to the irradiation dose, and that when the crystallite size is large (>100 Å), so that the diameter is greater than the distance between clusters, the number of clusters is independent of crystallite size and the thermal resistivity varies only as the square root of the dose. Unpublished work by Meyer [40] indicated that the irradiation effect on thermal conductivity is inversely proportional to the irradiation temperature from room temperature to 1400 C.

The thermal conductivity of graphite is affected by the size of the graphitic particles (grain size). However, this effect is different with different type of graphites, and no general conclusion can therefore be drawn. As discussed in detail before, due to the planar shape of the calcined petroleum coke particles, in the forming process the long axes of the particles tend to take a preferred orientation: either parallel to the direction of extrusion or perpendicular to the direction of molding pressure, and the final graphite product retains the same pattern of grain orientation. Therefore, the thermal conductivity is highly dependent on the grain orientation and also on the degree of ordering of the grains.

The graphitizing temperature has a tremendous effect on thermal conductivity. During graphitization, the thermal conductivity of the material can increase by a factor of the order of twenty-five [28]. This is due to the increased perfection, growth, and rearrangement of the graphite crystallites, these being quite small and in random arrangement in the gas-baked carbon piece. The thermal conductivity of any piece of graphite is, therefore, directly dependent upon the highest temperature reached in graphitization. The higher the graphitizing temperature, the greater the temperature uniformity and the longer the graphitizing time, the higher is the thermal conductivity of the end product. Consequently, the heat treatment associated with measurements on a sample of graphite made at temperatures higher than its graphitizing temperature may increase its thermal conductivity. It should be noted, as mentioned before, that some petroleum cokes are graphitized more easily than others and therefore the sensitivity of thermal conductivity to thermal history can vary considerably.

The thermal conductivity of graphite from room temperature to about 2000 K decreases gradually and monotonically with increasing temperature and varies roughly as T^{-1}, in accord with the theory of phonon conduction. Above 2000 K the thermal conductivity varies much more slowly than T^{-1} and in fact becomes nearly independent of temperature due to the contribution of ambipolar electronic thermal conduction, as discussed earlier. However, at very high temperatures approaching the sublimation temperature of graphite, the thermal conductivity of pitch-bonded graphite decreases abruptly, falling by about an order of magnitude in a relatively small temperature interval [41-43]. Euler [42] regarded this as being due to the loosening of the graphite structure at these very high temperatures, and a consequent large irreversible drop in density. However, Rasor and McClelland [41] found no permanent change in density from their measurements. Since the specific heat of graphite measured by them has an abrupt and large increase at about the same temperature at which the thermal conductivity has an abrupt and large decrease, they explained this striking feature being due to the formation of thermally produced lattice defects - vacant lattice sites, and suggested a vacancy concentration of about 0.5 atomic percent at the sublimation temperature and an energy of formation of 7.7 ±0.5 eV for the vacancies.

Golovina and Kotova [44] have demonstrated that when graphite is heated in a gaseous reagent such as carbon dioxide or oxygen at high temperatures above 2300 K, unsteady-state internal diffusion within the graphite specimen occurs such that carbon atoms diffuse from within the solid to the surface on which the reaction with the gas takes place. The density of the graphite decreases, and that of the surface layer reduces to about one half of the original density. With increase in temperature and reaction time the carbon atoms are removed from ever deeper layers of the graphite specimen and the depth of loosening increases. However, the density at the surface changes only insignificantly and remains at about one half of the original density for a wide range of temperatures and for various degrees of removal of graphite mass of 15 to 30 percent. The conditions of Golovina and Kotova differed from those of Euler [42, 43] and of Rasor and McClelland [41], furthermore, Anacker and Mannkopff [67] report experiments which yielded no marked drop in thermal conductivity, so more studies near the upper temperature limit of graphite are required.

A correlation between the thermal and electrical conductivities of graphite was first proposed by Powell in 1937 [45]. For Acheson graphite from room temperature to 1073 K he suggested the following equation for the variation of the Lorenz function with temperature:

$$L = k\sigma^{-1}T^{-1} = 0.123\ T^{-1.8} \tag{2}$$

or

$$k = 0.123\sigma T^{-0.8} \tag{3}$$

where L is the Lorenz function, k the thermal conductivity in Watt $cm^{-1}K^{-1}$, σ the electrical conductivity in $ohm^{-1}\ cm^{-1}$, and T the temperature in K. Based upon further available data, Powell [46] later proposed the equation

$$k = 2.2\sigma T^{-1.3} + 0.18 \tag{4}$$

for the Ceylon and Hilger and Acheson graphites and

$$k = 3.1\sigma T^{-1.3} + 0.25 \tag{5}$$

for the Cumberland graphites.

Currie, Hamister, and MacPherson [28] derived an empirical relationship between the room-temperature thermal conductivity and the room-temperature electrical resistivity of pitch-bonded artificial graphite based upon the data of Powell [45], Powell and Schofield [47], Johnson [48], Neubert [49], and of Micinski [50]. They claimed that the following equation would yield the thermal conductivity of graphite at 25 C accurate to within 5 percent:

$$k = 0.0013\rho^{-1} \tag{6}$$

where the thermal conductivity, k, is in Watt $cm^{-1}K^{-1}$ and the electrical resistivity, ρ, is in ohm cm and measured at 25 C.

Mason and Knibbs [51] demonstrated that for a given graphite the thermal resistivity varies linearly with electrical resistivity when either the orientation or the crystallinity varies. They attributed this correlation to the fact that the flow of both heat and electricity is restricted essentially to the crystal layer planes and that in both cases the flow is controlled by scattering at crystal boundaries. They derived the following relationship, applicable at 20 C,

$$k = \frac{1}{707\rho + 0.0813} \tag{7}$$

which was shown to hold fairly well for over forty graded graphites, and enables the thermal conductivity to be estimated from electrical measurements to within ±15 percent.

Although there are 580 curves listed in Table 15, yet most of the measurements are for low and/or moderate temperatures and many are for unidentified graphite specimens. It is found that no graphite has available thermal conductivity data covering the full range of temperature.

The graphites studied in the following section include Acheson graphite*, ATJ graphite, pyrolytic graphite, 875S graphite, and 890S graphite. They are selected mainly because they seem to be the only graphites with available thermal conductivity data covering a fairly wide range of temperature. This selection, therefore, does not give a fair representation of all the graphites in common usage.

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*It is understood that most of the other pitch-bonded artificial graphites can also be called Acheson graphite. Here this group is intended mainly for those early measurements in which the graphite specimens used were known only as Acheson graphite.

There are many other important graphites for which, unfortunately, the available thermal conductivity data are not sufficient at the present time to include them in this study. It is hoped that due to the current great interest in graphites many further measurements on thermal conductivity will be made over wide ranges of temperature and that in the subsequent updating and revision of this work many other graphites can then be included. It is interesting to note that in the Directory of Graphite Availability [52] published in 1963, there are listed over 230 grades of graphites manufactured by 18 companies in the United States. For many of these graphites there are not any published experimental thermal conductivity data available.

The available data for the five graphites being studied are separately plotted in Figures 18 to 22. The information on the specimens corresponding to the respective curves in the figures has been given in Table 15. Each figure includes two heavy broken lines which seem likely to represent the most probable curves for each graphite. However, due to the lack of experimental data in low and/or high temperature regions for most of these graphites, many sections of the recommended curves have been obtained by extensive extrapolations and are very tentative and subject to modification and revision in the light of further work.

The recommended thermal conductivity values are reported collectively in Figures 16 and 17 and in Tables 16a and 16b. Table 16a gives temperatures in degree K while Table 16b gives temperatures in degree C. In the tables, the third significant figure is given only for internal comparison and for smoothness and is not indicative of the degree of accuracy. Some pertinent comments regarding the treatment of the data for each graphite are given in the following section.

B. Thermal Conductivity of a Group of Selected Graphites

Acheson Graphite

Acheson graphite is generally referred to as the graphite manufactured by using the production process invented by Dr. E. G. Acheson (1856-1931) [53]. Before the second world war and especially in Europe, the commercially available artificial graphite was known only as Acheson graphite. Most of the thermal conductivity data for this group are from early measurements and are therefore of historical interest also.

There are 20 curves available. As shown in Figure 18 , the available data for specimens measured along the direction of extrusion cover the temperature range from 93 to 2000 K while those for specimens measured perpendicular to the direction of extrusion are over the range 93 to 3048 K. Most of the data were produced by Powell [45] and Powell and Schofield [47] for two different sets of specimens, and their data are in good agreement when taking the anisotropy of the specimens into account. Buerschaper's [54] data for the two principal directions(curves 44 and 45) near room temperature are also in agreement with their data. However, Buerschaper's data increase monotonically as the temperature decreases down to 93 K indicating that the thermal conductivity maxima are at temperatures at least below 93 K, which is considered very unlikely. Although there is no experimental information available for the locations of the thermal conductivity maxima, it is believed that the maxima of the curves would not be at temperatures lower than 250 K.

The recommended curve from 300 to 3000 K for the direction perpendicular to the axis of extrusion follows the curves of Powell and Schofield [47], while the curve for the direction parallel to the axis of extrusion from 300 to 1000 K passes through the mean of Powell's curves [45]. From these two sections of the recommended curves so obtained, the anisotropy ratio is calculated and is equal to 1.375 at 300 K and 1.36 at 1000 K. Extrapolating these two values to higher temperatures gives 1.349 at 1500 K, 1.339 at 2000 K, 1.328 at 2500 K, and 1.317 at 3000 K. Based upon these values for the anisotropy ratio, the curve for the direction parallel to the axis of extrusion is extrapolated from 1000 to 3000 K.

Both recommended curves have been extensively extrapolated from 300 K down to 0 K according to the general trend of the low-temperature curves of other graphites. This is intended mainly for indicating the trend of the thermal conductivity values of this graphite at low temperatures.

The uncertainty of the recommended values that are derived from experimental data is probably of the order of ±10 to ±20 percent, and that of the values obtained by extensive extrapolation is probably twice as great.

ATJ Graphite

ATJ graphite* is a pitch-bonded petroleum-coke-base graphite, produced by the Carbon Products Division of Union Carbide Corporation. It is a widely known premium grade graphite with very fine grains (0.006 inch maximum) and is formed by molding into rectangular blocks, 9 x 20 x 24 inches in size. Nominal room-temperature properties [29] are: bulk density 1.73 g cm^{-3} with standard deviation 0.036 g cm^{-3}(i.e., 2.1 percent), electrical resistivity 11.0 x 10^{-4} ohm cm (with grain), 14.5 x 10^{-4} ohm cm (across grain), and anisotropy in electrical resistivity 1.32.

As shown in Figure 19, there are nineteen curves available for the thermal conductivity of this graphite. The three curves 93, 111, and 120 for GBH graphite [41, 55, 56] have been included here. Since the two single data points (curve numbers 344 and 345) at room temperature are believed to be calculated values [29], the experimental data cover the temperature range only from 484 to 3276 K.

For the direction perpendicular to the molding pressure, the data of Lucks and Deem(curve 93)[55]are in good agreement with those of Fieldhouse, Lang, and Blau(curve 217)[57] in the narrow temperature range 650 to 800 K. Above 800 K these two sets of data diverge, and at 1200 K they differ by about 35 percent. At these higher temperatures Lucks and Deem's data (curve 93) appear to be high, which may probably be due to the uncertainty in the reference data at high temperatures in the early years for the Armco iron bar used as a comparative reference material. On the other hand, the data of Fieldhouse et al. (curve 217) at temperatures above 1000 K are too low, since their curve (217) decreases almost linearly to values at temperatures above 1420 K lower than their other curve (216), which is for a sample measured with heat flow parallel to the molding pressure. The recommended curve from 484 to 1000 K follows curves 93 and 217, and is extended in the temperature range 1400 to 2000 K through the mean of curves 269 and 270 of workers at the Parma Research Laboratory of Union Carbide Corporation [58] and in the range 2400 to 3273 K through the mean of curve 120 of Rasor and McClelland [41]. It is then extrapolated to 3800 K according to the general trend indicated by the data of Rasor and McClelland [41] for 875S graphite.

For the direction parallel to the molding pressure the recommended curve from 600 to 2000 K lies close to curve 216 of Fieldhouse, Lang, and Blau[57] and curve 271 of workers at Parma Research Laboratory [58], and is then extrapolated to 3800 K.

The resultant recommended curves yield anisotropy ratio of 1.32 at 300 K, decreasing to 1.29 at 1000 K, 1.25 at 2000 K, and 1.19 at 3800 K. Both curves have been extensively extrapolated from room temperature down to absolute zero according to the general trend of the low-temperature curves of other graphites.

The uncertainty of the recommended values that are derived from experimental data is probably of the order of ±10 to ±20 percent, and that of the values obtained by extensive extrapolation is probably twice as great.

Pyrolytic Graphite

Pyrolytic graphite is produced by the deposition of carbon from a gaseous hydrocarbon onto a heated surface at high temperature of the order of 2000 C. As shown in Figure 20, there are 77 curves available for this graphite.

The general feature of the thermal conductivity of pyrolytic graphite has been briefly reviewed in the INTRODUCTION. Figure 20 shows clearly the large anisotropy in the thermal conductivity. Since the thermal conductivity of this graphite is highly sensitive to small sample variations, curves for the samples measured in the same direction spread also into a very wide band. It has been noted [22] that significant variations in thermal conductivity can be encountered with pyrolytic graphites deposited at identical temperature. This effect is ascribed to be a result of influencing factors in the manufacturing procedure other than temperature.

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*This graphite was previously designated in the development stage as GBH graphite.

The highest thermal conductivity curve (No. 491) for the direction parallel to the layer planes is that of De Combarieu [59] for a specimen deposited at 2100 C and annealed under a pressure of 200 bars for 10 to 15 minutes at 2800 C. The recommended curve follows Combarieu's data to 300 K and is then extended to higher temperatures according to the temperature dependency indicated by Taylor's [60] curve (No. 519), which is for a sample annealed at 3300 C. At high temperatures the recommended curve lies close to curve 514 of Johnson and Watt [61]and nearly passes through a point (No. 558) obtained by Hoch and Vardi [62]. It is interesting to note that at room temperature the thermal conductivity of highly-oriented and well-annealed pyrolytic graphite in the direction parallel to the layer planes is 4.7, 5.0, and 11.3 times higher than the thermal conductivity of silver, copper, and tungsten, respectively, and is only slightly lower than that of Type IIa diamond. At 2000 K it is still 2.5 times higher than that of tungsten.

The recommended values for the direction perpendicular to the layer planes are derived from the values for the direction parallel to the layer planes based upon the assumed anisotropy ratio given as a function of temperature. The anisotropy ratio in the thermal conductivity of pyrolytic graphite at temperatures below 1 K lies between 2 and 3 as reported by Slack [25]. Its exact value is determined by the elastic constants and by the ellipsoidal shape of the crystallites. In the liquid-helium temperature region Klein and Holland [22] found that the ratio is close to 3, which remains the same for samples deposited at different temperatures, but rises rapidly with temperature above 20 K. For highly-oriented and well-annealed sample, Hooker, Ubbelohde, and Young [2] found that the ratio increases to about 100 at 90 K, 196 at 150 K, 215 at 200 K, 211 at 250 K, and 210 at 300 K. Taylor [60] also found that the anisotropy ratio for his samples is 210 at 300 K. From 300 to 900 K Taylor's data indicate a nearly constant anisotropy ratio. Since the data of Taylor [60] and of Hooker et al. [2] are close to that of De Combarieu [59] and since their samples are all similar, the above-mentioned values for the anisotropy ratio at different temperatures are adopted for deriving the recommended values for the direction perpendicular to the layer planes. The resulting curve has a maximum conductivity of 1.55 Watt $cm^{-1}K^{-1}$ at about 30 K, and lies close to the curves (No. 579, 498, and 499) of Hooker, Ubbelohde, and Young [63, 2] in the temperature range from 90 to 300 K. From 250 to 830 K it has the same temperature dependency as curve 520 of Taylor [60]. It is noted that the values are lower than the thermal conductivity of aluminum oxide by 3.7 and 5 times at room temperature and 2000 K, respectively.

The uncertainty of the recommended values for the direction parallel to the layer planes at temperatures below 1500 K is probably of the order of ±10 to ±20 percent, and that at temperatures above 1500 K is probably twice as great. The values for the direction perpendicular to the layer planes are intended only for indicating the general trend.

875S Graphite

875S graphite* is a medium-grain (0.032 inch maximum), pitch-bonded petroleum-coke-base graphite, which is formed by extrusion into rods 20 or 24 inches in diameter and 72 inches long. It is produced by Speer Carbon Co., with typical density 1.67 g cm^{-3} and typical ash content 0.70 percent [64]. As shown in Figure 21, there are six curves available for the thermal conductivity of this graphite over the temperature range from 433 to 3708 K.

For the direction perpendicular to the axis of extrusion, the data of Lucks and Deem (curve 94) [55] agree well with the higher curves (117, 114, and 115) of Rasor and McClelland [41]. Curve 117 is the result of measurements made after prolonged heating the specimen at temperatures greater than 2480 K and thus represents the stable thermal conductivity values at high temperatures. Accordingly, the recommended curve from 433 to 3800 K follows closely the curves 94, 117, 114, and 115.

For the direction parallel to the axis of extrusion, only the data of Fieldhouse, Hedge, and Waterman (curve 112) [56] are available. If a smooth curve is drawn through their data, the resulting curve, together with the recommended curve for the direction perpendicular to the axis of extrusion just obtained above, will give

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*This graphite was previously designated in the development stage as 7087 graphite.

anisotropy ratios of 1.64 at 800 K, 1.52 at 1400 K, and 1.49 at 1800 K. These values of the anisotropy ratio for the thermal conductivity are much greater than the anisotropy ratio of 1.19 for the electrical resistivity of this graphite as reported by Rasor and McClelland [41]. This is inconsistent with the statement of Rasor and McClelland [41] that these two anisotropy ratios are approximately the same. Since the data of Lucks and Deem [55] and of Rasor and McClelland [41] for the direction perpendicular to the axis of extrusion are in good agreement, curve 112 is suspected to be too high. This conclusion is further supported by the fact that, as shown in Figure 15, curve 112 is so high that it approaches or even exceeds some of the curves for the same temperature and direction for pyrolytic graphite and hot-pressed graphites of much greater anisotropy. It is decided therefore that the recommended curve will not follow curve 112.

It is noted that the anisotropy ratio of pitch-bonded graphite above room temperature is generally decreasing with increase in temperature. To give a little weight to curve 112, it is assumed that the anisotropy ratio of this graphite at 3800 K is 1.19, which is the anisotropy ratio of this graphite for the electrical resistivity as reported by Rasor and McClelland [41], and that the anisotropy ratio decreases by about 10 percent from room temperature to 3800 K. The latter assumption is based upon the anisotropy ratio of ATJ graphite which is also 1.19 at 3800 K as indicated by the derived recommended values and which decreases by about 10 percent from room temperature to 3800 K. Thus the recommended values from room temperature to 3800 K for the direction parallel to the axis of extrusion are calculated from the values for the direction perpendicular to the axis of extrusion according to the assumed values of anisotropy ratio.

Both of the recommended curves have been extensively extrapolated down to 0 K to indicate the general trend of the curves.

The uncertainty of the recommended values for the direction perpendicular to the axis of extrusion that are derived from experimental data is probably of the order of ±10 to ±20 percent, and that of the values obtained by extrapolation is probably twice as great. The values for the direction parallel to the axis of extrusion are intended only for indicating the general trend.

890S Graphite

890S graphite* is a fine-grain (0.008 inch maximum), pitch-bonded petroleum-coke-base graphite, which is formed by extrusion into rods 2.5 to 8 inches in diameter and 24 to 72 inches long. It is produced by Speer Carbon Company, with typical density 1.63 g cm^{-3} and typical ash content 0.08 percent [65]. As shown in Figure 22, there are six curves available for the thermal conductivity of this graphite over the temperature range from 798 to 3786 K.

For the direction perpendicular to the axis of extrusion, all the three available curves are of Rasor and McClelland [41]. A curve passing through the mean of their data from 1000 to 3800 K serves as the recommended curve.

For the direction parallel to the axis of extrusion, all the three curves, which cover the temperature range 798 to 1809 K, are of Fieldhouse, Hedge, Lang, Takada, and Waterman [66]. Of these three curves, curve 6, which is for the specimen heated only once, coincides with the curve of Rasor and McClelland, noting that they are for different directions. Curve 7, which is for the specimen heated twice, is higher than curve 6 by about 20 percent, and curve 8, which is for the specimen heated three times, crosses all the curves and is higher than curve 6 by 30 percent at 800 K and lower than Rasor and McClelland's curve by 25 percent at 1800 K. Under this confusing circumstance, a small section of the recommended curve has been drawn through the middle portion of curve 8, using as a guide the general trend of the other recommended curves.

From these two sections of the recommended curves the anisotropy ratio can be calculated and is equal to 1.18 at 1000 K. By assuming that the anisotropy ratio above room temperature decreases linearly with increase

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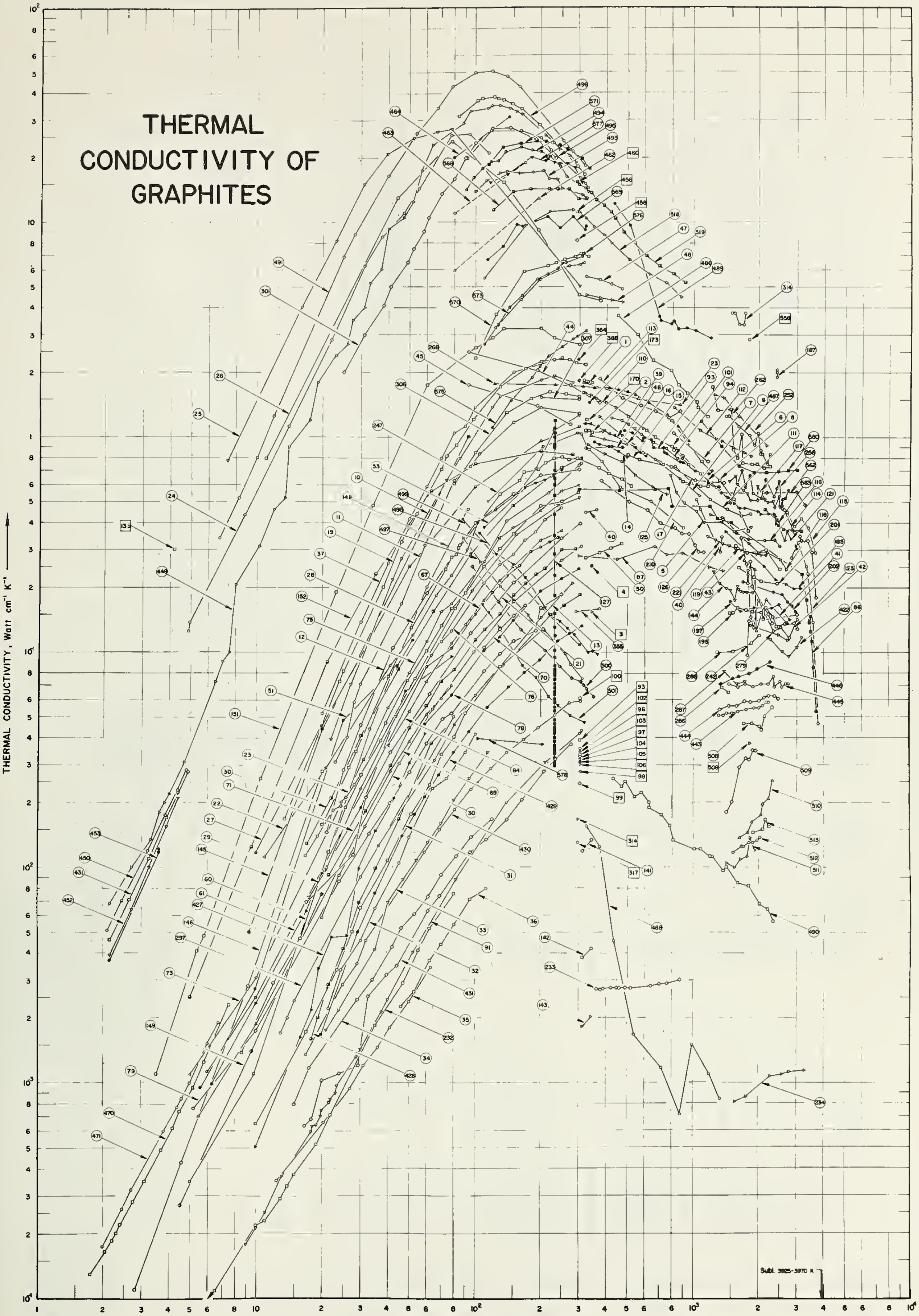
*This graphite was previously designated in the development stage as 3474D graphite.

in temperature and that at 3800 K it is equal to 1.08, which is the anisotropy ratio for the electrical resistivity of this graphite as reported by Rasor and McClelland [41], the recommended values from 1000 to 3800 K are obtained by calculation based upon the recommended values already derived for the direction perpendicular to the axis of extrusion.

Both recommended curves have been excessively extrapolated from 1000 K down to 0 K to indicate the general trend of the curves.

The uncertainty of the recommended values above 1000 K that are derived from experimental data is probably of the order of ±10 to ±20 percent; and that of the values obtained by extensive extrapolation is probably twice as great. The values below 1000 K are intended only for indicating the general trend.


