

THERMAL CONDUCTIVITIES OF MOLTEN METALS
PART 1 PURE METALS

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ABSTRACT

Thermal conductivity data for molten metals, published since the review of Touloukian et al in 1970, are collated and evaluated. Where possible recommended values are given. Where availability of data permit, the Wiedemann-Franz-Lorenz equation relating electrical and thermal conductivities has been assessed. It has been found to be valid for most pure metals at their melting point.

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Director, Centre for Materials Measurement and Technology.

SYMBOLS, UNITS

A	area, m^2
a	thermal diffusivity, m^2s^{-1}
b	temperature coefficient of thermal conductivity $\text{Wm}^{-1}\text{K}^{-2}$ liquid
L	experimental value of Lorenz function, $\text{W}\Omega\text{K}^{-2}$
L_0	theoretical value for Lorenz function, $2.445 \times 10^{-8} \text{ W}\Omega\text{K}^{-2}$
m	melting temperature eg λ^m thermal conductivity at melting point
q	heat flux, W
s	solid
λ	thermal conductivity, $\text{Wm}^{-1}\text{K}^{-1}$
λ^m	thermal conductivity at melting point, $\text{Wm}^{-1}\text{K}^{-1}$
σ	electrical conductivity, $\Omega^{-1}\text{m}^{-1}$
ρ	density, kgm^{-3}
T	temperature $^{\circ}\text{C}$, K
t	time, s
AHF	Axial heat flow method
CC	Concentric cylinder method
LP	Laser pulse method
ns	not stated
PP	Parallel plate method
RHF	Radial heat flow
PTW	Plane temperature wave method
RTW	Radial temperature wave method
THW	Transient hot wire method
WFL	Wiedemann-Franz-Lorenz relationship

1 INTRODUCTION

A large amount of data on the thermal conductivities of molten metals has been published since Touloukian et al [1] published their review in 1970. Furthermore, it has been shown that convection can have significant effect on thermal conductivities of liquids even for organic systems at ambient temperatures [2,3]. The problem of convection is much more severe at high temperatures since accurate temperature control becomes progressively more difficult as the temperature increases. Transient techniques have proved useful in minimising convectional contributions to the effective thermal conductivity of organic fluids and they are being used, increasingly, to determine the thermal conductivity of molten metals. However, there is still great uncertainty about the thermal conductivity data reported for high melting metals (such, iron, nickel and titanium) in the liquid state.

The principal aims of this work were to:

- (i) establish reliable thermal conductivity data for pure metals and commercial alloys involved in industrial high temperature processes to aid the mathematical modelling of the heat transfer of the process
- (ii) to obtain reliable thermal conductivity of pure metals to act as reference materials for the high-temperature calibration of relative methods such as that being used in our laboratory.

However, the published data for molten, commercial alloys cannot be critically evaluated before data for the parent metals and the methods used have been critically assessed. Consequently, thermal conductivity and diffusivity data for the elements have been reviewed in this report; data for commercial alloys will be assessed in the future.

2 DEFINITIONS OF THERMAL CONDUCTIVITY AND DIFFUSIVITY

Thermal conductivity (λ) can be defined as the heat flow (q) conducted across a unit area per second per unit temperature gradient

$$\lambda = - \frac{q}{A (dT/dx)} \quad (1)$$

In some methods it is not the thermal conductivity but the thermal diffusivity (α) which is determined;

$$\lambda = \alpha \cdot C_p \cdot \rho \quad (2)$$

this quantity represents the rate of heat diffusion per unit time. The relation between thermal diffusivity and thermal conductivity is given in Equation 2 where C_p is the heat capacity and ρ the density.

3 METHODS

3.1 EFFECT OF CONVECTION

When thermal conductivity measurements are carried out on liquids, the heat flux (q) can contain substantial contributions from convection and can lead to erroneously high values for the thermal conductivity. Consequently, great efforts are made to minimise convection by:

- (i) accurate temperature control of the sample and
- (ii) ensuring that the free surface of the liquid is at a marginally higher temperature than that of the base of the sample.

However, many metals melt at very high temperatures and in practice it is very difficult to provide the necessary control of temperature under these conditions. Consequently, in recent years transient and non-steady state methods have used increasingly to carry out measurements on liquid metals. In these experiments the measurements are carried out rapidly with a view to completing the experiment before the onset of convection.

3.2 RELATIONSHIP WITH ELECTRICAL CONDUCTIVITY

The principal mechanism for thermal conduction in pure metals in the liquid state is through the transport of electrons. Several investigators have shown experimentally that although the mechanism of phonon or lattice conduction can make a significant contribution at lower temperatures, electronic conduction is dominant at temperatures around the melting point. Under these latter conditions the Wiedemann-Franz-Lorenz (WFL) law relating the thermal (λ) and electrical (σ) conductivities can be used to derive λ either from either the electrical conductivity (σ) or resistivity ($1/\sigma$) measurements which are simpler to carry out. The WFL relation is given in Equation 3 where T the thermodynamic

temperature (K) and L_0 is the theoretical (Sommerfeld) Lorenz number which has a value of $2.445 \times 10^{-8} \text{ W}\Omega\text{K}^{-2}$

$$\lambda = L_0 T \sigma \quad (3)$$

In order to examine the validity of the WFL relation, values of the ratio of the experimental to theoretical values for the Lorenz function (L/L_0), for temperatures close to the melting point (where possible) are listed. It will be seen that for most metals, (L/L_0) is very close to unity and any small deviations from unity may be due to the uncertainties in the thermal conductivity measurements.

3.3 METHODS USED TO MEASURE THERMAL CONDUCTIVITIES AND DIFFUSIVITIES OF MOLTEN METALS

Several techniques have been used to determine thermal conductivities of molten metals and alloys. These can be classified into steady state, non-steady state and transient techniques.

Steady state techniques require very accurate temperature control to minimise convection. This becomes progressively more difficult as the temperature increases, and consequently these methods have mostly been used on low melting metals such as tin and lead.

Non-steady state and transient methods have been used with a view to completing the experiments before the onset of convection. In non-steady state measurements this is accomplished by using very high heating rates (up to 1000 K s^{-1}) so that the duration of experiments for the liquid phase is <0.2 second.

Transient experiments on liquids have indicated that convection occurs after ca 1 second [3] but the temperature differences in the transient techniques are of the order of 5K, compared with $>100\text{K}$ in the non-steady state experiments. These large temperature gradients may give rise to convective flows due to buoyancy and thermocapillary forces. Thus convective contributions to the thermal conductivity can not be ruled out in these non-steady state experiments, indeed there are some cases (eg Fe) where this appears to have occurred.

Transient techniques have become widely used for measurements on organic liquids since the measurements can be carried out rapidly in order to minimise convection. These techniques appear

to have a distinct advantage but may be limited in their application to temperatures of less than 1000 °C due to the fact that (i) insulators become electrical conductors at high temperature and (ii) reactions may occur between the liquid metal and the coatings at high temperatures.

3.3.1 Steady state techniques

Concentric cylinder method (CC)

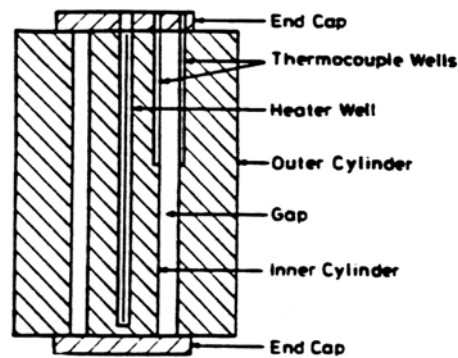


Figure Schematic diagram of the concentric cylinder method

In this method the molten sample is placed in the annulus between two concentric cylinders (Figure 1). A known heat flux (q) is supplied to the inner cylinder and the temperature difference (ΔT) between the two cylinder is monitored.

The thermal conductivity is calculated from Equation 4 where r_1 , r_2 and L denote the radii of the two cylinders and their length, respectively, where $r_2 > r_1$

$$\lambda = \frac{q \ln(r_2/r_1)}{2 \pi L \Delta T} \quad (4)$$

The major problems encountered with this method lie in correcting for (i) the heat transfer due to convection and radiation and (ii) heat losses from the ends of the apparatus.

Parallel plate method (PP)

The apparatus consists of two infinite, parallel plates and heat flows through the sample from the upper to the lower plate (Figure 2). The thermal conductivity is calculated from Equation 5 where A is the

area of the plate, and L is the distance between the plates.

The problems encountered are similar to those encountered with the concentric cylinder method. This method has been applied to measurements on molten tin and lead (Hemminger et al [4,5]).

$$\lambda = \frac{qL}{A\Delta T} \quad (5)$$

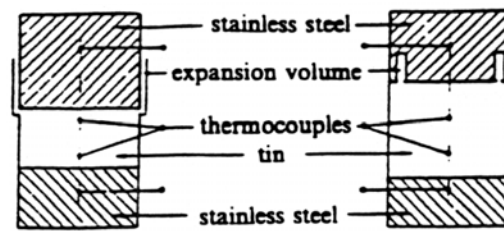


Figure 2 Schematic diagram of parallel plate apparatus (Hemminger [4,5])

Axial and radial heat flow methods

In the **axial heat flow (AHF)** method a known thermal flux is applied to one end of the sample and removed at the other end by a heat sink (Figure 3).

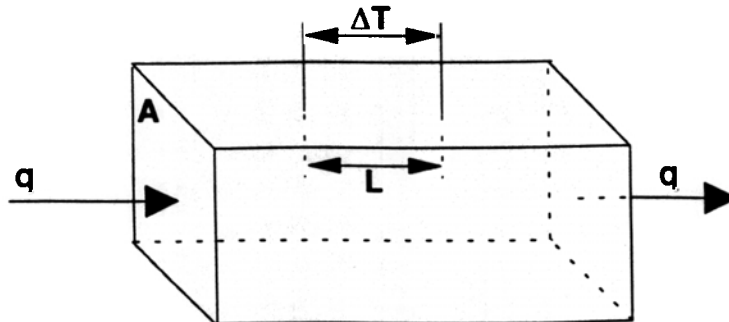


Figure 3 Schematic representation of heat flow method

For measurements on liquids the temperature gradient is in the vertical direction with the free surface of the liquid having the highest temperature. The principal problem encountered is related to the prevention of heat losses by convection and radiation; it is usually overcome by using insulating materials and heated guard shields. Heat loss problems become more severe as the temperature increases. The thermal conductivity can be calculated by Equation 6 where q is the heat flux, A the

area, L the distance between the thermocouples and subscript c denotes the cell.

$$\lambda = \frac{1}{A} \left(\frac{qL}{\Delta T} - \lambda_c A_c \right) \quad (6)$$

This apparatus has been used to determine the thermal conductivities of various liquid metals with low melting points, eg Hg, Pb, In and Ga

The **radial heat flow** (RHF) method is very similar and suffers similar problems to the axial method, but has a different geometry (Fig 4). The thermal conductivity is calculated by Eqn 7.

$$\lambda = \frac{2\pi q \Delta T}{\ln(r_2/r_1)} \quad (7)$$

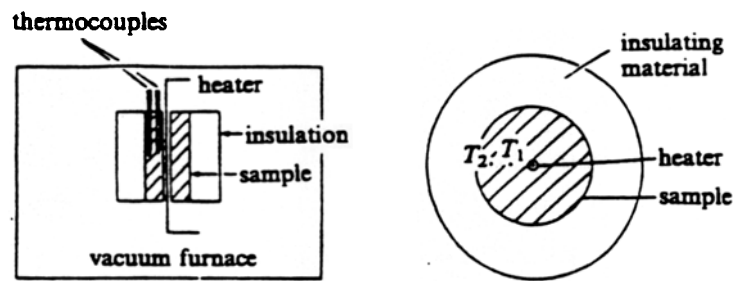


Figure 4 Schematic diagram of the radial heat flow method

3.3.2 Non-Steady State Methods

Radial temperature wave (RTW) technique

In this method the sample is usually cylindrically-shaped and a modulated heat supply is applied along the centre of the specimen. The variations in temperature are monitored on the outside of the sample. There is a phase lag between the input and output and this is related to the thermal diffusivity (α) of the sample. Thermal diffusivities can be derived from the amplitude of temperature oscillations and from the phase differences between them; thermal conductivities calculated by these two methods were found to be in good agreement. This technique has been widely used by Filippov and his various coworkers [6] to determine the thermal diffusivities of liquid metals.

Plane temperature wave (PTW) technique

This method has been widely-used by Zinovyev and coworkers [7]. It uses disc-shaped specimens (typically 0.2 mm thick) and plane temperature waves are derived by bombarding the specimen with a harmonically-modulated electron beam and monitoring the phase change of the temperature transient recorded on the other face of the specimen. Measurements can be obtained either at constant temperature or dynamically with heating rates up to 1000 Ksec⁻¹. The results of the two experiments were found to be in good agreement. For measurements on the liquid phase, only the central portion of the disc was allowed to melt, and readings were obtained for temperatures up to 150K above the liquidus. The thermal diffusivities for the liquid phase of high-melting metals such as Mo, Ti, Ir, Rh, Pt and Pd were obtained with this method. It could be argued that convectional contributions would tend to be small due to the short duration of the experiments in the liquid state, but the assumptions may not be valid since circulation flows could arise from the buoyancy and thermocapillary forces caused by the large temperature gradients. This method is sometimes referred to as the modulated beam technique.

3.3.3 Transient techniques

Transient hot wire (THW) method

In this method, current is applied to a fine wire of infinite length which acts both as a heating element and a resistance thermometer (Figure 5(a)). The wire is immersed in the melt and the temperature rise (ΔT) of the wire, is measured continuously whilst the current is applied. The thermal conductivity of the liquid is given by Eqn 8 where q is the heat input per unit length of wire, r_0 is the radius of the wire, a is the thermal diffusivity of the liquid, γ Euler's constant and t is time [2]. In some cases the wire has been replaced by a metal strip

$$\Delta T = \frac{q}{4\pi\lambda} \ln \left(\frac{4at}{r_0^2 \exp \gamma} \right) \quad (8)$$

This equation only applies when $(r_0^2/4at) \ll 1$. The thermal conductivity is obtained from the reciprocal of the slope of a plot of ΔT as a function of $\ln$ time. The onset of convection is observed as a departure from linearity of the ΔT versus $\ln$ time plot, as seen in Figure 5b. Nakamura et al [8] have shown that the onset of convection occur after about 1 second.

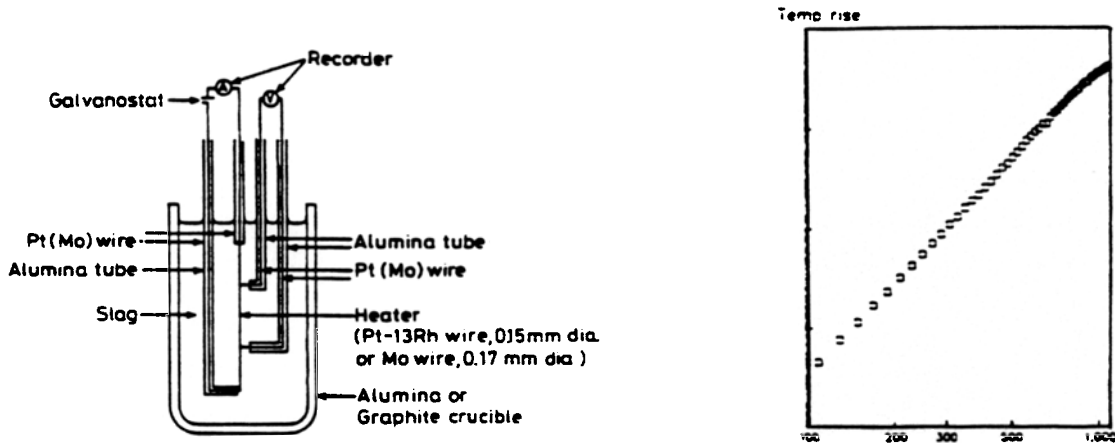


Figure 5 (a) Schematic diagram showing the transient hot wire method, Nagata et al (1984) and (b) a typical plot of ΔT as function of $\ln$ time, Powell 1991.

When this method is applied to electrically conducting melts it is necessary to apply a coating to the wire (or strip) to prevent electrical leakage into the melt. Various insulating techniques have been employed viz

- (i) using a glass capillary containing liquid Hg or Ga
- (ii) application of Al_2O_3 or other insulating oxide layers
- (iii) the oxidation of the metal wire to provide a protective coating.

However the application of this technique may be restricted to temperatures up to 1000 °C since with increasing temperatures the coatings become progressively (i) more conducting, (ii) more vulnerable to chemical attack, and (iii) the mismatch in thermal expansions of metal and coating become more pronounced and can lead to spalling.

Laser flash (or pulse) method

In this method a pulse of energy is focused on the front face of a disc-shaped sample and the temperature of the back face is monitored continuously. The temperature transient exhibits a maximum ($\Delta T_{\max}$) as a consequence of radiation losses, and it is customary to determine the time ($t_{0.5}$) required to obtain $0.5 \Delta T_{\max}$. The thermal diffusivity is derived from Eqn 9 where L is the thickness.

$$a = \frac{0.1388 L^2}{t_{0.5}} \quad (9)$$

In practice, other fractions (t_f) can also be used, but a different constant must be employed. This method has been widely used for measurements on solids. For use on liquids, it must be modified since it is necessary (i) to contain the sample and (ii) to mount the disc horizontally.

A laser is used to supply the heat pulse and the temperature of the back face is monitored by an infra-red detector (eg InSb or PbS). The sample is contained in silica or sapphire cells which are transparent to infra-red radiation [10-13]. A typical arrangement is shown in Figure 6. The thickness of the specimen must be carefully selected with regard to the thermal conductivity of the sample. Carbon is frequently applied to the surface of the metal to improve the absorption of the energy pulse. It is difficult to maintain disc shaped geometry for liquid metals which are non-wetting on sapphire (or silica) and consequently reliable measurements can not be obtained for these conditions. Corrections are usually applied to account for expansion of the metal. The method has been used for the measurements of the thermal diffusivities of Hg, Ga, Si, Al and Al alloys [10-13].

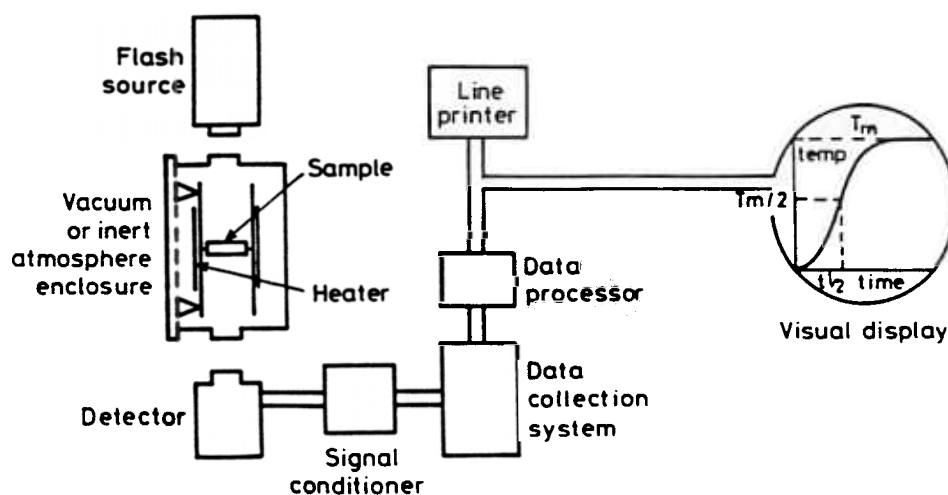


Figure 6 Schematic diagram illustrating (i) typical laser pulse apparatus used to determine thermal diffusivity of liquid metals and (ii) typical transient display.

The principal advantages of this technique are that:

- (i) it is robust and involves no contact between a probe and the melt
- (ii) the method is well-proven and widely used on solids.

Possible disadvantages of the method are

- (i) that transient times are typically 2-3 seconds and some convectional flows may be initiated which could affect the results
- (ii) reactions between the liquid metal and container may also affect the results and
- (iii) the application of carbon to improve energy absorption is not desirable for metals such as Fe which have appreciable carbon solubility.

4 EVALUATION OF DATA

In general convection will tend to increase the apparent thermal conductivity of the melt, thus lower values of the thermal conductivity are to be preferred, providing the results are not affected by other systematic errors associated with the experimental method.

Experience with using the transient hot wire method on organic liquids [9] has indicated that convection can occur as early as 1 second after the energy input. This has been corroborated by the work of Nakamura et al [3] who used the same technique to measure the thermal conductivity of mercury in microgravity. Consequently, there may be convectional contributions to the heat flux, even for methods (like the laser pulse technique) which typically takes 2-3 seconds to complete.

4.1 EVALUATION OF DATA OBTAINED USING TEMPERATURE WAVE TECHNIQUES

Much of the thermal conductivity data reported in the last 20 years for high-melting metals in the solid and liquid states has been obtained by two Russian groups using temperature wave methods. Filippov and collaborators [6] used the radial temperature wave technique and Zinovyev and associates [7] have employed the plane temperature wave method. The latter group used very high heating rates (up to

1000 Ks⁻¹) and were able to obtain very rapid measurements in the liquid states (0.2 to 0.3 seconds).

Powell [14] has questioned the reliability of the results obtained by Filippov [6] since the reported thermal conductivities for many molten metals remained constant over a large temperature range. Since so much data has been reported by these two groups, it is essential to establish the reliability of the techniques used. This assessment was carried out by

- (i) comparing the results obtained for the solid state with those reported in the literature
- (ii) comparing the results obtained for the liquid phase of low melting metals such as Hg, Ga, In, Sn, Ag and Pb with those obtained by conventional methods.