THERMAL CONDUCTIVITY OF GRAPHITES
THERMAL CONDUCTIVITY, Watt cm^{-1} K^{-1}
TEMPERATURE, K
10^2
8
6
5
4
3
2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
1
2
3
4
5
6
8
10
10^2
10^3
10^4
Subl. 3825-3970 K
496
571
494
577
495
493
464
463
462
460
568
456
569
458
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47
519
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486
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501
314
558
570
575
44
364
388
307
1
113
173
187
268
45
110
23
93
101
306
575
170
2
39
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16
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94
112
262
7
6
487
252
247
6
8
111
580
117
259
562
583
116
114
121
115
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201
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123
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422
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149
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210
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221
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119
43
144
197
195
4
127
3
355
13
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500
100
501
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76
78
279
286
242
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287
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429
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427
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431
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FIG 15

TABLE 15. SPECIFICATIONS OF THE SPECIMENS OF GRAPHITES

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	47	Raeth, C.H.	1944	L	317-345	1583	Specimen 2. 607 cm long and circular cross-sectional area 5. 068 cm^2; measured lengthwise.
2	47	Raeth, C.H.	1944	L	321-344	1583	Similar to the above specimen but only 2. 523 cm long and measured crosswise.
3	13	Weeks, J. L. and Seifert, R. L.	1953	C	343. 2	Acheson graphite	Density 1. 7 g cm^{-3}; heat flow direction perpendicular to the axis of extrusion; Armco iron used as the comparative standard.
4	13	Weeks, J. L. and Seifert, R. L.	1953	C	343. 2	Acheson graphite	Similar to the above specimen but heat flow parallel to the axis of extrusion.
5	48	Fieldhouse, I. B., Hedge, J. C., Lang, J. L., Takada, A. N., and Waterman, T. E.	1956	L	789-1869	GBE	Specimen 7 in. in dia and 1. 5 in. thick; density 1. 596 g cm^{-3}; measured with unidirectional heat flow through the disk.
6	48	Fieldhouse, I. B., et al.	1956	L	832-1284	3474D; 1	Similar to the above specimen but density 1. 612 g cm^{-3}.
7	48	Fieldhouse, I. B., et al.	1956	L	813, 1172	3474D; 2	Similar to the above specimen but the specimen being heated twice.
8	48	Fieldhouse, I. B., et al.	1956	L	798-1809	3474D; 3	Similar to the above specimen but the specimen being heated three times.
9	364	Kingery, W. D., Francl, J., Cable, R. L., and Vasilos, T.	1954	C	373-1073		Polycrystal; bulk density 1. 55 g cm^{-3}; porosity 30. 2%; dense Al_2O_3 used as the comparative material.
10	49	Tyler, W. W. and Wilson, A. C., Jr.	1953	L	22-280	Grade CS; A	Grade CS graphite (conventional coke base, pitch bonded and extruded); polycrystal; from National Carbon Co.; bulk density ~1. 70 g cm^{-3}; specimen axis perpendicular to the preferred C_0 axis orientation.
11	49	Tyler, W. W. and Wilson, A. C., Jr.	1953	L	23-300	Grade AGOT; B	Grade AGOT graphite with similar specifications as the above.
12	49	Tyler, W. W. and Wilson, A. C., Jr.	1953	L	21-300	Sample C	Polycrystal; natural graphite base, pitch bonded and molded; bulk density ~1. 80 g cm^{-3}; specimen axis perpendicular to the preferred C_0 axis orientation.
13	49	Tyler, W. W. and Wilson, A. C., Jr.	1953	L	26-280	Sample D	Similar to the above specimen but pitch bonded and molded from lampblack; bulk density ~1. 65 g cm^{-3}.
14	8	Sutton, W. H.	1960	L	351-497	Grade RT-0003 (Sample 1)	Specimen cut from a RT-0003 graphite block (National Carbon Co.); density ~1. 90 g cm^{-3}; heat flow perpendicular to grain orientation.
15	8	Sutton, W. H.	1960	L	500-1294	Grade RT-0003 (Sample 2)	Similar to the above specimen.
16	8	Sutton, W. H.	1960	L	339-495	Grade RT-0003 (Sample 3)	Similar to the above specimen but heat flow parallel to grain orientation; run No. 1.
17	8	Sutton, W. H.	1960	L	587-1394	Grade RT-0003 (Sample 3)	Second run of the above specimen.
18	8	Sutton, W. H.	1960	L	612-1384	Grade RT-0003 (Sample 3)	Third run of the above specimen.

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*See TPRC Data Book Vol. 3, Chapter 1, References [1]

TABLE 15. SPECIFICATIONS OF THE SPECIMENS OF GRAPHITES (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
19	50, 53, 163	Smith, A.W. and Rasor, N.S.	1954	E	14-320	AGOT-KC	Polycrystalline; extruded petroleum coke, pitch bonded; particle size 50 μ; crystallite size 0.3 μ; specimen size 0.10 x 0.03 x 1.25 in.; density 1.65 g cm^{-3} at 25 C; thermoelectric power -0.5 μ volt K^{-1}; Hall coefficient -0.6 emu; magneto resistivity 5.4 x 10^{-10} emu; electrical resistivity 6.2 milliohm cm; total magnetic susceptibility -20.44 x 10^{-6} cgs unit; orientation factor (ρ_{max}/ρ_{min}) = 2.0; measured parallel to the axis of extrusion.
20	50, 163	Smith, A.W. and Rasor, N.S.	1954	E	17-308	AGOT-KC	The above specimen exposed to neutron irradiation of 12.5 MWD/T (megawatt-days per ton) at <30 C.
21	50, 163	Smith, A.W. and Rasor, N.S.	1954	E	17-305	AGOT-KC	The above specimen exposed to neutron irradiaton of 48 MWD/T at <30 C.
22	50, 163	Smith, A.W. and Rasor, N.S.	1954	E	11-300	AGOT-KC	The above specimen exposed to neutron irradiation of 460 MWD/T at <30 C.
23	50, 163	Smith, A.W. and Rasor, N.S.	1954	E	17-308	AGOT-KC	The above specimen exposed to neutron irradiation of 1927 MWD/T at <30 C.
24	50, 358	Smith, A.W. and Rasor, N.S.	1954	C	4.9-116	Canadian natural graphite	Large crystallite (in the order of 10^{-2} cm); very low ash content; specimen size 1/4 x 1/20 x 1/100 in.; grade AWG graphite used as comparative material.
25	50, 358	Smith, A.W. and Rasor, N.S.	1954	C	7.3-300	Canadian natural graphite	Similar to the above specimen.
26	50, 358	Smith, A.W. and Rasor, N.S.	1954	C	11-299	Canadian natural graphite	Similar to the above specimen.
27	50	Smith, A.W. and Rasor, N.S.	1956	E	10-300	Pyrolytic graphite	Obtained by pyrolytic decomposition of a hydrocarbon; no pitch bonding.
28	50, 53, 163	Smith, A.W. and Rasor, N.S.	1954	E	20-520	AWG	Polycrystalline; molded petroleum coke; particle size 25 μ; crystallite size 0.2 μ; density 1.75 g cm^{-3} at 25 C; thermoelectric power +2.3 μ volt K^{-1}; Hall coefficient -0.47 emu; magneto resistivity 1.9 x 10^{-10} emu; electrical resistivity 14.3 milliohm cm; total susceptibility -20.60 x 10^{-6} cgs unit; orientation factor (ρ_{max}/ρ_{min}) = 1.3; measured parallel to the direction of the molding pressure.
29	50, 163	Smith, A.W. and Rasor, N.S.	1954	E	17-300	AWG	The above specimen exposed to neutron bombardment of 6 MWD/T at <60 C.
30	50, 163	Smith, A.W. and Rasor, N.S.	1954	E	20-308	AWG	The above specimen exposed to neutron bombardment of 22.7 MWD/T at <30 C.
31	50	Smith, A.W. and Rasor, N.S.	1956	E	10-205	SA-25	Polycrystalline; molded from lampblack; pitch bonded; particle size 0.3 μ; crystallite size 0.05 μ; density 1.55 g cm^{-3} at 25 C.
32	50	Smith, A.W. and Rasor, N.S.	1956	E	22-101	SA-25	The above specimen exposed to neutron bombardment of 12.5 MWD/T at ~30 C.
33	50	Smith, A.W. and Rasor, N.S.	1956	E	21-115	SA-25	The above specimen exposed to neutron bombardment of 22.7 MWD/T at ~30 C.
34	50	Smith, A.W. and Rasor, N.S.	1956	E	15-120	SA-25	The above specimen exposed to neutron bombardment of 146 MWD/T at ~30 C.
35	50	Smith, A.W. and Rasor, N.S.	1956	E	13-63	SA-25	The above specimen exposed to neutron bombardment of 460 MWD/T at ~30 C.
36	50	Smith, A.W. and Rasor, N.S.	1956	E	46-112	SA-25	The above specimen exposed to neutron bombardment of 460 MWD/T at ~30 C (probably second run of the above specimen).
37	50	Smith, A.W. and Rasor, N.S.	1956	E	20-250	AGOT-KC	The virgin specimen before bromination (experiment to show the effect of Br on thermal conductivity of graphite).

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*See TPRC Data Book Vol. 3, Chapter 1, References

TABLE 15. SPECIFICATIONS OF THE SPECIMENS OF GRAPHITES (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
38	50	Smith, A.W. and Rasor, N.S.	1956	E	10-300	AGOT-KC (Brom-graphite)	Brominated AGOT-KC graphite; 0.13 Br.
39	18	Powell, R.W. and Schofield, F.H.	1939	L	318-611	Acheson graphite; 1	Tubular specimen 75 cm long, 2.54 cm O.D., and 0.3 cm I.D.; electrical resistivity $\rho(0\text{ C}) = 0.00110$ ohm cm.
40	18	Powell, R.W. and Schofield, F.H.	1939	R	1048-1363	Acheson graphite; 2	Similar to the above specimen but $\rho(0\text{ C}) = 0.00105$ ohm cm.
41	18	Powell, R.W. and Schofield, F.H.	1939	R	1723-2713	Acheson graphite; 3	Similar to the above specimen but $\rho(0\text{ C}) = 0.00077$ ohm cm.
42	18	Powell, R.W. and Schofield, F.H.	1939	R	1798-3048	Acheson graphite; 4	Similar to the above specimen but $\rho(0\text{ C}) = 0.00077$ ohm cm.
43	18	Powell, R.W. and Schofield, F.H.	1939	R	1683-2343	Acheson graphite; 5	Similar to the above specimen but $\rho(0\text{ C}) = 0.00067$ ohm cm.
44	20	Buerschaper, R.A.	1944	F	93-373	Acheson graphite	Specimen 16 cm long, 2.9 cm in dia; cut from Acheson graphite electrode (from National Carbon Co.); specimen axis parallel to the electrode axis.
45	20	Buerschaper, R.A.	1944	F	93-373	Acheson graphite	Similar to the above specimen but cut perpendicular to the electrode axis.
46	19	Brown, A.R.G., Watt, W., Powell, R.W. and Tye, R.P.	1956	C	323-473	Commercial graphite	High purity; specimen (tubular) 4.5 cm long, 0.95 cm O.D., and 0.75 cm I.D.; density 1.65 g cm^{-3}; electrical resistivity at 20, 50, 100, 150, and 200 C being, respectively, 762, 760, 772, 790, and 816 μohm cm; a bar of iron of known thermal conductivity used as comparative material.
47	19	Brown, A.R.G., et al.	1956	C	323-473	Deposited carbon	Also known as pyrolytic graphite; 99.75 ±0.2 pure with undetectable ash content; deposited from AR grade benzene at 2100 C in a vacuum of 10^{-3} cm Hg; tubular specimen 4.5 cm long, 0.95 cm O.D., and 0.75 cm I.D.; density 1.65 g cm^{-3}; electrical resistivity at 20, 50, 100, 150, and 200 C being, respectively, 245, 230, 215, 200, and 195 μohm cm; measured parallel to axis of tube and parallel to the pronounced layered structure of the specimen.
48	19	Brown, A.R.G., et al.	1956	C	323-473	Deposited carbon	Similar to the above specimen but deposited at 2000 C; electrical resistivity at 20, 50, 100, 150, and 200 C being, respectively, 380, 360, 330, 305, and 290 μohm cm; measured parallel to axis of tube and parallel to the pronounced layered structure of the specimen.
49	19	Brown, A.R.G., et al.	1956	C	323-473	Deposited carbon	Similar to the above specimen but deposited at 1900 C; electrical resistivity at 20, 50, 100, 150, and 200 C being, respectively, 1.645, 1.585, 1.47, 1.37 and 1.27 milliohm cm; measured parallel to axis of tube and parallel to the pronounced layered structure of the specimen.
50	19	Brown, A.R.G., et al.	1956	C	323-473	Deposited carbon	Similar to the above specimen but deposited at 1800 C; electrical resistivity at 20, 50, 100, 150 and 200 C being, respectively, 3.23, 3.17, 3.065, 2.96, and 2.86 milliohm cm; measured parallel to axis of tube and parallel to the pronounced layered structure of the specimen.

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*See TPRC Data Book Vol. 3, Chapter 1, References

TABLE 15. SPECIFICATIONS OF THE SPECIMENS OF GRAPHITES (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
51	51	Deegan, G. E.	1956	E	5.6-78	C-369, No. 1 (grade AWG)	Specimen 10 mil thick cut from a block of pitch-bonded artificial graphite; electrical resistivity varied from 4.009 to 3.418 milliohm cm at 5.6 to 78 K respectively; irradiated at 103 K by 8.6 Mev protons of 0.65 μah cm^{-2} (micro ampere hr per square centimeter); measured parallel to molding pressure.
52	51	Deegan, G. E.	1956	E	6.0-190	C-369, No. 1 (grade AWG)	The above specimen pulse-annealed for 5 min at 225 K before irradiation; electrical resistivity varied from 3.901 to 2.439 milliohm cm at 6.0 to 190 K, respectively.
53	51	Deegan, G. E.	1956	E	78-250	C-369, No. 1 (grade AWG)	The above specimen pulse-annealed at 375 K before irradiation; electrical resistivity varied from 2.968 to 1.924 milliohm cm at 78 to 250 K respectively.
54	51	Deegan, G. E.	1956	E	78	C-369, No. 1 (grade AWG)	The above specimen measured at 78 K after being pulse-annealed at temperatures ranging from 125 to 375 K.
55	51	Deegan, G. E.	1956	E	110	C-369, No. 1 (grade AWG)	The above specimen measured at 110 K after being pulse-annealed at 225 and 375 K.
56	51	Deegan, G. E.	1956	E	130	C-369, No. 1 (grade AWG)	The above specimen measured at 130 K after being pulse-annealed at 225 and 375 K.
57	51	Deegan, G. E.	1956	E	150	C-369, No. 1 (grade AWG)	The above specimen measured at 150 K after being pulse-annealed at 225 and 375 K.
58	51	Deegan, G. E.	1956	E	170	C-369, No. 1 (grade AWG)	The above specimen measured at 170 K after being pulse-annealed at 225 and 375 K.
59	51	Deegan, G. E.	1956	E	190	C-369, No. 1 (grade AWG)	The above specimen measured at 190 K after being pulse-annealed at 225 and 375 K.
60	51	Deegan, G. E.	1956	E	8.6-297	C-369, No. 2 (grade AWG)	Similar to the above specimen but isothermal-annealed for 2 wks at 300 K; electrical resistivity varied from 4.139 to 2.372 milliohm cm at 8.6 to 297 K respectively; irradiated by protons of 0.31 μah cm^{-2}.
61	51	Deegan, G. E.	1956	E	6.3-78	C-369, No. 3 (grade AWG)	Similar to the above specimen but electrical resistivity varies from 5.155 to 4.822 milliohm cm at 6.3 to 78 K respectively; irradiated with protons at 103 K of 7.9 μah cm^{-2}.
62	51	Deegan, G. E.	1956	E	78-130	C-369, No. 3 (grade AWG)	The above specimen pulse-annealed for 5 min at 150 K; electrical resistivity varied from 4.895 to 4.736 milliohm cm at 78 to 130 K respectively.
63	51	Deegan, G. E.	1956	E	6.0-150	C-369, No. 3 (grade AWG)	The above specimen pulse-annealed at 175 K; electrical resistivity varied from 5.155 to 4.633 milliohm cm at 6.0 to 150 K respectively.
64	51	Deegan, G. E.	1956	E	78-170	C-369, No. 3 (grade AWG)	The above specimen pulse-annealed at 200 K; electrical resistivity varied from 4.754 to 4.408 milliohm cm at 78 to 170 K respectively.
65	51	Deegan, G. E.	1956	E	6.0, 78	C-369, No. 3 (grade AWG)	The above specimen pulse-annealed at 250 K; electrical resistivity at 6.0 and 78 K being, respectively, 4.557 and 4.291 milliohm cm.
66	51	Deegan, G. E.	1956	E	6.0, 78	C-369, No. 3 (grade AWG)	The above specimen pulse-annealed at 300 K; electrical resistivity at 6.0 and 78 K being, respectively, 4.179 and 4.30 milliohm cm.

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*See TPRC Data Book Vol. 3, Chapter 1, References

TABLE 15. SPECIFICATIONS OF THE SPECIMENS OF GRAPHITES (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
67	51	Deegan, G. E.	1956	E	6. 0-300	C-369, No. 3 (grade AWG)	The above specimen pulse-annealed at 375 K; electrical resistivity varied from 4. 295 to 2. 92 milliohm cm at 6. 0 to 300 K respectively.
68	51	Deegan, G. E.	1956	E	78	C-369, No. 3 (grade AWG)	The above specimen measured at 78 K after being pulse-annealed at temperatures from 125 to 375 K.
69	51	Deegan, G. E.	1956	E	5. 5-78	C-369, No. 4 (grade AWG)	Similar to the above specimen but not annealed; irradiated at 103 K by protons of 12. 8 μah cm^{-2}; electrical resistivity (before irradiation) varied from 5. 261 to 4. 943 milliohm cm at 5. 5 to 78 K respectively.
70	51	Deegan, G. E.	1956	E	78-170	C-369, No. 4 (grade AWG)	The above specimen pulse-annealed for 5 min at 200 K; electrical resistivity varied from 4. 935 to 4. 700 milliohm cm at 78 to 170 K respectively.
71	51	Deegan, G. E.	1956	E	6. 6-290	C-369, No. 4 (grade AWG)	The above specimen pulse-annealed at 375 K; electrical resistivity varied from 4. 362 to 3. 44 milliohm cm at 6. 6 to 290 K respectively.
72	51	Deegan, G. E.	1956	E	78	C-369, No. 4 (grade AWG)	The above specimen measured at 78 K after being pulse-annealed at temperatures ranging from 125 to 375 K.
73	51	Deegan, G. E.	1956	E	78	Brookhaven Sample (AWG)	Similar to the above specimen but being exposed to ~10^{18} neutrons cm^{-2}.
74	51	Deegan, G. E.	1956	E	5. 6-300	C-376, No. 1 (grade AWG)	Similar to the above specimen but irradiated at 300 K with an exposure of protons 1. 46 μah cm^{-2}; electrical resistivity varied from 3. 923 to 1. 964 milliohm cm at 5. 6 to 300 K respectively; not annealed.
75	51	Deegan, G. E.	1956	E	5. 2-300	C-376, No. 2 (grade AWG)	Similar to the above specimen but being irradiated with an exposure of protons at 2. 47 μah cm^{-2}; electrical resistivity varied from 4. 083 to 2. 214 milliohm cm at 5. 2 to 300 K respectively.
76	51	Deegan, G. E.	1956	E	6. 2-250	C-376, No. 3 (grade AWG)	Similar to the above specimen but being irradiated with an exposure of protons at 5. 8 μah cm^{-2}; electrical resistivity varied from 4. 290 to 2. 945 milliohm cm at 6. 2 to 250 K respectively.
77	51	Deegan, G. E.	1956	E	6. 4-250	C-376, No. 4 (grade AWG)	Similar to the above specimen but being irradiated with an exposure of 9. 3 μah cm^{-2}; electrical resistivity varied from 4. 350 to 3. 308 milliohm cm at 6. 4 to 250 K respectively.
78	51	Deegan, G. E.	1956	E	5. 6-250	C-376, No. 5 (grade AWG)	Similar to the above specimen but being irradiated with an exposure of 15. 9 μah cm^{-2}; electrical resistivity varied from 4. 465 to 3. 567 milliohm cm at 5. 6 to 250 K respectively.
79	51	Deegan, G. E.	1956	E	5. 2-250	C-376, No. 6 (grade AWG)	Similar to the above specimen but being irradiated with an exposure of 27. 5 μah cm^{-2}; electrical resistivity varied from 4. 653 to 3. 988 milliohm cm at 5. 2 to 250 K respectively.
80	51	Deegan, G. E.	1956	E	7. 6-300	C-381, No. 1 (grade AWG)	Similar to the above specimen but being irradiated at 423 K with an exposure of 0. 95 μah cm^{-2}; electrical resistivity varied from 3. 568 to 1. 743 milliohm cm at 7. 6 to 300 K respectively.
81	51	Deegan, G. E.	1956	E	7. 2-300	C-381, No. 2 (grade AWG)	Similar to the above specimen but being irradiated with an exposure of 3. 1 μah cm^{-2}; electrical resistivity varied from 3. 711 to 1. 827 milliohm cm at 7. 2 to 300 K respectively.
82	51	Deegan, G. E.	1956	E	6. 8-300	C-381, No. 3 (grade AWG)	Similar to the above specimen but being irradiated by protons of 4. 96 μah cm^{-2}; electrical resistivity varied from 3. 939 to 2. 016 milliohm cm at 6. 8 to 300 K respectively.
83	51	Deegan, G. E.	1956	E	7. 6-300	C-381, No. 4 (grade AWG)	Similar to the above specimen but being irradiated by protons of 11. 9 μah cm^{-2}; electrical resistivity varied from 4. 186 to 2. 304 milliohm cm at 7. 6 to 300 K respectively.

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*See TPRC Data Book Vol. 3, Chapter 1, References

TABLE 15. SPECIFICATIONS OF THE SPECIMENS OF GRAPHITES (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
84	51	Deegan, G. E.	1956	E	6. 8-250	C-381, No. 5 (grade AWG)	Similar to the above specimen but being irradiated by protons of 19. 7 μah cm^{-2}; electrical resistivity varied from 4. 426 to 2. 875 milliohm cm at 6. 8 to 250 K respectively.
85	51	Deegan, G. E.	1956	E	6. 4-300	C-381, No. 6 (grade AWG)	Similar to the above specimen but being irradiated by protons of 30. 2 μah cm^{-2}; electrical resistivity varied from 4. 545 to 2. 978 milliohm cm at 6. 4 to 300 K respectively.
86	52	Euler, J.	1956	E	300-3710	Spektral kohle 1	Large grained graphite electrode; measured in vacuum.
87	52	Euler, J.	1956	E	300-3710	Spektral kohle 2	Fine grained graphite electrode; measured in vacuum.
88	53	Rasor, N. S.	1955	E	13-300	Natural Ceylon block	Natural Ceylon graphite; size 0. 100 x 0. 020 x 1. 25 in. ; skew orientation.
89	53	Rasor, N. S.	1955	E	80-460	AWG	Made from petroleum coke; molded; specimen size 0. 100 x 0. 020 x 1. 25 in. ; room temp. properties: density 1. 75 g cm^{-3}, thermoelectric power + 2. 3 μvolt K^{-1}, Hall coefficient -0. 47 emu, magneto resistivity 1. 9 x 10^{-10} emu, electrical resistivity 14. 3 milliohm cm; total magnetic susceptibility -20. 6 x 10^{-6} cgs units, orientation factor $(\rho_{max}/\rho_{min}) = 1.0$.
90	53	Rasor, N. S.	1955	E	10-290	SA-25	Made from lampblack; molded; room temp. properties: density 1. 55 g cm^{-3}, thermoelectric power + 9. 6 μvolt K^{-1}, Hall coefficient + 0. 14 emu, magneto resistivity 0. 2 x 10^{-10} emu, electrical resistivity 43 milliohm cm, total magnetic susceptibility -20. 02 x 10^{-6} cgs unit, orientation factor $(\rho_{max}/\rho_{min}) = 1.0$.
91	53, 163	Rasor, N. S. and Smith, A. W.	1954	E	9. 0-309	AGOT	Index rod made from gas-baked coke (ungraphitized AGOT); extruded; room temp. properties: density 1. 56 g cm^{-3}, thermoelectric power + 1. 3 μvolt K^{-1}, Hall coefficient -0. 21 emu, magneto resistivity -0. 01 x 10^{-10} emu, electrical resistivity 65. 3 milliohm cm, total magnetic susceptibility -3. 08 x 10^{-6} cgs unit, orientation factor $(\rho_{max}/\rho_{min}) = 1.8$.
92	54	Euler, J.	1952	E	3150-3700		Manufactured graphite rod.
93	55	Lucks, C. F. and Deem, H. W.	1956	C	484-1227	Grade GBH	Molded graphite; from National Carbon Co. ; density 1. 75 g cm^{-3}; measured perpendicular to the direction of molding; Armco iron used as comparative material.
94	55	Lucks, C. F. and Deem, H. W.	1956	C	433-1182	Grade 7087	Extruded graphite; density 1. 71 g cm^{-3}; measured perpendicular to the direction of extrusion.
95	56	Fletcher, J. F. and Snyder, W. A.	1957		303. 2	Korite	Manufactured from Korite petroleum asphalt (from Standard Oil Co. , Indiana) and coke prepared from this asphalt; irradiated by exposing to neutrons of 150 MWD/T (megawatt-days per ton).
96	56	Fletcher, J. F. and Snyder, W. A.	1957		303. 2	Korite	The above specimen with neutron exposure of 325 MWD/T.
97	56	Fletcher, J. F. and Snyder, W. A.	1957		303. 2	Korite	The above specimen with neutron exposure of 830 MWD/T.
98	56	Fletcher, J. F. and Snyder, W. A.	1957		303. 2	Korite	The above specimen with neutron exposure of 1100 MWD/T.
99	56	Fletcher, J. F. and Snyder, W. A.	1957		303. 2	Korite	The above specimen with neutron exposure of 4270 MWD/T.
100	56	Fletcher, J. F. and Snyder, W. A.	1957		303. 2	CSF	Made from Cleves coke (Gulf Oil Co.) with Standard pitch (Barret No. 2, medium hard coal tar pitch); purified; exposed to neutrons of 500 MWD/T.

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*See TPRC Data Book Vol. 3, Chapter 1, References

TABLE 15. SPECIFICATIONS OF THE SPECIMENS OF GRAPHITES (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
101	56	Fletcher, J. F. and Snyder, W. A.	1957		303. 2	CSF	The above specimen with exposure of 1000 MWD/T.
102	56	Fletcher, J. F. and Snyder, W. A.	1957		303. 2	CSF	The above specimen with exposure of 1500 MWD/T.
103	56	Fletcher, J. F. and Snyder, W. A.	1957		303. 2	CSF	The above specimen with exposure of 2000 MWD/T.
104	56	Fletcher, J. F. and Snyder, W. A.	1957		303. 2	CSF	The above specimen with exposure of 2500 MWD/T.
105	56	Fletcher, J. F. and Snyder, W. A.	1957		303. 2	CSF	The above specimen with exposure of 3000 MWD/T.
106	56	Fletcher, J. F. and Snyder, W. A.	1957		303. 2	CSF	The above specimen with exposure of 3500 MWD/T.
107	175	Powell, R. W.	1937	C	613-1128	Acheson graphite	Specimen 1. 47 cm in dia and 20 cm long; machined from an Acheson graphite rod; electrical conductivity 1218, 1369, 1445, 1497, 1515, 1517, 1503, 1476, and 1444 ohm^{-1} cm^{-1} at 0, 100, 200, 300, 400, 500, 600, 700, and 1000 C respectively; Armco iron used as comparative material; measured in vacuum.
108	175	Powell, R. W.	1937	C	483-1113	Acheson graphite	Similar to the above specimen.
109	175	Powell, R. W.	1937	L	303-423	Acheson graphite	Specimen 3. 85 cm in dia and 38 cm long; measured in air.
110	175	Powell, R. W.	1937	L	313-588	Acheson graphite	Specimen 7. 34 cm in dia and 38 cm long; measured in air.
111	176	Fieldhouse, I. B., Hedge, J. C., and Waterman, T. E.	1956	L	829-1866	GBH	Grade GBH graphite from National Carbon Co.; density 1. 762 g cm^{-3}; measured with heat flow parallel to the axis of extrusion (should be axis of molding since it was molded).
112	176	Fieldhouse, I. B., Hedge, J. C., and Waterman, T. E.	1956	L	820-1865	7087	Grade 7087 graphite from Speer Carbon Co.; density 1. 698 g cm^{-3}; measured with heat flow parallel to the axis of extrusion.
113	129	Hansen, C. A.	1909	L	373-873	Acheson graphite	Specimen 8. 5 in. long and 1 in. in dia.
114	177	Rasor, N. S. and McClelland, J. D.	1957	R	2661-3708	7087	Extruded; coarse grain with small voids and fissures; specific gravity 1. 63; anisotropy ratio (ratio of electrical resistances measured normal and parallel to the extrusion axis) = 1. 19; measured normal to the extrusion axis, in inert gas at > 150 psi pressure.
115	177	Rasor, N. S. and McClelland, J. D.	1957	R	2733-3694	7087	Rerun of the above specimen with smaller heat rate.
116	177	Rasor, N. S. and McClelland, J. D.	1957	R	1351-2527	7087	The above specimen measured with heat flow radially inward.
117	177	Rasor, N. S. and McClelland, J. D.	1957	R	1289-2600	7087	The above specimen measured after prolonged heating at > 2200 C.
118	177	Rasor, N. S. and McClelland, J. D.	1957	R	1220-2700	GBE	Extruded; extremely coarse grained and fragile; voids and fissures up to 1/8 in. in dia; specific gravity 1. 57; anisotropy ratio 1. 18; measured normal to the extrusion axis in the heating-up period, in inert gas at > 150 psi pressure.
119	177	Rasor, N. S. and McClelland, J. D.	1957	R	1510-2507	GBE	The above specimen in the cooling-down period.
120	177	Rasor, N. S. and McClelland, J. D.	1957	R	1319-3277	GBH	Molded; very fine grained and uniform; specific gravity 1. 77; anisotropy ratio 0. 78; measured normal to the molding pressure, in inert gas at > 150 psi pressure.

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*See TPRC Data Book Vol. 3, Chapter 1, References

TABLE 15. SPECIFICATIONS OF THE SPECIMENS OF GRAPHITES (continued)

Cur. No.	Ref. No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
121	177	Rasor, N.S. and McClelland, J.D.	1957	R	1174-3017	3474 D	Extruded; very fine grained and uniform; specific gravity 1.67; anisotropy ratio 1.08; measured with heat flow radially inward and normal to the extrusion axis; pyrometer used to measure temperatures; measured in inert gas at >150 psi pressure.
122	177	Rasor, N.S. and McClelland, J.D.	1957	R	1002-1533	3474 D	The above specimen measured by using thermocouples to obtain temperatures.
123	177	Rasor, N.S. and McClelland, J.D.	1957	R	2540-3786	3474 D	The above specimen measured with heat flow radially outward and normal to the extrusion axis.
124	133	Francl, J. and Kingery, W.D.	1954	C	353-1093	Grade CS	Cubic specimen 1 x 1 x 1 in.; density 1.55 g cm^{-3}; dense alumina used as comparative standard.
125	133	Francl, J. and Kingery, W.D.	1954	C	328-1093	Grade CS	Similar to the above specimen but with cylindrical pores 0.146 cm in dia; porosity 9.8%.
126	133	Francl, J. and Kingery, W.D.	1954	C	378-1123	Grade CS	Similar to the above specimen but the porosity 19.6%.
127	178	Rasor, N.S.	1950	L	233.2	AGOT-KC	AGOT-KC graphite specimen 0.03 x 1/8 x 1 in.; irradiated with neutrons of 1927 MWD/T; pulse annealed for 1 min; measured under vacuum (<10^{-6} mm Hg) at constant temperature of -40 C to show the effect on thermal conductivity of the specimen after being annealed (except the ends) at different temperatures.
128	178	Rasor, N.S.	1950	L	233.2	AGOT-KC	The above specimen irradiated at 212 MWD/T; both ends annealed.
129	178	Rasor, N.S.	1950	L	233.2	AGOT-KC	The above specimen irradiated at 1927 MWD/T with both ends annealed.
130	179	Icole, M.	1912	L	352-828		Specimen 18 mm in dia and 0.79 cm long.
131	106	Noguchi, T. and Miyazaki, Y.	1956	C	336.7	Acheson, No. 1	Artificial graphite electrode 80 mm in dia, 125 mm long; apparent density 1.40 g cm^{-3}; electrical resistivity 0.00123 ohm cm; copper used as comparative material.
132	106	Noguchi, T. and Miyazaki, Y.	1956	C	334.2	Acheson, No. 2	Similar to the above specimen but the apparent density 1.399 g cm^{-3}; electrical resistivity 0.00121 ohm cm.
133	106	Noguchi, T. and Miyazaki, Y.	1956	C	328.7	Domestic (Japan) No. 1	Similar to the above specimen but the apparent density 1.501 g cm^{-3}; electrical resistivity 0.00108 ohm cm.
134	106	Noguchi, T. and Miyazaki, Y.	1956	C	329.7	Domestic (Japan) No. 2	Similar to the above specimen but the apparent density 1.520 g cm^{-3}; electrical resistivity 0.00118 ohm cm.
135	106	Noguchi, T. and Miyazaki, Y.	1956	C	326.7	Domestic (Japan) No. 3	Similar to the above specimen but the apparent density 1.533 g cm^{-3}; electrical resistivity 0.00093 ohm cm.
136	106	Noguchi, T. and Miyazaki, Y.	1956	C	331.7	Domestic (Japan) No. 4	Similar to the above specimen but the apparent density 1.59 g cm^{-3}; electrical resistivity 0.00085 ohm cm.
137	106	Noguchi, T. and Miyazaki, Y.	1956	C	337.2	Domestic (Japan) No. 5	Similar to the above specimen but the apparent density 1.586 g cm^{-3}; electrical resistivity 0.00094 ohm cm.
138	106	Noguchi, T. and Miyazaki, Y.	1956	C	344.7	Domestic (Japan) No. 6	Similar to the above specimen but the apparent density 1.591 g cm^{-3}; electrical resistivity 0.00096 ohm cm.
139	106	Noguchi, T. and Miyazaki, Y.	1956	C	337.2	Domestic (Japan) No. 7	Similar to the above specimen but the apparent density 1.60 g cm^{-3}; electrical resistivity 0.00099 ohm cm.
140	108	Taylor, T.S.	1920	L	323-363		Solid specimen 1.04 in. thick; specific gravity 1.56.

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TABLE 15. SPECIFICATIONS OF THE SPECIMENS OF GRAPHITES (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
141	108	Taylor, T.S.	1920	L	313, 343		Powder (through 20-mesh on 40-mesh) specimen 0.476 in. thick; specific gravity 0.70.
142	108	Taylor, T.S.	1920	L	313, 343		Powder (through 40-mesh) specimen 0.476 in. thick; specific gravity 0.42.
143	108	Taylor, T.S.	1920	L	313, 343		Powder (through 100-mesh) specimen 0.476 in. thick; specific gravity 0.48.
144	357	Thielke, N.R. (compiler)	1959	L	1246-2045	SA-25	Emissivity 0.83.
145	158	Berman, R.	1952	L	9.3-93	I	Artificial graphite; made by extrusion which produced a slight anisotropy; crystal size (perpendicular to c-axis) 2000 Å; density 1.80 g cm^{-3}; electrical resistivity 1.09 and 0.6 milliohm cm at 90 and 290 K respectively; measured parallel to the axis of extrusion.
146	158	Berman, R.	1952	L	2.8-20	I	Similar to the above specimen but the density 1.78 g cm^{-3}; electrical resistivity 1.76 and 1.09 milliohm cm at 90 and 290 K respectively; measured perpendicular to the axis of extrusion.
147	158	Berman, R.	1952	L	4.8-275	II	Similar to the above specimen but the crystal size 1000 Å; density 1.60 g cm^{-3}; electrical resistivity at 4, 20, 90 and 290 K being, respectively, 2.3, 2.3, 1.7, and 1.08 milliohm cm; measured parallel to the axis of extrusion.
148	158	Berman, R.	1952	L	5-93	II	The above specimen measured perpendicular to the axis of extrusion; electrical resistivity at 4, 20, 90, and 290 K being, respectively, 3.0, 2.9, 2.2, and 1.35 milliohm cm.
149	158	Berman, R.	1952	L	4.5-93	III	Similar to the above specimen but the crystal size 300 Å; density 1.77 g cm^{-3}; electrical resistivity at 90 and 290 K being 3.01 and 2.33 milliohm cm; measured parallel to the extrusion axis.
150	158	Berman, R.	1952	L	10-95	III	Similar to the above specimen but the density 1.76 g cm^{-3}; electrical resistivity 3.91 and 2.77 milliohm cm at 90 and 290 K respectively; measured perpendicular to the extrusion axis.
151	158	Berman, R.	1952	L	3.5-300	IV	Natural graphite; highly anisotropic; crystal size 2000 Å; density ~2.25 g cm^{-3}; electrical resistivity 1.16, 1.17, 1.21, and 0.98 milliohm cm at 4, 20, 90, and 290 K respectively; measured perpendicular to the preferred direction of c-axis.
152	158	Berman, R.	1952	L	5.0-280	IV	The above specimen measured parallel to c-axis; electrical resistivity at 4, 20, 90, and 290 K being, respectively, 5.3, 5.4, 5.4, and 4.1 milliohm cm.
153	355	Goldsmid, H.J. and Lacklison, D.E.	1965	L	4.2	Pyrolytic graphite	Rectangular block of pyrolytic graphite provided by G. E. Research Lab; reheated to 3500 C after deposition; electrical conductivity in zero magnetic field 7.8 x 10^{5} ohm^{-1} cm^{-1}.
154	359	Garth, R.C. and Sailor, V. L.	1949	L	333.2	AGOT, I	Cylindrical specimen 3.5 in. in dia and 4 in. long; cylinder axis parallel to the axis of extrusion.
155	359	Garth, R.C. and Sailor, V. L.	1949	L	333.2	AGOT, I	The above specimen, run No. 2.
156	359	Garth, R.C. and Sailor, V. L.	1949	L	333.2	AGOT, I	The above specimen, run No. 3.
157	359	Garth, R.C. and Sailor, V. L.	1949	L	333.2	AGOT, I	The above specimen, run No. 4.
158	359	Garth, R.C. and Sailor, V. L.	1949	L	333.2	AGOT, I	The above specimen, run No. 5.
159	359	Garth, R.C. and Sailor, V. L.	1949	L	333.2	AGOT, I	The above specimen, run No. 6.

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* See TPRC Data Book Vol. 3, Chapter 1, References

TABLE 15. SPECIFICATIONS OF THE SPECIMENS OF GRAPHITES (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
160	359	Garth, R. C. and Sailor, V. L.	1949	L	333. 2	AGOT, I	Measurement of the above specimen to show the "Bashing effect" by striking each end of the cylinder 10 times and 12 times around the circumference with a plastic hammer on a piece of wood on top of the cylindrical specimen. (Bashing is the hitting of the specimen hard enough to break crystallites apart but not enough to break the specimen.)
161	359	Garth, R. C. and Sailor, V. L.	1949	L	333. 2	AGOT, I	The above specimen treated again with 20 blows on each end and 20 blows on the circumference.
162	359	Garth, R. C. and Sailor, V. L.	1949	L	333. 2	AGOT, I	The above specimen treated again with 10 blows on each end and 20 blows around the circumference but with steel hammer with 2 steel plates at each end of the specimen.
163	359	Garth, R. C. and Sailor, V. L.	1949	L	333. 2	AGOT, I	Cylindrical specimen 3. 5 in. in dia and 4 in. long; cylinder axis at right angle to the extrusion axis.
164	359	Garth, R. C. and Sailor, V. L.	1949	L	333. 2	AGOT, I	The above specimen measured after striking each end 10 times and 12 times around the circumference with a plastic hammer on a piece of wood on top of the specimen.
165	359	Garth, R. C. and Sailor, V. L.	1949	L	333. 2	AGOT, I	The above specimen treated again with 20 blows on each end and 20 blows on the circumference with the same hammer.
166	359	Garth, R. C. and Sailor, V. L.	1949	L	331. 2	AGOT, II	Cylindrical specimen 3. 5 in. in dia and 4 in. long; cylinder axis parallel to the extrusion axis.
167	359	Garth, R. C. and Sailor, V. L.	1949	L	331. 2	AGOT, II	The above specimen, run No. 2.
168	359	Garth, R. C. and Sailor, V. L.	1949	L	331. 2	AGOT, II	The above specimen, run No. 3.
169	359	Garth, R. C. and Sailor, V. L.	1949	L	331. 2	AGOT, II	The above specimen, run No. 4.
170	359	Garth, R. C. and Sailor, V. L.	1949	L	324. 2	AGOT, II	Cylindrical specimen 3. 5 in. in dia and 4 in. long; cylinder axis at right angle to the extrusion axis.
171	359	Garth, R. C. and Sailor, V. L.	1949	L	337. 2	AGOT, V	Similar to the above specimen but the cylinder axis parallel to the extrusion axis.
172	359	Garth, R. C. and Sailor, V. L.	1949	L	338. 2	AGOT, V	Similar to the above specimen but the cylinder axis perpendicular to the extrusion axis.
173	359	Garth, R. C. and Sailor, V. L.	1949	L	335. 2	AGOT, VI	Similar to the above specimen but the cylinder axis parallel to the extrusion axis.
174	359	Garth, R. C. and Sailor, V. L.	1949	L	335-415	AGOT, VI	Similar to the above specimen.
175	359	Garth, R. C. and Sailor, V. L.	1949	L	339. 2	AGOT, VI	Similar to the above specimen but the cylinder axis perpendicular to the extrusion axis.
176	359	Garth, R. C. and Sailor, V. L.	1949	L	336. 2	AGHT, III	Similar to the above specimen but the cylinder axis parallel to the extrusion axis.
177	359	Garth, R. C. and Sailor, V. L.	1949	L	336. 2	AGHT, III	Similar to the above specimen but the cylinder axis at right angle to the extrusion axis.
178	359	Garth, R. C. and Sailor, V. L.	1949	L	339. 2	AGHT, III	Similar to the above specimen but the direction of cutting the specimen perpendicular to the above one.
179	359	Garth, R. C. and Sailor, V. L.	1949	L	343. 2	AGHT, IV	Similar to the above specimen but the cylinder axis parallel to the axis of extrusion.
180	359	Garth, R. C. and Sailor, V. L.	1949	L	337. 2	AGHT, IV	Similar to the above specimen but the cylinder axis perpendicular to the extrusion axis.
181	359	Garth, R. C. and Sailor, V. L.	1949	L	344. 2	AGHT, IV	Similar to the above specimen with the cylinder axis perpendicular to the extrusion axis but the direction of cutting the specimen perpendicular to that of the above specimen.

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*See TPRC Data Book Vol. 3, Chapter 1, References

TABLE 15. SPECIFICATIONS OF THE SPECIMENS OF GRAPHITES (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
182	359	Garth, R.C. and Sailor, V.L.	1949	L	343.2	AGHT, VII	Similar to the above specimen but the cylinder axis parallel to the extrusion axis.
183	359	Garth, R.C. and Sailor, V.L.	1949	L	341.2	AGHT, VII	Similar to the above specimen but the cylinder axis perpendicular to the extrusion axis.
184	359	Garth, R.C. and Sailor, V.L.	1949	L	344.2	AGHT, VII	Similar to the above specimen with the cylinder axis perpendicular to the extrusion axis but the direction of cutting of the specimen normal to the above one.
185	180	Mrozowski, S., Andrew, J.F., Juul, N., Strauss, H.E., and Wobschall, D.C.	1961	L	1428-3148	AGSR	Graphite rod from National Carbon Co.; apparent density 1.54 g cm^{-3} (grade AGSR); heat treated to 3100 C; measured at 1 in. Hg above the atmospheric pressure.
186	180	Mrozowski, S., et al.	1961	L	1838.2	AGSR	The above specimen measured at a fixed temperature to show the effect of pressure (approx from 0 to 60 in. Hg pressure).
187	180	Mrozowski, S., et al.	1961	L	2423.2	AGSR	The above specimen measured within the same pressure range but at a higher temperature.
188	180	Mrozowski, S., et al.	1961	L	2973.2	AGSR	The above specimen measured within the same pressure range but at a higher temperature.
189	180	Mrozowski, S., et al.	1961	L	1838.2	Lab. prepared rod	Made from soft filler - soft binder mixture particles (200/270 mesh size); heat treated to 3100 C; apparent density 1.58 g cm^{-3}; measured in the same pressure range as the above specimen.
190	180	Mrozowski, S., et al.	1961	L	2394.2	Lab. prepared rod	The above specimen measured in the same pressure range at a higher temperature.
191	180	Mrozowski, S., et al.	1961	L	2913.2	Lab. prepared rod	The above specimen measured in the same pressure range at a higher temperature.
192	180	Mrozowski, S., et al.	1961	L	1829.2	Lab. prepared rod	Made from a soft filler - soft binder mixture; coke (28/35 mesh size) used as filler; very porous; apparent density 1.25 g cm^{-3}; measured in the same pressure range as the above specimen.
193	180	Mrozowski, S., et al.	1961	L	2433.2	Lab. prepared rod	The above specimen measured under pressures ranging from 0 to 55.5 in. Hg.
194	180	Mrozowski, S., et al.	1961	L	2973.2	Lab. prepared rod	The above specimen measured under pressures ranging from 31 to 55.5 in. Hg.
195	180	Mrozowski, S., et al.	1961	L	1473-2933	Test rod No. 1	Material from National Carbon Co.; graphitized to 3000 C; the pressure within the test chamber kept at 1-2 in. Hg above atmospheric pressure by releasing or admitting argon at various temperature levels.
196	180	Mrozowski, S., et al.	1961	L	1773-2523	Test rod No. 1	Second run of the above specimen.
197	180	Mrozowski, S., et al.	1961	L	1478-2968	Test rod No. 1	Third run of the above specimen.
198	180	Mrozowski, S., et al.	1961	L	1643-2433	Test rod No. 2 (U.B. Carbon)	Specimen made from 50 parts of Texas coke (65/100 mesh as the first filler), another 50 parts of Texas coke (200/270 mesh as the second filler), and 40 parts of M-30 coal tar pitch as the binder; extruded; graphitized to 3000 C; apparent density 1.53 g cm^{-3}; measured in argon atmosphere at 1-2 in. Hg above atmospheric pressure.
199	180	Mrozowski, S., et al.	1961	L	1513-2933	Test rod No. 2 (U.B. Carbon)	Second run of the above specimen.

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*See TPRC Data Book Vol. 3, Chapter 1, References

TABLE 15. SPECIFICATIONS OF THE SPECIMENS OF GRAPHITES (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
200	180	Mrozowski, S., et al.	1961	L	1983.2	Test rod No. 2 (U. B. Carbon)	Third run of the above specimen.
201	180	Mrozowski, S., et al.	1961	L	1638-2448	Test rod No. 2 (U. B. Carbon)	Fourth run of the above specimen.
202	180	Mrozowski, S., et al.	1961	L	1713-2983	Test rod No. 3 (U. B. Carbon)	Specimen made from 100 parts of 200/270 mesh size Texas coke as filler, 50 parts of M-30 coal tar pitch as the binder; extruded; graphitized to 3000 C; apparent density 1.53 g cm^{-3}; measured in argon atmosphere at 1-2 in. Hg above atmospheric pressure.
203	180	Mrozowski, S., et al.	1961	L	1663-2993	Test rod No. 3 (U. B. Carbon)	Second run of the above specimen.
204	180	Mrozowski, S., et al.	1961	L	1783-3273	Test rod No. 4 (U. B. Carbon)	Specimen similarly prepared as the above with slight increase in density to 1.58 g cm^{-3}.
205	181	National Carbon Co.	1959		298.2	TS-148	Specimen made by National Carbon Co.; baked to 1425 C; typical impurities after baking 0.15 ash and 0.042 H; apparent density 1.682 g cm^{-3}; electrical resistivity 1557 μohm cm; measured with grain.
206	181	National Carbon Co.	1959		298.2	TS-148	Similar to the above specimen but electrical resistivity 2594 μohm cm; measured against grain.
207	181	National Carbon Co.	1959		298.2	TS-160	Similar to the above specimen but with 0.13 ash after baking; apparent density 1.685 g cm^{-3}; electrical resistivity 2122 μohm cm; measured with grain.
208	181	National Carbon Co.	1959		298.2	TS-160	Similar to the above specimen but measured against grain; electrical resistivity 3006 μohm cm.
209	181	National Carbon Co.	1959		298.2	TS-160	Similar to the above specimen but baked to 2800 C; apparent density 1.785 g cm^{-3}; electrical resistivity 1842 μohm cm; measured with grain.
210	159, 356	Snyder, T.M. and Kamm, R.L.	1955, 1942	L	308-903		Glycerine coated; specimen sandwiched between 2 copper disks; the heater being electrically operated.
211	159	Snyder, T.M. and Kamm, R.L.	1955	L	308-373		Similar to the above specimen but being sandwiched between 2 silver disks.
212	159	Snyder, T.M. and Kamm, R.L.	1955	C	323.2		Glycerine coated graphite; boiling water used as heater; brass and steel used as comparative materials.
213	159	Snyder, T.M. and Kamm, R.L.	1955	L	313-873		Long graphite rod used as specimen; intended to eliminate errors due to uneven flow of heat into and out of the specimen.
214	159	Snyder, T.M. and Kamm, R.L.	1955	C	323.2	Karbate 2	Commercial impregnated graphite; brass used as the comparative material.
215	159	Snyder, T.M. and Kamm, R.L.	1955	C	323.2	Karbate 22	Similar to the above specimen.
216	348	Fieldhouse, I.B., Lang, J.I., and Blau, H.H., Jr.	1960	R	610-1922	Siliconized ATJ	Ash content 0.2%; specimen composed of 15 disks; three of which 1 in. thick, twelve others 0.5 in. thick; each with a dia of 3 ±0.002 in.; maximum grain size ~0.006 in.; made from blocks of ATJ graphite size 9 x 20 x 24 in.; machined prependicular to grain orientation; siliconized.
217	348	Fieldhouse, I.B., et al.	1960	R	650-1929	Siliconized ATJ	Similar to the above specimen but machined parallel to grain orientation.

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*See TPRC Data Book Vol. 3, Chapter 1, References

TABLE 15. SPECIFICATIONS OF THE SPECIMENS OF GRAPHITES (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
218	182	VanSant, J. H.	1961	R	1422-2422	Sample A	Limited impregnated graphite normal to the extrusion axis; specimen in the form of a short tube with an outer dia of about 3 in. and a wall thickness of about 1/4 in.; experiment performed in helium for temperatures <1540 C, for temperatures higher than this, argon was used instead.
219	182	VanSant, J. H.	1961	R	1367-2255	Sample B	Similar to the above specimen but more fully impregnated.
220	182	VanSant, J. H.	1961	R	1417-2255	Sample C	Similar to the above specimen.
221	183	Gumenyuk, V. S. and Lebelev, V. V.	1961	E	1173-2273		Spectrally pure; two wires each ~ 1 mm in dia used as the test specimen; annealed in high vacuum at 1700 C for 1 hr; measured in high vacuum.
222	184	Childers, H. M. and Cerceo, J. M.	1961	P	1193		Measured in a vacuum of 10^{-5} mm Hg; run No. 1.
223	184	Childers, H. M. and Cerceo, J. M.	1961	P	1185		The above specimen, run No. 2.
224	184	Childers, H. M. and Cerceo, J. M.	1961	P	1185		The above specimen, run No. 3.
225	184	Childers, H. M. and Cerceo, J. M.	1961	P	1194		The above specimen, run No. 4.
226	184	Childers, H. M. and Cerceo, J. M.	1961	P	1189		The above specimen, run No. 5.
227	184	Childers, H. M. and Cerceo, J. M.	1961	P	1189		The above specimen, run No. 6.
228	185	Atomic International Div., N. American Aviation, Inc.	1960	R	653-963	LBR (grade TSP)	Nuclear graphite grade TSP from Nat. Carbon Co.; irradiated with 5×10^{20} neutron cm^{-2} at about 315 C.
229	185	Atomic International Div., N. American Aviation, Inc.	1960	R	703-898	LBR (grade TSP)	The above specimen annealed in vacuum at 1000 C for 1 hr.
230	185	Atomic International Div., N. American Aviation, Inc.	1960	R	723-898	LBR (grade TSP)	The above specimen before irradiation and not annealed.
231	339	Zavaritskii, N. V. and Zeldovich, A.	1956	L	2.2-95	AUG-4	Resin bonded graphite; annealed to 2000 C.
232	339	Zavaritskii, N. V. and Zeldovich, A.	1956	L	2.8-80	AUG-3	Resin bonded graphite; annealed to 1500 C.
233	326	Kozak, M. I.	1952	R	363-873	Acheson 2301	Powder; 99 pure; apparent density 0.69 g cm^{-3}; measured after repeated heating.
234	161	Kasatochkin, V. I., Zamoluev, V. K., Kaverov, A. T., and Usenbaev, K.	1960	P	1573-3273	Graphitized carbon black	99.65 C, 0.27 H, 0.08 O, and 0.01 ash; particle size $<1\ \mu$; heat treated at 2500 C for 30 min (equivalent to a degree of graphitization of 0.77).
235	243	Neel, D. S., Pears, C. D., and Oglesby, S., Jr.	1962	R	517-1160	ATJ	Molded and fired; maximum exposure temperature 2843 C; specimen 3/4 in. in dia and 3/4 in. long; no deterioration found on the specimen after the experiment.
236	243	Neel, D. S., Pears, C. D., and Oglesby, S., Jr.	1962	R	1261-1992	ATJ	Another run of the above specimen.
237	243	Neel, D. S., et al.	1962	R	1258-2369		Another run of the above specimen.
238	243	Neel, D. S., et al.	1962	R	1425-1769		Another run of the above specimen.
239	243	Neel, D. S., et al.	1962	R	832-837		Another run of the above specimen.
240	243	Neel, D. S., et al.	1962	R	558-560		Another run of the above specimen.

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*See TPRC Data Book Vol. 3, Chapter 1, References

TABLE 15. SPECIFICATIONS OF THE SPECIMENS OF GRAPHITES (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
241	243	Neel, D.S., et al.	1962	R	2383-2505	ATJ	Another run of the above specimen.
242	243	Neel, D.S., et al.	1962	R	2783-3050	ATJ	Another run of the above specimen.
243	243	Neel, D.S., et al.	1962	R	2622-3022	ATJ	Another run of the above specimen.
244	15	Jamieson, C. P. and Mrozowski, S.	1956	L	115-385		Polycrystalline; made from 69.14% Kendall coke (soft type carbon), 29.17% medium grade coal tar pitch, and 1.43% Vacwax 80 (from Socony Vacuum Oil Co.); extruded; baked for 5 days to 1100 C; density after baking 1.49 g cm^{-3}; heat treated again to 2100 C; crystallite dia 98 Å
245	15	Jamieson, C. P. and Mrozowski, S.	1956	L	115-385		Similar to the above specimen but heat treated to 2200 C; crystallite dia 128 Å.
246	15	Jamieson, C. P. and Mrozowski, S.	1956	L	115-385		Similar to the above specimen but heat treated to 2300 C; crystallite dia 184 Å.
247	15	Jamieson, C. P. and Mrozowski, S.	1956	L	115-385		Similar to the above specimen but heat treated to 2430 C; crystallite dia 290 Å.
248	366	Breckenridge, R. G. (Project Coordinator)	1960		1170-2450	Sample No. 1 (R-0008)	Grade R-0008 (a high quality graphite).
249	366	Breckenridge, R. G.	1960		1170-2600	Sample No. 2 (R-0008)	Similar to the above specimen.
250	366	Breckenridge, R. G.	1960		1115-2725	Sample No. 3 (R-0008)	Similar to the above specimen.
251	340	Hoch, M. and Vardi, J.	1962	→	1260-2199	ZT type graphite; G-5, G-9	Thermal conductivity data in the z-direction (k_z) determined simultaneously with thermal conductivity in the r-direction k_r (see next curve) from 4 cylindrical specimens made from ZT type graphite of National Carbon Co.; density 2.00 g cm^{-3}; anisotropy ratio of electrical resistivity ρ(z-direction)/ρ(r-direction) = 2.86 at room temperature; the specimens each about 2.54 cm in dia and about 0.3-0.6 cm thick; during measurement the specimens were heated in vacuum by high frequency induction; thermal conductivity determined by equating the heat conduction in specimen to the heat loss by radiation assuming the emissivity of a gray body; the analysis required 2 specimens of different thickness to solve simultaneously for k_z and k_r at a certain temperature.
252	340	Hoch, M. and Vardi, J.	1962	→	1260-2199	ZT type graphite; G-5, G-9	k_r determined simultaneously with the above curve.
253	340	Hoch, M. and Vardi, J.	1962	→	1817	Pyrolytic graphite; P-3, P-3A	Pyrolytic graphite obtained from General Electric Co.; 2.3 cm dia x 0.1~0.4 cm thick; k_z determined by using the same method as that for the above specimens.
254	340	Hoch, M. and Vardi, J.	1962	→	1817	Pyrolytic graphite; P-3, P-3A	k_r determined simultaneously with the above curve.
255	334	Juul, N., Sato, S., and Strauss, H. E.	1963	L	1353-2303		Made from soft filler and hard binder carbon; heat treated to 2100 C for 15 min.
256	334	Juul, N., et al.	1963	L	1383-2583		The above specimen heat treated to 2400 C for 15 min.