The results reported for the solid phase of high-melting metals are given below and inspections of the relevant graphs show that there is, in general, good agreement between the values obtained by Zinovyev et al or Filippov et al and those obtained by other workers. Any disagreement tends to be less than the combined experimental uncertainty ($\pm 10\%$) of the two methods. Furthermore, experimental disagreements could arise from differences in the purity, inhomogeneities and orientation (for non-cubic samples) of the specimens

With regard to the comparison of results from the liquid phase, Zinovyev et al [88] reported a values for molten silver which are in excellent agreement with recommended values [1].

Filippov [6] has reported thermal conductivities for several molten metals but comparison is difficult since in many cases their results were obtained at temperatures several hundred degrees above the melting point (Ga, Ce, Ge). Thermal conductivity values at the melting point (λ^m) for Cu, Sn and Pb were in agreement with accepted values but the case of Sn and Pb, values of ($d\lambda/dT$) diverged from other reported values. However it is noticeable that Banchila and Filippov [16] using the same technique subsequently reported positive ($d\lambda/dT$) values and thermal conductivities which were in agreement with accepted values. Although there may be some reservations about ($d\lambda/dT$) values cited by Filippov [6] it is considered that the thermal conductivity (λ^m) cited by Zinovyev and Filippov and their associates are usually reliable to the quoted accuracy of $\pm 5\%$.

4.2 THERMAL CONDUCTIVITY VALUES DERIVED BY LORENZ RELATIONSHIP

The principal carriers for the thermal conduction in solid metals are electrons and lattice waves ('phonons'). However, for temperatures close to the melting point of pure metals, electronic conduction is the predominant mechanism and lattice conduction is negligible. For electronic conduction, the Wiedemann-Franz-Lorenz (WFL) law, given in Eqn 3, relates electrical and thermal conductivities. For most pure metals in the liquid the Lorenz number, L , derived from the experimental values of λ and σ , is close to the theoretical value, L_0 . Where workers have recorded both λ and σ , values of the ratio (L/L_0) are reported. In addition, values of λ have been calculated from published electrical conductivity data using the WFL law. The electrical resistivity ($1/\sigma$) data given in the review of Iida and Guthrie [17] have been predominantly used in this report, other sources of resistivity data are specified.

4.3 THERMAL CONDUCTIVITIES OF THE SOLID AT THE MELTING POINT

Since electronic conduction in metals is predominant at high temperatures, empirical rules relating the ratio of the thermal conductivities of the solid and liquid phases at the melting point (λ_s^m/λ_l^m) to the entropy of fusion (ΔS^m) have been proposed [18,19]. These are similar to the Mott relationship [20] linking (σ_s^m/σ_l^m) to ΔS^m . For this reason the recorded values of λ_l^m are λ_s^m are also reported in the following text. Where the conductivity is known to be anisotropic in the solid values for the polycrystalline material are quoted.

5 RESULTS

Thermal conductivity data given below are arranged in alphabetical order of the symbols of the element. Thermal diffusivity data have been converted to thermal conductivities using the values for C_p and density (ρ) reported by Dinsdale [21] and Iida and Guthrie [17], respectively. However in some cases these conversions have been carried out by the investigators and the resulting thermal conductivities have been accepted and plotted. These cases are denoted by reference to the investigators in the comments section eg Ag: Converted from a [88]. Earlier thermal conductivity data are represented by the values recommended by Touloukian et al [1] and these are compared with more

recent work in the Figures. The temperature dependence of λ_1 is given in the form of Equation 11.

$$\lambda_l = \lambda_l^m + b(T-T^m) \quad (Wm^{-1}K^{-1}) \quad (11)$$

Ag

Zinovyev et al [88] have reported data obtained by the PTW method, given in Table 1, values for the solid and liquid phases were in excellent agreement with those recommended by Touloukian et al [1], as can be seen from Figure 7. The results derived from calculations based on the WFL rule (Equation 3) are in good agreement with the experimental values.

Table 1
Details of thermal conductivity ($\text{Wm}^{-1}\text{K}^{-1}$) determinations

References	Method	Temperature Range, °C	λ_1^m	10^2b	λ_s^m	L/L_0	Comment
Zinovyev [88]	PTW	430-1030	180	-	357	1	Converted from a [88]

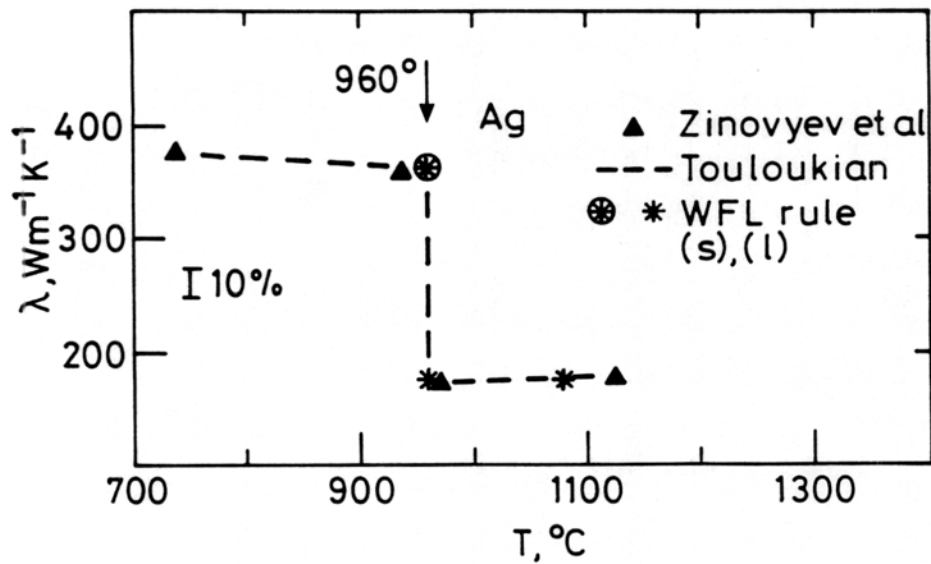


Figure 7 Thermal conductivity of silver as a function of temperature

recommended values:

$$\lambda_s^m = 363 \text{ Wm}^{-1}\text{K}^{-1}; \quad \lambda_l^m = 175 \text{ Wm}^{-1}\text{K}^{-1}$$

$$\lambda_l = 175 + 4.3 \times 10^{-2} (T - 962) \text{ Wm}^{-1}\text{K}^{-1}$$

Al

Experimental details of two laser pulse investigations on pure Al are given in Table 2 and it can be seen from Figure 8 that the results obtained are in good agreement, within experimental uncertainty ($\pm 5\%$), with the results cited by Touloukian [1].

Table 2
Details of thermal conductivity ($\text{Wm}^{-1}\text{K}^{-1}$) determinations

Reference	Method	Temperature Range, °C	λ_1^m	$10^{-2}b$	λ_s^m	L/L_0	Comments
Schriempf [10]	LP	20-800					Converted from a values [10]. Experimental uncertainty $\pm 30\%$
Preston Mills [12]	LP	690-975	92	4.0	212		Converted from a values [12]. Experimental uncertainty $\pm 5\%$
Takuchev et al [87]	acoustic	700-1390				1.004	L/L_0 quoted is an average value [87]

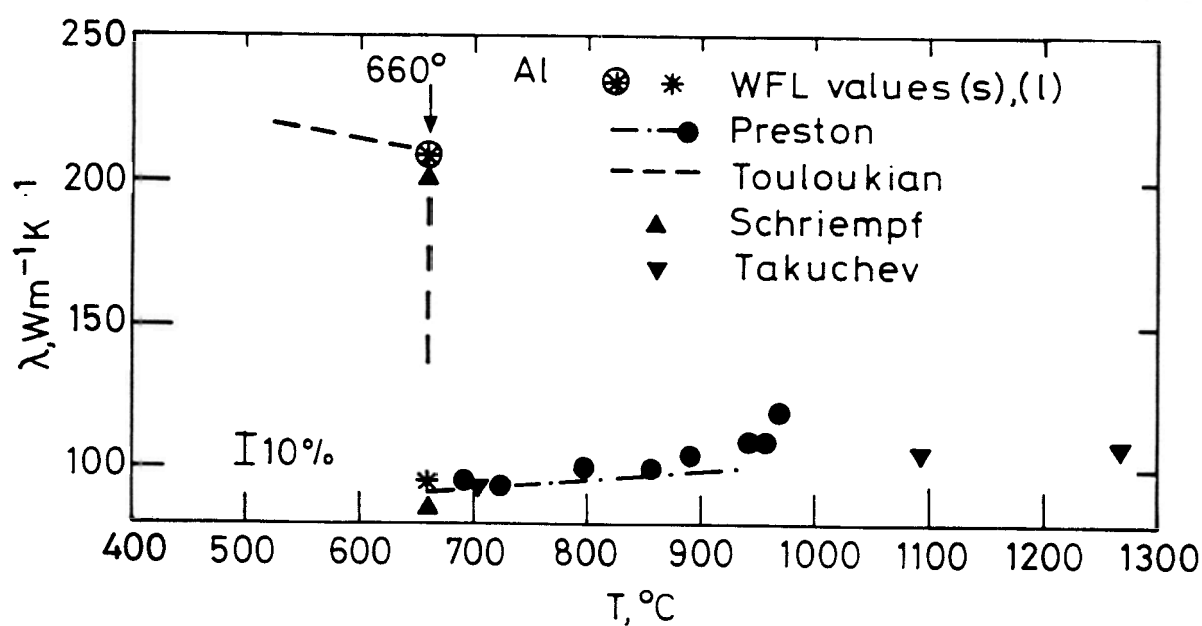


Figure 8 Thermal conductivity of Al as a function of temperature

recommended relationships:

$$\lambda_s^m = 211 \text{ Wm}^{-1}\text{K}^{-1}; \quad \lambda_1^m = 91 \text{ Wm}^{-1}\text{K}^{-1}$$

$$\lambda_1 = 91 + 3.4 \times 10^{-2}(T - 660)$$

Au

Zinovyev et al [88] have reported data obtained by the PTW method, given in Table 3, values for the solid and liquid phases were in excellent agreement with those recommended by Touloukian et al [1], as can be seen from Figure 9. Values calculated using the WFL expression are in good agreement with those measured by Zinovyev.

Table 3
Details of thermal conductivity ($\text{Wm}^{-1}\text{K}^{-1}$) determinations

Reference	Method	Temperature Range, °C	λ_l^m	10^2b	λ_s^m	L/L_0	Comments
Zinovyev [88]	PTW	-173 to 1600	105		245	1	Converted from a [88]

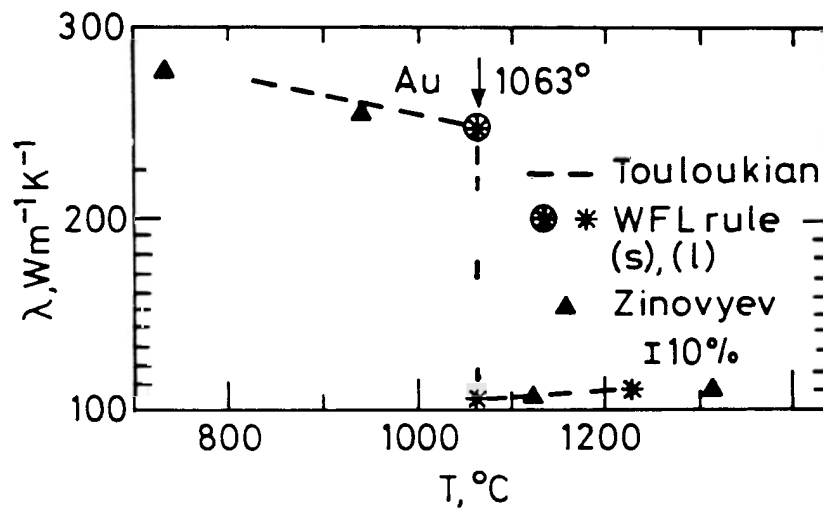


Figure 9 Thermal conductivity of Au as a function of temperature.

recommended values:

$$\lambda_s^m = 247 \text{ Wm}^{-1}\text{K}^{-1}; \quad \lambda_l^m = 105 \text{ Wm}^{-1}\text{K}^{-1}$$

$$\lambda_l = 105 + 3 \times 10^{-2}(T-1063) \text{ Wm}^{-1}\text{K}^{-1}$$

Bi

Details of the experimental study carried out on Bi are summarised in Table 4 and the results are shown in Figure 10. It can be seen that there is some agreement between the Filippov study and the values derived from calculations based on the published resistivity data [17] away from the melting point. The resistivity values are some 20% lower than the Touloukian recommended values.

Table 4
Details of thermal conductivity ($\text{Wm}^{-1}\text{K}^{-1}$) determinations

Reference	Method	Temperature Range, °C	λ_1^m	10^2b	λ_s^m	L/L_o	Comments
Filippov [6]	RTW	220-800	12	0	4		Converted from a values [6]

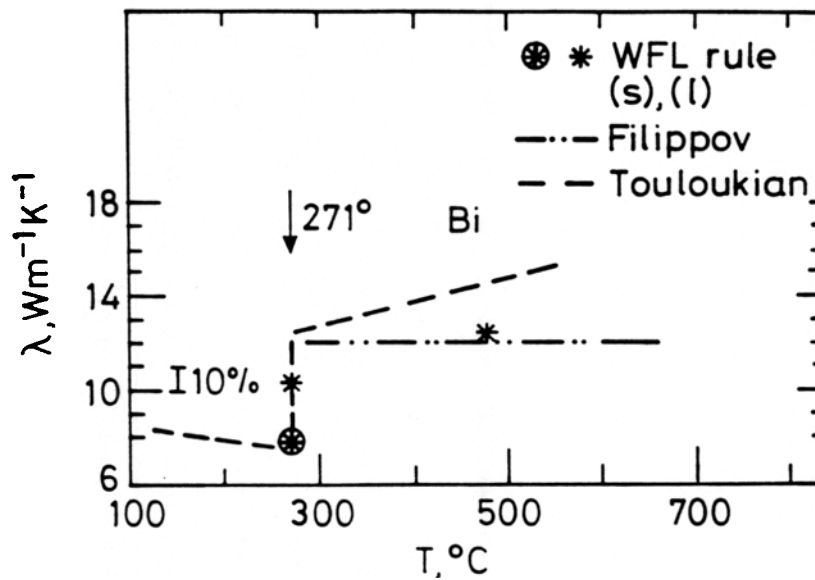


Figure 10 Thermal conductivity of Bi as a function of temperature.

recommended values:

$$\lambda_s^m = 7.6 \text{ Wm}^{-1}\text{K}^{-1}; \quad \lambda_1^m = 12 \text{ Wm}^{-1}\text{K}^{-1}$$

$$\lambda_1 = 12 + 1 \times 10^{-2} (T-271) \text{ Wm}^{-1}\text{K}^{-1}$$

Cd

Filippov [6] reported thermal conductivities (Figure 11) which are in reasonable agreement with the values recommended by Touloukian et al [1]. Powell [14] has questioned the temperature dependence of λ_l values reported by Filippov and has suggested that the $\lambda(\text{Cd})$ results may have been affected by Cd vaporisation.

Table 5
Details of thermal conductivity ($\text{Wm}^{-1}\text{K}^{-1}$) determinations

Reference	Method	Temperature Range, °C	λ_l^m	10^2b	λ_s^m	L/L_o	Comments
Filippov [6]	RTW	200-600	34	0	90	-	Converted from a values [6]

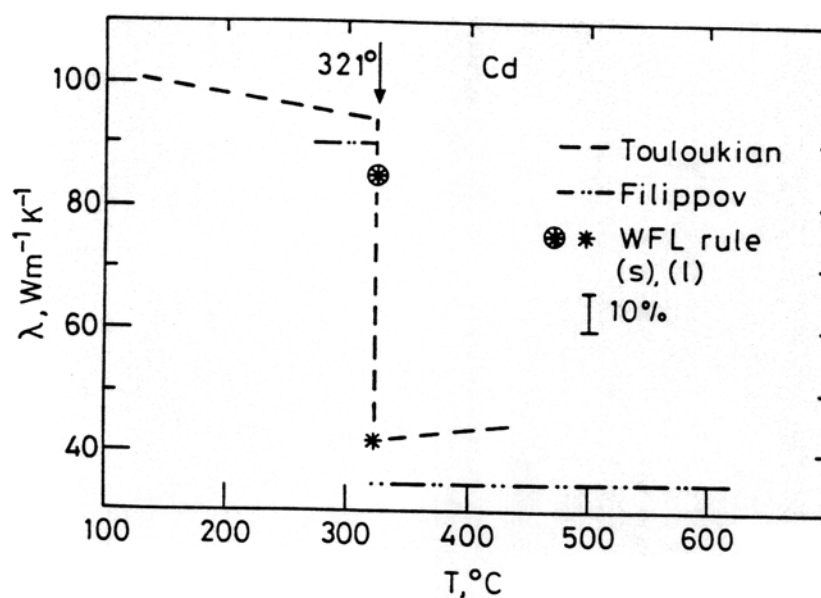


Figure 1 Thermal conductivity of Cd as a function of temperature.

The following values are recommended:

$$\lambda_s^m = 93 \text{ Wm}^{-1}\text{K}^{-1}; \quad \lambda_l^m = 41 \text{ Wm}^{-1}\text{K}^{-1}$$

$$\lambda_l = 41 + 3.3 \times 10^{-2} (T - 321) \text{ Wm}^{-1}\text{K}^{-1}$$

Ce

Details of the various investigations are summarised in Table 6 and the results obtained are given in Figure 12.

Table 6
Details of thermal conductivity ($\text{Wm}^{-1} \text{K}^{-1}$) determinations

Reference	Method	Temperature Range, °C	λ_1^m	10^2b	λ_s^m	L/L_0	Comments
Mardykin Vertman [22]	RTW	900-1330	26			≈ 1	Converted from a values [22]
Novikov Madykin [23]	RTW	900-1300	24		36	≈ 1	Converted from a values [23]
Atalla et al [24]	RTW	930-1530	(19)				Converted from a values [24]
Filippov [6]	RTW	800-1400	26	0			Converted from a values [6]
Wittenberg [25]	RTW	200-875	16 ± 3		18 ± 4		Converted from a values [25]
Zinovyev [89]	PTW	280-875	23		22.3		Converted from a values [89]

Thermal conductivities calculated from the electrical resistivity data due to Novikov and Mardykin are also shown in Figure 12.

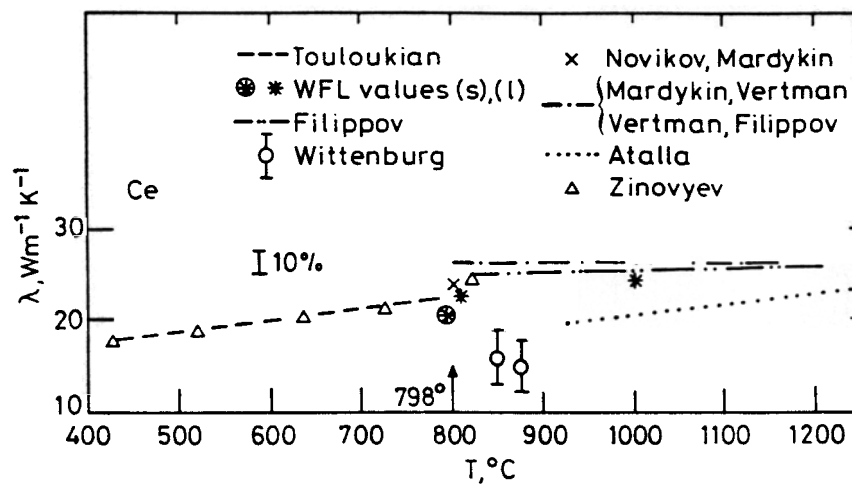


Figure 12 Thermal conductivity of Ce as a function of temperature.

recommended values:

$$\lambda_1^m = 22 \text{ Wm}^{-1} \text{K}^{-1}$$

$$\lambda_1 = 22 + 1.25 \times 10^{-2}(T - 798) \text{ Wm}^{-1} \text{K}^{-1}.$$

Co

Details of the two studies carried out on liquid Co are given in Table 7 and these results for the solid phase are compared with those reported by Zinovyev et al [7]. Thermal conductivities were calculated using the WFL rule using the resistivity data due to Kita et al as cited by Iida and Guthrie [17].