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*See TPRC Data Book Vol. 3, Chapter 1, References

TABLE 15. SPECIFICATIONS OF THE SPECIMENS OF GRAPHITES (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimens Designations	Composition (weight percent), Specifications, and Remarks
257	335	Pike, J. N.	1963		1170-2340	No. 1	Specimen 7 cm long, 1 cm wide and 1 mm thick; made by molding a selected coke-base mixture in one particular direction; impregnated and pressed at high temperatures; all surfaces milled, slightly sand blasted; apparent density 2.15 g cm^{-3}; measured approx. parallel to the grain direction with a tilt angle of 8.1 degrees.
258	335	Pike, J. N.	1963		1180-2760	No. 1	Second run of the above specimen.
259	335	Pike, J. N.	1963		1180-2400	No. 2	Similar to the above specimen but measured perpendicular to the grain direction with a tilt angle of 8.1 degrees.
260	335	Pike, J. N.	1963		1180-2350	No. 2	Second run of the above specimen.
261	335	Pike, J. N.	1963		1200-2180	No. 3	Similar to the above specimen but measured parallel to the grain direction with a tilt angle of 8.1 degrees.
262	335	Pike, J. N.	1963		1220-2280	No. 4	Similar to the above specimen.
263	335	Pike, J. N.	1963		1220-2630	No. 5	Similar to the above specimen but with different dimensions of 7 x 6 x 0.1 cm; measured perpendicular to the grain direction with a tilt angle of 8.1 degrees.
264	341	Wagner, P., Driesner, A. R., and Kmetko, E. A.	1958	L	1623-2773	H4LM graphite	Specimen 8 in. long and 1/2 in. in dia; density 1.72 g cm^{-3}; heat flow parallel to grain; zero uranium content.
265	341	Wagner, P., et al.	1958	L	1593-2823	LDH graphite	Specimen 8 in. long and 1/2 in. in dia; density 1.73 g cm^{-3}; heat flow parallel to grain; uranium content 0.125 mg cm^{-3} of carbon.
266	341	Wagner, P., et al.	1958	L	1623-2823	CK graphite	Specimen 8 in. long and 1/2 in. in dia; density 1.71 g cm^{-3}; heat flow parallel to grain; zero uranium content.
267	341	Wagner, P., et al.	1958	L	1653-2823	LDC graphite	Specimen 8 in. long and 1/2 in. in dia; density 1.66 g cm^{-3}; heat flow parallel to grain; uranium content 0.25 mg cm^{-3} of carbon.
268	342	Crary, A. P.	1933	L	123-973	Acheson graphite	Two cylindrical blocks of graphite 10.2 cm in dia and 17.8 cm long placed in a vertical position end to end with a flat electric heater between them.
269	343	Breckenridge, R. G. (Project coordinator)	1959	E	1400-2000	ATJ graphite	Rectangular bars fabricated by molding; size 1 x 1 x 10 cm; specific gravity 1.74; measured perpendicular to c-axis; data averaged from measurements of 4 specimens.
270	343	Breckenridge, R. G.	1959	E	1400-1900	ATJ graphite	Similar to the above specimens but data averaged from 3 other specimens.
271	343	Breckenridge, R. G.	1959	E	1300-1900	ATJ graphite	Similar to the above specimens but with specific gravity of 1.69; data averaged from 4 specimens; measured parallel to the molding pressure.
272	343	Breckenridge, R. G.	1959	E	1300-2200	Boronated graphite	Rectangular specimen 0.1 x 1 x 10 cm (after extrusion and baking at 3273 K) cut from the portion near the parent rod center; the rod being made of a mixture of lampblack, coke, boron carbide, and pitch with a boron content of 1.3% and specific gravity of 1.79.
273	343	Breckenridge, R. G.	1959	E	1300-2465	Boronated graphite	Similar to above specimen but cut from the portion near the center of the parent rod.
274	343	Breckenridge, R. G.	1959	E	1300-2200	Boronated graphite	Similar to above specimen but cut from the portion near the center of the parent rod.

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TABLE 15. SPECIFICATIONS OF THE SPECIMENS OF GRAPHITES (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
275	344	Mrozowski, S., Andrew, J.F., Juul, N., Strauss, H.E., Tsuzuku, T., and Wobschall, D.C.	1962	R	1513-2048		Extruded test rod made from a mixture of 100 parts of soft filler coke particles (200/270 mesh) and 50 parts of M-30 soft binder, baked and heat treated to 3273 K; apparent density 1.54 g cm^{-3}.
276	344	Mrozowski, S., et al.	1962	R	1533-1933		The above specimen, run 2.
277	344	Mrozowski, S., et al.	1962	R	1653-2393		The above specimen, run 3.
278	344	Mrozowski, S., et al.	1962	R	1833-3268		The above specimen, run 4.
279	344	Mrozowski, S., et al.	1962	R	1833-2743		The above specimen, run 5.
280	344	Mrozowski, S., et al.	1962	R	1683-1963		The above specimen, run 6.
281	344	Mrozowski, S., et al.	1962	R	1643-1703		Test rod made from 100 parts of soft coke (50 parts 65/100 mesh and 50 parts 200/270 mesh) and 35 parts of hard binder, baked and graphitized to a temperature of 3273 K prior to testing; apparent density 1.65 g cm^{-3}.
282	344	Mrozowski, S., et al.	1962	R	1643-2013		The above specimen, run 2.
283	344	Mrozowski, S., et al.	1962	R	1753-2453		The above specimen, run 3.
284	344	Mrozowski, S., et al.	1962	R	1683-2093		The above specimen, run 4.
285	344	Mrozowski, S., et al.	1962	R	1643-2123		The above specimen, run 5.
286	344	Mrozowski, S., et al.	1962	R	1363-1453	U.B. graphite	Carbon rod sample extruded from a soft filler, soft binder mixture, baked to a temperature of 1273 K; heat treated at 1473 K.
287	344	Mrozowski, S., et al.	1962	R	1393-1733	U.B. graphite	Similar to above specimen except heat treated at 1773 K.
288	344	Mrozowski, S., et al.	1962	R	1293-2013	U.B. graphite	Similar to above specimen except heat treated at 2073 K.
289	344	Mrozowski, S., et al.	1962	R	1393-2333	U.B. graphite	Similar to above specimen except heat treated at 2373 K.
290	344	Mrozowski, S., et al.	1962	R	1393-2603	U.B. graphite	Similar to above specimen except heat treated at 2673 K.
291	344	Mrozowski, S., et al.	1962	R	1403-2933	U.B. graphite	Similar to above specimen except heat treated at 2773 K.
292	344	Mrozowski, S., et al.	1962	R	1293-3093	U.B. carbon	Carbon rod sample extruded from a mixture of soft-filler and hard binder, baked and graphitized to a temperature of 3373 K.
293	344	Mrozowski, S., et al.	1962	R	1603-3073	U.B. carbon	The above specimen, run 2.
294	344	Mrozowski, S., et al.	1962	R	1413-3103	U.B. carbon	The above specimen, run 3.
295	344	Mrozowski, S., et al.	1962	R	1513-3153	U.B. carbon	The above specimen, run 4.
296	344	Mrozowski, S., et al.	1962	R	1953-2953	U.B. carbon	The above specimen, run 5.
297	345	Bowman, J.C., Krumhansl, J.A., and Meers, J.T.	1958	L	13-275	SA-25	Specimen prepared from lampblack base; molded with a coal-tar pitch binder; measurements made under high vacuo.
298	345	Bowman, J.C., et al.	1958	L	20-273	C-15	Specimen prepared from petroleum-coke base; molded with coal-tar pitch binder; baked at 2673 K; equivalent bromine residue 0.75 weight percent; measurements made under high vacuum.

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*See TPRC Data Book Vol. 3, Chapter 1, References

TABLE 15. SPECIFICATIONS OF THE SPECIMENS OF GRAPHITES (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
299	345	Bowman, J.C., et al.	1958	L	18.5-273	C-15	Similar to the above specimen but baked at 2873 K and with an equivalent bromine residue of 0.5%.
300	345	Bowman, J.C., et al.	1958	L	18-300	C-15	Similar to the above specimen but baked at 3073 K and with an equivalent bromine residue of 0.25%.
301	345	Bowman, J.C., et al.	1958	L	25-235	Pyrolytic graphite filament	Specimen of fibrous structure prepared by pyrolysis of methane on a hot carbon wire; measurements made under high vacuum.
302	346	Durand, R.E. and Klein, D.J.	1956	R	80-300	AGOT-CSF-MTR	Specimen size 0.02 x 0.125 x 1 in.; exposed to 6.4 x 10^{19} fast neutrons cm^{-2} and 5.8 x 10^{20} thermal neutron cm^{-2} at 698 K.
303	346	Durand, R.E. and Klein, D.J.	1956	R	80-300	AGOT-CSF-MTR	Similar to the above specimen but exposed to 4.3 x 10^{19} fast neutrons cm^{-2} and 2.6 x 10^{20} thermal neutrons cm^{-2} at 933 K.
304	346	Durand, R.E. and Klein, D.J.	1956	R	80-300	AGOT-CSF-MTR	Similar to the above specimen but exposed to 8.5 x 10^{19} fast neutrons cm^{-2} and 2.6 x 10^{20} thermal neutrons cm^{-2} at 908 K.
305	346	Durand, R.E. and Klein, D.J.	1956	R	220-300	AGOT-CSF-MTR	Similar to the above specimen but exposed to 4.9 x 10^{19} fast neutrons cm^{-2} and 1.5 x 10^{20} thermal neutron cm^{-2} at 938 K.
306	346	Durand, R.E. and Klein, D.J.	1956	R	80-300	CSF-MTR	Virgin 10 mil sample.
307	346	Durand, R.E. and Klein, D.J.	1956	R	200, 300	CSF-MTR	Virgin 20 mil sample.
308	296	Sibley, L.B., Allen, C.M., Zielenbach, C.L., Peterson, C.L., and Goldthwaite, W.H.	1958		293-1273		Impervious graphite.
309	338	Downey, H.A. and Micinski, E.	1948		1273, 1873	EBP	Rectangular block; 24 x 20 x 6 in.; molded; baked; cut at an angle to give both against and with the grain orientation.
310	338	Downey, H.A. and Micinski, E.	1948		1273, 1873	AUC	Rod; 12 in. in dia; extruded; baked; specially cut to give an across grain orientation.
311	338	Downey, H.A. and Micinski, E.	1948		1273, 1873	CS-312	Similar to the above specimen.
312	338	Downey, H.A. and Micinski, E.	1948		1273, 1873	C-18	Rectangular block; 24 x 20 x 6 in.; molded; baked; cut at angle to give both against and with the grain orientation.
313	338	Downey, H.A. and Micinski, E.	1948		1273, 1873	L-117	Rod; 3 in. in dia; extruded; baked; specially cut to give an across grain orientation.
314	338	Piper, E.L.	1955		298.2	Porous-40	Molded; baked at 1000 C; specially cut to give with the grain orientation.
315	338	Piper, E.L.	1955		298.2	Porous-60	Similar to the above specimen.
316	338	Piper, E.L.	1955		298.2	255	Molded; baked.
317	338	Piper, E.L.	1955		298.2	CS-112	Rod; 1.125 in. in dia; extruded; baked; specially cut to give with the grain orientation.
318	338	Gardner, L.	1955		1355-2303	CS-312	Similar to the above specimen but the dia, 12 in.
319	338	Meers, J.T.	1956		15.2-296	CEQ	Rectangular block; 6 x 5 x 3 in.; molded; baked; specially cut to give 'with the grain orientation'.

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*See TPRC Data Book Vol. 3, Chapter 1, References

TABLE 15. SPECIFICATIONS OF THE SPECIMENS OF GRAPHITES (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
320	338	Industrial Graphite Eng. Handbook National Carbon Co.	1962		298. 2	AGSR	Graphite stocks 1-2. 75 in. in dia; grain size 0. 016 in. ; bulk density 1. 58 g cm^{-3}; electrical resistivity 839 μohm cm; with grain orientation.
321	338	Industrial Graphite Eng. Handbook National Carbon Co.	1962		298. 2	AGSR	Similar to the above but electrical resistivity 1500 μohm cm; across grain orientation.
322	338	Industrial Graphite Eng. Handbook National Carbon Co.	1962		298. 2	AGSR	Graphite stocks 3-5. 75 in. in dia; grain size 0. 03; bulk density 1. 58 g cm^{-3}; electrical resistivity 864 μohm cm; with grain orientation.
323	338	Industrial Graphite Eng. Handbook National Carbon Co.	1962		298. 2	AGSR	Similar to the above but electrical resistivity 1280 μohm cm; across grain orientation.
324	338	Industrial Graphite Eng. Handbook National Carbon Co.	1962		298. 2	AGSR	Graphite stocks 6-12 in. in dia; grain size 0. 06 in. ; bulk density 1. 57 g cm^{-3}; electrical resistivity 885 μohm cm; with grain orientation.
325	338	Industrial Graphite Eng. Handbook National Carbon Co.	1962		298. 2	AGSR	Similar to the above but electrical resistivity 1110 μohm cm; across grain orientation.
326	338	Industrial Graphite Eng. Handbook National Carbon Co.	1962		298. 2	AGSR	Graphite stocks 14-35 in. in dia; grain size 0. 25 in. ; bulk density 1. 54 g cm^{-3}; electrical resistivity 965 μohm cm; with grain orientation.
327	338	Industrial Graphite Eng. Handbook National Carbon Co.	1962		298. 2	AGSR	Similar to the above but electrical resistivity 1130 μohm cm; across grain orientation.
328	338	Industrial Graphite Eng. Handbook National Carbon Co.	1962		298. 2	AGA	Graphite stocks >35 in. in dia; grain size 0. 5 in. ; bulk density 1. 65 g cm^{-3}; electrical resistivity 1040 μohm cm; with grain orientation.
329	338	Industrial Graphite Eng. Handbook National Carbon Co.	1962		298. 2	AGA	Similar to the above but electrical resistivity 1090 μohm cm; across grain orientation.
330	338	Industrial Graphite Eng. Handbook National Carbon Co.	1962		298. 2	AGSX	Graphite stocks 1-2. 75 in. in dia; grain size 0. 016 in. ; bulk density 1. 67 g cm^{-3}; electrical resistivity 799 μohm cm; with grain orientation.
331	338	Industrial Graphite Eng. Handbook National Carbon Co.	1962		298. 2	AGSX	Similar to the above but electrical resistivity 1330 μohm cm; across grain orientation.
332	338	Industrial Graphite Eng. Handbook National Carbon Co.	1962		298. 2	AGSX	Graphite stocks 3-5. 75 in. in dia; grain size 0. 03 in; bulk density 1. 69 g cm^{-3}; electrical resistivity 821 μohm cm; with grain orientation.
333	338	Industrial Graphite Eng. Handbook National Carbon Co.	1962		298. 2	AGSX	Similar to the above but electrical resistivity 1390 μohm cm; across grain orientation.
334	338	Industrial Graphite Eng. Handbook National Carbon Co.	1962		298. 2	AGSX	Graphite stocks 6-12 in. in dia; grain size 0. 06 in. ; bulk density 1. 71 g cm^{-3}; electrical resistivity 820 μohm cm; with grain orientation.
335	338	Industrial Graphite Eng. Handbook National Carbon Co.	1962		298. 2	AGSX	Similar to the above but electrical resistivity 1010 μohm cm; across grain orientation.
336	338	Industrial Graphite Eng. Handbook National Carbon Co.	1962		298. 2	CS	Graphite stocks 1-2. 75 in. in dia; grain size 0. 016 in. ; bulk density 1. 68 g cm^{-3}; electrical resistivity 819 μohm cm; with grain orientation.
337	338	Industrial Graphite Eng. Handbook National Carbon Co.	1962		298. 2	CS	Similar to the above but electrical resistivity 1310 μohm cm; across grain orientation.

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* See TPRC Data Book Vol. 3, Chapter 1, References

TABLE 15. SPECIFICATIONS OF THE SPECIMENS OF GRAPHITES (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
338	338	Industrial Graphite Eng. Handbook National Carbon Co.	1962		298.2	CS	Graphite stocks 3-18 in. in dia; grain size 0.03 in.; bulk density 1.72 g cm^{-3}; electrical resistivity 860 μohm cm; with grain orientation.
339	338	Industrial Graphite Eng. Handbook National Carbon Co.	1962		298.2	CS	Similar to the above but electrical resistivity 1100 μohm cm; across grain orientation.
340	338	Industrial Graphite Eng. Handbook National Carbon Co.	1962		298.2	ATL	Graphite stocks 20-24 in. in dia; grain size 0.03 in.; bulk density 1.70 g cm^{-3}; electrical resistivity 890 μohm cm; with grain orientation.
341	338	Industrial Graphite Eng. Handbook National Carbon Co.	1962		298.2	ATL	Similar to the above but electrical resistivity 1070 μohm cm; across grain orientation.
342	338	Industrial Graphite Eng. Handbook National Carbon Co.	1962		298.2	ATL	Graphite stocks 30-50 in. in dia; grain size 0.03 in.; bulk density 1.78 g cm^{-3}; electrical resistivity 1130 μohm cm; with grain orientation.
343	338	Industrial Graphite Eng. Handbook National Carbon Co.	1962		298.2	ATL	Similar to the above but electrical resistivity 1180 μohm cm; across grain orientation.
344	338	Industrial Graphite Eng. Handbook National Carbon Co.	1962		298.2	ATJ	Graphite stocks size 9 x 20 x 24 in.; grain size 0.006 in.; bulk density 1.73 g cm^{-3}; electrical resistivity 1100 μohm cm; with grain orientation.
345	338	Industrial Graphite Eng. Handbook National Carbon Co.	1962		298.2	ATJ	Similar to the above but electrical resistivity 1450 μohm cm; across grain orientation.
346	338	Industrial Graphite Eng. Handbook National Carbon Co.	1962		298.2	AUC	Graphite stocks 1-8 in. in dia; grain size 0.016 in.; bulk density 1.68 g cm^{-3}; electrical resistivity 790 μohm cm; with grain orientation.
347	338	Industrial Graphite Eng. Handbook National Carbon Co.	1962		298.2	AUC	Similar to the above but electrical resistivity 1230 μohm cm; across grain orientation.
348	338	Industrial Graphite Eng. Handbook National Carbon Co.	1962		298.2	AUC	Graphite stocks 9-18 in. in dia; grain size 0.03 in.; bulk density 1.69 g cm^{-3}; electrical resistivity 767 μohm cm; with grain orientation.
349	338	Industrial Graphite Eng. Handbook National Carbon Co.	1962		298.2	AUC	Similar to the above but electrical resistivity 978 μohm cm; across grain orientation.
350	338	Industrial Graphite Eng. Handbook National Carbon Co.	1962		298.2	CEQ	Graphite stocks 6 x 5 x 2.875 in.; grain size 0.008 in.; bulk density 1.55 g cm^{-3}; electrical resistivity 5029 μohm cm; with grain orientation.
351	338	Industrial Graphite Eng. Handbook National Carbon Co.	1962		298.2	CDA	Graphite stocks size 6 x 5 x 2.6875 in.; grain size 0.006 in.; bulk density 1.62 g cm^{-3}; electrical resistivity 1072 μohm cm; with grain orientation.
352	338	Industrial Graphite Eng. Handbook National Carbon Co.	1962		298.2	CDA	Similar to the above but electrical resistivity 1640 μohm cm; across grain orientation.
353	338	Industrial Graphite Eng. Handbook National Carbon Co.	1962		298.2	CDG	Graphite stocks size 12 x 12 x 0.25 to 12 x 12 x 1 in.; grain size 0.016 in.; bulk density 1.36 g cm^{-3}; electrical resistivity 1351 μohm cm; with grain orientation.
354	338	Industrial Graphite Eng. Handbook National Carbon Co.	1962		298.2	CDG	Similar to the above but the sizes 15 x 18 x 0.25 to 15 x 18 x 2 in.; bulk density 1.40 g cm^{-3}; electrical resistivity 1522 μohm cm.
355	337	Barratt, T.	1914		290, 373	Pencil lead graphite	Cylindrical rod; 0.183 cm in dia, 10.4 cm long; specific gravity 2.11; specimen made from a 'Kohinor' pencil lead grade 6H.

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*See TPRC Data Book Vol. 3, Chapter 1, References

TABLE 15. SPECIFICATIONS OF THE SPECIMENS OF GRAPHITES (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
356	347	Dull, R.B.	1964	L	298.2	ZTA	Bulk density 1.940 g cm^{-3}; electrical resistivity 6.97 x 10^{-4} ohm cm; with grain.
357	347	Dull, R.B.	1964	L	298.2	ZTA	Bulk density 1.940 g cm^{-3}; electrical resistivity 21.87 x 10^{-4} ohm cm; across grain.
358	347	Dull, R.B.	1964	L	298.2	ZTA	Bulk density 1.924 g cm^{-3}; electrical resistivity 7.24 x 10^{-4} ohm cm; with grain.
359	347	Dull, R.B.	1964	L	298.2	ZTA	Bulk density 1.924 g cm^{-3}; electrical resistivity 21.90 x 10^{-4} ohm cm; across grain.
360	347	Dull, R.B.	1964	L	298.2	ZTA	Bulk density 1.953 g cm^{-3}; electrical resistivity 6.91 x 10^{-4} ohm cm; with grain.
361	347	Dull, R.B.	1964	L	298.2	ZTA	Bulk density 1.953 g cm^{-3}; electrical resistivity 23.18 x 10^{-4} ohm cm; across grain.
362	347	Dull, R.B.	1964	L	298.2	ZTA	Bulk density 1.942 g cm^{-3}; electrical resitivity 6.70 x 10^{-4} ohm cm; with grain.
363	347	Dull, R.B.	1964	L	298.2	ZTA	Bulk density 1.942 g cm^{-3}; electrical resistivity 18.95 x 10^{-4} ohm cm; across grain.
364	347	Dull, R.B.	1964	L	298.2	ZTA	Bulk density 1.955 g cm^{-3}; electrical resistivity 6.87 x 10^{-4} ohm cm; with grain.
365	347	Dull, R.B.	1964	L	298.2	ZTA	Bulk density 1.955 g cm^{-3}; electrical resistivity 22.04 x 10^{-4} ohm cm; across grain.
366	347	Dull, R.B.	1964	L	298.2	ZTA	Bulk density 1.923 g cm^{-3}; electrical resistivity 7.07 x 10^{-4} ohm cm; with grain.
367	347	Dull, R.B.	1964	L	298.2	ZTA	Bulk density 1.923 g cm^{-3}; electrical resistivity 22.67 x 10^{-4} ohm cm; across grain.
368	347	Dull, R.B.	1964	L	298.2	ZTA	Bulk density 1.932 g cm^{-3}; electrical resistivity 7.43 x 10^{-4} ohm cm; with grain.
369	347	Dull, R.B.	1964	L	298.2	ZTA	Bulk density 1.932 g cm^{-3}; electrical resistivity 16.09 x 10^{-4} ohm cm; across grain.
370	347	Dull, R.B.	1964	L	298.2	ZTA	Bulk density 1.92 g cm^{-3}; electrical resistivity 7.76 x 10^{-4} ohm cm; with grain.
371	347	Dull, R.B.	1964	L	298.2	ZTA	Bulk density 1.92 g cm^{-3}; electrical resistivity 16.45 x 10^{-4} ohm cm; across grain.
372	347	Dull, R.B.	1964	L	298.2	ZTA	Bulk density 1.93 g cm^{-3}; electrical resistivity 7.54 x 10^{-4} ohm cm; with grain.
373	347	Dull, R.B.	1964	L	298.2	ZTA	Bulk density 1.93 g cm^{-3}; electrical resistivity 15.84 x 10^{-4} ohm cm; across grain.
374	347	Dull, R.B.	1964	L	298.2	ZTA	Bulk density 1.95 g cm^{-3}; electrical resistivity 6.66 x 10^{-4} ohm cm; with grain.
375	347	Dull, R.B.	1964	L	298.2	ZTA	Bulk density 1.95 g cm^{-3}; electrical resistivity 15.82 x 10^{-4} ohm cm; across grain.
376	347	Dull, R.B.	1964	L	298.2	ZTA	Bulk density 1.94 g cm^{-3}; electrical resistivity 7.42 x 10^{-4} ohm cm; with grain.
377	347	Dull, R.B.	1964	L	298.2	ZTA	Bulk density 1.94 g cm^{-3}; electrical resistivity 16.18 x 10^{-4} ohm cm; across grain.
378	347	Dull, R.B.	1964	L	298.2	ZTB	Bulk density 1.98 g cm^{-3}; electrical resistivity 6.68 x 10^{-4} ohm cm; with grain.
379	347	Dull, R.B.	1964	L	298.2	ZTB	Bulk density 1.98 g cm^{-3}; electrical resistivity 19.74 x 10^{-4} ohm cm; across grain.
380	347	Dull, R.B.	1964	L	298.2	ZTB	Bulk density 1.97 g cm^{-3}; electrical resistivity 6.96 x 10^{-4} ohm cm; with grain.
381	347	Dull, R.B.	1964	L	298.2	ZTB	Bulk density 1.97 g cm^{-3}; electrical resistivity 17.81 x 10^{-4} ohm cm; across grain.
382	347	Dull, R.B.	1964	L	298.2	ZTB	Bulk density 1.99 g cm^{-3}; electrical resistivity 6.43 x 10^{-4} ohm cm; with grain.
383	347	Dull, R.B.	1964	L	298.2	ZTB	Bulk density 1.99 g cm^{-3}; electrical resistivity 21.13 x 10^{-4} ohm cm; across grain.
384	347	Dull, R.B.	1964	L	298.2	ZTC	Bulk density 1.93 g cm^{-3}; electrical resistivity 6.97 x 10^{-4} ohm cm; with grain.
385	347	Dull, R.B.	1964	L	298.2	ZTC	Bulk density 1.93 g cm^{-3}; electrical resistivity 11.97 x 10^{-4} ohm cm; across grain.
386	347	Dull, R.B.	1964	L	298.2	ZTC	Bulk density 1.92 g cm^{-3}; electrical resistivity 7.15 x 10^{-4} ohm cm; with grain.

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*See TPRC Data Book Vol. 3, Chapter 1, References

TABLE 15. SPECIFICATIONS OF THE SPECIMENS OF GRAPHITES (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
387	347	Dull, R. B.	1964	L	298. 2	ZTC	Bulk density 1. 92 g cm^{-3}; electrical resistivity 11. 00 x 10^{-4} ohm cm; across grain.
388	347	Dull, R. B.	1964	L	298. 2	ZTC	Bulk density 1. 94 g cm^{-3}; electrical resistivity 6. 90 x 10^{-4} ohm cm; with grain.
389	347	Dull, R. B.	1964	L	298. 2	ZTC	Bulk density 1. 94 g cm^{-3}; electrical resistivity 13. 21 x 10^{-4} ohm cm; across grain.
390	347	Dull, R. B.	1964	L	298. 2	ZTD	Bulk density 2. 01 g cm^{-3}; electrical resistivity 5. 41 x 10^{-4} ohm cm; with grain.
391	347	Dull, R. B.	1964	L	298. 2	ZTD	Bulk density 2. 01 g cm^{-3}; electrical resistivity 7. 88 x 10^{-4} ohm cm; across grain.
392	347	Dull, R. B.	1964	L	298. 2	ZTE	Bulk density 1. 96 g cm^{-3}; electrical resistivity 8. 94 x 10^{-4} ohm cm; with grain.
393	347	Dull, R. B.	1964	L	298. 2	ZTE	Bulk density 1. 96 g cm^{-3}; electrical resistivity 20. 40 x 10^{-4} ohm cm; across grain.
394	347	Dull, R. B.	1964	L	298. 2	ZTF	Bulk density 1. 99 g cm^{-3}; electrical resistivity 7. 31 x 10^{-4} ohm cm; with grain.
395	347	Dull, R. B.	1964	L	298. 2	ZTF	Bulk density 1. 99 g cm^{-3}; electrical resistivity 20. 50 x 10^{-4} ohm cm; across grain.
396	347	Dull, R. B.	1964	L	298. 2	ZTF	Bulk density 1. 99 g cm^{-3}; electrical resistivity 7. 24 x 10^{-4} ohm cm; with grain.
397	347	Dull, R. B.	1964	L	298. 2	ZTF	Bulk density 1. 99 g cm^{-3}; electrical resistivity 21. 48 x 10^{-4} ohm cm; across grain.
398	347	Dull, R. B.	1964	L	298. 2	RVA	Bulk density 1. 84 g cm^{-3}; electrical resistivity 12. 21 x 10^{-4} ohm cm; with grain.
399	347	Dull, R. B.	1964	L	298. 2	RVA	Bulk density 1. 84 g cm^{-3}; electrical resistivity 15. 73 x 10^{-4} ohm cm; across grain.
400	347	Dull, R. B.	1964	L	298. 2	RVA	Bulk density 1. 825 g cm^{-3}; electrical resistivity 12. 25 x 10^{-4} ohm cm; with grain.
401	347	Dull, R. B.	1964	L	298. 2	RVA	Bulk density 1. 825 g cm^{-3}; electrical resistivity 16. 87 x 10^{-4} ohm cm; across grain.
402	347	Dull, R. B.	1964	L	298. 2	RVA	Bulk density 1. 842 g cm^{-3}; electrical resistivity 12. 34 x 10^{-4} ohm cm; with grain.
403	347	Dull, R. B.	1964	L	298. 2	RVA	Bulk density 1. 842 g cm^{-3}; electrical resistivity 15. 20 x 10^{-4} ohm cm; across grain.
404	347	Dull, R. B.	1964	L	298. 2	RVA	Bulk density 1. 844 g cm^{-3}; electrical resistivity 12. 06 x 10^{-4} ohm cm; with grain.
405	347	Dull, R. B.	1964	L	298. 2	RVA	Bulk density 1. 844 g cm^{-3}; electrical resistivity 15. 65 x 10^{-4} ohm cm; across grain.
406	347	Dull, R. B.	1964	L	298. 2	RVC	Bulk density 1. 84 g cm^{-3}; electrical resistivity 13. 08 x 10^{-4} ohm cm; with grain.
407	347	Dull, R. B.	1964	L	298. 2	RVC	Bulk density 1. 84 g cm^{-3}; electrical resistivity 16. 41 x 10^{-4} ohm cm; across grain.
408	347	Dull, R. B.	1964	L	298. 2	RVC	Bulk density 1. 84 g cm^{-3}; electrical resistivity 12. 71 x 10^{-4} ohm cm; with grain.
409	347	Dull, R. B.	1964	L	298. 2	RVC	Bulk density 1. 84 g cm^{-3}; electrical resistivity 16. 03 x 10^{-4} ohm cm; across grain.
410	347	Dull, R. B.	1964	L	298. 2	RVC	Bulk density 1. 85 g cm^{-3}; electrical resistivity 13. 13 x 10^{-4} ohm cm; with grain.
411	347	Dull, R. B.	1964	L	298. 2	RVC	Bulk density 1. 85 g cm^{-3}; electrical resistivity 16. 75 x 10^{-4} ohm cm; across grain.
412	347	Dull, R. B.	1964	L	298. 2	RVD	Bulk density 1. 87 g cm^{-3}; electrical resistivity 12. 62 x 10^{-4} ohm cm; with grain.
413	347	Dull, R. B.	1964	L	298. 2	RVD	Bulk density 1. 87 g cm^{-3}; electrical resistivity 21. 64 x 10^{-4} ohm cm; across grain.
414	347	Dull, R. B.	1964	L	298. 2	RVD	Bulk density 1. 87 g cm^{-3}; electrical resistivity 12. 52 x 10^{-4} ohm cm; with grain.
415	347	Dull, R. B.	1964	L	298. 2	RVD	Bulk density 1. 87 g cm^{-3}; electrical resistivity 21. 72 x 10^{-4} ohm cm; across grain.
416	347	Dull, R. B.	1964	L	298. 2	RVD	Bulk density 1. 87 g cm^{-3}; electrical resistivity 12. 72 x 10^{-4} ohm cm; with grain.

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*See TPRC Data Book Vol. 3, Chapter 1, References

TABLE 15. SPECIFICATIONS OF THE SPECIMENS OF GRAPHITES (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
417	347	Dull, R.B.	1964	L	298.2	RVD	Bulk density 1.87 g cm^{-3}; electrical resistivity 21.54 x 10^{-4} ohm cm; across grain.
418	347	Dull, R.B.	1964	L	298.2	CFW	Bulk density 1.90 g cm^{-3}; electrical resistivity 11.98 x 10^{-4} ohm cm; with grain.
419	347	Dull, R.B.	1964	L	298.2	CFW	Bulk density 1.90 g cm^{-3}; electrical resistivity 12.60 x 10^{-4} ohm cm; across grain.
420	347	Dull, R.B.	1964	L	298.2	CFZ	Bulk density 1.91 g cm^{-3}; electrical resistivity 12.77 x 10^{-4} ohm cm; with grain.
421	347	Dull, R.B.	1964	L	298.2	CFZ	Bulk density 1.91 g cm^{-3}; electrical resistivity 16.08 x 10^{-4} ohm cm; across grain.
422	160	Mrozowski, S., Andrew, J.F., Repetski, J., Strauss, H.E., and Wobschall, D.C.	1958	R	1593-3198		Specimen 0.5 in. in dia, 8 in. long; prepared by mixing 100 parts (by weight) of raw Texas coke (calcined for 4 hrs at 1200 C in a baking furnace, crushed and ground) and 40 parts of Medium No. 30 coal tar pitch (supplied by Barrett Co.) for 15 min at 160 C and also 3 parts of extrusion oil (Vacwax 80 of Socony Vacuum Co.) mixed again at 150 C for 5 hrs; extruded and baked at 1000 C; graphitized in nitrogen atmosphere at 3100 C for 10 min.
423	160	Mrozowski, S., et al.	1958	R	2189-3033		Similar to the above but using Texas coke of 200/270 mesh as raw material and extruded at 8200 psi.
424	160	Mrozowski, S., et al.	1958	R	1906-3200		Similar to the above but using Texas coke of 100/150 mesh as raw material and extruded at 6100 psi.
425	160	Mrozowski, S., et al.	1958	R	2078-3134		Similar to the above but using Texas coke of 28/35 mesh as raw material and extruded at 4100 psi.
426	160	Mrozowski, S., et al.	1958	R	2068-2815		The above specimen measured in high vacuum chamber.
427	163	Rasor, N.S. and Smith, A.W.	1954	E	10-306	SA-25	Molded lampblack; density 1.55 g cm^{-3} at room temperature; thermoelectric power +9.0 μ volt K^{-1}; Hall coefficient +0.14 emu; magneto resistivity 0.2 x 10^{-10} emu; electrical resistivity 65.3 x 10^{-3} ohm cm; total susceptibility -21.02 x 10^{-6} cgs unit; and orientation factor ρ_{max}/ρ_{min} = 1.0.
428	163	Rasor, N.S. and Smith, A.W.	1954	E	18-302	SA-25	The above specimen exposed to neutron irradiation of 12.5 MWD/CT (megawatt days per central metric ton of uranium) at <30 C.
429	163	Rasor, N.S. and Smith, A.W.	1954	E	17-310	SA-25	The virgin specimen exposed to neutron irradiation of 22.7 MWD/CT at <30 C.
430	163	Rasor, N.S. and Smith, A.W.	1954	E	15-305	SA-25	The virgin specimen exposed to neutron irradiation of 146 MWD/CT at <30 C.
431	163	Rasor, N.S. and Smith, A.W.	1954	E	17-309	SA-25	The virgin specimen exposed to neutron irradiation of 460 MWD/CT at <30 C.
432	265	Mrozowski, S., Andrew, J.F., Juul, N., Okada, J., Strauss, H.E., and Wobschall, D.C.	1960	R	1418-3188	Graphitized carbon rod	Specimen made from 100 parts of calcined Texas coke (28/35 mesh), 44 parts of coal tar pitch; extruded and baked to 1200 C; density after baking 1.25 g cm^{-3}; graphitized to 3100 C; measured in argon atmosphere at 1-2 in. Hg above atmospheric pressure.
433	265	Mrozowski, S., et al.	1960	R	1503-3073	Graphitized carbon rod	Specimen 1.36 in. in dia; made from 100 parts of filler (50 parts of 65/100 mesh and 50 parts of 200/270 mesh Texas coke) and 40 parts of M-30 coal tar pitch as binder; extruded at 7000 psi; graphitized to 3100 C.
434	265	Mrozowski, S., et al.	1960	R	1363-3183	Graphitized carbon rod	Specimen 1.61 in. in dia; made from 100 parts of filler (50 parts of 65/100 mesh and 50 parts 200/270 mesh) and 35 parts of phenol benzaldehyde as binder; extruded at 5300 psi; graphitized to 3100 C.

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*See TPRC Data Book Vol. 3, Chapter 1, References

TABLE 15. SPECIFICATIONS OF THE SPECIMENS OF GRAPHITES (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
435	265	Mrozowski, S., et al.	1960	R	1373-2773	Graphitized carbon rod	Specimen 1.24 in. in dia; made from 100 parts of filler (50 parts of 100/150 mesh and 50 parts of <270 mesh phenol formaldehyde) and 48 parts of M-30 coal tar pitch as binder; extruded at 2300 psi; graphitized to 3100 C.
436	265	Mrozowski, S., et al.	1960	R	1403-3273	Graphitized carbon rod	Specimen 1.57 in. in dia; made from 100 parts of filler (50 parts of 100/150 mesh and 50 parts of <270 mesh phenol formaldehyde) and 43 parts binder; extruded at 11500 psi; graphitized to 3100 C.
437	367	Mrozowski, S., Andrew, J.F., Juul, N., Sato, S., Strauss, H.E., and Tsuzuku, T.	1963	R	1343-2313		Prepared by mixing 50 parts 65/100 mesh and 50 parts <200 mesh soft filler (soft Texas coke), and 40 parts soft binder (M-30 pitch); extruded to 1/2 in. dia; baked for 4 days to 1000 C; density after baking 1.55 g cm^{-3}; heat treated at 2100 C for 10 min; measured in an argon atmosphere (pressure approx one atm.).
438	367	Mrozowski, S., et al.	1963	R	1303-2603		The above specimen heat treated at 2400 C for 10 min.
439	367	Mrozowski, S., et al.	1963	R	1303-2948		The above specimen heat treated at 2800 C for 10 min.
440	367	Mrozowski, S., et al.	1963	R	1353-2303		Prepared by mixing 50 parts 65/100 mesh and 50 parts 200/270 mesh soft filler (soft Texas coke), and 35 parts hard binder (phenol benzaldehyde); extruded to 1/2 in. dia; baked for 4 days to 1000 C; density after baking 1.56 g cm^{-3}; heat treated at 2100 C for 10 min; measured in an argon atmosphere (pressure approx. 1 atm.).
441	367	Mrozowski, S., et al.	1963	R	1383-2583		The above specimen heated at 2400 C for 10 min.
442	367	Mrozowski, S., et al.	1963	R	1373-2973		The above specimen heated at 2800 C for 10 min.
443	367	Mrozowski, S., et al.	1963	R	1318-2233		Prepared by mixing 50 parts 100/150 mesh and 50 parts <270 mesh hard filler (phenol formaldehyde), and 48 parts soft binder (M-30 pitch); extruded to 1/2 in. dia; baked for 4 days to 1000 C; density after baking 1.14 g cm^{-3}; heat treated at 2100 C for 10 min; measured in an argon atmosphere (pressure approx 1 atm.).
444	367	Mrozowski, S., et al.	1963	R	1323-2473		The above specimen heat treated at 2400 C for 10 min.
445	367	Mrozowski, S., et al.	1963	R	1333-2763		The above specimen heat treated at 2800 C for 10 min.
446	367	Mrozowski, S., et al.	1963	R	1343-2263		Prepared by mixing 50 parts 100/150 mesh and 50 parts <270 mesh hard filler (phenol formaldehyde), and 43 parts hard binder (phenol benzaldehyde); extruded to 1/2 in. dia; baked for 4 days to 1000 C; density after baking 1.22 g cm^{-3}; heat treated at 2100 C for 10 min; measured in an argon atmosphere (pressure approx 1 atm.).
447	367	Mrozowski, S., et al.	1963	R	1368-2523		The above specimen heat treated at 2400 C for 10 min.
448	367	Mrozowski, S., et al.	1963	R	1438-2893		The above specimen heat treated at 2800 C for 10 min.
449	349	Holland, M.G., Klein, C.A., and Straub, W.D.	1966	L	2.2-290	Pyrolytic graphite	Well graphitized and highly heat treated (at 3250 C) pyrolytic graphite; measured in the layer-plane direction; in zero magnetic field.
450	349	Holland, M.G., et al.	1966	L	2.1-4.8	Pyrolytic graphite	The above specimen measured in a magnetic field of 550 gauss applied in the c-axis direction.
451	349	Holland, M.G., et al.	1966	L	2.2-4.9	Pyrolytic graphite	The above specimen in a field of 1015 gauss.

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*See TPRC Data Book Vol. 3, Chapter 1, References

TABLE 15. SPECIFICATIONS OF THE SPECIMENS OF GRAPHITES (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
452	349	Holland, M. G., et al.	1966	L	2.2-4.9	Pyrolytic graphite	The above specimen in a field of 2115 gauss.
453	349	Holland, M. G., et al.	1966	L	2.2-3.6	Pyrolytic graphite	The above specimen in a field of 3805 gauss.
454	349	Holland, M. G., et al.	1966	L	2.2-3.9	Pyrolytic graphite	The above specimen in a field of 8405 gauss.
455	349	Holland, M. G., et al.	1966	L	3.1-4.8	Pyrolytic graphite	The above specimen in a field of 12600 gauss.
456	350	Taylor, R.	1965	P	293.2	Pyrolytic graphite	Specimen ~0.5 in. long; graphitized at 2910 C; specific heat 0.168 cal g^{-1} C^{-1} at 20 C; measured in the a-axis direction.
457	350	Taylor, R.	1965	P	293.2	Pyrolytic graphite	Similar to the above specimen but about 0.2 in. long; measured in the c-axis direction.
458	350	Taylor, R.	1965	P	293.2	Pyrolytic graphite	Specimen ~0.5 in. long; graphitized at 2800 C; specific heat 0.168 cal g^{-1} C^{-1} at 20 C; measured in the a-axis direction.
459	350	Taylor, R.	1965	P	293.2	Pyrolytic graphite	Similar to the above specimen but ~0.2 in. long; measured in the c-axis direction.
460	350	Taylor, R.	1965	P	293.2	Pyrolytic graphite	Similar to the above specimen but ~0.5 in. long; strain annealed at 3300 C; measured in the a-axis direction.
461	350	Taylor, R.	1965	P	293.2	Pyrolytic graphite	Similar to the above specimen but ~0.2 in. long; measured in the c-axis direction.
462	351	Mills, J. J., Morant, R. A., and Wright, D. A.	1965	L	80, 195	Pyrolytic graphite	Specimen ~0.2 mm thick; cut from a pyrolytic graphite bar which was made at a deposition temperature of 2700 C.
463	351	Mills, J. J., et al.	1965	L	80, 170	Pyrolytic graphite	Similar to the above specimen but deposition temperature 2920 C.
464	351	Mills, J. J., et al.	1965	L	80, 144	Pyrolytic graphite	Similar to the above specimen but deposition temperature 2980 C.
465	352	Slack, G. A.	1962	L	5.0-300	PG-O	Specimen 0.7 cm long and having a square cross-sectional area of 0.17 cm^2; made from pyrolytic graphite deposited at 2250 C on a substrate of commercial graphite in a methane atmosphere at 2250 C and at a total pressure of 20 mm Hg; graphite crystallites shaped like oblate ellipsoids (with rotational symmetry about the c-axis), of minor dia (parallel to c-axis) = 140 Å and major dia (perpendicular to c-axis) = 280 Å; these crystallites with an average angular tilt of 22 degrees from the c-axis formed columnar bundles of 0.1 cm in dia; density of the specimen 2.194 g cm^{-3}; electrical conductivity 1.98 ohm^{-1} cm^{-1} at 298 K; sound velocity 3.4 x 10^5 cm sec^{-1} at 9.8 megacycles sec^{-1} and at 300 K; free from any visible cracks along the [0001] planes; heat flow parallel to the c-axis.
466	352	Slack, G. A.	1962	L	3.2-300	PG-O	Similar to the above specimen but 1.9 cm long with a square cross-sectional area of 0.14 cm^2; electrical conductivity 1.85 x 10^3 ohm^{-1} cm^{-1} at 298 K; sound velocity 4.7 x 10^5 cm sec^{-1} at the same conditions as above; heat flow perpendicular to c-axis.

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*See TPRC Data Book Vol. 3, Chapter 1, References

TABLE 15. SPECIFICATIONS OF THE SPECIMENS OF GRAPHITES (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
467	353	Klein, C.A. and Holland, M.G.	1964	L	1.8-300	RAY-17	Specimen of pyrolytic graphite in its "as-deposited" condition; manufactured by Raytheon's Adv. Mat. Dept. with a deposition temperature of 1700 C; crystallite size 180 Å; density 2.13 g cm^{-3}; cut parallel to the layer plane.
468	353	Klein, C.A. and Holland, M.G.	1964	L	1.9-295	RAY-23	Similar to the above specimen but the deposition temperature, 2300 C; density 2.22 g cm^{-3} and crystallite size 285 Å; parallel to the layer plane.
469	353	Klein, C.A. and Holland, M.G.	1964	L	3.4-80	RAY-23	Similar to the above specimen but cut perpendicular to the layer plane.
470	353	Klein, C.A. and Holland, M.G.	1964	L	1.8-7.5	RAY-19	Similar to the above specimen but the deposition temperature, 1900 C; crystallite size 240 Å, and density 2.19 g cm^{-3}; cut parallel to the layer plane.
471	353	Klein, C.A. and Holland, M.G.	1964	L	2.0-6.8	RAY-21	Similar to the above specimen but the deposition temperature, 2100 C; crystallite size 270 Å, and density 2.20 g cm^{-3}; cut parallel to the layer plane.
472	353	Klein, C.A. and Holland, M.G.	1964	L	3.1-300	RAY-21	Similar to the above specimen but cut perpendicular to the layer plane.
473	353	Klein, C.A. and Holland, M.G.	1964	L	1.9-300	HTM	Specimen of pyrolytic graphite in its "as-deposited" condition; obtained from High Temp. Mat. Inc.; deposition temperature ~2100 C; density 2.19 g cm^{-3}; cut parallel to the layer plane.
474	353	Klein, C.A. and Holland, M.G.	1964	L	4.3-290	HTM	Similar to the above specimen but cut perpendicular to the layer plane.
475	354	Mason, I.B. and Knibbs, R.H.	1962	C	323-873	EY9	Specimen made from Morgan Crucible Co. graphite; cut parallel to the direction of extrusion; density 1.64 g cm^{-3}; electrical resistivity at 88, 205, 320, 420, and 545 C being, respectively, 1.93, 1.71, 1.53, 1.40, and 1.30 milliohm cm; Armco iron used as the comparative material.
476	354	Mason, I.B. and Knibbs, R.H.	1962	C	313-828	EY9	Similar to the above specimen but cut perpendicular to the direction of extrusion; electrical resistivity at 70, 185, 350, and 425 C being, respectively, 2.87, 2.58, 2.21, and 2.05 milliohm cm.
477	354	Mason, I.B. and Knibbs, R.H.	1962	C	321-916	HX10	Specimen made from material of Harwell Graphite Plant; cut parallel to the direction of extrusion; density 1.87 g cm^{-3}; electrical resistivity at 83, 195, 360, and 450 C being, respectively, 1.50, 1.30, 1.10, and 1.02 milliohm cm.
478	354	Mason, I.B. and Knibbs, R.H.	1962	C	321-838	British Reactor Grade A	Specimen cut parallel to the direction of extrusion; density 1.73 g cm^{-3}; electrical resistivity at 100, 200, 300, 400, and 450 C being, respectively, 0.60, 0.53, 0.48, 0.45, and 0.44 milliohm cm.
479	354	Mason, I.B. and Knibbs, R.H.	1962	C	321-846	British Reactor Grade A	Similar to the above specimen but cut perpendicular to the direction of extrusion; electrical resistivity at 100, 200, and 300 C being, respectively, 1.03, 0.90, and 0.82 milliohm cm.
480	354	Mason, I.B. and Knibbs, R.H.	1962	C	318-816	British Reactor Grade A	Similar to the above specimen but cut parallel to the direction of extrusion.
481	354	Mason, I.B. and Knibbs, R.H.	1962	C	318-823	British Reactor Grade A	Similar to the above specimen but cut perpendicular to the direction of extrusion.
482	354	Mason, I.B. and Knibbs, R.H.	1962	C	313-831	British Reactor Grade Carbon	British Reactor grade carbon stock graphitized to 2100 C; not impregnated; cut parallel to the direction of extrusion; density 1.62 g cm^{-3}; electrical resistivity at 100, 200, 300, 400, and 500 C being, respectively, 3.10, 2.87, 2.67, 2.49, and 2.33 milliohm cm.

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*See TPRC Data Book Vol. 3, Chapter1, References

TABLE 15. SPECIFICATIONS OF THE SPECIMENS OF GRAPHITES (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
483	354	Mason, I.B. and Knibbs, R.H.	1962	C	313-798	British Reactor Grade Carbon	Similar to the above specimen but graphitized to 2300 C; density 1.68 g cm^{-3}; electrical resistivity at 100, 200, 300, 400, and 500 C being, respectively, 2.35, 2.08, 1.85, 1.64, and 1.46 milliohm cm.
484	354	Mason, I. B. and Knibbs, R.H.	1962	C	313-753	British Reactor Grade Carbon	Similar to the above specimen but graphitized to 2600 C; density 1.62 g cm^{-3}; electrical resistivity at 100, 200, 300, 400, and 500 C being, respectively, 1.17, 1.02, 0.92, 0.85, and 0.80 milliohm cm.
485	354	Mason, I. B. and Knibbs, R.H.	1962		303-901	British Reactor Grade Carbon	Similar to the above specimen but graphitized to 2820 C; density 1.65 g cm^{-3}; electrical resistivity at 100, 200, 300, 400, 500, 600, and 700 C being, respectively, 0.78, 0.71, 0.67, 0.65, 0.64, 0.65, and 0.67 milliohm cm.
486	361	Pappis, J. and Blum, S. L.	1961	C	375-1175	Pyrolytic graphite	Highly regenerative pyrolytic graphite; as deposited; the pyrolytic graphite obtained by passing methane on a graphite slab in the resistance furnace at 2100 C; density 2.20 g cm^{-3}; measured parallel to the basal planes using dense sintered alumina as a comparative material.
487	361	Pappis, J. and Blum, S. L.	1961	R	1430-2275	Pyrolytic graphite	Similar to the above specimen but using another apparatus for high temperature range.
488	361	Pappis, J. and Blum, S. L.	1961	R	325-1350	Pyrolytic graphite	Similar to the above specimen but being heat treated for 3 hrs at 2900 C; measured perpendicular to the basal planes.
489	361	Pappis, J. and Blum, S. L.	1961	C	435-1205	Pyrolytic graphite	Similar to the above specimen but heat treated 1 hr at 2900 C; measured parallel to the basal plane using dense sintered alumina as a comparative material.
490	361	Pappis, J. and Blum, S. L.	1961	R	330-2340	Pyrolytic graphite	Similar to the above specimen but without heat treatment; measured perpendicular to the basal plane.
491	360	De Combaricu, A.	1965	L	6.8-320	Pyrolytic graphite No. 1	Pyrolytic graphite specimen size 1 x 5 x 50 mm; the graphite deposition temperature 2100 C; annealed under a pressure of 100 bars for 10-15 min at 2800 C; measured parallel to the graphite basal planes.
492	360	De Combaricu, A.	1965	L	5.5-320	Pyrolytic graphite No. 2	Similar to the above specimen
493	362	Hooker, C.N., Ubbelohde, A.R., and Young, D.A.	1965	L	100-325	Pyrolytic graphite AB 3	Pyrolytic graphite deposited at 2150 C; annealed at 3000 C; measured parallel to the basal planes.
494	362	Hooker, C.N., et al.	1965	L	91-330	Pyrolytic graphite IFP41	Similar to the above specimen but also hot pressed at 2850 C under 400 Kg cm^{-2}; measured parallel to the basal planes.
495	362	Hooker, C.N., et al.	1965	L	91-330	Pyrolytic graphite IFP56	Similar to the above specimen.
496	362	Hooker, C.N., et al.	1965	L	84-318	Pyrolytic graphite IFPA57	Similar to the above specimen but hot pressed at 2850 C and annealed at 3500 C under 10 Kg cm^{-2} for 1/2 hr; measured parallel to the basal planes.
497	362	Hooker, C.N., et al.	1965	L	88-310	Pyrolytic graphite IFPA57	The above specimen measured in the c-axis direction.
498	362	Hooker, C.N., et al.	1965	L	105-365	Pyrolytic graphite AB4	Pyrolytic graphite deposited at 2150 C; annealed at 3250 C in induction furnace; measured in the c-axis direction.