Table 7
Details of thermal conductivity ($\text{Wm}^{-1}\text{K}^{-1}$) determinations

Reference	Method	Temperature Range, °C	λ_l^m	$10^3 b$	λ_s^m	L/L_o	Comments
Zinovyev et al [7,26]	PTW	1220-1600	44	-	46	0.95	Converted from a values [7,26]
Ostrovskii et al [31]	ns	ns	36			1.19	Experimental uncertainty $\pm 20\%$

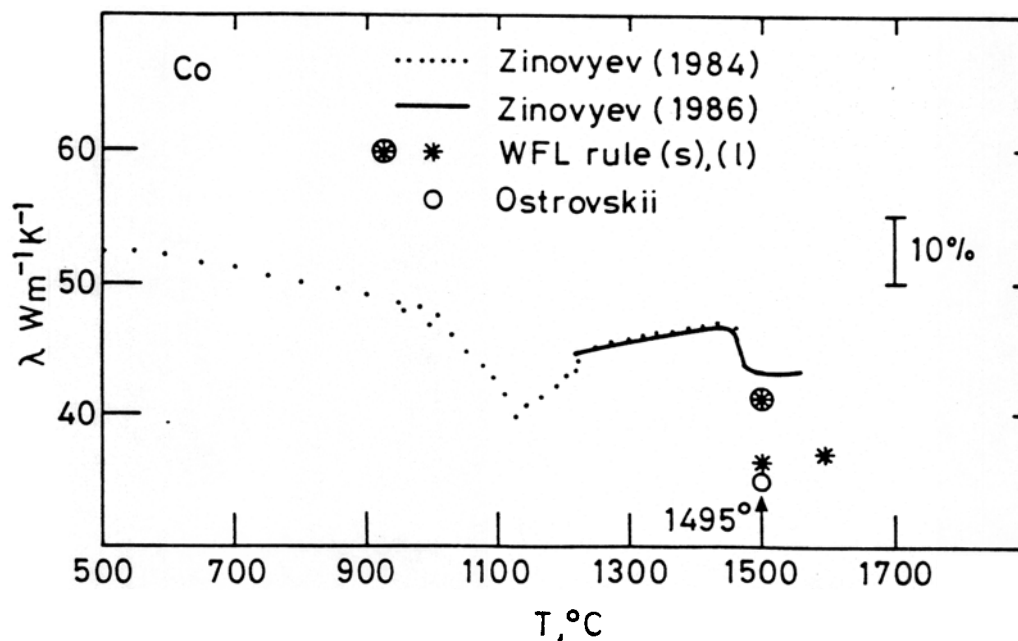


Figure 13 Thermal conductivity of Co as a function of temperature.

There is appreciable scatter in electrical resistivity values reported for Co(l). As can be seen from Figure 13 the WFL values are ca. $7 \text{ Wm}^{-1} \text{ K}^{-1}$ lower than the experimental value reported by Zinovyev et al [7]. However the discrepancy falls within the combined experimental uncertainties of the various measurements. There are larger temperature gradients in the liquid pool formed in the experiments reported by Zinovyev et al which could give rise to buoyancy and thermocapillary convection; the

lower (WFL) values have been tentatively accepted.

recommended values:

$$\lambda_s^m = 45 \text{ Wm}^{-1} \text{ K}^{-1}; \quad \lambda_l^m = 36 \text{ Wm}^{-1} \text{ K}^{-1}$$

Cr

No published values could be found for the thermal conductivity of liquid Cr. Values reported for the solid [7] are shown in Figure 14 and those calculated using the WFL relationship for the liquid phase using the electrical resistivity data reported by Zytveld [30] are also given.

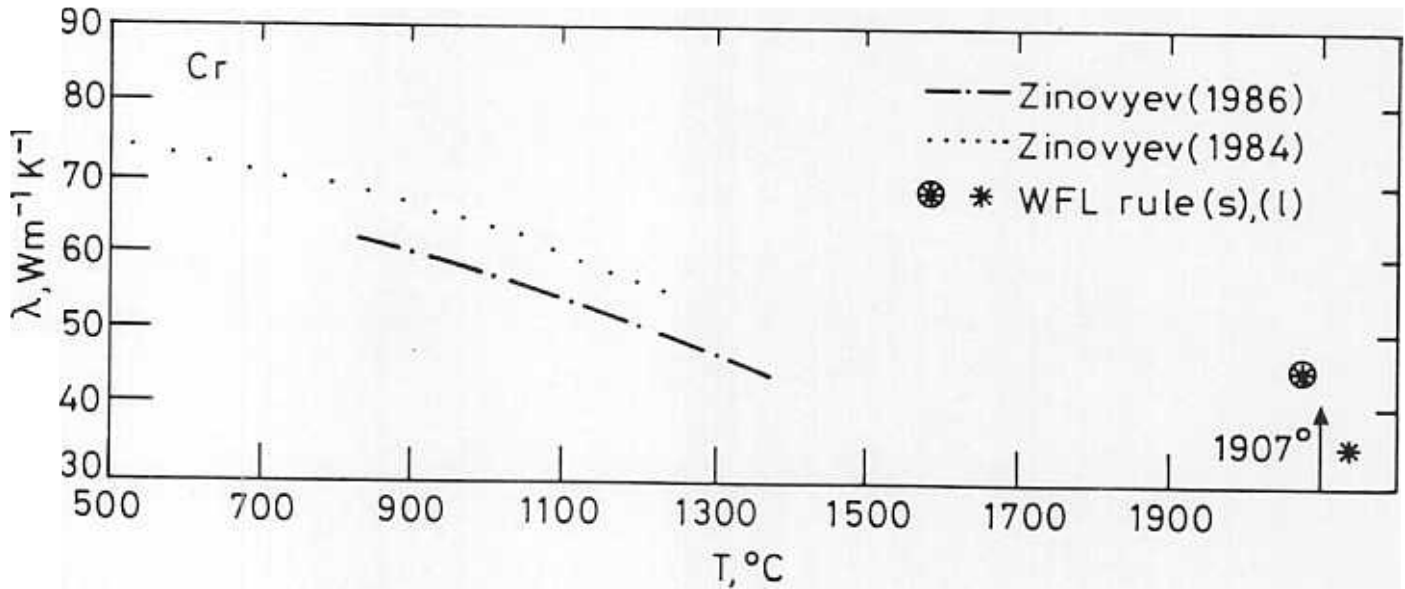


Figure 14 Thermal conductivity of Cr as a function of temperature.

recommended values:

$$\lambda_s^m = 45 \text{ Wm}^{-1}\text{K}^{-1}; \lambda_l^m = 35 \text{ Wm}^{-1}\text{K}^{-1}$$

Cs

There have been no published data for Cs since the review of Touloukian [1]. It can be seen from Figure 15 values calculated using the WFL expression are in good agreement with those recommended by Touloukian et al [1].

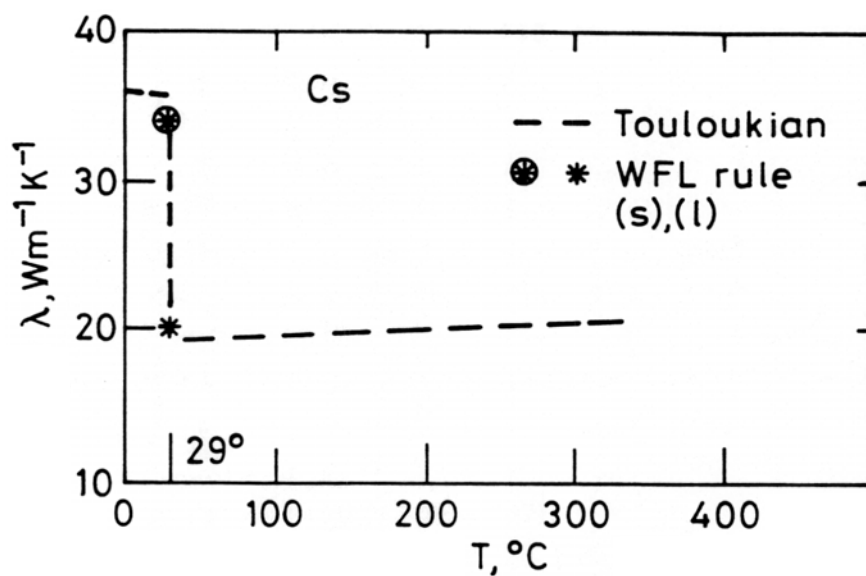


Figure 15 Thermal conductivity of Cs as a function of temperature.

recommended values:

$$\lambda_s^m = 35.9 \text{ Wm}^{-1} \text{ K}^{-1}; \quad \lambda_l^m = 20 \text{ Wm}^{-1} \text{ K}^{-1}$$

$$\lambda_l = 20 + 0.27 \times 10^{-2} (T - 29) \text{ Wm}^{-1} \text{ K}^{-1}$$

Cu

Experimental details of the various investigations are given in Table 8 and in Figure 16. The values are compared with those recommended by Touloukian et al [1]. It can be seen that there is good agreement between the values reported by Tye and Hayden [31], Filippov [6], Zinovyev [88] and Touloukian et al [1]. The values calculated from the WFL rule are in excellent agreement with Zinovyev's [88] experimental values.

Table 8
Details of thermal conductivity ($\text{Wm}^{-1}\text{K}^{-1}$) determinations

Reference	Method	Temperature Range, °C	λ_l^m	10^3b	λ_s^m	L/L_0	Comments
Tye, Hayden [31]	AHF	1027-1227	164.3	2.67		1.06	
Szelagowski [93]	LP	200-1370	130.9	9.45	342.8		Converted from a values
Filippov [6]	RTW	850-1500	168.6	- 1.67	280		Converted from a values [6]
Zinovyev [88]	PTW	0-1300	160		330	1	Converted from a values [88]

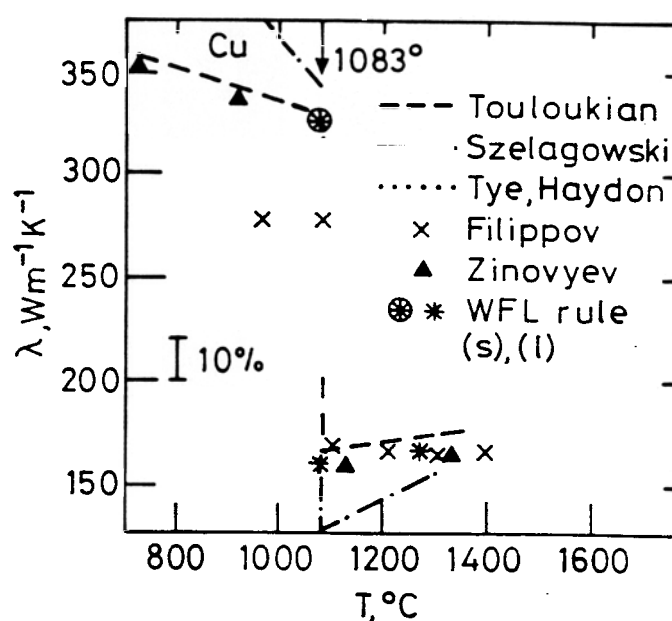


Figure 16 Thermal conductivity of copper as a function of temperature.

recommended values:

$$\lambda_s^m = 330 \text{ Wm}^{-1} \text{ K}^{-1}; \quad \lambda_l^m = 163 \text{ Wm}^{-1} \text{ K}^{-1}.$$

$$\lambda_l = 163 + 2.67 \times 10^{-2} (T - 1083) \text{ Wm}^{-1} \text{ K}^{-1}.$$

Dy

Banchila and Filippov [32] reported the results of a study using the RTW method for Dy(s,l). The thermal diffusivity, a , was found to show no decrease at the melting point and the temperature dependence for the liquid phase was given by

$$a_l = 8.5 + 0.046 \times 10^{-3} (T - 1684)$$

Thermal conductivities for Dy(l) could not be calculated since no data could be found the density of the liquid metal.

Fe

There has only been two investigations carried out on liquid Fe, details are given in Table 9. The results for the solid state recorded in these investigations are compared with those reported in other studies in Figure 17. The measurement of Zinovyev et al [7,28] indicate a higher value for the thermal conductivity of the liquid (λ_l^m) than that for the solid (λ_s^m) in contrast to the values calculated by the WFL rule which suggest $\lambda_l^m < \lambda_s^m$. The discrepancy between the experimental and calculated (WFL) values lies well within the total experimental uncertainties associated with the measurement of thermal diffusivity and electrical resistivity.

Table 9
Details of thermal conductivity ($\text{Wm}^{-1}\text{K}^{-1}$) determinations

Reference	Method	Temperature Range, °C	λ_l^m	$10^2 b$	λ_s^m	L/L_0	Comments
Zinovyev et al [7,27, 28]	PTW	100-1560	36		33		Converted from a values [28]
Ostrovskii et al [29]	ns	ns	26	-	-	-	penetration radiation method

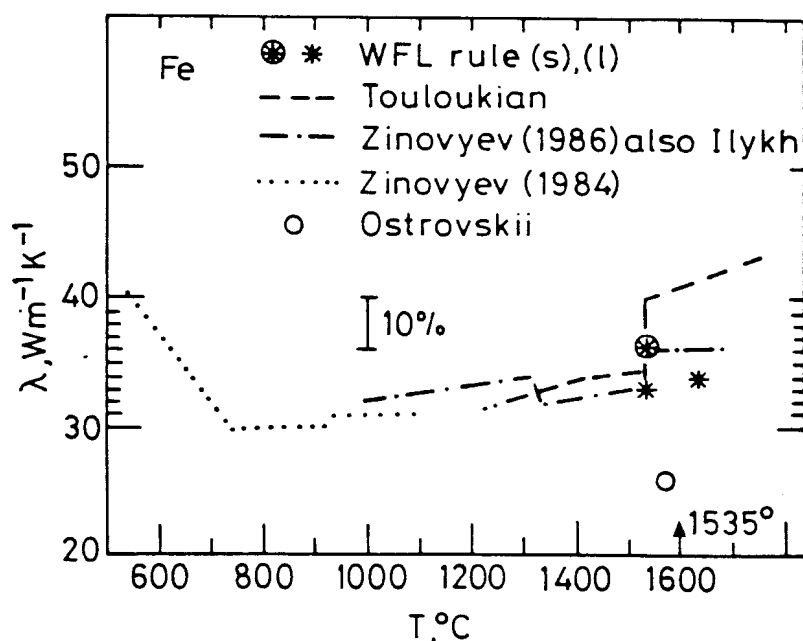


Figure 17 Thermal conductivity of Fe as a function of temperature.

The following values are tentatively recommended:

$$\lambda_s^m = 34 \text{ Wm}^{-1} \text{ K}^{-1}; \quad \lambda_l^m = 33 \text{ Wm}^{-1} \text{ K}^{-1}$$

Ga

Experimental details of the various investigations are given in Table 10 and the results are given in Figure 18.

Table 10
Details of thermal conductivity ($\text{Wm}^{-1}\text{K}^{-1}$) determinations

Reference	Method	Temperature Range, °C	λ_1^m	$10^{-2}b$	λ_s^m	L/L_0	Comments
Schriempf [33]	LP	45-500	27.5	5.8		1.0	Converted from a values
Filippov [6]	RTW	800-1200		0			Converted from a values [6]
Seidensticker [35]	AHF	280-550	70 ± 7				
Magmedov [36]	AHF	0-570	29.8	6.6	24.1		
Gamazov [38]	ns	280-1000					Comparative technique

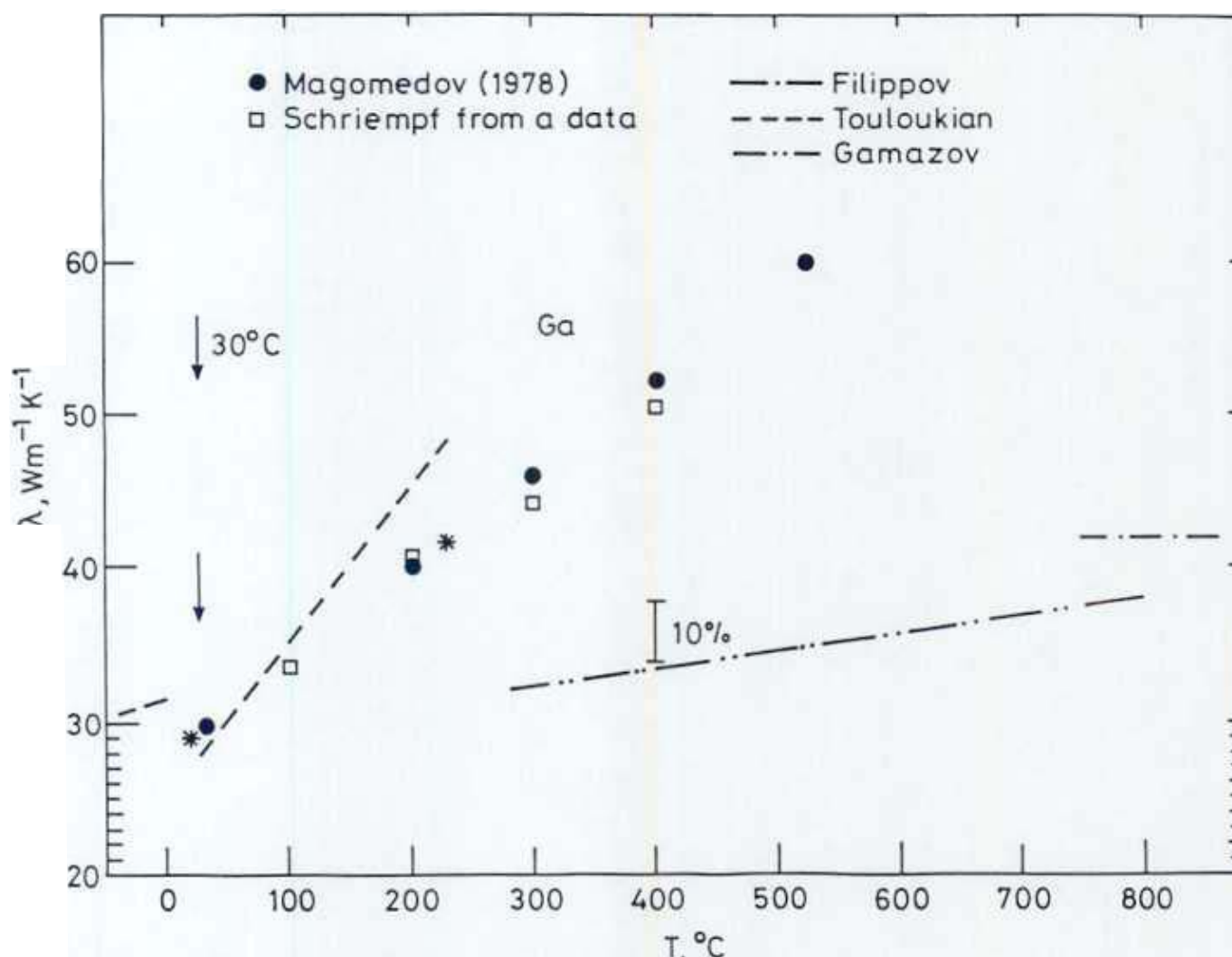


Figure 18 Thermal conductivity of Ga as a function of temperature

recommended values are:

$$\lambda_l^m = 28 \text{ Wm}^{-1} \text{ K}^{-1}$$

$$\lambda_l = 28 + 6.2 \times 10^{-2} (T - 30) \text{ Wm}^{-1} \text{ K}^{-1}$$

Gd

The details of the experimental studies are outlined in Table 11. and the results are compared with those reported by Touloukian et al [1] in Figure 19. It can be seen that the thermal conductivities from the two studies are in reasonable agreement.

Table 11
Details of thermal conductivity ($\text{Wm}^{-1} \text{K}^{-1}$) determinations

Reference	Method	Temperature Range, °C	λ_1^m	$10^{-2}b$	λ_s^m	L/L_0	Comments
Novikov [91]	RTW	830-1800	16	1.9	18		Converted from a values [91]
Zinovyev [92]	PTW	600 - 1350	19		19	0.95	Converted from a values [92]

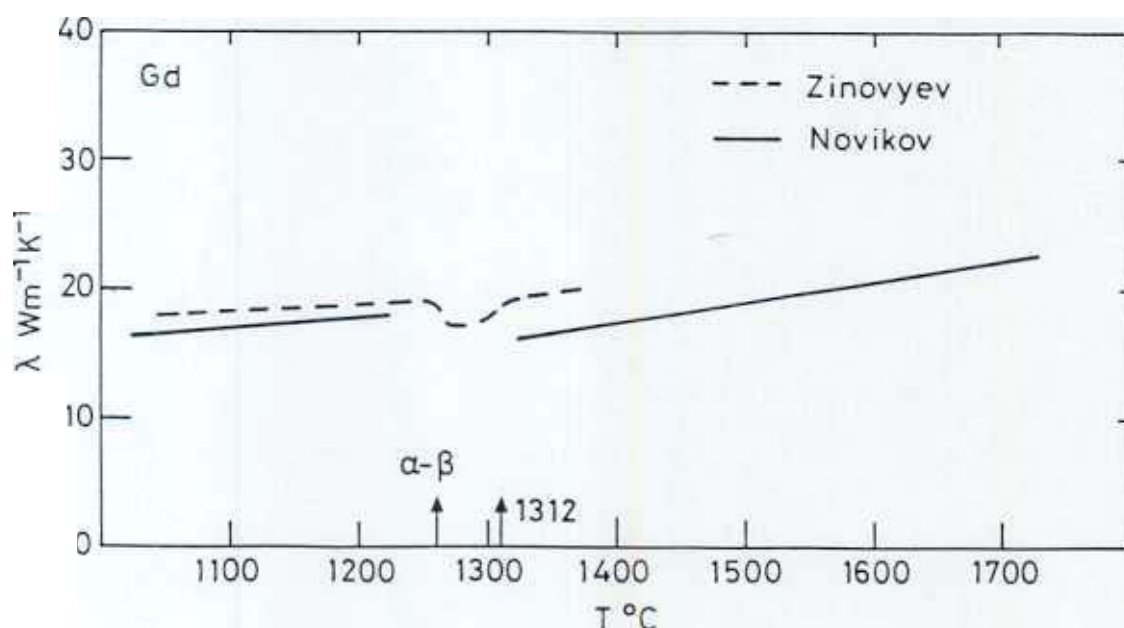


Figure 19 Thermal conductivity values of Gd as a function of temperature recommended values:

$$\lambda_s^m = 19 \text{ Wm}^{-1} \text{K}^{-1}; \quad \lambda_1^m = 19 \text{ Wm}^{-1} \text{K}^{-1}$$

$$\lambda_1 = 19 + 1.9 \times 10^{-2} (T - 1312) \text{ Wm}^{-1} \text{K}^{-1}$$

Ge

Details of the various measurements are given in Table 12 and the results are shown in Figure 20. It can be seen that there are large differences in results reported by various investigators.