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*See TPRC Data Book Vol. 3, Chapter 1, References

TABLE 15. SPECIFICATIONS OF THE SPECIMENS OF GRAPHITES (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
499	362	Hooker, C. N., et al.	1965	L	88-303	Pyrolytic graphite AB1	Similar to the AB3 specimen but measured in the c-axis direction.
500	362	Hooker, C. N., et al.	1965	L	97-350	Pyrolytic graphite IFP25	Similar to the IFP41 specimen but measured in the c-axis direction.
501	336	Hooker, C. N., et al.	1965	L	107-318	Pyrolytic graphite IFP25/N4	The above specimen exposed to 2 x 10^{18} fast neutron cm^{-2} at 30 C; measured in the c-axis direction.
502	336	Powell, R. W., Tye, R. P., and Metcalf, S. C.	1965		323. 2	EY9	Grade EY9 graphite from Morgan Crucible Co.; electrical resistivity 1. 71 milliohm cm at room temperature.
503	336	Powell, R. W., et al.	1965		323. 2	EY9	Similar to the above specimen but electrical resistivity 1. 86 milliohm cm at room temperature.
504	336	Powell, R. W., et al.	1965		323. 2	EY9	Similar to the above specimen but electrical resistivity 1. 89 milliohm cm at room temperature.
505	397	Bortz, S. A. and Connors, C. L.	1966		364-2239	JTA; 7-F-12	Measured in the with-the-grain direction.
506	363	Wheeler, M. J.	1965	P	1575-2400	EY9A	Density 1. 76 g cm^{-3}; data calculated from measurements of thermal diffusivity; specific heat data from "Nuclear Graphite" by Nightingale, R. E., Yoshikawa, H. H., and Losty, H. H. W., 1962.
507	363	Wheeler, M. J.	1965	P	1320-2380	Moderator graphite	Density 1. 71 g cm^{-3}; data calculated from measurements of thermal diffusivity and specific heat data from the same source as above.
508	365	Johnson, W. and Watt, W.	1963	R	1712-2308	Pyrolytic graphite A1	Specimen 11 cm long, 1. 713 cm O. D., and 1. 465 cm I. D.; pyrolytic graphite deposited at 1800 C from hexane at a total pressure of 35 cm Hg (partial pressure of hexane 7 cm Hg); the hydrogen carrier gas flows at a rate of 500 cm^3 min^{-1}; the specimen heat treated for 2 hrs at 2800 C; density 1. 71 g cm^{-3}; data obtained by the first method (direct heating of the graphite tube).
509	365	Johnson, W. and Watt, W.	1963	R	1426-1945	Pyrolytic graphite A1	The above specimen measured by the third method (separate heater inserted in the tube).
510	365	Johnson, W. and Watt, W.	1963	R	1637-2313	Pyrolytic graphite A2	Specimen 11 cm long, 1. 728 cm O. D., and 1. 39 cm I. D.; deposited at 2100 C from hexane by a method similar to the above; heat treated for 2 hrs at 2800 C; density 2. 21 g cm^{-3}; data obtained by the first method.
511	365	Johnson, W. and Watt, W.	1963	R	1420-2009	Pyrolytic graphite A2	The above specimen measured by the third method.
512	365	Johnson, W. and Watt, W.	1963	R	1530-2043	Pyrolytic graphite B1	Specimen 11 cm long, 1. 75 cm O. D., and 1. 394 cm I. D.; deposited in the same way as the above specimen; heat treated for 1. 25 hrs at 2600 C; density 2. 20 g cm^{-3}; data obtained by the second method (an improvement of the first method to decrease the end contact resistance of the graphite tube).
513	365	Johnson, W. and Watt, W.	1963	R	1895-2231	Pyrolytic graphite B1	The above specimen measured by the third method.
514	365	Johnson, W. and Watt, W.	1963	R	1504-1736	Pyrolytic graphite B1	Thermal conductivity parallel to the basal planes of the above specimen.

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*See TPRC Data Book Vol. 3, Chapter 1, References

TABLE 15. SPECIFICATIONS OF THE SPECIMENS OF GRAPHITES (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
515	365	Johnson, W. and Watt, W.	1963	R	1422-2056	Pyrolytic graphite B2	Specimen 11 cm long, 1.75 cm O.D., and 1.351 cm I.D.; deposited and heat treated in the same way as the above specimen; density 2.20 g cm^{-3}; data obtained by the third method.
516	368	Jain, S.C. and Krishnan, K.S.	1954	E	1300-2000	Acheson graphite	Long thin rod of Acheson graphite electrically heated in vacuo; electrical resistivity at 470, 600, 800, 1000, 1200, 1400, 1600, 1800, 2000, and 2070 K being, respectively, 0.7, 0.645, 0.606, 0.615, 0.640, 0.675, 0.7175, 0.765, 0.8175, and 0.840 milliohm cm.
517	368	Jain, S.C. and Krishnan, K.S.	1954	E	1200-1450	Acheson graphite	Data for a short rod of Acheson graphite.
518	369	Taylor, R.	1966	P	110-880	Pyrolytic graphite specimen 42	Specimen 0.5 in. long, made from as deposited pyrolytic graphite; annealed at 2900 C for 1 hr in an inert gas atmosphere; thermal conductivity parallel to the deposition plane calculated from measurements of thermal diffusivity, a constant density of 2.20 g cm^{-3}, and the best fit specific heat data from Magnus, 1923, Schläpfer and Debrunner 1924, Jacobs and Deem 1956, Wagman et al. 1945, and Rossini et al. 1953.
519	369	Taylor, R.	1966	P	90-920	Pyrolytic graphite specimen 90	Specimen also 0.5 in. long supplied by General Electric Co. (structurally more perfect than the above specimen); annealed at 3300 C in inert gas; thermal conductivity parallel to the deposition plane calculated by using the same information as above.
520	369	Taylor, R.	1966	P	85-830	Pyrolytic graphite specimen 90	The above specimen measured perpendicular to the deposition plane.
521	391	Bocquet, M. and Micaud, G.	1964	E	295-511	ZTA	Prepared from coke L, supplied by Péchiney Co., by extruding into a 10 mm dia bar; the graphite was impregnated once with tar; measured along the a-axis.
522	391	Bocquet, M. and Micaud, G.	1964	E	298-536	ZTA	Similar to the above; measured along the c-axis.
523	391	Bocquet, M. and Micaud, G.	1964	E	306-714	ZTA	Similar to the above; the dia was a bit smaller and measured along the a-axis.
524	391	Bocquet, M. and Micaud, G.	1964	E	321-721	ZTA	Similar to the above; measured along the c-axis.
525	391	Bocquet, M. and Micaud, G.	1964	E	302-598	ZTA	Prepared from coke L, supplied by Péchiney Co. by extruding into 10 mm dia bar; the graphite was impregnated once with tar; measured along the c-axis.
526	391	Bocquet, M. and Micaud, G.	1964	E	307-605	ZTA	Similar to the above specimen except neutron irradiated at 350 C.
527	391	Bocquet, M. and Micaud, G.	1964	E	311-506	ZTA	Similar to the above specimen except neutron-irradiated at 250 C.
528	391	Bocquet, M. and Micaud, G.	1964	E	393-411	ZTA	Similar to the above specimen except neutron-irradiated at 150 C.
529	392	Schweitzer, D. and Singer, R.	1961		446-868	AGOT	Density 1.73 g cm^{-3}; grain size >0.032 in.
530	392	Schweitzer, D. and Singer, R.	1961		469-873	MH4LM	Density 1.90 g cm^{-3}; grain size >0.032 in.
531	392	Schweitzer, D. and Singer, R.	1961		471-875	MH4LM	Similar to the above specimen except irradiated in Material Testing Reactor at 475 C by a neutron flux of 3.5 x 10^{19} nvt with energy >0.1 Mev.
532	392	Schweitzer, D. and Singer, R.	1961		471-874	ATL-82-1	Grain size 0.016 to 0.03 in.
533	392	Schweitzer, D. and Singer, R.	1961		471-873	ATL-82-2	Similar to the above specimen; irradiated in Hanford reactor at 360 to 420 C by a neutron flux of 3.2 x 10^{20} nvt with energy >0.1 Mev.

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TABLE 15. SPECIFICATIONS OF THE SPECIMENS OF GRAPHITES (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
534	392	Schweitzer, D. and Singer, R.	1961		472-874	ATL-82-3	Similar to the above specimen except irradiated in Material Testing Reactor at 475 C by a neutron flux of 3. 6 x 10^{19} nvt with energy >0. 1 Mev.
535	392	Schweitzer, D. and Singer, R.	1961		468-868	R0025-1	Obtained from National Carbon Co. ; grain size <0. 016 in.
536	392	Schweitzer, D. and Singer, R.	1961		468-869	R0025-2	Similar to the above specimen.
537	392	Schweitzer, D. and Singer, R.	1961		472-867	R0025-3	Similar to the above specimen; irradiated in Testing Reactor at 360 to 420 C by a neutron flux of 3. 6 x 10^{19} nvt with energy >0. 1 Mev.
538	392	Schweitzer, D. and Singer, R.	1961		471-865	R0025-3A	The above specimen annealed at 925 C for 16 hrs.
539	392	Schweitzer, D. and Singer, R.	1961		473-737	AGOT AK-2	Obtained from Brookhaven pile; density 1. 73 g cm^{-3}; grain size >0. 032 in.
540	392	Schweitzer, D. and Singer, R.	1961		475-829	AGOT AK-1	Similar to the above specimen; irradiated in Brooklyn National Lab. reactor at 30-50 C by a neutron flux of 1655 megawatt days/adjacent ton.
541	392	Schweitzer, D. and Singer, R.	1961		474-830	AGOT JK-1	Similar to the above specimen except irradiated in Brooklyn National Lab. reactor at 30-50 C by a neutron flux of 1686 megawatt days/adjacent ton.
542	392	Schweitzer, D. and Singer, R.	1961		469-836	AGOT JK-1	The above specimen annealed at 1400 C for 1 hr.
543	392	Schweitzer, D. and Singer, R.	1961		463-829	AGOT JK-2	Similar to the above specimen except annealed at 800 C for 1 hr.
544	392	Schweitzer, D. and Singer, R.	1961		475-829	AGOT LK-1	Obtained from Brookhaven pile; density 1. 73 g cm^{-3}; grain size >0. 032 in. ; irradiated in Brooklyn National Lab. reactor at 30-50 C by a neutron flux of 1685 megawatt days/ adjacent ton.
545	392	Schweitzer, D. and Singer, R.	1961		465-835	AGOT LK-1	The above specimen annealed at 1000 C for 1 hr.
546	392	Schweitzer, D. and Singer, R.	1961		469-835	AGOT LK-2	Similar to the above specimen except annealed at 1200 C for 1 hr.
547	392	Schweitzer, D. and Singer, R.	1961		475-829	AGOT CK-1	Obtained from Brookhaven pile; density 1. 73 g cm^{-3}; grain size >0. 032 in. ; irradiated in Brooklyn National Lab. reactor at 30-50 C by a neutron flux of 1685 megawatt days/ adjacent ton.
548	392	Schweitzer, D. and Singer, R.	1961		464-829	AGOT CK-1	The above specimen annealed at 600 C for 1 hr.
549	392	Schweitzer, D. and Singer, R.	1961		468-834	AGOT PK-1	Similar to the above specimen except annealed at 1100 C for 1 hr.
550	393	Meyer, R.A. and Koyama, K.	1963	C	324-1069	AGOT	1 in. dia x 0. 250 in. thick; supplied by National Carbon Co. ; Armco iron used as comparative standard.
551	393	Meyer, R.A. and Koyama, K.	1963	→	1145-2443	AGOT	1 x 0. 25 x 0. 05 in. ; supplied by National Carbon Co. ; measured in vacuum, the method consists of obtaining the steady-state temperatures at centers of the narrow and wide faces of specimen by optical pyrometry, specimen electrically heated; thermal conductivity calculated from measured temperatures, emittance of the specimen, dimensions of the specimen, and the Stefan-Boltzmann constant.
552	393	Meyer, R.A. and Koyama, K.	1963	R	1145-2044	AGOT	Cylindrical specimen obtained from National Carbon Co.
553	340	Hoch, M. and Vardi, J.	1962	→	1671	ZT type graphite G 3A	Thermal conductivity data in the z-direction (k_z) determined simultaneously with thermal conductivity in the r-direction (k_r, see next curve) from 4 cylindrical specimens made from ZT type graphite of National Carbon Co. ; density 1. 980 g cm^{-3}; anisotropy ratio of electrical resistivity ρ(z-direction)/ρ(r-direction) = 2. 50 at room temperature; the specimens each about 2. 537 cm dia x 1. 126 cm thick being heated in vacuum by high frequency induction, thermal conductivity determined by equating the heat conduction in specimen to the heat loss by radiation assuming the emissivity of a gray body, the analysis required 2 specimens of different thickness to solve simultaneously for k_z and k_r at a certain temperature.

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[*] See TPRC Data Book Vol. 3, Chapter 1, References

TABLE 15. SPECIFICATIONS OF THE SPECIMENS OF GRAPHITES (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
554	340	Hoch, M. and Vardi, J.	1962	→	1671	ZT type graphite G3A	k_r determined simultaneously with the above curve.
555	340	Hoch, M. and Vardi, J.	1962	→	1671	ZT type graphite G7	Similar to the above specimen except with size 2.539 cm dia x 0.287 cm thick and density 1.978 g cm^{-3}; k_z was measured.
556	340	Hoch, M. and Vardi, J.	1962	→	1671	ZT type graphite G7	k_r determined simultaneously with the above curve.
557	340	Hoch, M. and Vardi, J.	1962	→	1808	Pyrolytic graphite; P1	Supplied by General Electric Co.; 2.540 cm dia x 0.238 cm thick; k_z determined by using the same method as that for the above specimen.
558	340	Hoch, M. and Vardi, J.	1962	→	1808	Pyrolytic graphite; P1	k_r determined simultaneously with the above curve.
559	336	Powell, R.W., Tye, R.P., and Metcalf, S.C.	1965		673-1173	EY9 graphite	Obtained from Morgan Crucible Co.; electrical resistivity 1790 ~1850 μohm cm at room temperature; data reported were mean values.
560	394	Digesu, F.L. and Pears, C.D.	1965	R	1367-3311	CFZ grade	99.74 C, < 0.6 H, 0.19 ash, 0.07 CaO, 0.02 Al_2O_3, 0.04 total sulfur, and < 0.01 sulfide sulfur; specimens 1 in. long, 1 in. O.D., and 0.25 in. I.D.; supplied by Union Carbide Co.; heat flow measured parallel to cylindrical axis; with grain; bulk density (mean value) 1.899 g cm^{-3}; thermal conductivity data calculated from the mean values of 9 specimens (standard deviation 0.0946, 0.0609, 0.0786, 0.0963, and 0.111 at 1366.5, 2199.8, 2755.4, 3033.2, and 3310.9 K, respectively).
561	394	Digesu, F.L. and Pears, C.D.	1965	R	1367-3311	CFZ grade	Similar to the above specimens except bulk density (mean value) 1.908 g cm^{-3}; standard deviation 0.0891, 0.129, 0.0986, 0.0968, and 0.0544 at 1366.5, 2199.8, 2755.4, 3033.2, and 3310.9 K, respectively.
562	394	Digesu, F.L. and Pears, C.D.	1965	R	1367-3311	CFZ grade	Similar to the above specimens except specimen orientation across grain; bulk density (mean value) 1.896 g cm^{-3}; standard deviation 0.0661, 0.0749, 0.0711, 0.0606, and 0.0526 at 1366.5, 2199.8, 2755.4, 3033.2, and 3310.9 K, respectively.
563	394	Digesu, F.L. and Pears, C.D.	1965	R	1367-3311	CFZ grade	Similar to the above specimens except bulk density (mean value) 1.906 g cm^{-3}; standard deviation 0.0535, 0.0362, 0.0799, 0.0862, and 0.0539 at 1366.5, 2199.8, 2755.4, 3033.2, and 3310.9 K, respectively.
564	394	Digesu, F.L. and Pears, C.D.	1965	C	338.7	CFZ grade	99.74 C, < 0.6 H, 0.19 ash, 0.07 CaO, 0.02 Al_2O_3, 0.04 total sulfur and < 0.01 sulfide sulfur; specimens 1 in. in dia and 1 in. long; supplied by Union Carbide Co.; with grain; bulk density (mean value) 1.903 g cm^{-3}; thermal conductivity data from the mean values of 10 specimens (standard deviation 0.0937 at 338.7 K); Armco iron used as comparative material.
565	394	Digesu, F.L. and Pears, C.D.	1965	C	338.7	CFZ grade	Similar to the above specimens except bulk density (mean value) 1.907 g cm^{-3}; standard deviation 0.108 at 338.7 K.
566	394	Digesu, F.L. and Pears, C.D.	1965	C	338.7	CFZ grade	Similar to the above specimens except bulk density (mean value) 1.881 g cm^{-3}; standard deviation 0.0317 at 338.7 K.
567	394	Digesu, F.L. and Pears, C.D.	1965	C	338.7	CFZ grade	Similar to the above specimens except bulk density (mean value) 1.907 g cm^{-3}; standard deviation 0.0288 at 338.7 K.

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*See TPRC Data Book Vol. 3, Chapter 1, References

TABLE 15. SPECIFICATIONS OF THE SPECIMENS OF GRAPHITES (continued)

Cur. No.	Ref.* No.	Author(s)	Year	Met'd. Used	Temp. Range (K)	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
568	395	Hooker, C. N., Ubbelohde, A. R., and Young, D. A.	1963	L	122-324	Pyrolytic; A_2	Specimen approx. 0. 2 x 1. 5 x 8 cm thickness parallel to c-axis; made from pyrolytic graphite (inner layer of sample) deposited at 2150 C from methane atmosphere at 10 cm Hg pressure; in its "as deposited" condition; scattering length 18000 Å; heat flow perpendicular to c-axis.
569	395	Hooker, C. N., et al.	1963	L	115-324	Pyrolytic; A_1	Specimen approx. 0. 2 x 1. 5 x 8 cm, thickness parallel to c-axis; made from pyrolytic graphite deposited at 2180 C from methane atmosphere at 10 cm Hg pressure; in its "as deposited" condition; scattering length 12,000 Å;heat flow perpendicular to c-axis.
570	395	Hooker, C. N., et al.	1963	L	100-331	Pyrolytic; A_3	Similar to the above specimen but deposited at 2000 C with scattering length 5000 Å; heat flow perpendicular to c-axis.
571	395	Hooker, C. N., et al.	1963	L	116-335	Pyrolytic; AB_1	Similar to the above specimen but deposited at 2150 C and annealed at 3000 C for 30 min; scattering length 36000 Å; heat flow perpendicular to c-axis.
572	395	Hooker, C. N., et al.	1963	L	115-327	Pyrolytic; AB_2	Similar to the above specimen except scattering length 33000 Å; heat flow perpendicular to c-axis.
573	395	Hooker, C. N., et al.	1963	L	125-316	Pyrolytic; A_2	Specimen approx. 0. 2 x 1. 5 x 8 cm, thickness parallel to c-axis; made from pyrolytic graphite (outer layer of sample) deposited at 2150 C and at 10 cm Hg pressure; in its "as deposited" condition; scattering length 5000 Å; heat flow perpendicular to c-axis.
574	395	Hooker, C. N., et al.	1963	L	115-327	Pyrolytic; AB_2	Specimen 0. 2 x 1. 5 x 8 cm, thickness parallel to c-axis; made from pyrolytic graphite deposited at 2150 C from methane atmosphere at 10 cm Hg pressure; annealed at 3000 C for 30 min; scattering length 36000 Å; measured in vacuum of $<10^{-5}$ mm Hg pressure; heat flow parallel to c-axis.
575	395	Hooker, C. N., et al.	1963	L	120-327	Pyrolytic; N_1	Specimen obtained by sealing AB_2 in an evacuated silica tube and irradiating it in a cooled (~30 C) hollow fuel element in B. E. P. O. at Harwell to an integrated fast neutron dose of about 4 x 10^{18} nvt; heat flow parallel to c-axis; measured in vacuum of $<10^{-5}$ mm Hg pressure.
576	395	Hooker, C. N., et al.	1963	L	111-316	Pyrolytic; N_2	The above specimen annealed in vacuo at 240 C for 70 hrs; heat flow parallel to c-axis; measured in vacuum of $<10^{-5}$ mm Hg pressure.
577	395	Hooker, C. N., et al.	1963	L	118-331	Pyrolytic; N_3	The above specimen annealed in vacuo at 1220 C for 6 hrs; heat flow parallel to c-axis; measured in vacuum of $<10^{-5}$ mm Hg pressure.
578	395	Hooker, C. N., et al.	1963	L	104-306	Pyrolytic; A_1	Specimen 0. 2 x 1. 5 x 8 cm, thickness parallel to c-axis; made from pyrolytic graphite deposited at 2180 C from methane atmosphere at 10 cm Hg pressure; in its "as deposited" condition; scattering length 12000 Å; measured in vacuum of $<10^{-5}$ mm Hg pressure; heat flow parallel to c-axis.
579	395	Hooker, C. N., et al.	1963		89-302	Pyrolytic; AB_1	Similar to the above specimen except deposited at 2150 C and annealed at 3000 C for 30 min; scattering length 36000 Å; heat flow parallel to c-axis.
580	396	Kaspar, J.	1967		1088-3030	Supertemp Pyrolytic Graphite	Annealed; electrical conductivity 9.54, 7.73, 6.40, 5.42, 4.72, 4.19, 3.71, and 3.28 x 10^3 $ohm^{-1}cm^{-1}$ at 1088, 1365, 1643, 1920, 2198, 2475, 2753, and 3030 K, respectively.

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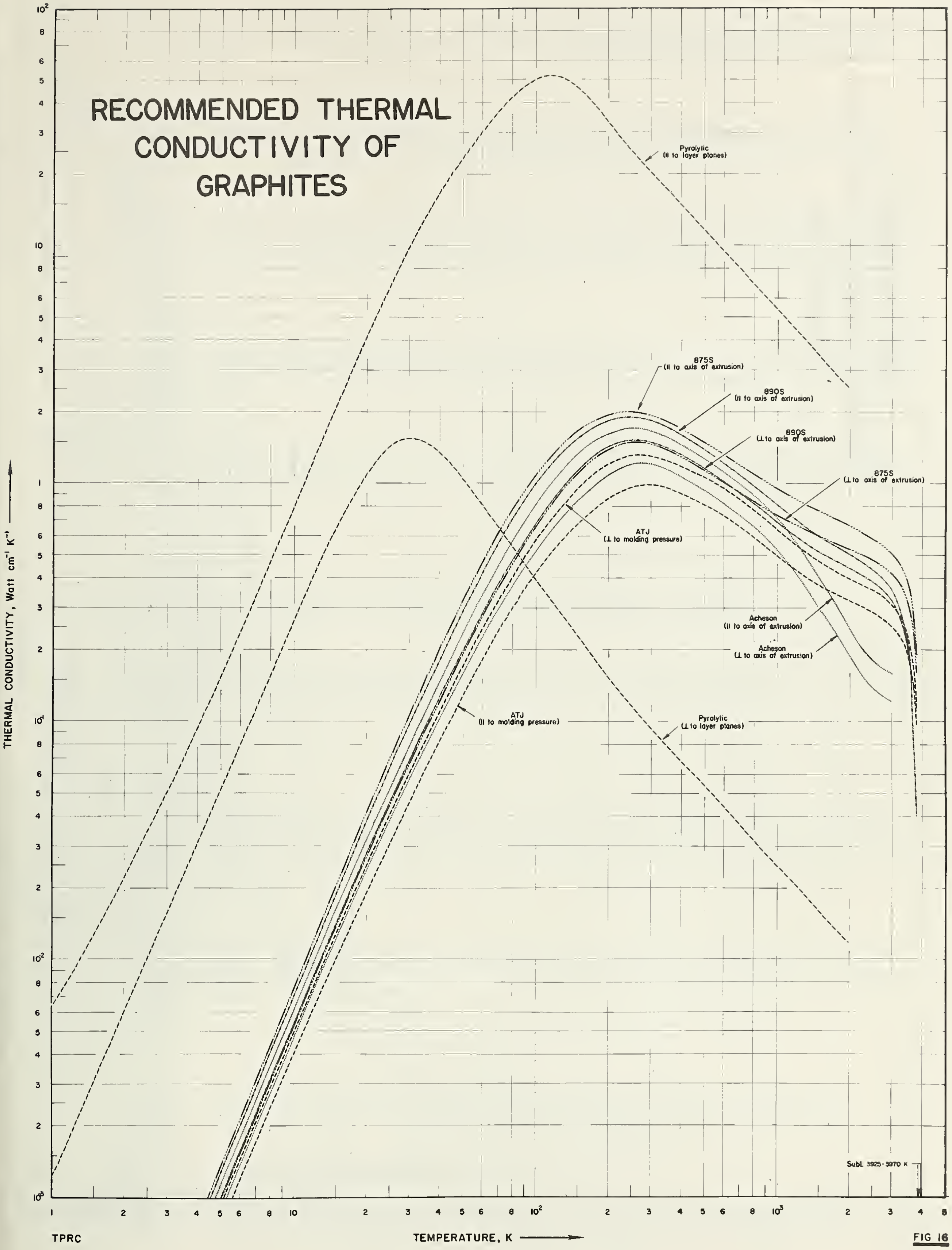
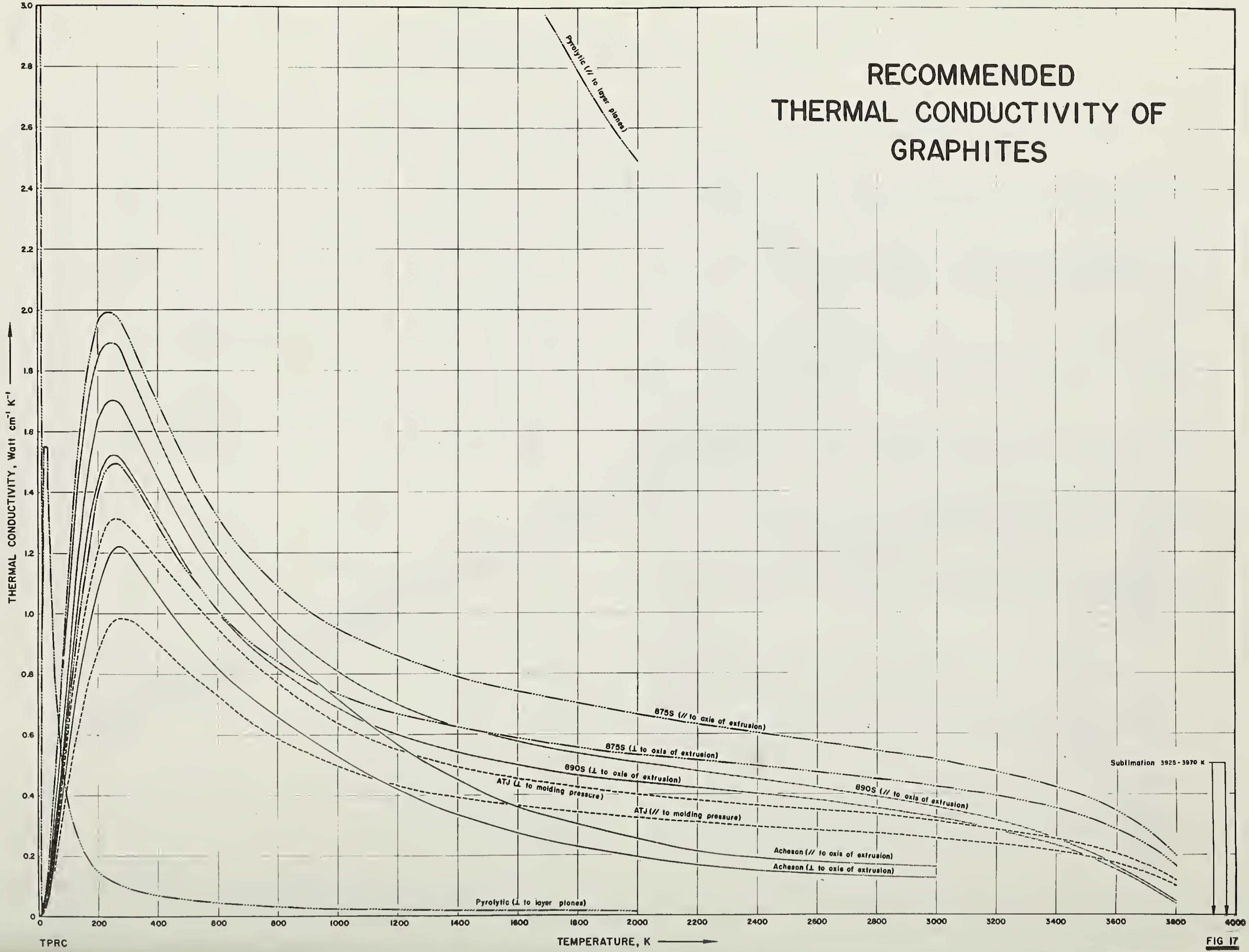
* See TPRC Data Book Vol. 3, Chapter 1, References