Table 12
Details of thermal conductivity ($\text{Wm}^{-1}\text{K}^{-1}$) determinations

Reference	Method	Temperature Range, °C	λ_l^m	$10^{-2}b$	λ_s^m	L/L_0	Comments
Glazov et al [39]	CC	100-1200	25	1.5	16	0.6	
Filippov [6]	RTW	850	50	0	18		Converted from a values [6]
Taylor et al [40]	LP	800-1000	39.1	-	14.3		Converted from a values

The thermal conductivities were also calculated from the WFL value but there are large discrepancies in electrical resistivity data listed in the review due to Iida and Guthrie [17]. These differences can be seen clearly in the derived thermal conductivity values (Figure 20). It is difficult to recommend thermal conductivity values for the liquid phase since two WFL values support Filippov's thermal conductivity data whilst another supports the value derived from Taylor et al. Sample purity could possibly have strong influence on the results. Taylor's results are tentatively accepted.

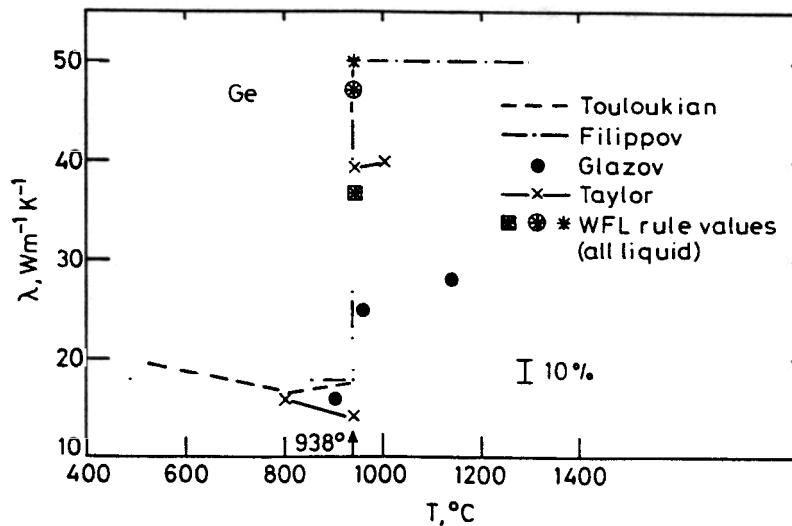


Figure 20 Thermal conductivity of Ge as a function of temperature.

recommended values are:

$$\lambda_s^m = 15 \text{ Wm}^{-1} \text{ K}^{-1}; \quad \lambda_l^m = 39 \text{ Wm}^{-1} \text{ K}^{-1}$$

Hf

Details of the thermal conductivity measurements made on Hf are given in Table 13 and the results are shown in Figure 21. Filippov [6] obtained thermal conductivity data using the RTW method for solid Hf at high temperatures. Values reported by Peletskii et al [41] for the solid phase were > 10% lower than those obtained by Filippov (Figure 20) this discrepancy may be related to the sample purity. A value of $\lambda_s^m = 39.2 \text{ Wm}^{-1}\text{K}^{-1}$ was derived from the electrical resistivity reported by Desai et al [42] and Peletskii et al [41], this value is consistent with values derived from the $\lambda - (T)$ relationship reported by Filippov [6].

Table 13
Details of thermal conductivity ($\text{Wm}^{-1}\text{K}^{-1}$) determinations

Reference	Method	Temperature Range, °C	λ_l^m	10^2b	λ_s^m	L/L_o	Comments
Filippov [6]	RTW	827-1827					Converted from a values [6]
Peletskii [41]	AHF	100-1600					

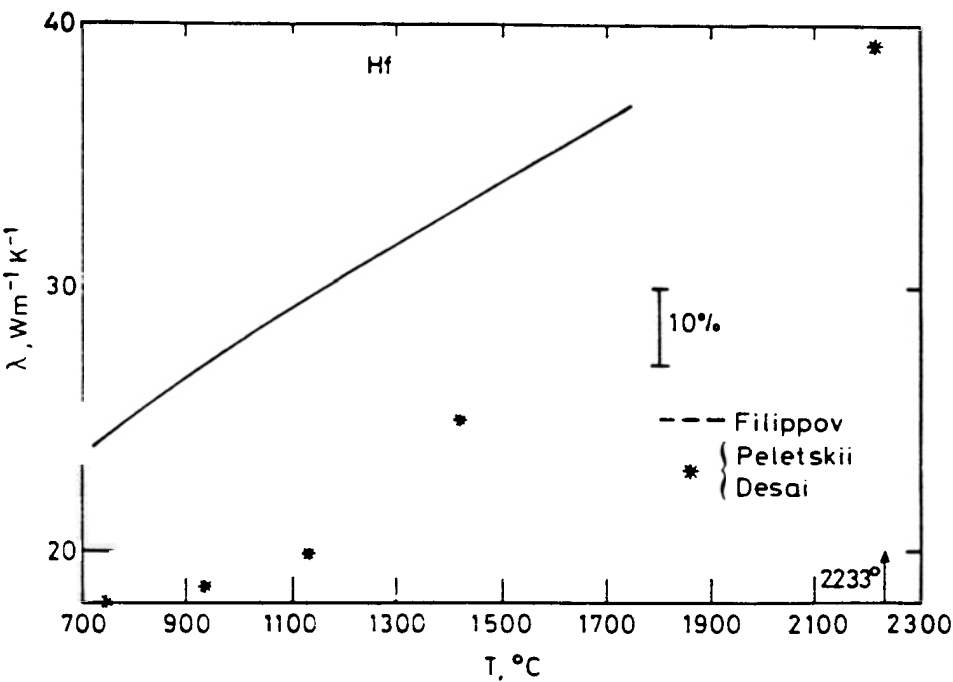


Figure 21 Thermal conductivity of Hf as a function of temperature.

recommended value

$$\lambda_s^m = 39 \text{ Wm}^{-1} \text{ K}^{-1}$$

Hg

Experimental details of the more recent investigations are given in Table 14 and the results are compared with those reported by Touloukian et al [1] in Figure 22.

Table 14
Details of thermal conductivity ($\text{Wm}^{-1} \text{K}^{-1}$) determinations

Reference	Method	Temperature Range, °C	T°C*	λ_1^m *	$10^2 b$	L/L_0	Comments
Duggin [43]	AHF	27 - 110	77	8.7	1.05	0.98 to 1.03	
Nakamura [44] [3]	THW	27 - 110	27 57 87	7.9 8.5 8.7			W-probe coated with $\text{Al}_2\text{O}_3 \pm 10\%$ uncertainty
Ang et al [13]	LP	-150 to 100					Converted from a values [13]. Results in agreement with Touloukian et al [1].
Sundqvist [45]	AHF		47	8.1 ± 0.4			
Schriempf [10]	LP	13-300	13 300	7.78			Converted from a values. Error $\pm 5\%$ in a;
Cook [46]	AHF		330	8.31 ± 1.75			
Nakamura et al [47]	THW		- 4	6.7			13% below data due to [1]. Used magnetic field to suppress convection.
Brooks et al [94]	THW	25-50	25	7.8			Oxidized alumel probe

* indicates thermal conductivity quoted at temperature #

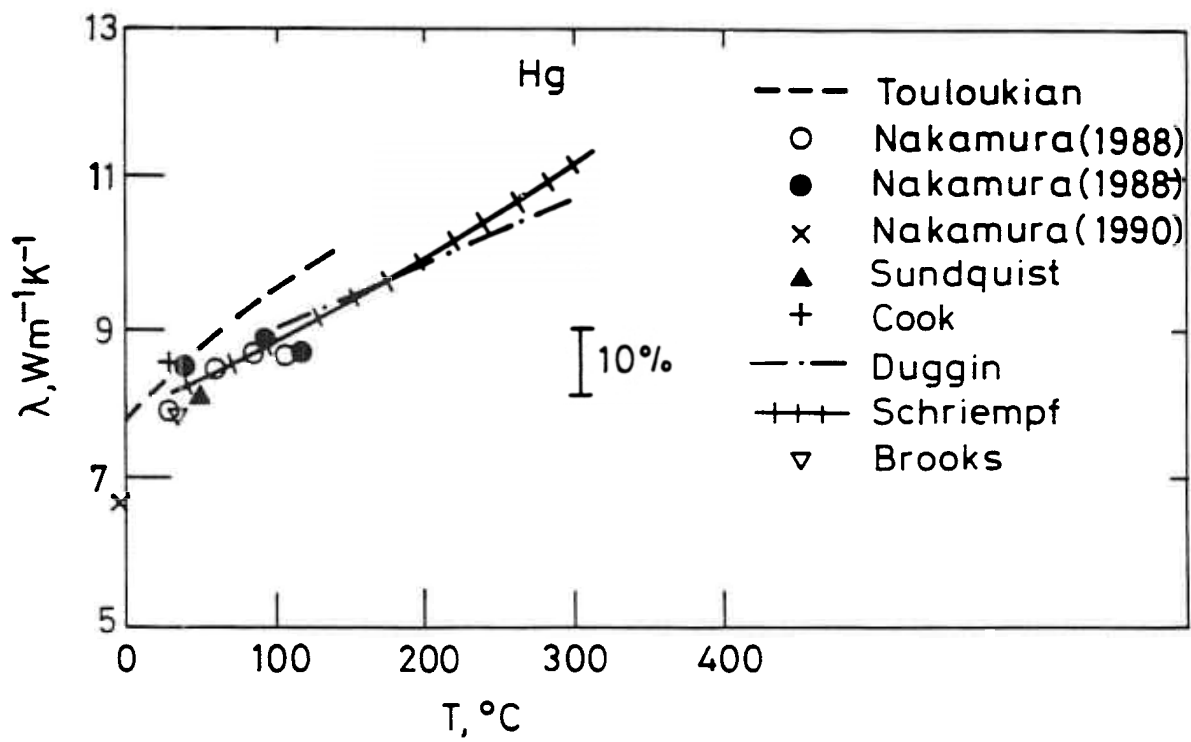


Figure 22 Thermal conductivity of Hg as a function of temperature.

recommended values for:

$$\lambda_1 = 7.2 + 1.4 \times 10^{-2} T \quad \text{Wm}^{-1}\text{K}^{-1}$$

In

Details of the various experimental determinations are given in Table 15 and the results of the study are given in Figure 23.

Table 15
Details of thermal conductivity ($\text{Wm}^{-1} \text{K}^{-1}$) determinations

Reference	Method	Temperature Range, °C	λ_1^m	$10^2 b$	λ_s^m	L/L_0	Comments
Atalla et al [24]	RTW	900 - 1750					Converted from a values [24]
Duggin [48]	AHF	50 - 560	38	0.5	77		
Osipenko [50]	PP	100 - 600	35.5		80		
Goldratt [51]	AHF	110-210	36		76	1.09	
Khusainova Pavlova [52]	RTW	475-975					

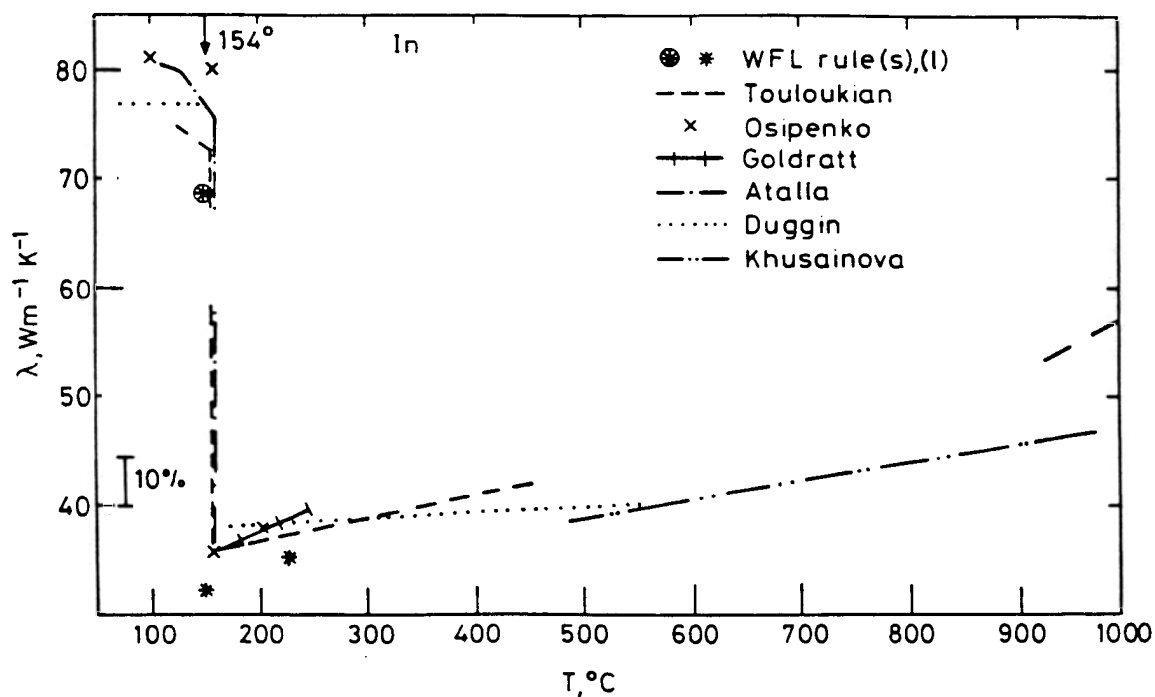


Figure 23 Thermal conductivity of In as a function of temperature.
recommended values:

$$\lambda_s^m = 76 \text{ Wm}^{-1} \text{K}^{-1} ; \quad \lambda_1^m = 38 \text{ Wm}^{-1} \text{K}^{-1}$$

$$\lambda_1 = 38 + 2 \times 10^{-2} (T - 154) \text{ Wm}^{-1} \text{K}^{-1}$$

Ir

Experimental details of the measurements carried out on solid and liquid Ir are given in Table 16 and the results are shown in Figure 24. It can be seen that there is good agreement between the results of the various studies on the solid phase. At temperatures close to the melting point, the conduction was virtually pure electronic (L/L_o) = 1.

Table 16
Details of thermal conductivity ($\text{Wm}^{-1} \text{K}^{-1}$) determination

Reference	Method	Temperature Range, °C	λ_l^m	$10^2 b$	λ_s^m	L/L_o	Comments
Filippov [6]	RTW	930 - 2230			105*		Converted from a values [6], only solid
Geld et al [54]	PTW	1200 - 2100			98*		Converted from a values [54], only solid
Vlasov et al [55]	PTW	930 - 2500	76		95	1.0	Converted from a values [55]

* Extrapolated value

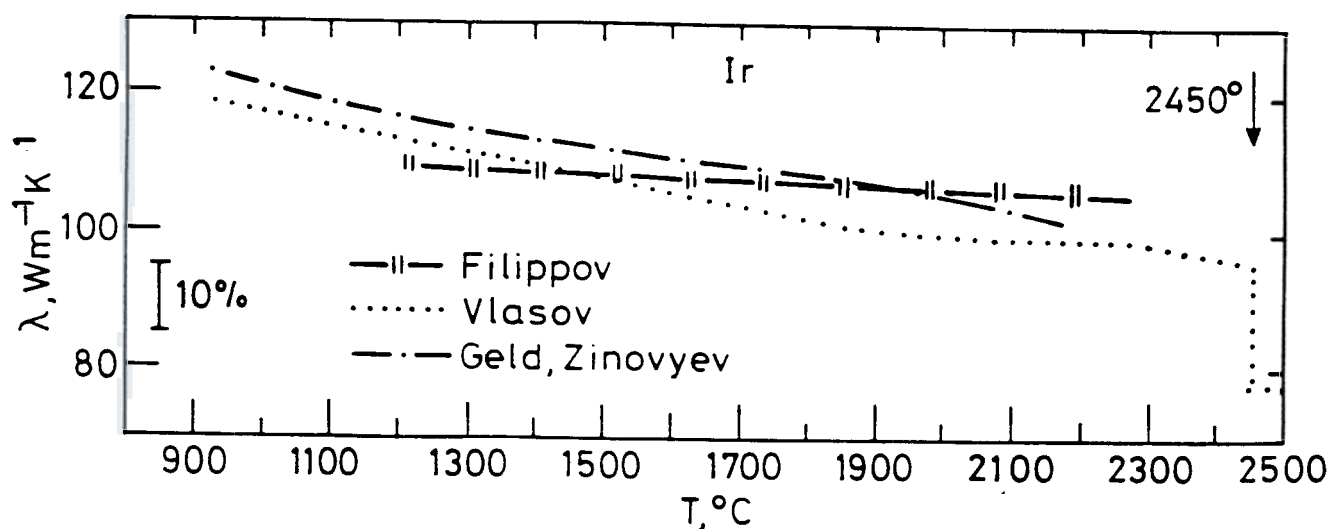


Figure 24 Thermal conductivity of Ir as a function of temperature.

Recommended values:

$$\lambda_s^m = 95 \text{ Wm}^{-1} \text{K}^{-1}; \quad \lambda_l^m = 76 \text{ Wm}^{-1} \text{K}^{-1}$$

K

The details of the experimental study are outlined in Table 17 and the results are compared with those reported by Touloukian et al [1] in Figure 25. It can be seen that the thermal conductivities measured by Cook [90] are in reasonable agreement with both the results around the melting point recommended by Touloukian et al and those derived from WFL calculations but the temperature coefficient ($d\lambda/dT$) is less negative than that given by Touloukian et al. Mean values have been adopted.

Table 17
Details of thermal conductivity ($\text{Wm}^{-1} \text{K}^{-1}$) determinations

Reference	Method	Temperature Range, °C	λ_1^m	$10^2 b$	λ_2^m	L/L_0	Comments
Cook [90]	AHF	62 - 427	58.6	-5	-	0.93	

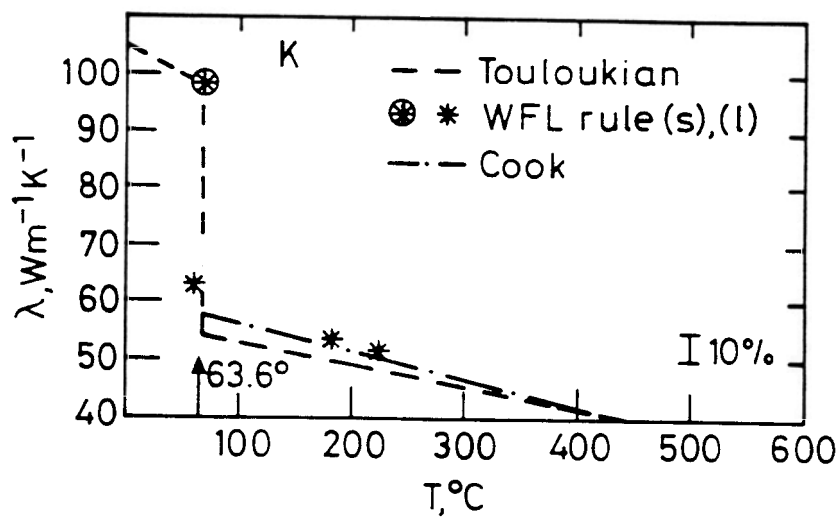


Figure 25 Thermal conductivity values of K as a function of temperature

Recommended values:

$$\begin{aligned} \lambda_s^m &= 98.5 \text{ Wm}^{-1} \text{K}^{-1}; & \lambda_l^m &= 56 \text{ Wm}^{-1} \text{K}^{-1} \\ \lambda_1 &= 56 - 3.8 \times 10^{-2} (T - 64) \text{ Wm}^{-1} \text{K}^{-1} \end{aligned}$$

La

Details of the various determinations are summarised in Table 18 and the results are compared in Figure 26. Literature values for C_p [21] and ρ [17] were used to convert thermal diffusivity (α) values into thermal conductivities.

Table 18
Details of thermal conductivity ($\text{Wm}^{-1} \text{K}^{-1}$) determinations

Reference	Method	Temperature Range, °C	λ_1^m	$10^2 b$	λ_2^m	L/L_0	Comments
Mardykin et al [57]	RTW	1000 - 1530	16.6	0.33			Converted from α values
Atalla [58]	RTW	920 - 1230	15.7	1.0	-		Converted from α values
Banchila Filippov [32]	RTW	920 - 1600	17.3	1.0		1.0	Converted from α values [32]
Wittenberg [25]	RTW	700-1000				0.86	Converted from α values [25]

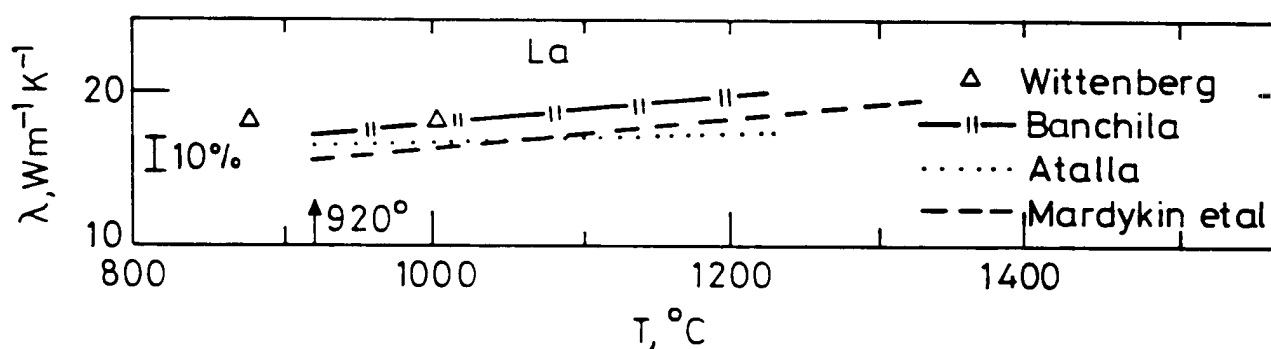


Figure 26 Thermal conductivity of La as a function of temperature.

Recommended values:

$$\lambda_1^m = 17 \text{ Wm}^{-1} \text{K}^{-1}$$

$$\lambda_1 = 17 + 0.5 \times 10^{-2} (T - 920) \text{ Wm}^{-1} \text{K}^{-1}$$

Li

Thermal conductivities reported by Shpilrain and Krainov [59] and Novikov et al [64] (see Table 19 and Figure 27) are both in good agreement with the values recommended by Touloukian et al [1].

Table 19
Details of thermal conductivity ($\text{Wm}^{-1} \text{K}^{-1}$) determinations

Reference	Method	Temperature Range, °C	λ_l^m	$10^{-2}b$	λ_s^m	L/L_o	Comments
Shpilrain, Krainova [59]	AHF	130 - 900	44.5		49		
Novikov et al [64]	AHF	280 - 1100	43.8				

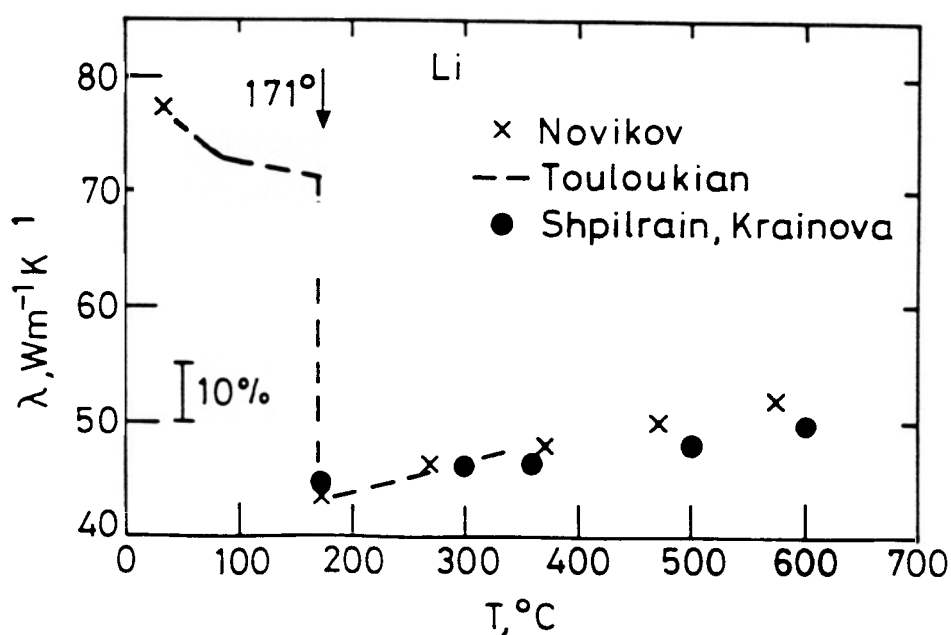


Figure 27 Thermal conductivity of Li as a function of temperature.

Recommended values:

$$\lambda_s^m = 71 \text{ Wm}^{-1} \text{K}^{-1}; \quad \lambda_l^m = 43 \text{ Wm}^{-1} \text{K}^{-1}$$

$$\lambda_l = 43 + 2 \times 10^{-2} (T - 171) \text{ Wm}^{-1} \text{K}^{-1}$$

Mg

No measurements have been reported for the thermal conductivity of Mg since the review due to Touloukian et al [1]. The results are shown in Figure 28. The good agreement between Touloukian et al [1] and the WFL rule is misleading. There was no liquid thermal conductivity data for Mg available to Touloukian et al [1] for their review and it is likely that they used the WFL rule to make their recommendations.

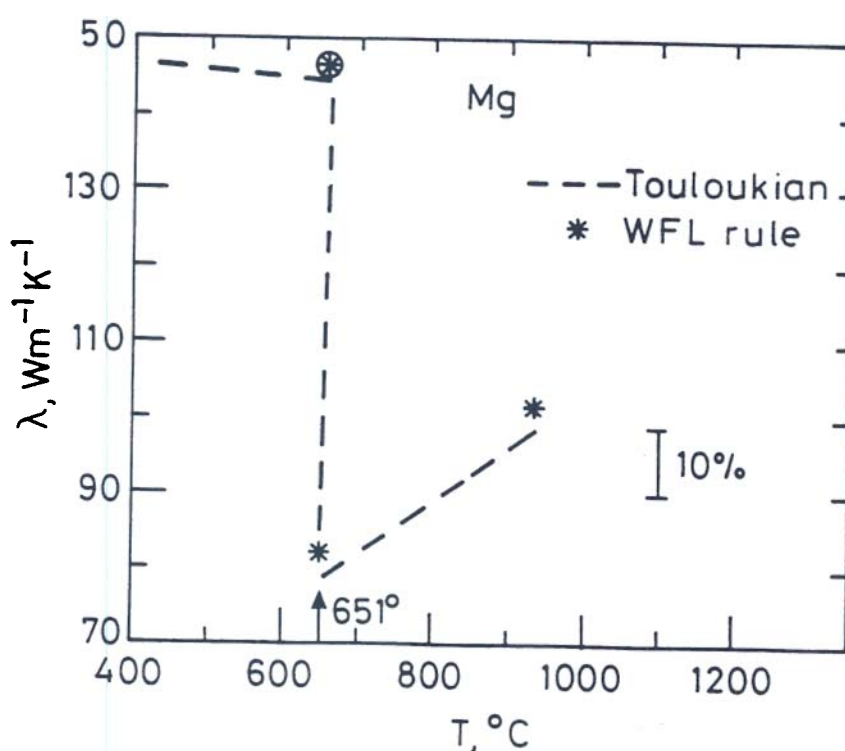


Figure 28 Thermal conductivity of Mg as a function of temperature.

Recommended values:

$$\lambda_s^m = 145 \text{ Wm}^{-1} \text{ K}^{-1}; \quad \lambda_l^m = 79 \text{ Wm}^{-1} \text{ K}^{-1}$$

$$\lambda_l = 79 + 7 \times 10^{-2} (T - 650) \text{ Wm}^{-1} \text{ K}^{-1}$$

Mn

Zinovyev et al [7] using the PTW method have reported values for the solid phase, (Figure 29). Extrapolation of these data leads to a value of λ_s^m of ca. $25 \text{ Wm}^{-1} \text{ K}^{-1}$. It is difficult to derive reliable values for the λ_s^m and λ_l^m from WFL calculations since the electrical resistivity results reported for the melting range are very scattered, with values varying between 40 and $170 \times 10^{-8} \text{ ohm}$. Extrapolation of the resistivity - (T) relationship for the solid phase recommended by Desai et al [60] provides support for the higher value due to Akshentsev et al [61]. Using these data in the WFL relationship produced values of $\lambda_s^m = 23.1 \text{ Wm}^{-1} \text{ K}^{-1}$ and $\lambda_l^m = 22 \text{ Wm}^{-1} \text{ K}^{-1}$. The former value being in good agreement with the λ_s^m derived from the results reported by Zinovyev et al [7].

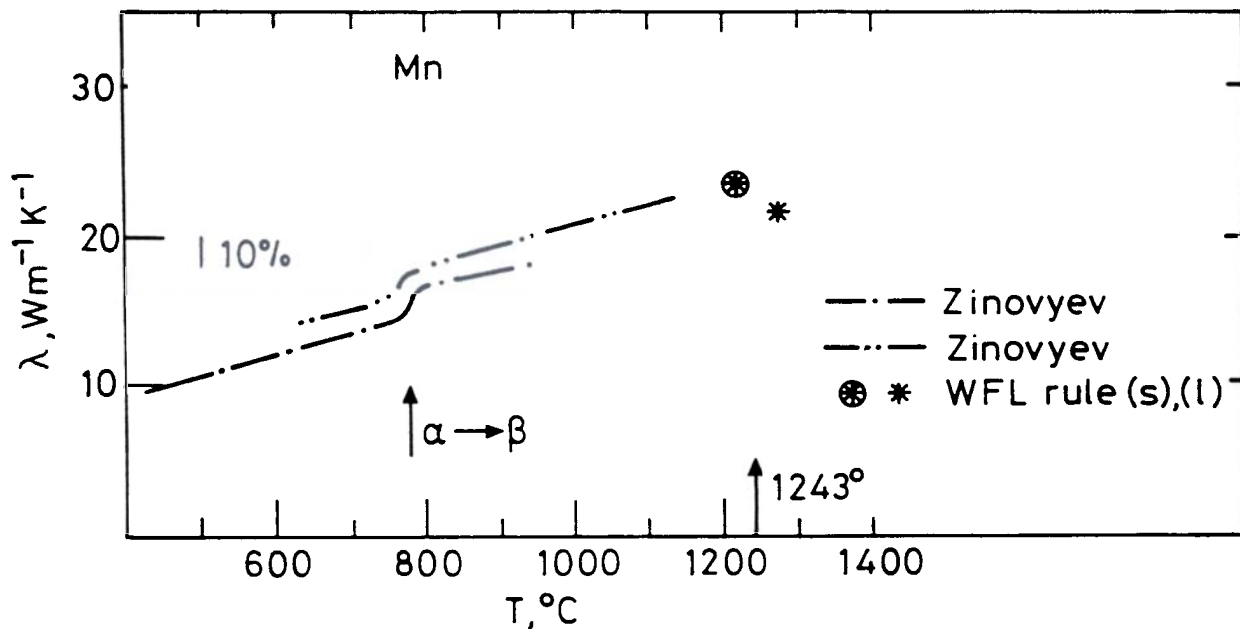


Figure 29 Thermal conductivity of Mn as a function of temperature.

Recommended values:

$\lambda_s^m = 24 \text{ Wm}^{-1} \text{ K}^{-1}; \quad \lambda_l^m = 22 \text{ Wm}^{-1} \text{ K}^{-1}$
--

Mo

Details of the thermal conductivity measurements carried out on Mo are given in Table 20 and the results are shown in Figure 30. The only thermal conductivity values reported for the liquid Mo are the two studies reported by Taluts et al [62,63]. The results of these studies are compared with those reported for the solid phase [6]. All thermal conductivity values for temperatures above 1200°C fall within a band of 10% uncertainty.

Table 18
Details of the thermal conductivity ($\text{Wm}^{-1} \text{K}^{-1}$) determinations

Reference	Method	Temperature Range, °C	λ_l^m	$10^2 b$	λ_s^m	L/L_o	Comments
Filippov [6]	RTW	727 - 2700			97*		Converted from a values [6]
Taluts et al [62]	PTW	727 - 2727	75	-	91	1.0	Converted from a values [62]
Taluts et al [63]	PTW	727 - 2800	72	-	87		Converted from a values [63]

* Extrapolated value

Values of the thermal conductivity were calculated by the WFL relationship using the electrical resistivity data recommended by Desai et al [42], it can be seen that these values are identical with those given by Taluts et al [63].

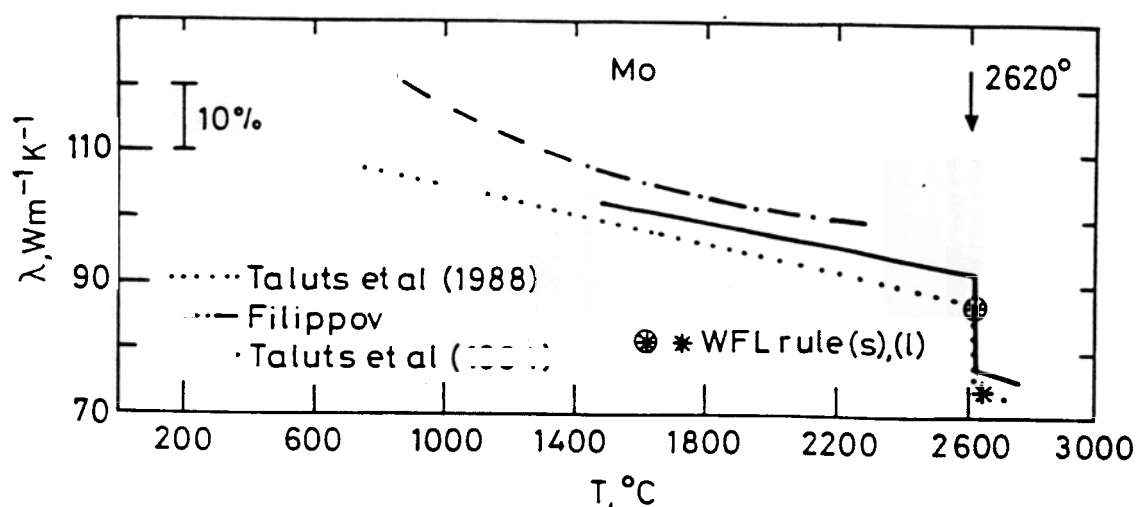


Figure 30 Thermal conductivity of Mo as a function of temperature.

Recommended values:

$$\lambda_s^m = 87 \text{ Wm}^{-1} \text{K}^{-1}; \quad \lambda_l^m = 72 \text{ Wm}^{-1} \text{K}^{-1}$$

Na

The details of the more recent investigations are summarised in Table 21 and the results are compared with those recommended by Touloukian et al [1] in Figure 31.

Table 21
Details of thermal conductivity ($\text{Wm}^{-1} \text{K}^{-1}$) determinations

Reference	Method	Temperature Range, °C	λ_1^m	$10^2 b$	λ_s^m	L/L_o	Comments
Novikov et al [75]	AHF	250 - 830	91.4				

The results obtained by Novikov et al [64] are in good agreement with those recommended by Touloukian et al [1].

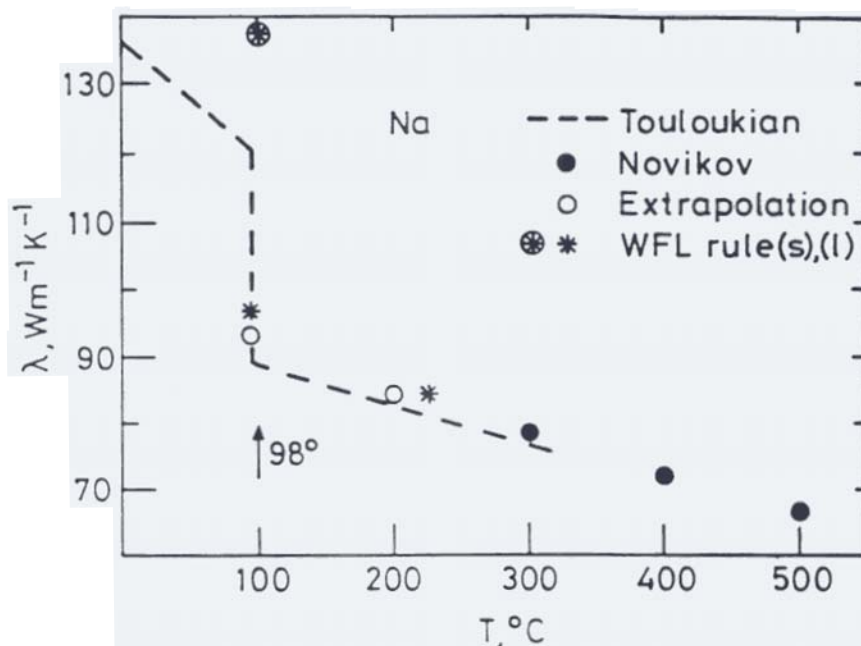


Figure 31 Thermal conductivity of Na as a function of temperature.

Recommended values

$$\lambda_s^m = 120 \text{ Wm}^{-1} \text{K}^{-1}; \quad \lambda_1^m = 88 \text{ Wm}^{-1} \text{K}^{-1}$$

$$\lambda_1 = 88 - 5 \times 10^{-2} (T - 98) \text{ Wm}^{-1} \text{K}^{-1}$$

Nb

The details of high temperature investigations are given in Table 22 and the results are compared with other measurements reported for solid Nb [65] in Figure 32. It can be seen that the values reported for the solid lie within a band of 10%. It can be seen that there is a small peak immediately below the melting point which did not occur in electrical resistivity and which was attributed to the creation of vacancies (an extrapolated value is preferred for λ_s^m) [63,64].

Table 22
Details of thermal conductivity ($\text{Wm}^{-1} \text{K}^{-1}$) determinations

Reference	Method	Temperature Range, °C	λ_l^m	$10^{-2}b$	λ_s^m	L/L_0	Comments
Filippov [6]	RTW	730 - 1930			73*		Converted from a values [6]
Zinovyev et al [66]	PTW	730 - 2500			78*		Converted from a values [66]
Taluts et al [63]	PTW	730 - 2500	66	-	73	1.0	Converted from a values [63]

* Extrapolated value

Values of thermal conductivity of Nb(l) were also derived from the WFL Rule using the electrical resistivity data of Gallob et al [67].

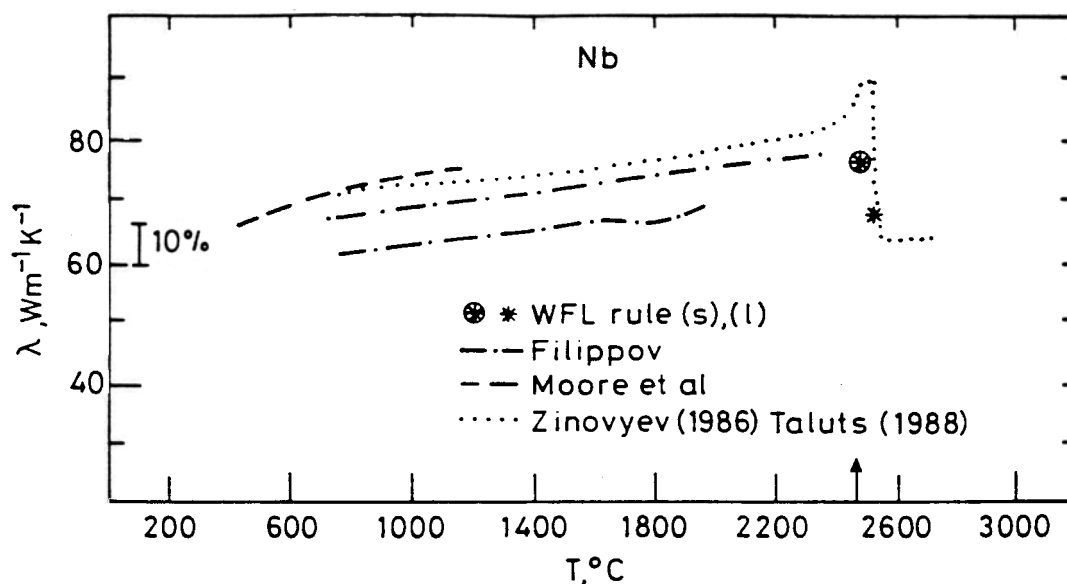


Figure 32 Thermal conductivity of Nb as a function of temperature.

Recommended values:

$\lambda_s^m = 78 \text{ Wm}^{-1} \text{K}^{-1}$	$\lambda_l^m = 62 \text{ Wm}^{-1} \text{K}^{-1}$
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Nd

Details of the thermal conductivity investigation are given in Table 23 and the results are shown in Figure 33.