RECOMMENDED THERMAL CONDUCTIVITY OF GRAPHITES

TPRC

FIG 16



RECOMMENDED
THERMAL CONDUCTIVITY OF
GRAPHITES

FIG 17

TABLE 16a. RECOMMENDED THERMAL CONDUCTIVITY OF GRAPHITES*

Thermal Conductivity, k, Watt $cm^{-1} K^{-1}$

	Acheson Graphite		ATJ Graphite		Pyrolytic Graphite		875S Graphite		890S Graphite		
T, K	∥ to axis of extrusion	⊥ to axis of extrusion	⊥ to direction of molding pressure	∥ to direction of molding pressure	∥ to basal planes	⊥ to basal planes	∥ to axis of extrusion	⊥ to axis of extrusion	∥ to axis of extrusion	⊥ to axis of extrusion	T, K
0	0	0	0	0	0	0	0	0	0	0	0
10	(0.0061)	(0.0047)	(0.0049)	(0.004)	0.81	0.27	(0.0075)	(0.0053)	(0.007)	(0.0054)	10
20	(0.032)	(0.024)	(0.025)	(0.019)	4.2	1.08	(0.041)	(0.027)	(0.038)	(0.028)	20
30	(0.079)	(0.057)	(0.06)	(0.046)	9.9	1.55	(0.106)	(0.067)	(0.097)	(0.069)	30
40	(0.148	(0.103)	(0.11)	(0.083)	16.3	1.35	(0.20)	(0.123)	(0.18)	(0.127)	40
50	(0.235)	(0.16)	(0.17)	(0.13)	23.0	1.03	(0.32)	(0.193)	(0.29)	(0.20)	50
60	(0.34	(0.23)	(0.25)	(0.18)	29.8	0.81	(0.46)	(0.275)	(0.42)	(0.29)	60
70	(0.45)	(0.30)	(0.32)	(0.24)	36.5	0.65	(0.62)	(0.37)	(0.56)	(0.38)	70
80	(0.57)	(0.37)	(0.41)	(0.30)	42.9	0.54	(0.77)	(0.46)	(0.71)	(0.48)	80
90	(0.69)	(0.44)	(0.49)	(0.36)	47.3	0.46	(0.93)	(0.56)	(0.85)	(0.58)	90
100	0.82	0.52	(0.58)	(0.42)	49.8	0.39	(1.08)	(0.66)	(1.00)	(0.68)	100
150	1.32	0.84	(0.94)	(0.67)	45.3	0.23	(1.67)	(1.10)	(1.55)	(1.14)	150
200	1.62	1.08	(1.20)	(0.86)	32.5	0.15	(1.95	(1.39)	(1.83)	(1.42)	200
250	1.70	1.21	(1.31)	(0.97)	24.5	0.116	(1.99)	(1.49)	(1.89)	(1.52)	250
273	1.69	1.22	(1.31)	(0.98)	22.3	0.106	(1.97)	(1.49)	(1.87)	(1.51)	273
300	1.65	1.20	1.29	0.98	20.0	0.095	(1.92)	(1.46)	(1.82)	(1.48)	300
350	1.55	1.13	1.24	0.95	16.9	0.080	(1.81)	(1.38)	(1.71)	(1.40)	350
400	1.45	1.06	1.18	0.90	14.6	0.070	(1.69)	(1.29)	(1.59)	(1.32)	400
500	1.27	0.93	1.06	0.81	11.4	0.054	(1.49)	1.14	(1.38)	(1.15)	500
600	1.12	0.82	0.95	0.73	9.3	0.044	(1.32)	1.01	(1.21)	(1.01)	600
700	1.00	0.73	0.85	0.65	7.9	0.038	(1.19)	0.92	(1.08)	(0.90)	700
800	0.90	0.66	0.77	0.59	6.8	0.032	(1.09)	0.84	0.97	(0.82)	800
900	0.80	0.59	0.70	0.54	6.0	0.028	1.01	0.78	0.88	(0.75)	900
1000	0.72	0.53	0.64	0.49	5.3	0.025	0.94	0.73	0.81	(0.69)	1000
1100	0.64	0.47	0.59	0.46	4.8	0.023	0.90	0.70	0.75	0.64	1100
1200	0.57	0.42	0.55	0.43	4.4	0.021	0.86	0.67	0.70	0.60	1200
1300	0.50	0.37	0.52	0.41	4.0	0.019	0.82	0.64	0.66	0.57	1300
1400	0.45	0.33	0.49	0.39	3.7	0.017	0.79	0.62	0.63	0.54	1400
1500	0.40	0.30	0.47	0.37	3.4	0.016	0.76	0.60	0.60	0.52	1500
1600	0.36	0.27	0.45	0.36	3.2	0.015	0.74	0.58	0.57	0.50	1600
1700	0.33	0.25	0.44	0.35	3.0	0.014	0.72	0.57	0.55	0.48	1700
1800	0.30	0.23	0.42	0.34	2.8	0.013	0.70	0.55	0.54	0.47	1800
1900	0.28	0.21	0.41	0.33	2.6	0.0125	(0.68	0.54	(0.52)	0.45	1900
2000	0.25	0.19	0.40	0.32	2.5	0.012	(0.66)	0.53	(0.50)	0.44	2000
2200	(0.21)	0.164	0.38	0.31			(0.63)	0.51	(0.48)	0.42	2200
2400	(0.193)	0.145	0.36	0.29			(0.60)	0.49	(0.45)	0.40	2400
2600	(0.176)	0.133	0.35	0.28			(0.57)	0.47	(0.42)	0.38	2600
2800	(0.166)	0.126	0.33	0.27			(0.54)	0.45	(0.39)	0.35	2800
3000	(0.161)	0.122	0.31	0.25			(0.51)	0.42	(0.36)	0.32	3000
3200			0.28	(0.23)			(0.47)	0.39	(0.31)	0.28	3200
3400			(0.25)	(0.21)			(0.42)	0.35	(0.25)	0.23	3400
3600			(0.20)	(0.17)			(0.34)	0.28	(0.16)	0.15	3600
3800			(0.113)	(0.095)			(0.19)	(0.16)	(0.043)	(0.04)	3800

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*Values in parentheses are extensively extrapolated. In the table the third significant figure is given only for internal comparison and for smoothness and is not indicative of the degree of accuracy.

TABLE 16b. RECOMMENDED THERMAL CONDUCTIVITY OF GRAPHITES*

Thermal Conductivity, k, Watt cm^{-1} C^{-1}

	Acheson Graphite		ATJ Graphite		Pyrolytic Graphite		875S Graphite		890S Graphite		
T, C	// to axis of extrusion	⊥ to axis of extrusion	⊥ to direction of molding pressure	// to direction of molding pressure	// to layer planes	⊥ to layer planes	// to axis of extrusion	⊥ to axis of extrusion	// to axis of extrusion	⊥ to axis of extrusion	T, C
-150	1.07	0.68	(0.76)	(0.55)	50.4	0.302	(1.39)	(0.88)	(1.28)	(0.90)	-150
-100	1.49	0.96	(1.08)	(0.77)	38.9	0.185	(1.84)	(1.27)	(1.70)	(1.29)	-100
- 50	1.68	1.16	(1.28)	(0.92)	28.3	0.133	(1.98)	(1.46)	(1.88)	(1.49)	- 50
0	1.69	1.22	(1.31)	(0.98)	22.3	0.106	(1.97)	(1.49)	(1.87)	(1.51)	0
25	1.65	1.20	1.29	0.98	20.1	0.096	(1.92)	(1.46)	(1.82)	(1.48)	25
50	1.61	1.17	1.27	0.97	18.5	0.088	(1.87)	(1.43)	(1.77)	(1.45)	50
100	1.50	1.10	1.21	0.92	15.8	0.075	(1.76)	(1.34)	(1.66)	(1.37)	100
200	1.32	0.96	1.09	0.84	12.2	0.059	(1.54)	1.18	(1.44)	(1.19)	200
300	1.16	0.85	0.98	0.75	9.8	0.047	(1.36)	1.04	(1.26)	(1.05)	300
400	1.03	0.75	0.88	0.67	8.3	0.039	(1.22)	0.94	(1.11)	(0.93)	400
500	0.92	0.67	0.79	0.61	7.1	0.034	(1.12)	0.86	(1.00)	(0.84)	500
600	0.82	0.60	0.71	0.55	6.2	0.030	1.03	0.79	0.91	(0.76)	600
700	0.74	0.54	0.65	0.50	5.5	0.026	0.96	0.74	0.83	(0.70)	700
800	0.66	0.48	0.60	0.47	4.9	0.023	0.91	0.71	0.77	0.65	800
900	0.59	0.43	0.56	0.44	4.5	0.021	0.87	0.68	0.72	0.61	900
1000	0.52	0.38	0.53	0.41	4.1	0.0195	0.83	0.65	0.67	0.58	1000
1100	0.47	0.34	0.50	0.39	3.8	0.0179	0.80	0.63	0.64	0.55	1100
1200	0.42	0.31	0.48	0.38	3.5	0.0166	0.77	0.61	0.61	0.52	1200
1300	0.38	0.28	0.46	0.36	3.2	0.0154	0.74	0.59	0.58	0.50	1300
1400	0.34	0.25	0.44	0.35	3.0	0.0144	0.72	0.57	0.56	0.48	1400
1500	0.31	0.23	0.43	0.34	2.8	0.0135	0.70	0.55	0.54	0.46	1500
1600	0.28	0.21	0.41	0.33	2.6	0.0127	(0.68)	0.54	(0.52)	0.45	1600
1700	0.26	0.195	0.40	0.32	2.5	0.0121	(0.66)	0.53	(0.51)	0.44	1700
1800	(0.24)	0.180	0.39	0.31			(0.65)	0.52	(0.49)	0.43	1800
1900	(0.22)	0.167	0.38	0.31			(0.64)	0.51	(0.48)	0.42	1900
2000	(0.21)	0.156	0.37	0.30			(0.62)	0.50	(0.47)	0.41	2000
2200	(0.186)	0.140	0.36	0.29			(0.59)	0.48	(0.44)	0.39	2200
2400	(0.172)	0.130	0.34	0.28			(0.56)	0.46	(0.41)	0.37	2400
2600	(0.165)	0.125	0.32	0.26			(0.53)	0.44	(0.38)	0.34	2600
2800			0.30	(0.25)			(0.49)	0.41	(0.34)	0.31	2800
3000			0.27	(0.23)			(0.45)	0.37	(0.29)	0.27	3000
3200			(0.24)	(0.20)			(0.39)	0.33	(0.23)	0.21	3200
3400			(0.18)	(0.15)			(0.29)	0.25	(0.13)	0.12	3400

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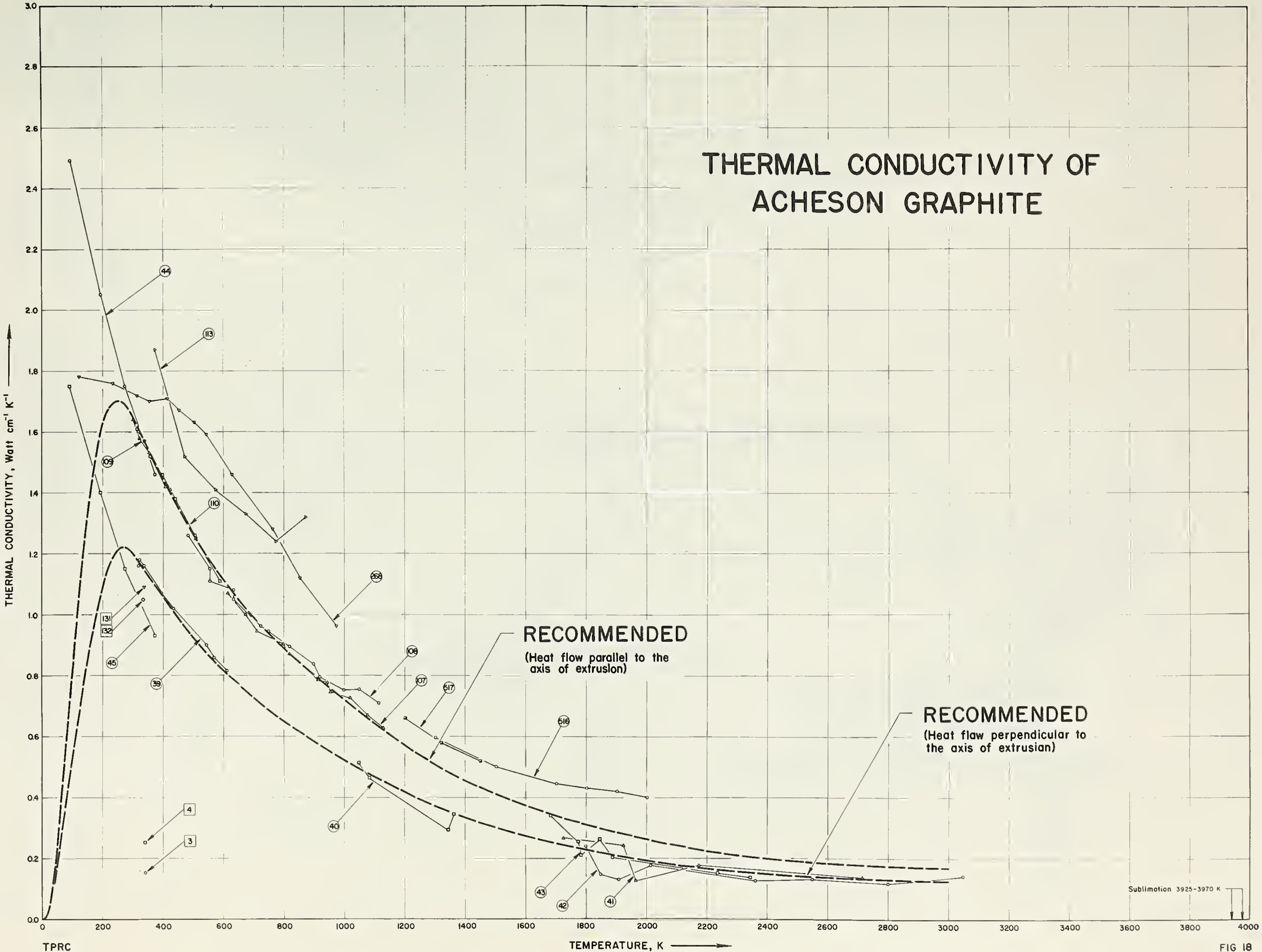
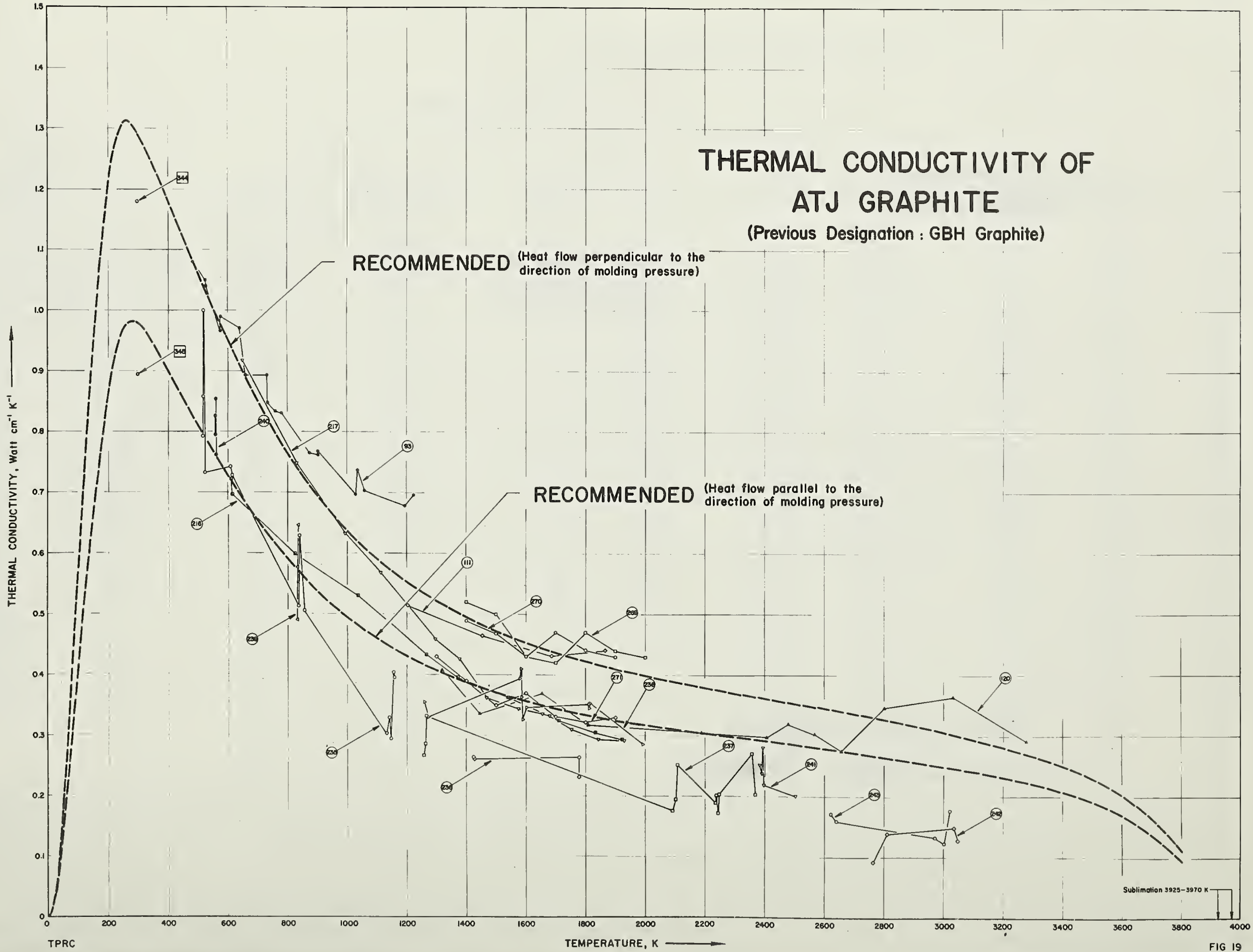
* Values in parentheses are extensively extrapolated. In the table the third significant figure is given only for internal comparison and for smoothness and is not indicative of the degree of accuracy.

THERMAL CONDUCTIVITY OF ACHESON GRAPHITE



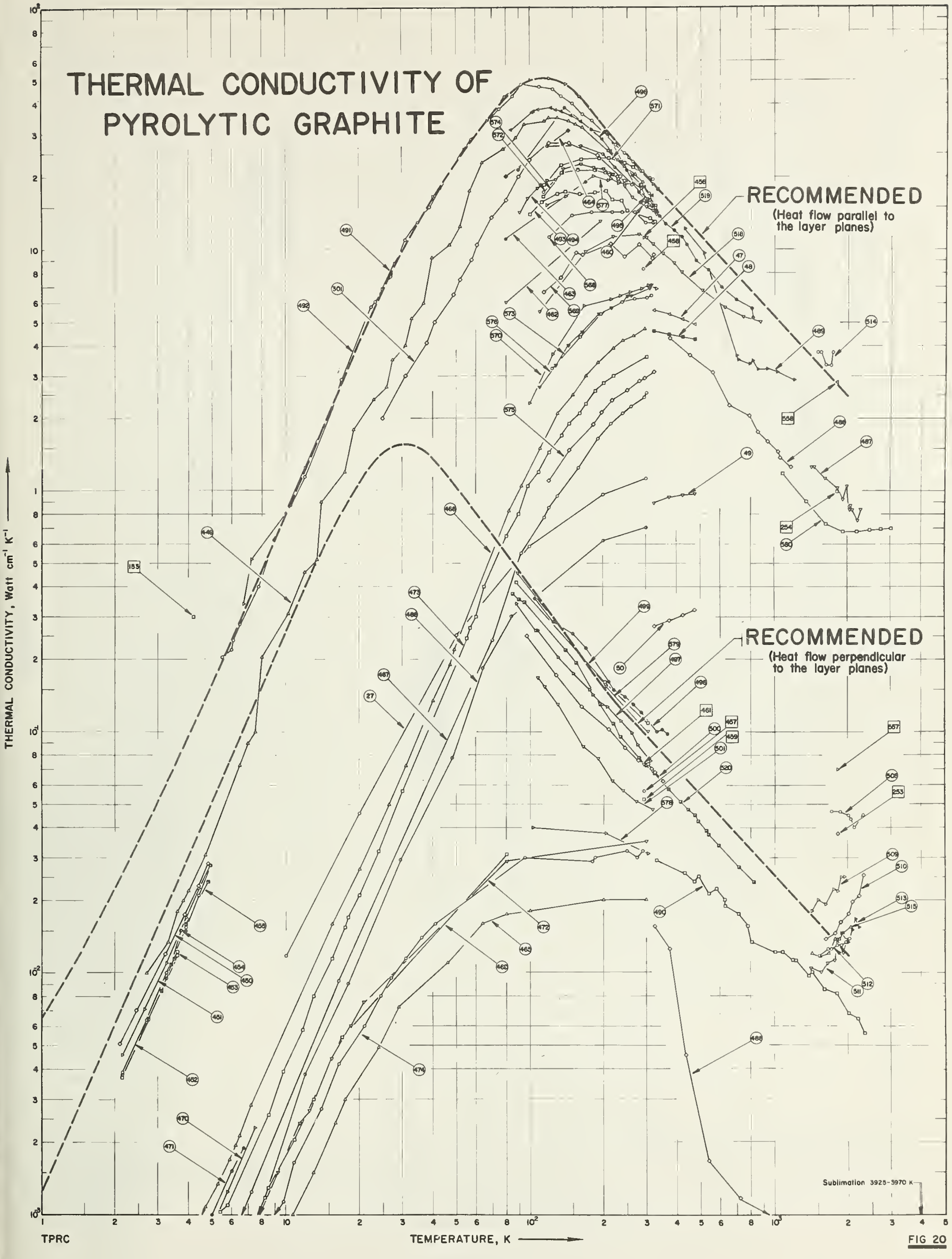
TPRC

FIG 18



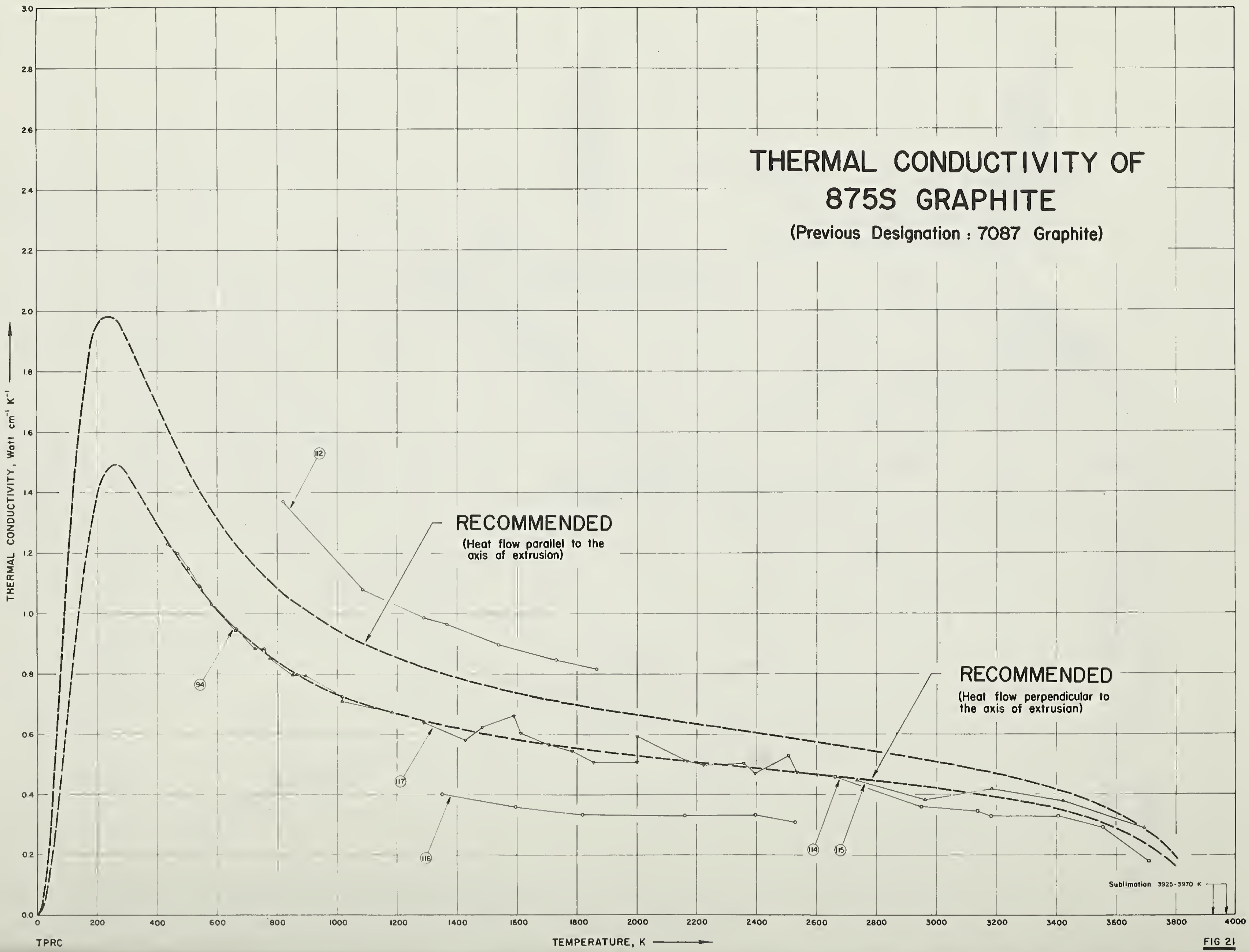
THERMAL CONDUCTIVITY OF ATJ GRAPHITE
(Previous Designation : GBH Graphite)