Table 23
Details of thermal conductivity ($\text{Wm}^{-1} \text{K}^{-1}$) determinations

Reference	Method	Temperature Range, °C	λ_1^m	10^3b	λ_s^m	L/L_o	Comments
Atalla et al [24]	RTW	980 - 1400	18.4	0.53	-		Converted from a values [24]
Mardykin et al [68]	RTW	1020-1320	21				Converted from a values [68]

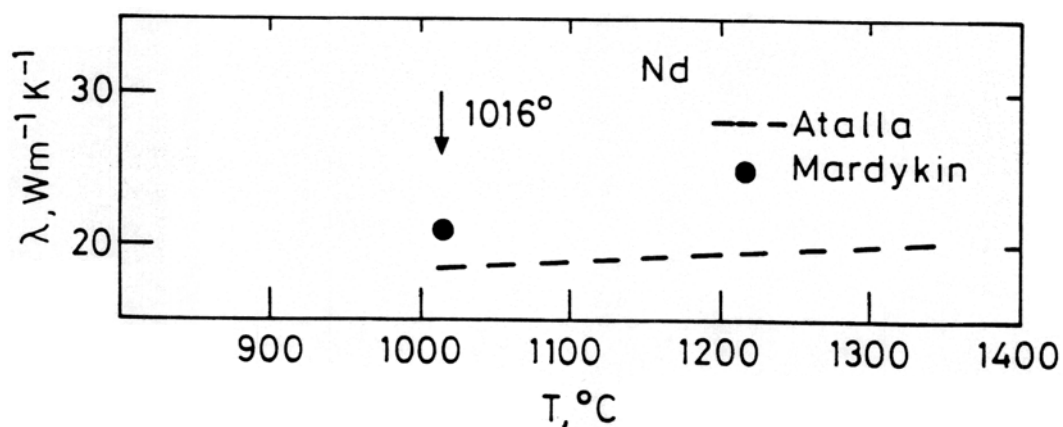


Figure 33 Thermal conductivity of Nd(l) as a function of temperature.

Recommended values:

$$\lambda_1^m = 18.4 \text{ Wm}^{-1}\text{K}^{-1}$$

$$\lambda_1 = 18.4 + 0.53 \times 10^{-2} (T - 1016) \text{ Wm}^{-1}\text{K}^{-1}$$

Ni

The details of thermal conductivity determinations on Ni(l) are summarised in Table 24. The results of the investigation by Zinovyev et al [7] on solid Ni are compared with those of other studies [27] in Figure 34. It can be seen that there is good agreement. The value cited by Ostrovskii et al [29] for liquid Ni has a quoted uncertainty of $\pm 20\%$. Values calculated from the WFL rule are appreciably lower ($5 \text{ Wm}^{-1} \text{ K}^{-1}$) than the measured values by Zinovyev et al, although the discrepancy is less than the combined uncertainty associated with the measurements of thermal diffusivity ($\pm 5\%$) and electrical resistivity ($\pm 3\%$).

Table 24
Details of thermal conductivity ($\text{Wm}^{-1} \text{ K}^{-1}$) determinations

Reference	Method	Temperature Range, °C	λ_l^m	$10^2 b$	λ_s^m	L/L_o	Comments
Ostrovskii et al [21]	ns	ns	68 ± 13				
Zinovyev et al [7]	PTW	100 - 1700	60		70	0.91	Converted from a values [7]. Values for solid agree with Zinovyev et al [27]

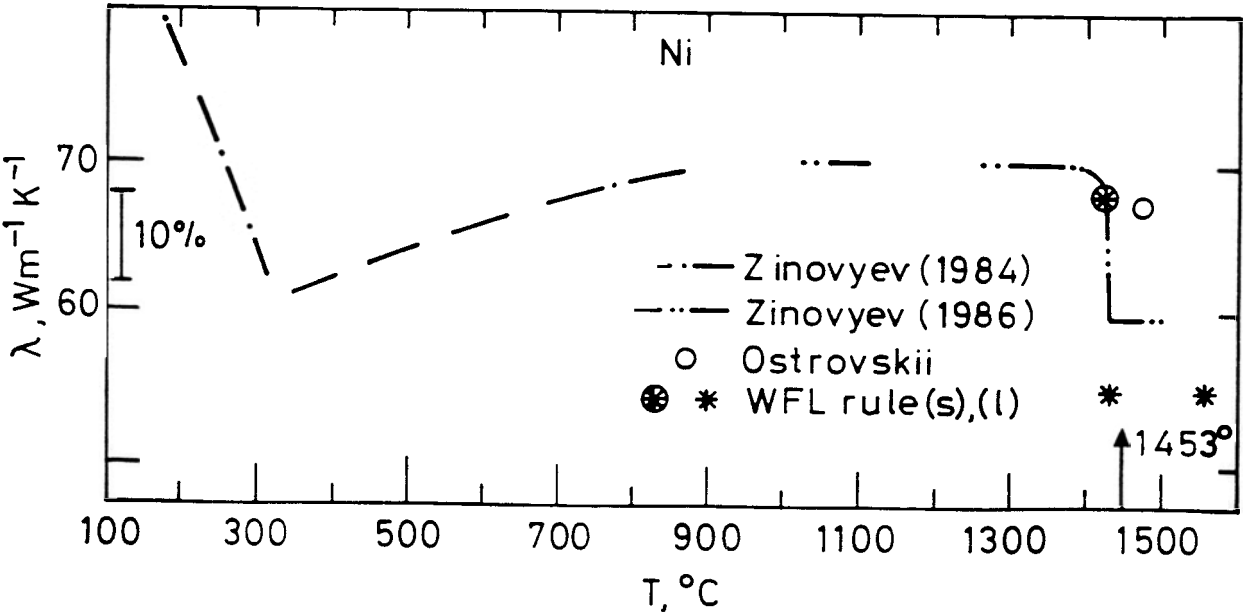


Figure 34 Thermal conductivity of Ni as a function of temperature.

Recommended values:

$\lambda_s^m = 70 \text{ Wm}^{-1} \text{ K}^{-1}; \quad \lambda_l^m = 60 \text{ Wm}^{-1} \text{ K}^{-1}$

Pb

Details of the various investigations are given in Table 25 and the thermal conductivity results are compared in Figure 35.

Table 25
Details of thermal conductivity ($\text{Wm}^{-1} \text{K}^{-1}$) determinations

Reference	Method	Temperature Range, °C	λ_1^m	$10^2 b$	λ_2^m	L/L_0	Comments
Osipenko [50]	PP	100 - 600	16	1.5	29		
Filippov [6]	RTW	327 - 1000	16	0			Converted from a values [6]
Banchila Filippov [16]	RTW	800 - 1800	20*	0.36			Converted from a values [16]
Duggin [58]	AHF	327 - 600	15	-0.34			
Wittenberg [25]	RTW	450 - 650	14.5	2.0			Converted from a values [25]
Hemminger [4]	PP	100 - 500	15.6	1.1	29.6		
Nakamura et al [69]	THW	327 - 727	14.6	0.6			

* Extrapolated value

The lower values reported by Hemminger [4], Duggin [48] and Nakamura et al [69] are preferred since convectional contributions were probably less in these studies. It can be seen that values calculated by the WFL Rule are in good agreement with the lower values.

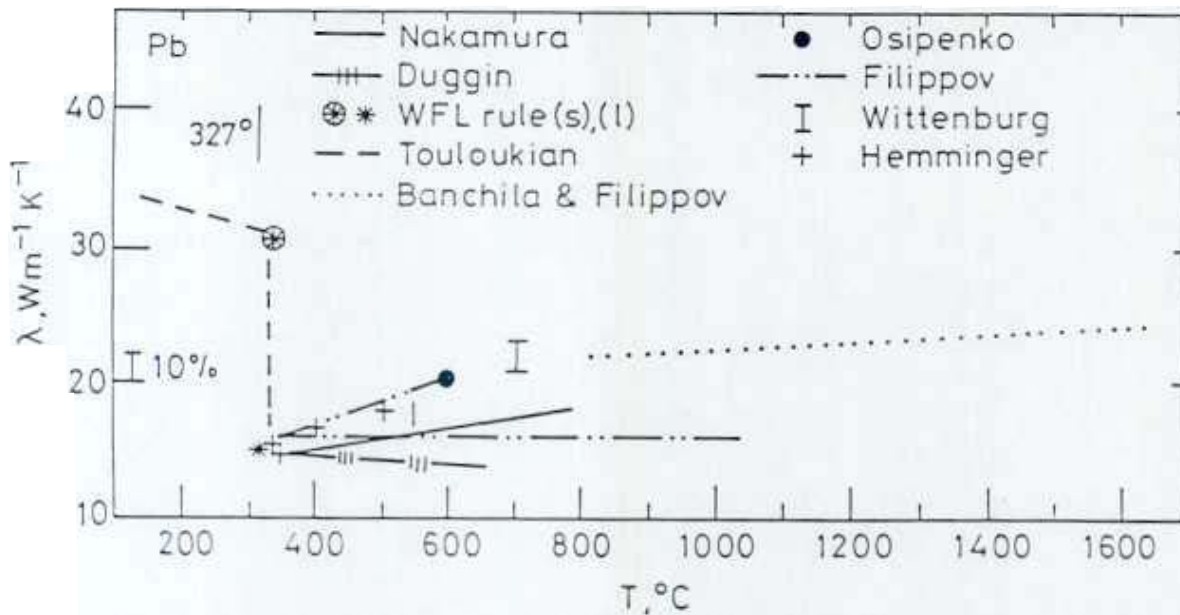


Figure 35 Thermal conductivity of Pb as a function of temperature.

Recommended values:

$$\begin{aligned} \lambda_0^m &= 30 \text{ Wm}^{-1} \text{K}^{-1}; & \lambda_1^m &= 15 \text{ Wm}^{-1} \text{K}^{-1} \\ \lambda_1 &= 15 + 0.75 \times 10^{-2} (T - 327) \text{ Wm}^{-1} \text{K}^{-1} \end{aligned}$$

Pd

The only investigation carried out on liquid Pd is that due to Vlasov et al [55], details are given in Table 26. The results obtained for solid Pd [70] are compared with those obtained by other workers in Figure 36 and it can be seen that any discrepancy in the reported values lies within the combined experimental uncertainty (10%).

Table 26
Details of thermal conductivity ($\text{Wm}^{-1} \text{K}^{-1}$) determinations

Reference	Method	Temperature Range, °C	λ_l^m	10^{-6}	λ_s^m	L/L_o	Comments
Vlasov et al [55]	PTW	500 - 1550	(87)		102 (99)	1.05	Converted from a values]

() denotes values calculated from thermal diffusivity results using recommended ρ [17] and C_p [21] values

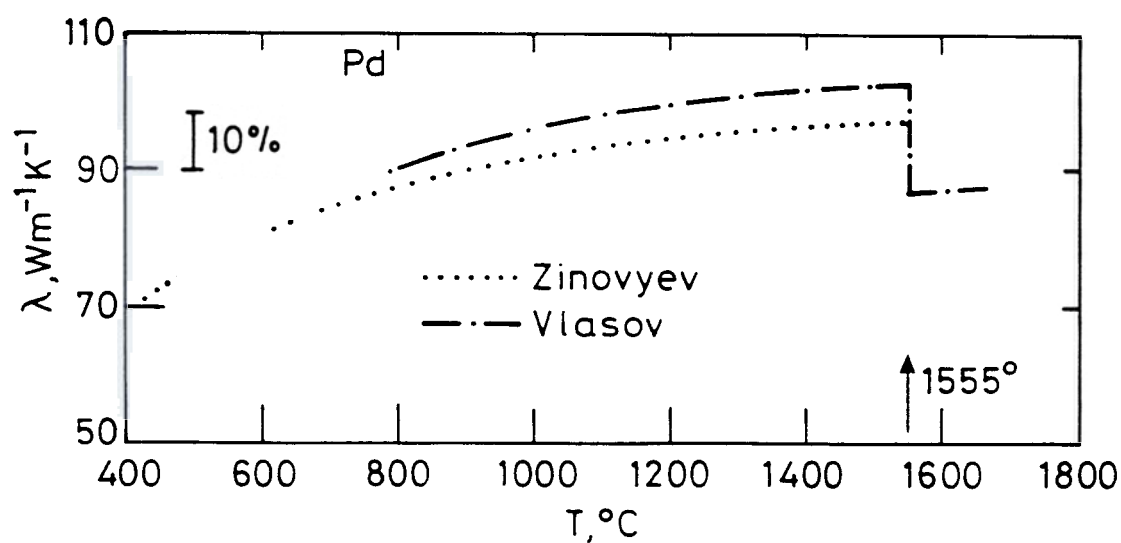


Figure 36 Thermal conductivity of Pd as a function of temperature.

Recommended values:

$$\lambda_s^m = 99 \text{ Wm}^{-1} \text{K}^{-1}; \quad \lambda_l^m = 87 \text{ Wm}^{-1} \text{K}^{-1}$$

Pr

Details of the two investigations are given in Table 27 and the results are plotted in Figure 37. It can be seen that the difference in the results is ca 28% at the melting point and ca 50% at 1230 °C, even though the same technique was used in both investigations.

Table 27
Details of thermal conductivity ($\text{Wm}^{-1} \text{K}^{-1}$) determinations

Reference	Method	Temperature Range, °C	λ_l^m	$10^2 b$	λ_s^m	L/L_o	Comments
Banchila Filippov [71]	RTW	930 - 1230	20.0	0.37			Converted from a values [71]
Mardykin Kashin [72]	RTW	930 - 1730	25.6	1.7		ca 1.0	Converted from a values [72] $(\lambda_{\text{air}}/\lambda_{\text{liq}}) \pm 1.1$ to 1.2

It can also be seen in Figure 37 that the WFL calculations yield values which are close to the mean when using the resistivities cited by Mardykin and Kashin [71]. Mean values have been tentatively adopted.

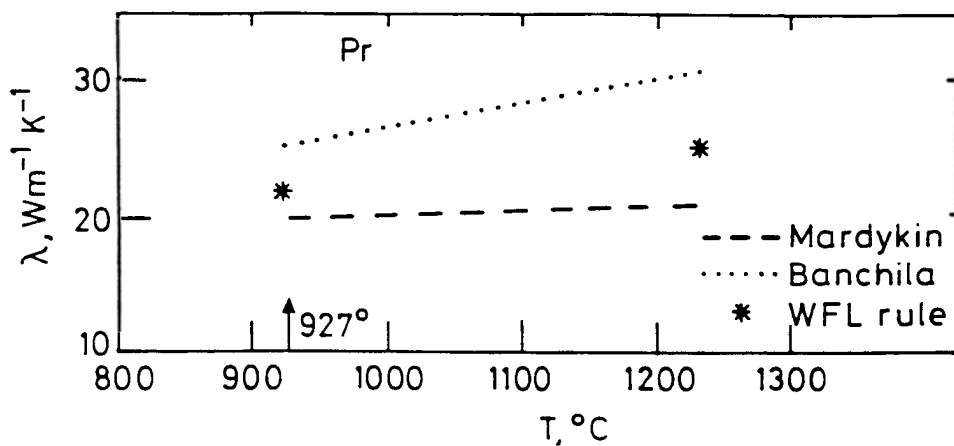


Figure 37 Thermal conductivity of Pr(l) as a function of temperature.

Adopted values:

$$\lambda_l = 22 + 1.4 \times 10^{-2} (T - 931) \text{ Wm}^{-1} \text{K}^{-1}$$

Pt

Only one investigation has been carried out on Pt(l); details are given in Table 28. The solid results of this study are compared in Figure 38 with those obtained by other workers [70]. It can be seen that there is excellent agreement between the results of the various investigations.

Table 28
Details of thermal conductivity ($\text{Wm}^{-1} \text{K}^{-1}$) determinations

Reference	Method	Temperature Range, °C	λ_1^m	$10^2 b$	λ_s^m	L/L_n	Comments
Vlasov et al [55]	PTW	800 - 1800	53		80	1.01	Converted from a values

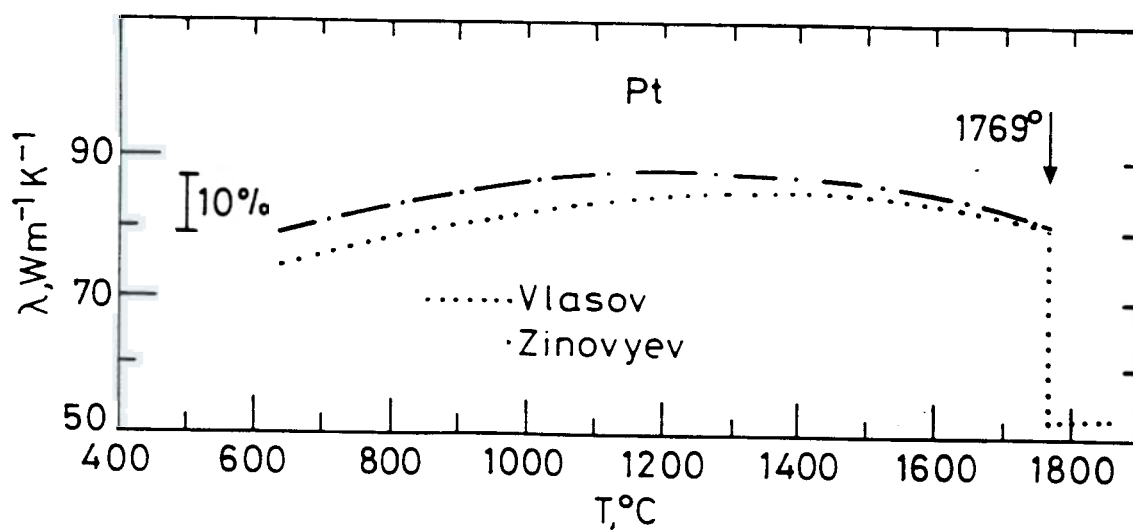


Figure 38 Thermal conductivity of Pt as a function of temperature.

Recommended values:

$\lambda_s^m = 80 \text{ Wm}^{-1} \text{K}^{-1}$	$\lambda_1^m = 53 \text{ Wm}^{-1} \text{K}^{-1}$
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Rb

Only one study on Rb(l) has been reported [73] since the review of Touloukian [1], and the results are shown in Figure 39. It can be seen that the results agree well with the thermal conductivity values calculated from the WFL rule and those recommended by Touloukian et al [1]. The good agreement between Touloukian et al [1] and the WFL rule is misleading. There was no liquid thermal conductivity data for Rb available to Touloukian et al [1] for their review and it is likely that they used the WFL rule to make their recommendations. Details of the investigation are given in Table 29.

Table 29
Details of thermal conductivity ($\text{Wm}^{-1} \text{K}^{-1}$) determinations

Reference	Method	Temperature Range, °C	λ_l^m	$10^2 b$	λ_s^m	L/L_o	Comments
Shpilrain Krainova [73]	AHF	87-788	33.2	-1.9	-	0.94	

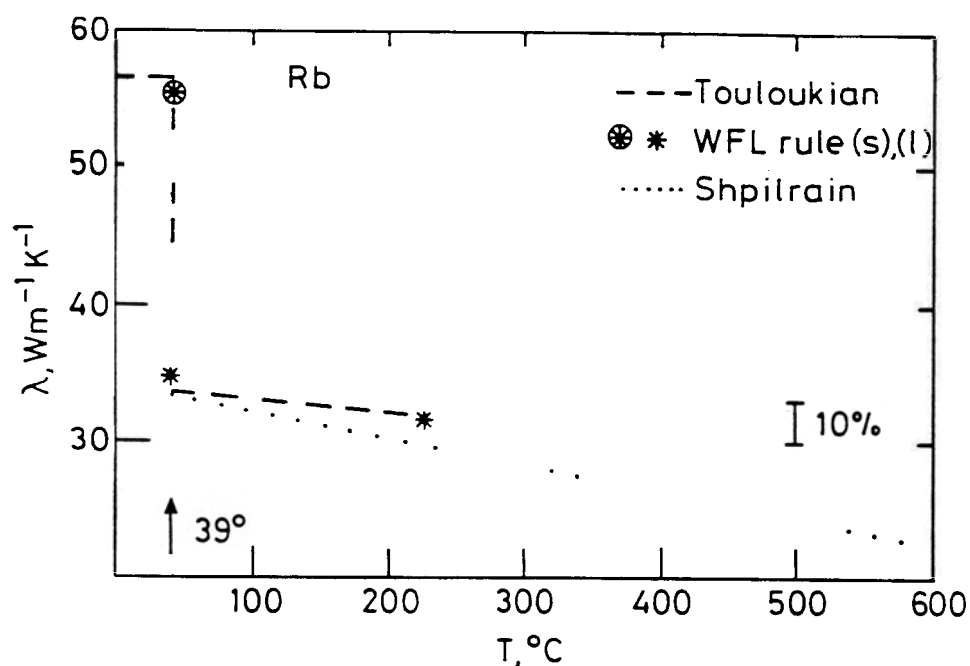


Figure 39 Thermal conductivity of Rb as a function of temperature.

Recommended values:

$$\lambda_s^m = 58 \text{ Wm}^{-1} \text{K}^{-1}; \quad \lambda_l^m = 33.2 \text{ Wm}^{-1} \text{K}^{-1}$$

$$\lambda_l = 33.2 - 1.9 \times 10^{-2} (T - 39) \text{ Wm}^{-1} \text{K}^{-1}$$

Re

Only one investigation has reported values for the thermal diffusivity of Re(l) in the melting range. Details of this study are given in Table 30. The results for solid Re are compared with those obtained in other investigations in Figure 40. It can be seen that when allowance is made for differences in sample purity and the orientation of the sample, the reported values are in reasonable agreement.

Table 30

Details of thermal conductivity ($\text{Wm}^{-1} \text{K}^{-1}$) determination

Reference	Method	Temperature Range, °C	λ_l^m	$10^2 b$	λ_s^m	L/L_o	Comments
Vlasov et al [74]	PTW	1330-3200	55		63.5		Converted from a values

Vlasov et al [74] were unable to convert thermal diffusivity into thermal conductivity for temperatures $> 2130^\circ\text{C}$ due to absence of C_p data in this temperature range. Thermal conductivity values were calculated using the C_p values of 42.5 and $50 \text{ Jmol}^{-1} \text{K}^{-1}$ for solid and liquid phases [21], respectively and $\rho = 18700 \text{ kg m}^{-3}$ [88]. It can be seen from Figure 40 that the λ_l^m value obtained is lower than the WFL value obtained by Vlasov et al [74].

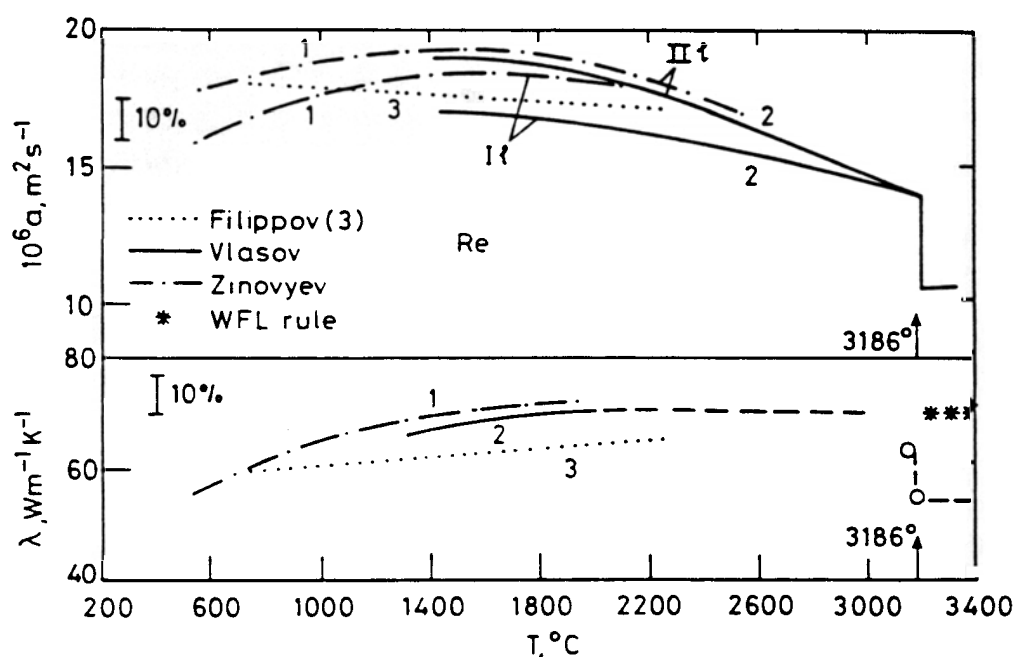


Figure 40 (i) for thermal diffusivity (a) and (ii) thermal conductivity (λ) of Re as a function of temperature; O denotes λ value calculated from the values of ' a ' reported by Vlasov.

Recommended values:

$a_l^m = 14 \text{ m}^2 \text{s}^{-1}$	$a_l^m = 11 \text{ m}^2 \text{s}^{-1}$
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Rh

Details of the only investigation carried out on liquid Rh are given in Table 31 and the results for the solid phase are compared with other high temperature studies [6,76] in Figure 41. It can be seen that:

- (i) that the results of the various studies on the solid diverge by up to 15%
- (ii) that values of λ_1^m and λ_s^m calculated from the thermal diffusivity using recommended values of ρ and C_p [21] are 20% higher than those reported by Vlasov et al [55].

The latter is probably due to the C_p values used by Vlasov et al in the calculations, this may also account for some of the divergence in the solid phase values of λ .

Table 31
Details of thermal conductivity ($\text{Wm}^{-1}\text{K}^{-1}$) determinations

Reference	Method	Temp Range, °C	λ_1^m	$10^3 b$	λ_s^m	L/L_0	Comment
Vlasov et al [55]	PTW	700-2300	57 (69)	-	90 (110)	0.96	Converted from a values [55]

() denotes values calculated from thermal diffusivity results using recommended ρ [17] and C_p [21] values

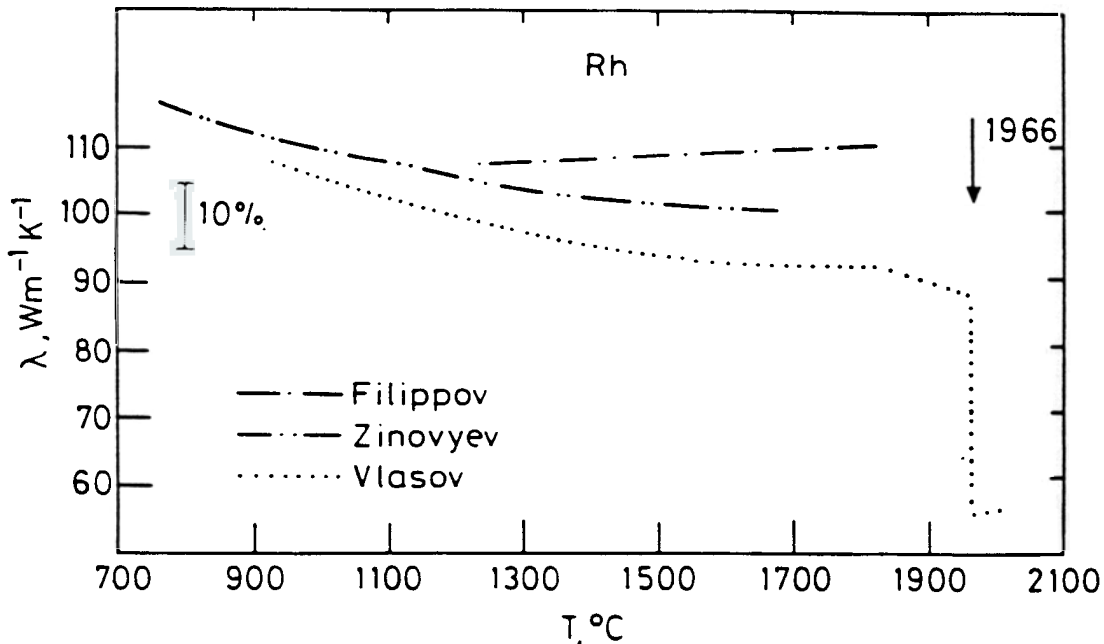


Figure 41 Thermal conductivity of Rh as a function of temperature

The recommended values of λ_m^s and λ_1^m are these based on (i) the thermal diffusivity measurements of Vlasov et al and (ii) the recommended values for ρ and C_p .

$$\lambda_s^m = 110 \text{ Wm}^{-1} \text{K}^{-1}; \quad \lambda_1^m = 69 \text{ Wm}^{-1} \text{K}^{-1}$$

Sb

Details of the thermal conductivity measurements on Sb(l) are outlined in Table 32 and the results are given in Figure 42.

Table 32
Details of thermal conductivity ($\text{Wm}^{-1}\text{K}^{-1}$) determinations

Reference	Method	Temp Range. °C	λ_l^m	$10^{-2}b$	λ_s^m	L/L_o	Comment
Filippov [6]	RTW	900-1200	20*	0			Converted from a values [6]

* Extrapolated value

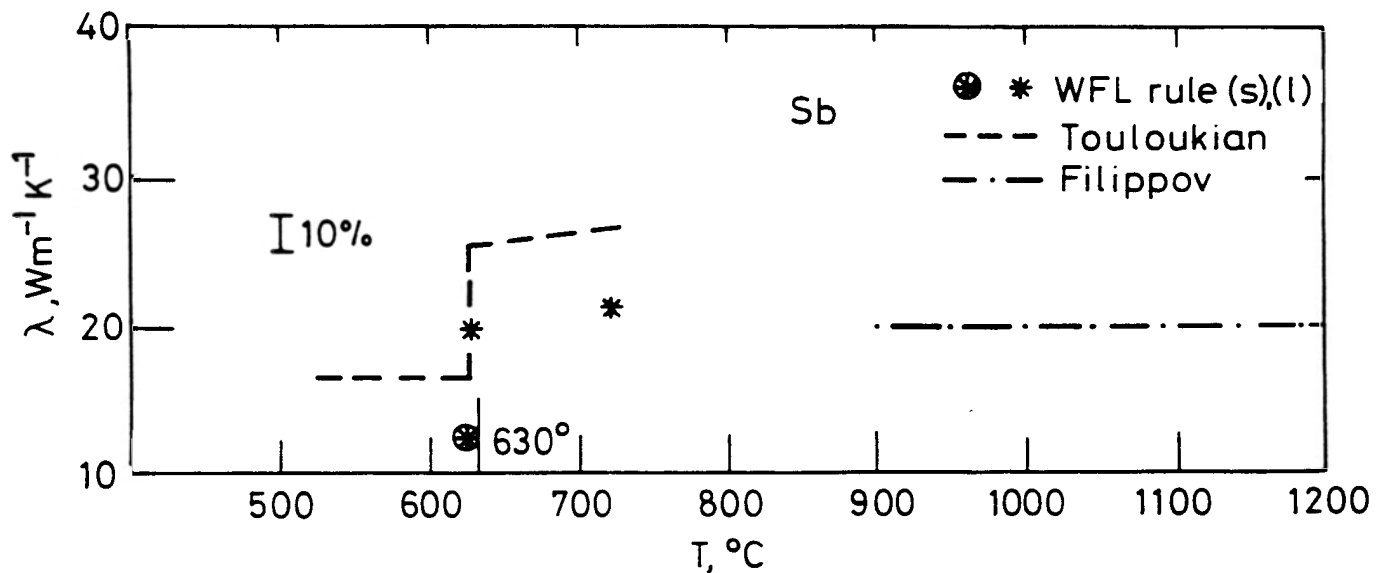


Figure 42 Thermal conductivity of Sb as a function of temperature

Recommended values:

$$\lambda_s^m = 17 \text{ Wm}^{-1}\text{K}^{-1}; \quad \lambda_l^m = 26 \text{ Wm}^{-1}\text{K}^{-1}$$

$$\lambda_l = 26 + 1 \times 10^{-2}(T - 630) \text{ Wm}^{-1}\text{K}^{-1}$$

Sc

Only one investigation has reported values for the thermal conductivity of Sc(l). Details of this study are outlined in Table 33 and the values are given in Figure 43. The results for Sc(s) are compared with those reported in a previous study by Zinovyev [27].

Table 33
Details of thermal conductivity ($\text{Wm}^{-1}\text{K}^{-1}$) determinations

Reference	Method	Temp Range, °C	λ_l^m	10^2b	λ_s^m	L/L_o	Comment
Zinovyev et al [7]	RTW	700-1600	28.5		24.5	-1.0	Converted from a values [7]

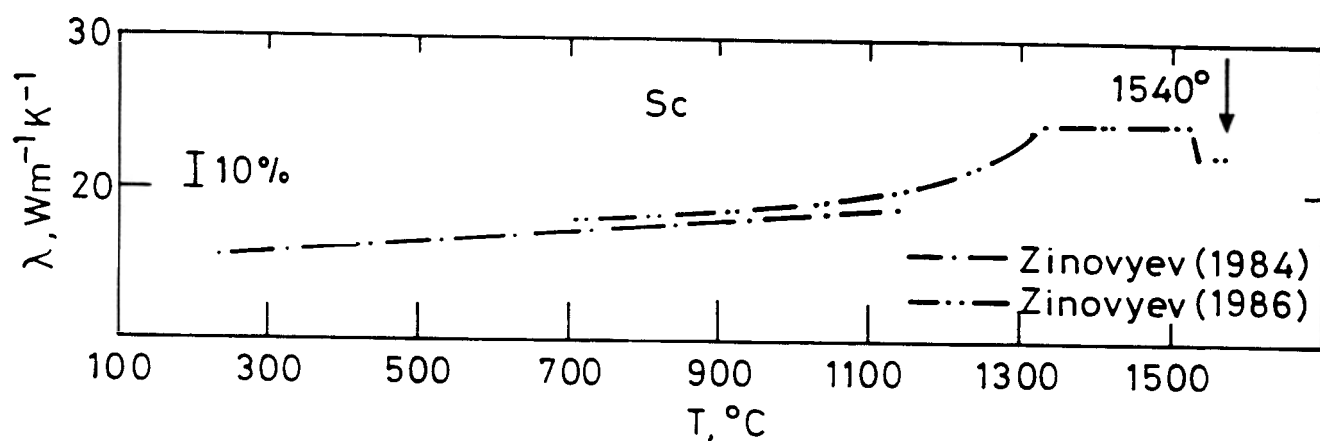


Figure 43 Thermal conductivity of Sc as a function of temperature

Recommended values:

$$\lambda_s^m = 24.5 \text{ Wm}^{-1}\text{K}^{-1} \quad \lambda_l^m = 22.5 \text{ Wm}^{-1}\text{K}^{-1}$$

Si

Details of the two investigations are given in Table 34 and the results are shown in Figure 44. The value reported by Yamamoto et al [77] is in good agreement with those calculated from electrical resistivities by the WFL rule.

Table 34
Details of thermal conductivity ($\text{Wm}^{-1}\text{K}^{-1}$) determinations

Reference	Method	Temp Range, °C	λ_l^m	$10^3 b$	λ_s^m	L/L_0	Comment
Yamamoto et al [77]	LP	25-1450	56	26			Converted from a values, SiC cell used

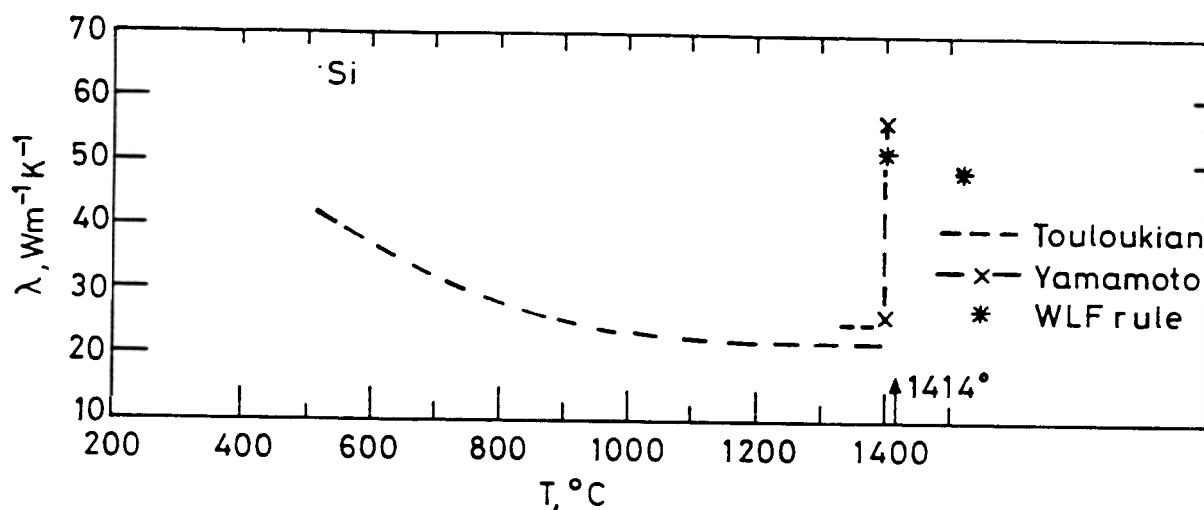


Figure 44 Thermal conductivity of Si as a function of temperature

Recommended values:

$$\lambda_s^m = 25 \text{ Wm}^{-1}\text{K}^{-1}; \quad \lambda_l^m = 56 \text{ Wm}^{-1}\text{K}^{-1}$$

Sn

Details of the various investigations are given in Table 35 and the results are shown in Figure 45.

Table 35
Details of thermal conductivity ($\text{Wm}^{-1}\text{K}^{-1}$) determinations

Reference	Method	Temp Range, °C	λ_1^m	10^2b	λ_s^m	L/L_0	Comment
Otter, Arles [78]	LP	1000-1800	38.6*	1.308		1.02*	*at 1000°C, Converted from a values [78]
Banchila, Filippov [16]	RTW	850-1700	33*	2.0			$\lambda_{900} = 41 \text{ Wm}^{-1}\text{K}^{-1}$
Filippov [6]	RTW	500-1300	28		57		Converted from a values [6]
Osipenko [50]	PP	100-600	30		60		
Hemminger [5]	PP	230-500	27	2.6	59.5	1.05	
Zinovyev et al [15]	PTW	450-800	27	0	56		Converted from a values [15]

* Extrapolated value

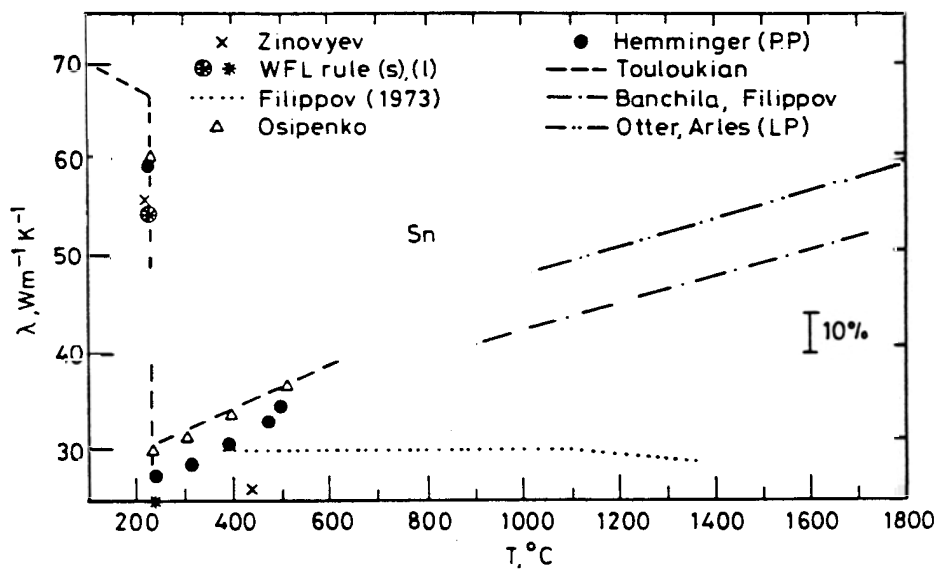


Figure45 Thermal conductivity of Sn as a function of temperature

Recommended values:

$$\lambda_l^m = 27 \text{ Wm}^{-1}\text{K}^{-1}$$

$$\lambda_l = 27 + 2 \times 10^{-2}(T - 232) \text{ Wm}^{-1}\text{K}^{-1}$$

Ta

Only one investigation has reported values for the thermal conductivity of liquid Ta, experimental details are outlined in Table 36. The results for the solid phase are compared with those reported by Filippov [6]. In Figure 46 it can be seen that the results of the various studies lie within the combined uncertainty (10%) of the experimental methods. Taluts et al [63] suggested that the peak which occurs in conductivity just below the melting point may be due to the diffusion of vacancies. Thermal conductivity values were derived from the WFL relationship using both the resistivity values reported by Gallop et al [67] and Desai et al [42]. It can be seen from Figure 46 that latter values are consistent with the measurements of Taluts et al.

Table 36
Details of thermal conductivity ($\text{Wm}^{-1} \text{K}^{-1}$) determinations

References	Method	Temperature Range, °C	λ_l^m	$10^2 b$	λ_s^m	L/L_0	Comment
Taluts et al [63,66]	PTW	730-3000 °C	58	-	70	1.0	Converted from a values [63,66]

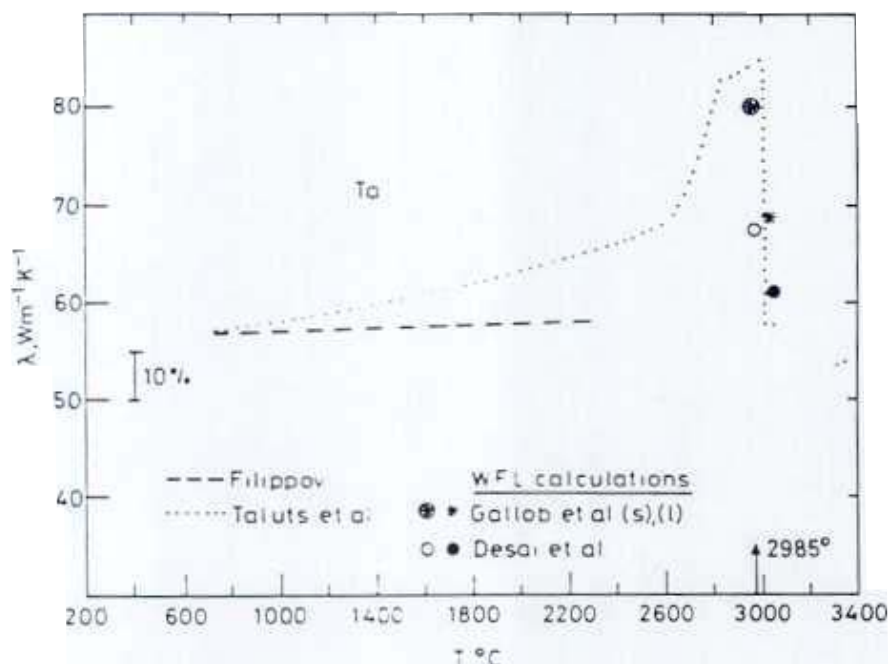


Figure 46 Thermal conductivity of Ta as a function of temperature

Recommended values

$$\lambda_s^m = 70 \text{ Wm}^{-1}\text{K}^{-1}; \quad \lambda_l^m = 58 \text{ Wm}^{-1}\text{K}^{-1}$$

Ti

Three investigations (all from the same laboratory) have measured thermal conductivities of liquid Ti. Details of the study are given in Table 37 and the results for the solid state are compared with those reported in other studies [6,27] in Figure 47. It can be seen that the discrepancy in the results does not exceed the combined uncertainty (10%) of the experimental methods. The most recent study indicated a slightly higher conductivity for the liquid than in the solid phase close to the melting point. The values derived from the WFL rule using the electrical resistivities reported by Seydel and Fücke [82] were lower ($\lambda_l^m = 28.4 \text{ Wm}^{-1}\text{K}^{-1}$) and showed a slight decrease in λ on melting.