FIG 19


THERMAL CONDUCTIVITY OF PYROLYTIC GRAPHITE
RECOMMENDED
(Heat flow parallel to the layer planes)
RECOMMENDED
(Heat flow perpendicular to the layer planes)
Sublimation 3925-3970 K
THERMAL CONDUCTIVITY, Watt cm⁻¹ K⁻¹
TEMPERATURE, K
10³
10
10⁻¹
10⁻²
10⁻³
1
2
3
4
5
6
8
10
10²
10³

TPRC

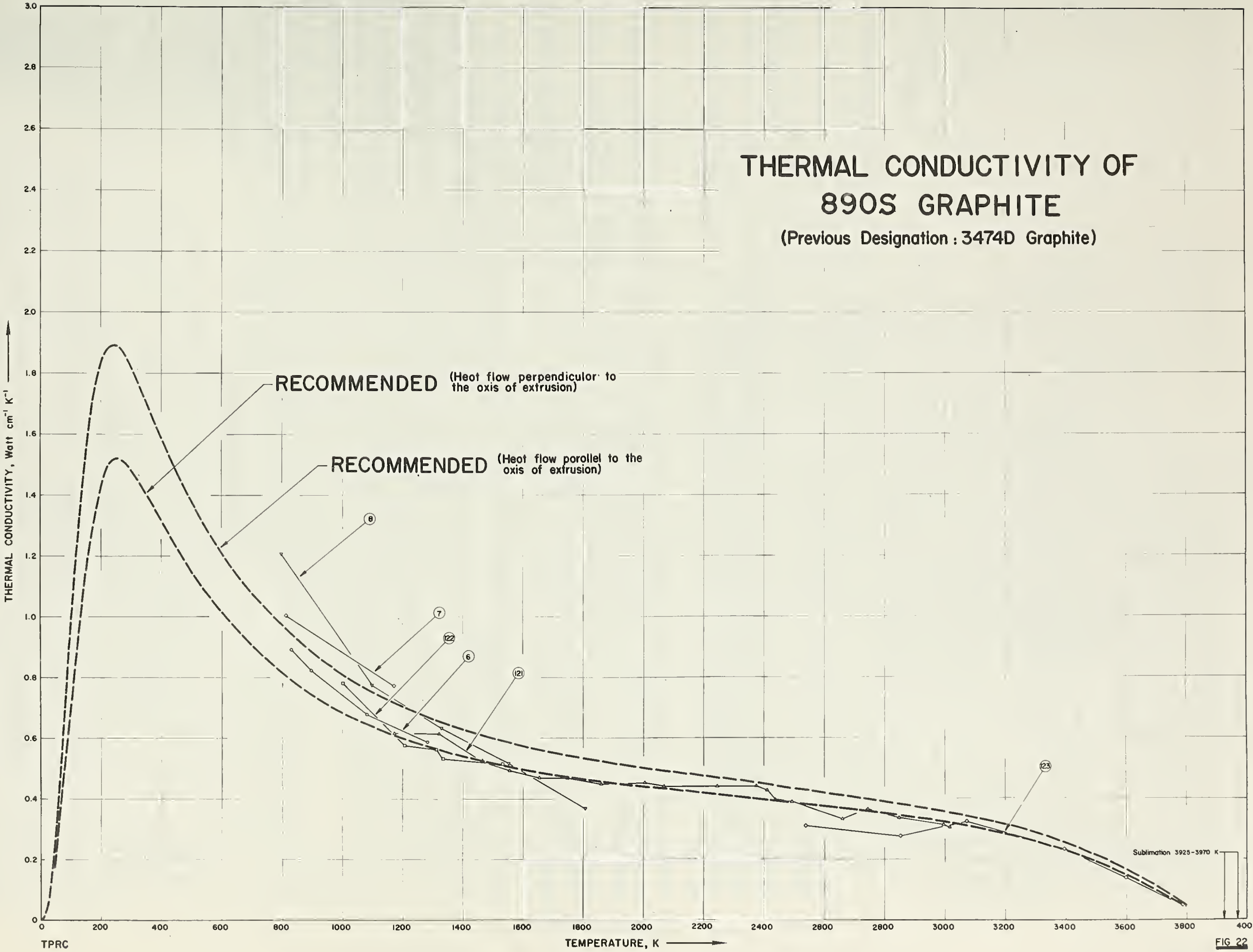
FIG 20



THERMAL CONDUCTIVITY OF 875S GRAPHITE

(Previous Designation : 7087 Graphite)

FIG 21


THERMAL CONDUCTIVITY OF
890S GRAPHITE
(Previous Designation : 3474D Graphite)
RECOMMENDED (Heat flow perpendicular to the axis of extrusion)
RECOMMENDED (Heat flow parallel to the axis of extrusion)
8
7
122
6
121
123
Sublimation 3925-3970 K
THERMAL CONDUCTIVITY, Watt cm⁻¹ K⁻¹
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
TEMPERATURE, K

TPRC

FIG 22

C. References

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PART III

THERMAL CONDUCTIVITY OF GASES

PART III - THERMAL CONDUCTIVITY OF GASES

A. Introduction

Recent developments have resulted in more accurate experimental and theoretical methods of determining the thermal conductivity of gases at high temperatures. Despite such developments, data obtained by older techniques for more moderate temperatures still, in some cases, differ by a significant amount. In the analyses which follow, preference has been given to experimental data over theoretical values, or, where only theoretical values exist, to those derived by the most reliable basis.

B. Thermal Conductivity of a Group of Selected Gases

Acetone

Most of the experimental data for the thermal conductivity of gaseous acetone are reported from two laboratories [254; 367, 368, 370]* while two other values [212] are available. In addition two correlations [223; 601, 602] have been made, the former with no source references and the latter based upon [254, 367, 368, 370].

In an analysis of these data, the Vargaftik method of plotting the logarithm of thermal conductivity as a function on the logarithm of absolute temperature was tested and the best curve through the available points was found to differ insignificantly from a straight line. The recommended values were therefore obtained by assuming a straight line relationship, the data of [367, 368, 370] being preferred over those of [254]. The departure plot shows that all the experimental data points except three values of [254] fall close to such a correlation and that the average deviation is about one percent. The three data points of [254] are some four to six percent lower. More experimental measurements are desirable to confirm the accuracy of the choice made above.

The accuracy of the recommended values can be assessed at within two percent for temperatures below 450 K and possibly as low as eight percent for the highest temperature tabulated.

Ammonia

Several measurements of the thermal conductivity of gaseous ammonia made over moderately large temperature ranges [51, 95, 96, 105, 568, 587-589], for smaller ranges or single temperatures [14, 59, 86, 187, 228] and correlations [105, 187, 223, 521] have been compared with more recent experimental and correlated values [59, 644-647].

The trend with temperature of the Keyes [187] correlation appears to be erroneous above 400 K and was ignored in the preparation of the recommended values. More difficult to explain are the published data of Ziebland et al. [646] which are higher than his preliminary values [589] and which, with the exception of two data points [568, 644], are higher than all other values. The measurements of Baker and Brokaw [644], while paralleling the Ziebland values below 400 K, exhibit a trend at higher temperatures more in agreement with all other work.

The recommended values were therefore chosen to fall near the average of all measurements for temperatures below 400 K and to approach the trend in the Geier and Schafer data [587] for the highest temperatures. The conclusion which can be drawn from the departure plot is that the recommended values should be accurate to about 1.5 percent for temperatures below 400 K and possibly ten percent for the highest temperature tabulated. More precise estimation will require more accurate measurements to be undertaken in order to resolve differences of up to thirteen percent which exist between present data.

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* Reference numbers used in the text and figures of Part III of this report refer to the references listed in the section of References in TPRC Data Book Volume 2, Chapter 1.

Methane

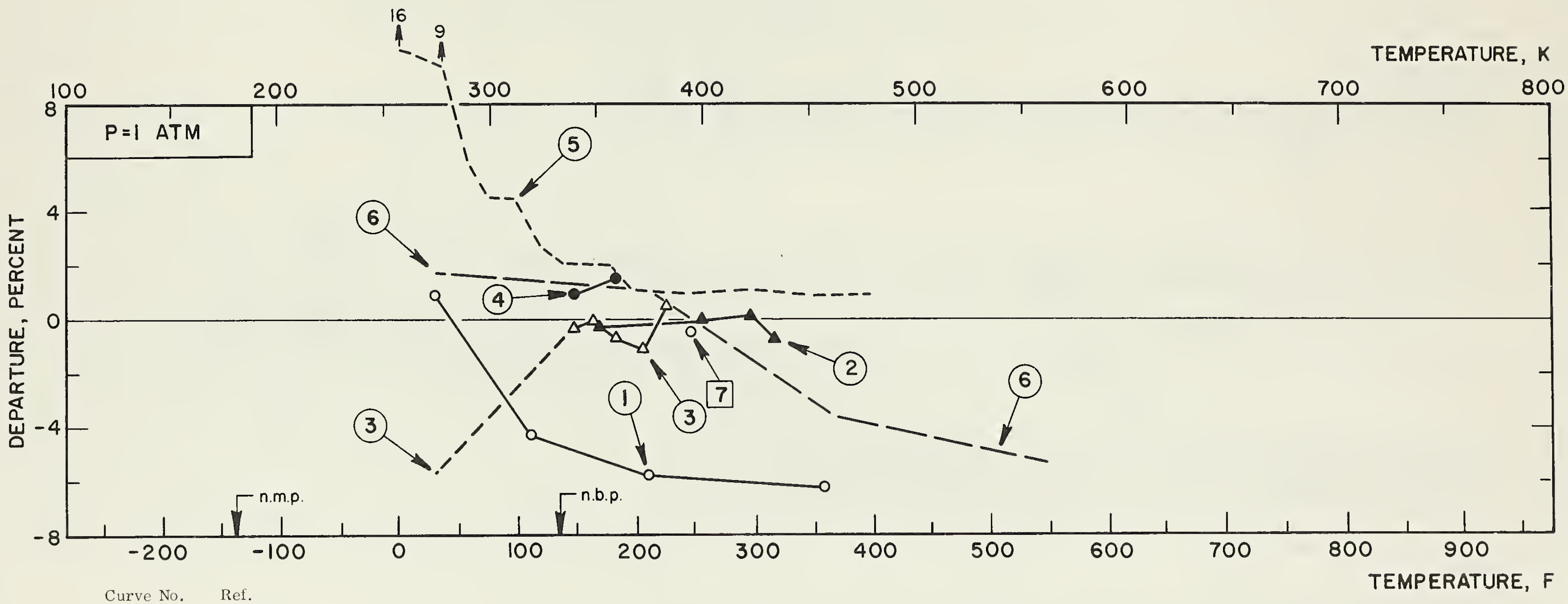
About twenty measurements of the thermal conductivity of gaseous methane at atmospheric pressure have been reported, of which eleven [96, 168, 187, 305, 331, 587, 603, 645, 649, 650, 651] extend over appreciable temperature ranges. A graphical plotting of all the data revealed reasonable agreement below about 300 K and relatively poor agreement above 400 K. After a careful analysis of the differing data it was decided to base the higher temperature values upon the measurements of Geier and Schafer [587] which, as can be ascertained from the departure plots, fall almost exactly midway between the extremes of other measurements for temperatures above about 525 K. Even the Geier and Schafer data appear somewhat uncertain in trend for temperatures above 800 K and this fact has limited the extent of the extrapolation of the values to higher temperatures.

The recommended values were obtained from a smooth curve drawn through all the data for temperatures below 400 K and through the Geier and Schafer data for higher temperatures. The recommended values are considered accurate to within one percent for temperatures below 300 K, two percent for temperatures between 300 and 425 K and six percent for all other temperatures tabulated.

TABLE 17. THERMAL CONDUCTIVITY OF GASEOUS ACETONE (mW cm^{-1} K^{-1})

T, K	k
250	0.0803
260	0.0867
270	0.0933
280	0.1002
290	0.1073
300	0.1146
310	0.1222
320	0.1300
330	0.1380
340	0.1463
350	0.1548
360	0.1635
370	0.1725
380	0.1817
390	0.1911
400	0.2008
410	0.2106
420	0.2206
430	0.2309
440	0.2412
450	0.252
460	0.263
470	0.275
480	0.286
490	0.298
500	0.310

FIGURE 23. DEPARTURE PLOT FOR THERMAL CONDUCTIVITY OF GASEOUS ACETONE

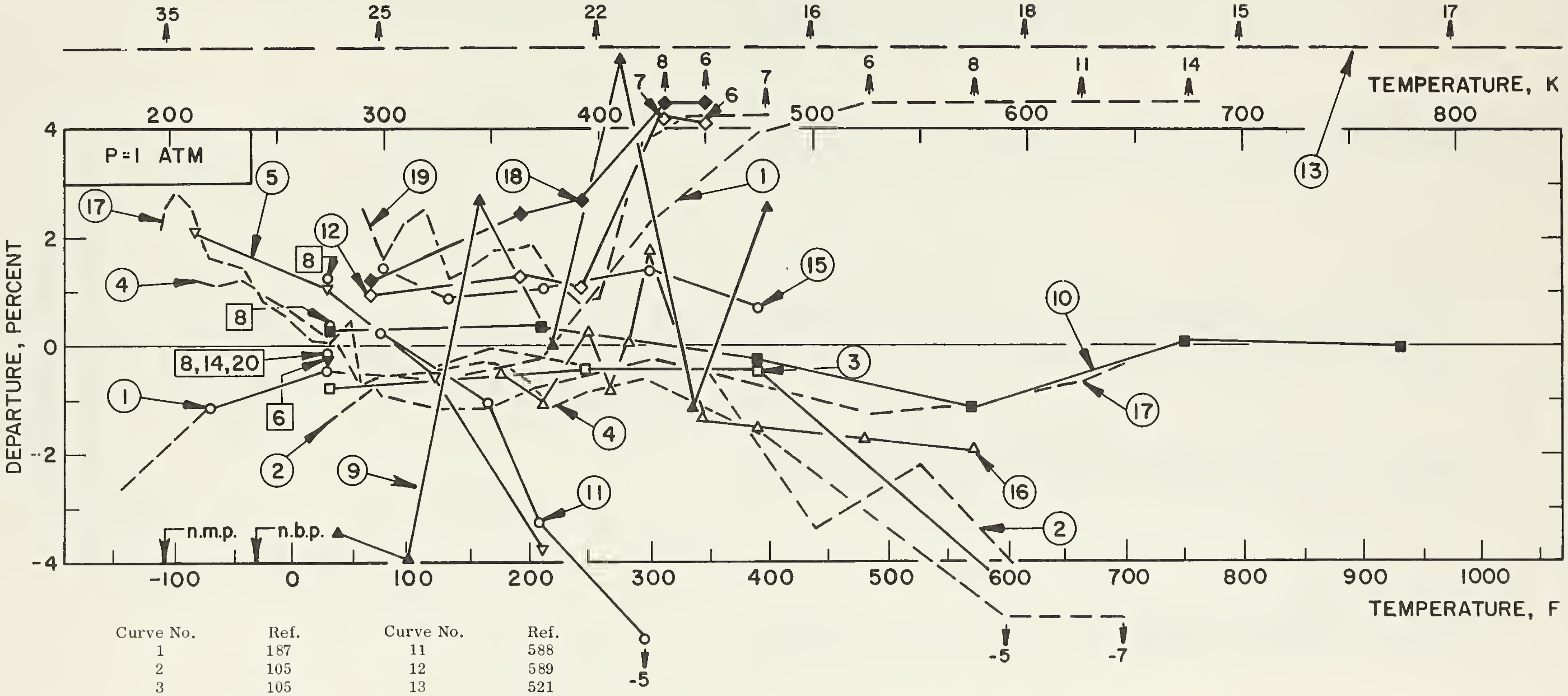


Curve No.	Ref.
1	254, 3, 51
2	370
3	367
4	212
5	223
6	601, 602
7	368

TABLE 18. THERMAL CONDUCTIVITY OF GASEOUS AMMONIA (mW cm^{-1} K^{-1})

T, K	k	T, K	k
200	0.153	550	0.580
210	0.162	560	0.595
220	0.171	570	0.610
230	0.180	580	0.625
240	0.188	590	0.640
250	0.197	600	0.656
260	0.206	610	0.671
270	0.215	620	0.686
280	0.225	630	0.702
290	0.235	640	0.717
300	0.246	650	0.733
310	0.256	660	0.749
320	0.267	670	0.764
330	0.279	680	0.780
340	0.290	690	0.795
350	0.302	700	0.811
360	0.314	710	0.828
370	0.327	720	0.844
380	0.339	730	0.861
390	0.352	740	0.877
400	0.364	750	0.894
410	0.377	760	0.910
420	0.390	770	0.927
430	0.404	780	0.944
440	0.418	790	0.962
450	0.433	800	0.979
460	0.447	810	0.996
470	0.462	820	1.012
480	0.476	830	1.029
490	0.491	840	1.046
500	0.506	850	1.063
510	0.520	860	1.080
520	0.535	870	1.096
530	0.550	880	1.113
540	0.565	890	1.130
		900	1.146

FIGURE 24. DEPARTURE PLOT FOR THERMAL CONDUCTIVITY OF GASEOUS AMMONIA

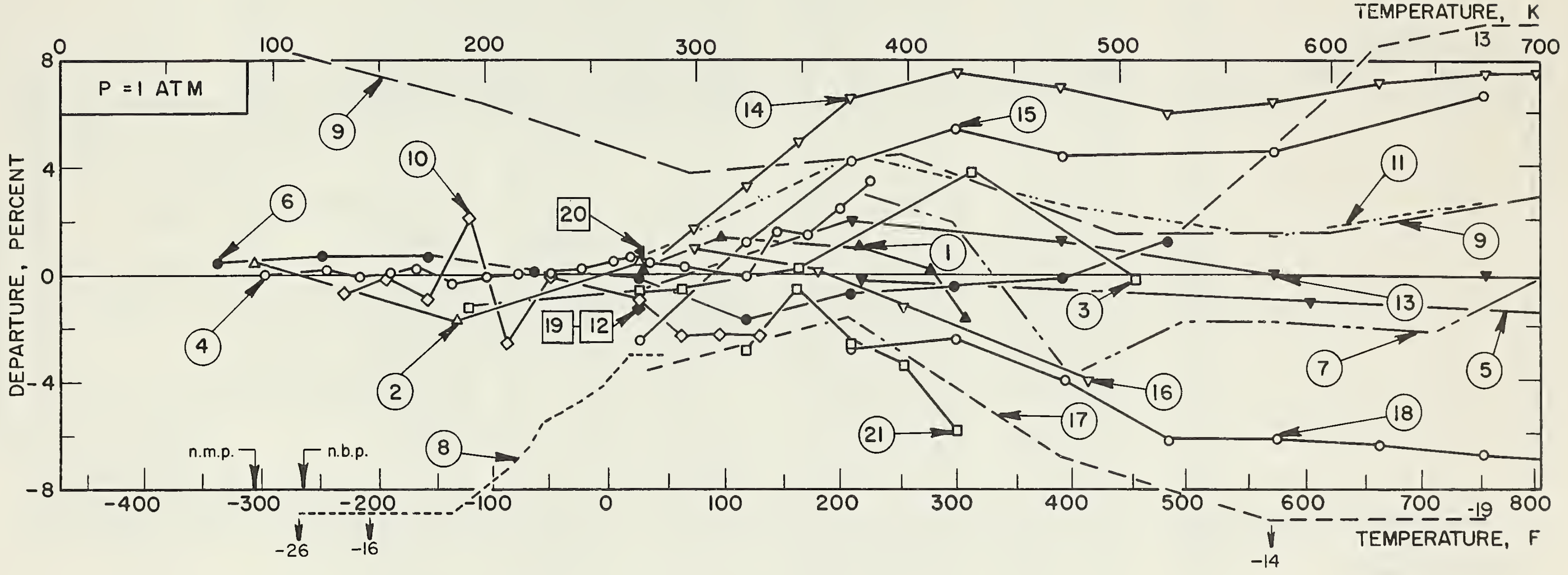


Curve No.	Ref.	Curve No.	Ref.
1	187	11	588
2	105	12	589
3	105	13	521
4	223	14	59
5	51, 95, 96	15	644
6	86	16	645
7	228	17	645
8	14	18	646
9	568	19	646
10	587	20	647

TABLE 19. THERMAL CONDUCTIVITY OF GASEOUS METHANE (mW cm^{-1} K^{-1})

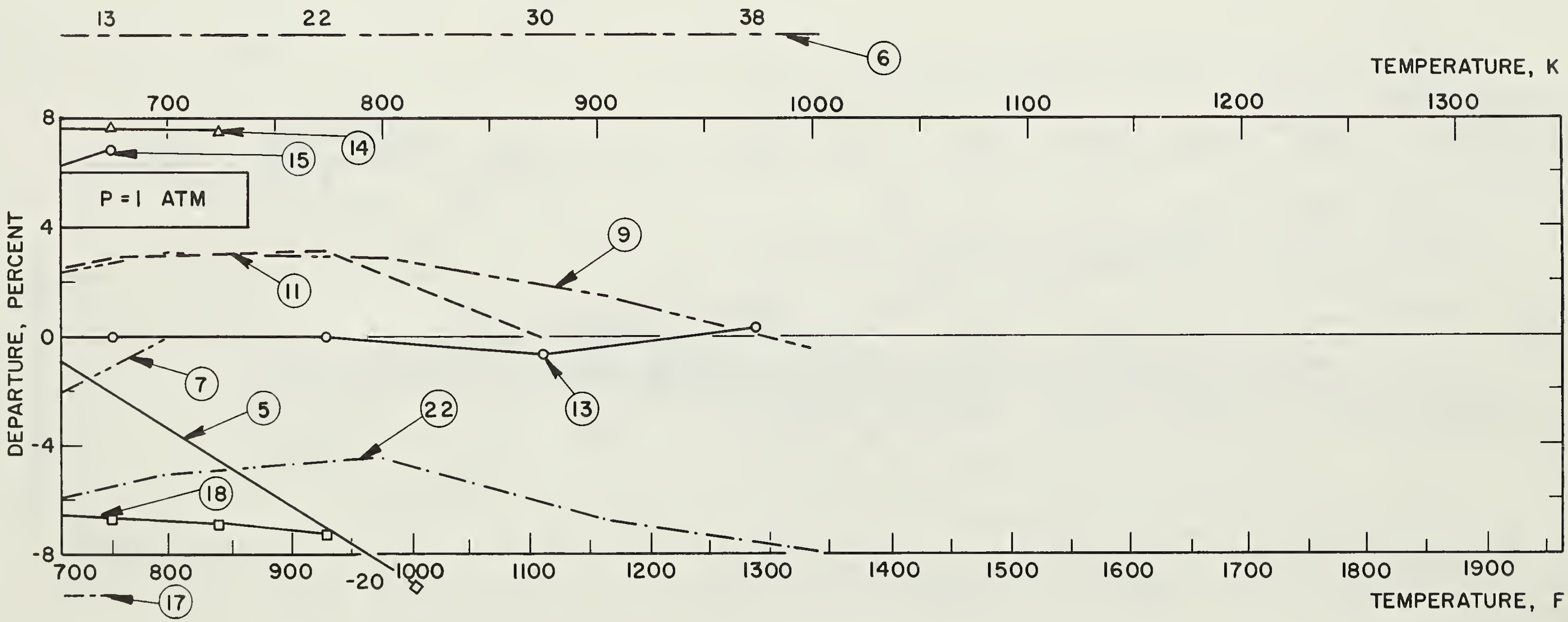
T, K	k	T, K	k	T, K	k
100	0.106	400	0.484	700	1.041
110	0.117	410	0.501	710	1.060
120	0.128	420	0.519	720	1.079
130	0.139	430	0.537	730	1.098
140	0.150	440	0.556	740	1.117
150	0.162	450	0.574	750	1.137
160	0.173	460	0.593	760	1.157
170	0.184	470	0.613	770	1.178
180	0.195	480	0.633	780	1.199
190	0.207	490	0.652	790	1.220
200	0.218	500	0.671	800	1.241
210	0.230	510	0.690	810	1.262
220	0.242	520	0.710	820	1.283
230	0.254	530	0.729	830	1.305
240	0.266	540	0.749	840	1.326
250	0.277	550	0.767	850	1.348
260	0.289	560	0.786	860	1.370
270	0.301	570	0.804	870	1.392
280	0.314	580	0.823	880	1.415
290	0.329	590	0.840	890	1.438
300	0.343	600	0.858	900	1.460
310	0.357	610	0.876	910	1.482
320	0.371	620	0.894	920	1.505
330	0.384	630	0.912	930	1.527
340	0.399	640	0.930	940	1.550
350	0.412	650	0.948	950	1.573
360	0.426	660	0.967	960	1.597
370	0.440	670	0.985	970	1.620
380	0.455	680	1.004	980	1.643
390	0.469	690	1.022	990	1.666
				1000	1.690

FIGURE 25. DEPARTURE PLOT FOR THERMAL CONDUCTIVITY OF GASEOUS METHANE



Curve	Reference	Curve	Reference
1	652	11	601, 602
2	96	12	379
3	645	13	587
4	168	14	649
5	64, 65	15	650
6	187	16	331
7	223	17	651
8	85, 167	18	305
9	521	19	237
10	603	20	97
		21	651

FIGURE 25. DEPARTURE PLOT FOR THERMAL CONDUCTIVITY OF GASEOUS METHANE (Continued)



Curve No.	Ref.
5	64, 65
6	187
7	223
9	521
11	601, 602
13	587
14	649
15	650
17	651
18	305
22	648

THE NATIONAL BUREAU OF STANDARDS

The National Bureau of Standards[1] provides measurement and technical information services essential to the efficiency and effectiveness of the work of the Nation's scientists and engineers. The Bureau serves also as a focal point in the Federal Government for assuring maximum application of the physical and engineering sciences to the advancement of technology in industry and commerce. To accomplish this mission, the Bureau is organized into three institutes covering broad program areas of research and services:

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—Applied Mathematics—Electricity—Metrology—Mechanics—Heat—Atomic Physics—Physical Chemistry—Radiation Physics—Laboratory Astrophysics[2]—Radio Standards Laboratory,[2] which includes Radio Standards Physics and Radio Standards Engineering—Office of Standard Reference Data.

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[1] Headquarters and Laboratories at Gaithersburg, Maryland, unless otherwise noted; mailing address Washington, D. C., 20234.

[2] Located at Boulder, Colorado, 80302.

[3] Located at 5285 Port Royal Road, Springfield, Virginia 22151.

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