Table 37
Details of thermal conductivity ($\text{Wm}^{-1}\text{K}^{-1}$) determinations

References	Method	Temperature Range, °C	λ_l^m	$10^2 b$	λ_s^m	L/L_o	Comment
Geld et al [80]	PTW	1170-1730	30		30		Converted from a values [80]
Polev et al [81]	PTW	830-1690					Thermal diffusivity results only
Zinovyev et al [7]	PTW	730-1740	34		30	0.90	Converted from a values [7]

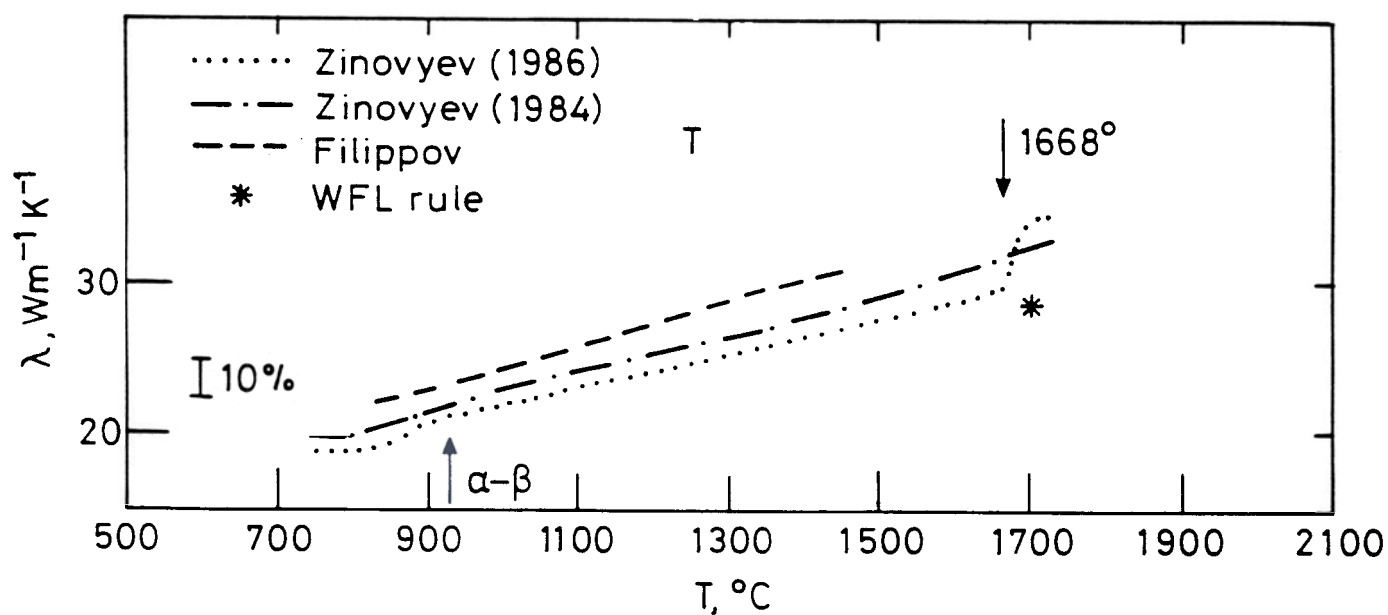


Figure 47 Thermal conductivity of Ti as a function of temperature

Recommended values:

$$\lambda_s^m = 31 \text{ Wm}^{-1}\text{K}^{-1}; \quad \lambda_l^m = 31 \text{ Wm}^{-1}\text{K}^{-1}$$

V

Only one investigation has reported thermal conductivity values for V(l). Details of this study are outlined in Table 38 and the results for the solid phase are compared with those reported by Filippov [6] in Figure 48. The discrepancies between the various investigations are roughly compatible with the combined experimental uncertainties (10%). Zinovyev et al [63, 66] have suggested that the peak in thermal conductivity just below the melting point was caused by the diffusion of vacancies (an equivalent peak did not occur in resistivity - temperature curve). This can be seen in Figure 47 where thermal conductivities have been calculated using the WFL rule and the electrical resistivity recommended by Desai et al [99]. These values were found to be in good agreement with the experimental values for λ_s .

Table 38

Details of thermal conductivity ($\text{Wm}^{-1}\text{K}^{-1}$) determinations

References	Method	Temperature Range, °C	λ_l^m	$10^3 b$	λ_s^m	L/L_0	Comment
Filippov [6]	RTW	827-1627					Converted from a values [16]
Zinovyev et al [7, 63, 76]	PTW	730-1980	43.5	-	51	0.98	Converted from a values [7,63,76]

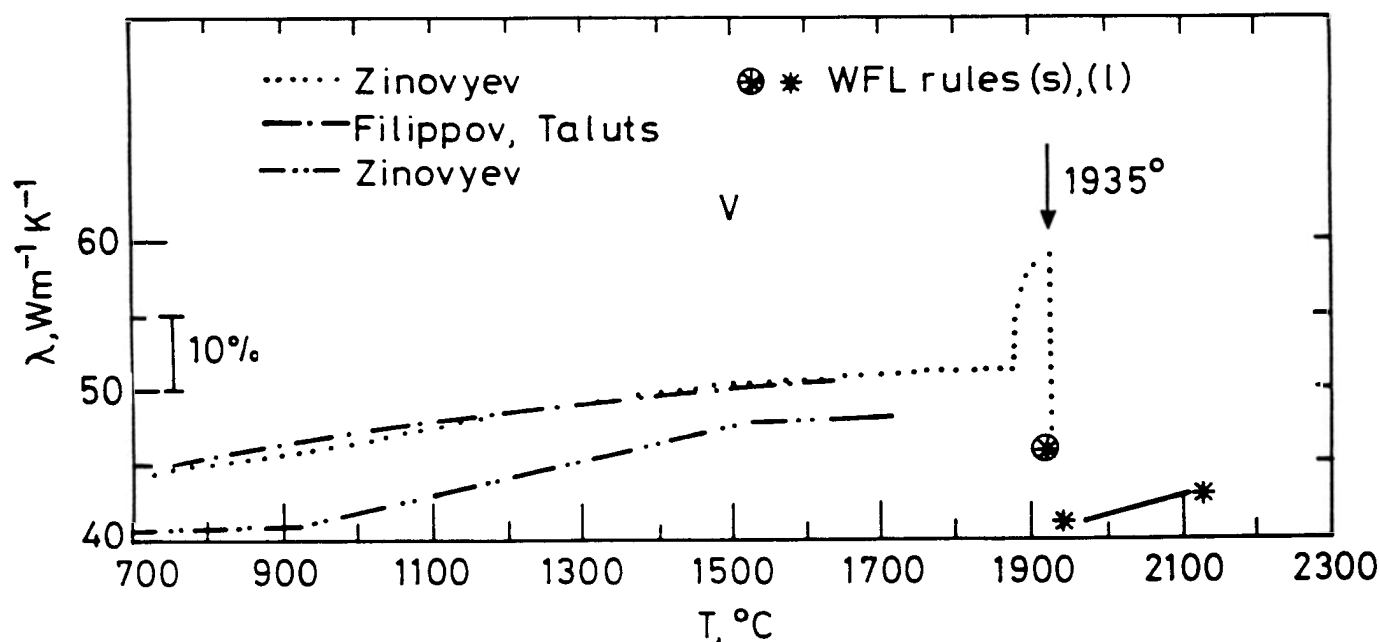


Figure 48 Thermal conductivity of V as a function of temperature.

Recommended values:

$$\lambda_s^m = 51 \text{ Wm}^{-1}\text{K}^{-1}; \quad \lambda_l^m = 43.5 \text{ Wm}^{-1}\text{K}^{-1}$$

W

Only one investigation has reported values for the liquid phase. Details are given in Table 39 and the results for the solid phase are compared in Figure 49 with those reported in other studies [6, 84]. It can be seen that the thermal conductivities for the solid lie within the combined uncertainties of the experiments (10%). Thermal conductivities were calculated using the WFL rule and the electrical resistivity data recommended by Desai et al [47]; values of $\lambda_s^m = 74$ and $\lambda_l^m = 68 \text{ Wm}^{-1}\text{K}^{-1}$ were derived, the latter being in good agreement with the measured value.

Table 39
Details of thermal conductivity ($\text{Wm}^{-1}\text{K}^{-1}$) determinations

References	Method	Temperature Range, °C	λ_l^m	$10^2 b$	λ_s^m	L/L_o	Comment
Taluts et al [63]	PTW	730-3430	63.2		95*	0.98	Converted from a values [63]

* extrapolated value

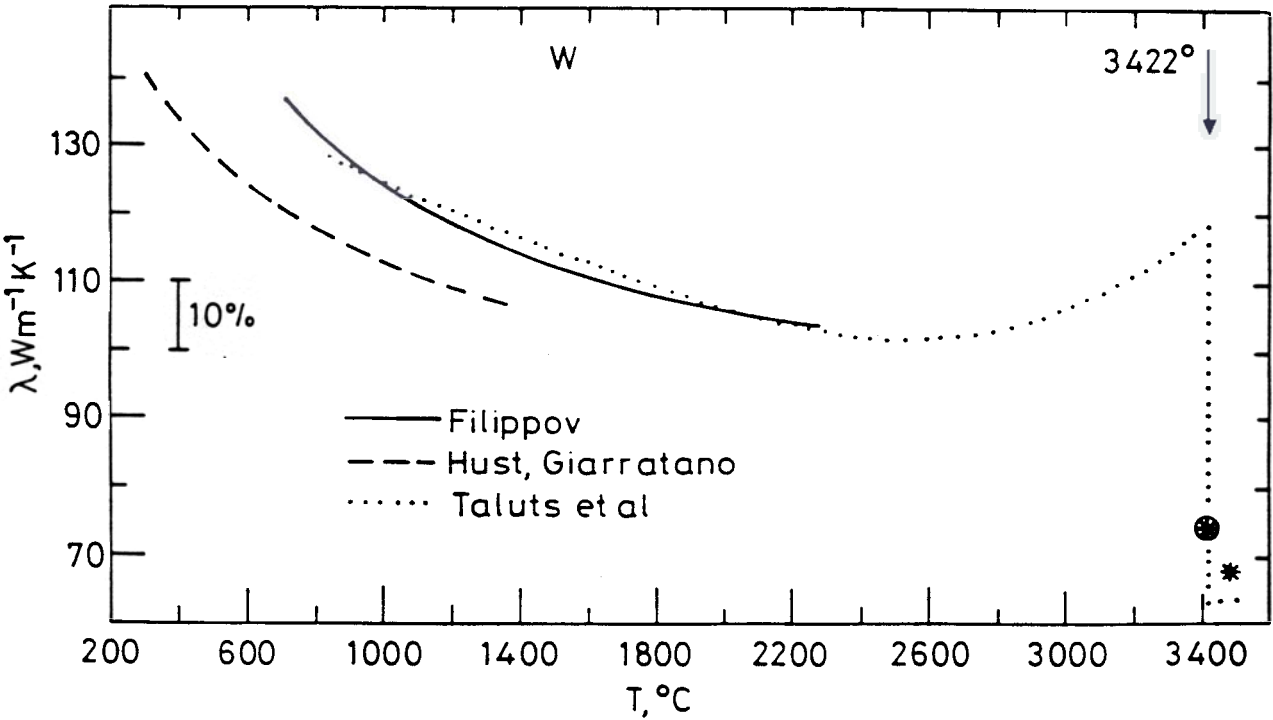


Figure 49 Thermal conductivity of W as a function of temperature

Recommended values:

$\lambda_s^m = 95 \text{ Wm}^{-1}\text{K}^{-1}; \quad \lambda_l^m = 63 \text{ Wm}^{-1}\text{K}^{-1}$

Zn

Details of the recent thermal conductivity measurements on Zn(l) are summarised in Table 40 and the results are shown in Figure 50.

Table 40
Details of thermal conductivity ($\text{Wm}^{-1}\text{K}^{-1}$) determinations

References	Method	Temperature Range, °C	λ_l^m	10^2b	λ_s^m	L/L_o	Comment
Magmedov [36]		0-500		4	91		

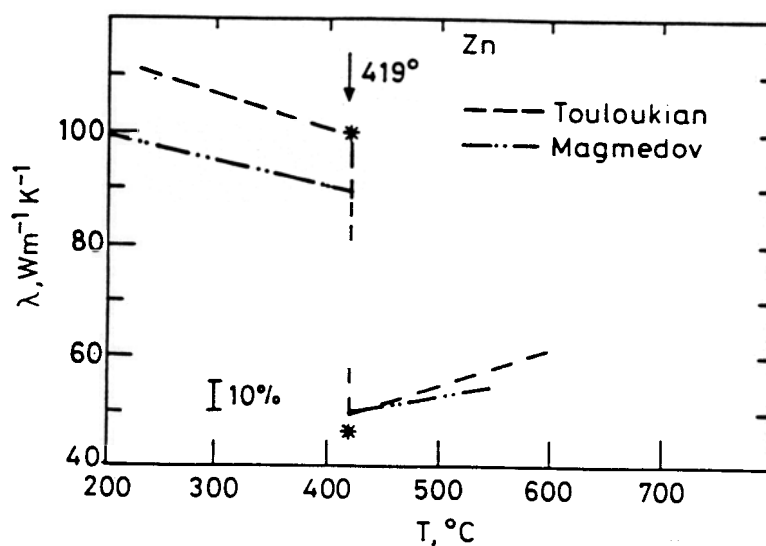


Figure 50 Thermal conductivity of Zn as a function of temperature

Recommended values:

$$\lambda_s^m = 90 \text{ Wm}^{-1}\text{K}^{-1}; \quad \lambda_l^m = 50 \text{ Wm}^{-1}\text{K}^{-1}$$

$$\lambda_l = 50 + 6 \times 10^{-2}(T-419) \text{ Wm}^{-1}\text{K}^{-1}$$

Zr

The details of the only high temperature investigation are given in Table 41 and the results are shown in Figure 51. No data have been reported for the liquid phase but Desai et al [83] and Korobenko and Savinskii [86] have reported electrical resistivity data from which values of 39.5 and 37.7 $\text{Wm}^{-1}\text{K}^{-1}$ respectively for λ_s^m , and $\lambda_l^m = 36.5 \text{ Wm}^{-1}\text{K}^{-1}$ were calculated using the WFL relationship. The values for λ_s^m are in excellent agreement with that derived by extrapolating the α -(T) relationship reported by Filippov [6].

Table 41
Details of thermal conductivity ($\text{Wm}^{-1}\text{K}^{-1}$) determinations

References	Method	Temperature Range, °C	λ_l^m	$10^3 b$	λ_s^m	L/L_0	Comment
Filippov [6]	RTW	830-1830			37.5*		Converted from α values [6]

* Extrapolated value

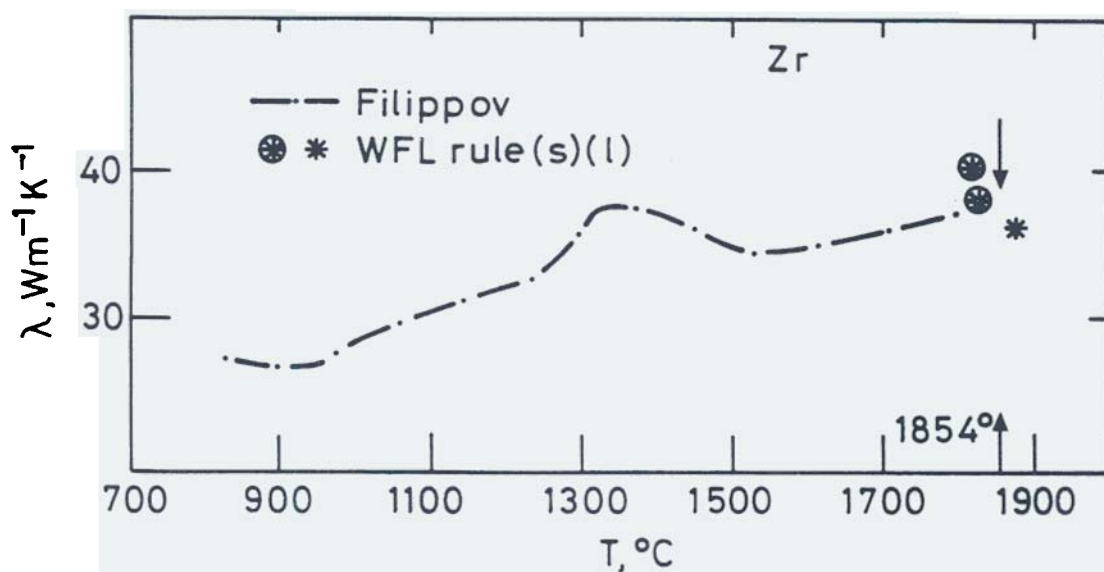


Figure 51 Thermal conductivity of Zr as a function of temperature

Recommended values:

$$\lambda_s^m = 38 \text{ Wm}^{-1}\text{K}^{-1}; \quad \lambda_l^m = 36.5 \text{ Wm}^{-1}\text{K}^{-1}$$

6 SUMMARY OF RESULTS

Table 42

Summary of Thermal Conductivities and Lorenz Ratios at Melting Points For Pure Metals

	T^m (K)	λ_t^m ($W^3m^{-1} K^{-1}$)	λ_l^m ($W^3m^{-1} K^{-1}$)	$10^2 b$ ($Wm^{-1}K^{-2}$)	(L^m/L_o^m)	
					solid	liquid
Ag	1235	363	175	4.3	1.0	1.0
Al	933	211	91	0.34	1.0	1.0
Au	1090	247	105	3.0	1.0	1.0
Bi	545	7.6	12	1.0	1.0	1.2
Cd	594	41	93	3.3	1.07	1.0
Ce	1072	-	22	1.25	-	1.0
Co	1768	45	36	-	1.07	-
Cr	2180	45	35	-	-	-
Cs	302	35.9	20	0.27	1.05	1.0
Cu	1358	330	163	2.67	1.0	1.0
Fe	1811	34	33	-	0.95	1.06
Ga	303	-	28	4.5	-	1.0
Gd	1585	19	19	1.9	-	-
Ge	1211	15	39	-	-	-
Hf	2506	39	-	-	-	-
Hg	234	-	-	-	-	-
In	430	76	38	0.9	1.1	1.1
Ir	2719	95	76	-	-	-
K	337	98.5	56	-3.8	1	0.9
La	1193	-	17	0.5	-	-
Li	454	71	43	2	-	-
Mg	923	145	79	7	-	-
Mn	1519	24	22	-	1.0	-
Mo	2896	87	72	-	1.0	1.0
Na	371	120	88	-5	-	-
Nb	2750	78	62	-	-	-
Nd	1289	-	18.4	0.53	-	-
Ni	1728	70	60	-	1.0	1.09
Pb	601	30	15	0.75	1.0	1.0
Pd	1828	99	87	-	-	-
Pr	1204	-	22	1.4	0.91	-
Pt	2042	80	53	-	-	-
Rb	312	58	33.2	-1.9	-	0.96
Re	3459	65+/-5	55	-	-	-
Rh	2237	110	69	-	-	-
Sb	904	17	26	1.0	-	1.5
Sc	1814	24.5	22.5	-	-	-
Si	1687	25	56	-	-	-
Sn	505	-	27	2	-	1.05
Ta	3290	70	58	-	-	-
Ti	1941	31	31	-	-	1.1
V	2183	51	43.5	-	-	1.0
W	3695	95	63	-	-	0.98
Zn	693	90	50	6	0.90	1.04
Zr	2128	38	36.5	-	-	-

7 CONCLUSIONS

- 1 Experimental values have been reported for the thermal conductivities of most liquid metals, including the high melting metals such as W and Ta.
2. The results obtained by Zinovyev et al and Filippov et al for high temperature measurements using the plane and radial temperature wave methods, respectively, would appear to be accurate within 10%.
3. For some metals, such as Re, the absence or uncertainties in data for the C_p and/or the density at high temperatures lead to large uncertainties in the thermal conductivity values derived from thermal diffusivity measurements.
- 4 In one or two systems, eg Fe and Ti, the thermal conductivities measured for the liquid are higher than that for the solid (λ_s^m), this may indicate a convective contribution to the measured thermal diffusivity since the WFL rule calculations show $\lambda_s^m > \lambda_l^m$.
5. For all metals, the values of λ_l^m and λ_s^m derived from the WFL rule were always within the combined uncertainty associated with thermal conductivity ($>\pm 5\%$) and electrical resistivity ($\pm 3\%$) measurements. This indicates that the conduction mechanism is predominantly electronic in the region of the melting point and suggests that WFL values for λ_l^m are accurate to $<\pm 10\%$.

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