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in Science and Technology**

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**Metals: Electronic
Transport Phenomena**

Subvolume a



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LANDOLT-BÖRNSTEIN

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in Science and Technology

New Series

Editor in Chief: K.-H. Hellwege

Group III: Crystal and Solid State Physics

Volume 15

Metals: Electronic

Transport Phenomena

Subvolume a

J. Bass · K.H. Fischer

Editors: K.-H. Hellwege and J.L. Olsen



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Vorwort

Diese Zusammenstellung von Tabellen und Diagrammen ist ein Teil eines Programms, das eine vollständige und kritische Sammlung der zuverlässigen Daten aus der Metallphysik anstrebt. Da eine vollständige derartige Zusammenstellung noch nicht existiert, sollen diese Daten einem echten Bedürfnis sowohl von Experimentatoren wie von Theoretikern entgegenkommen.

Die Gruppe III in der Neuen Serie des Landolt-Börnstein-Tabellenwerkes ist der Kristall- und Festkörper-Physik gewidmet. Der Band III/15, zu dem der hier vorgelegte Teilband 15a gehört, wird alle bis 1981 publizierten Ergebnisse über elektrische Transportphänomene in Metallen berücksichtigen. Sowohl experimentell wie auch theoretisch gewonnene Daten sind aufgenommen.

Um die Publikationen zu beschleunigen, werden die Beiträge der verschiedenen Autoren in den beiden Teilbänden 15a und 15b zum Druck gegeben, sobald die Manuskripte fertiggestellt sind. Die Tabellen erscheinen somit in chronologischer statt in thematischer Reihenfolge. Eine systematische Übersicht ist im vorderen Buchdeckel abgedruckt.

Dieser Teilband enthält zwei Hauptbeiträge: einen über die elektrische Leitfähigkeit in reinen Metallen und verdünnten Legierungen, und einen über die elektrischen Transport- und thermodynamischen Eigenschaften von Kondo- und Spinfluktuations-Systemen sowie Spingläsern. Ferner behandelt ein kurzer Beitrag den Einfluß der Dicke von Drähten und Folien auf die Thermokraft.

Im allgemeinen wird die in der Literatur gebräuchliche Nomenklatur einschließlich der Symbole auch in den Tabellen verwendet; wegen Einzelheiten sei der Leser auf die Einführungen zu den verschiedenen Beiträgen verwiesen.

Unser besonderer Dank gilt den Autoren, die sich der großen und äußerst mühevollen Aufgabe unterzogen haben, die Daten für diesen Teilband zu sammeln und in Tabellen und Abbildungen kritisch aufzuarbeiten. Wir sind überzeugt, daß ihr Beitrag von hohem Wert für die Physik sein wird, und wir hoffen, daß die Autoren hierin den Lohn für ihre harte und sorgfältige Arbeit finden werden.

Unser Dank gilt auch der Landolt-Börnstein-Redaktion, insbesondere Herrn Dr. H. Seemüller für die redaktionelle Betreuung dieses Teilbandes, sowie Frau D. Dolle und Frau H. Weise für die sorgfältige Überprüfung der Manuskripte und Druckfahnen.

Dem Springer-Verlag danken wir für die verständnisvolle Zusammenarbeit bei der Fertigstellung.

Wie alle anderen Landolt-Börnstein-Bände wird auch dieser Teilband ohne Zuschüsse von anderer Seite publiziert.

Darmstadt und Zürich, September 1982

Die Herausgeber

Preface

The present collection of tables and diagrams is part of a programme aiming at a complete and critical tabulation of reliable data relevant to metal physics. No such complete collection exists elsewhere, so that these tables should fill a real need of both experimental and theoretical physicists.

Group III in the New Series of the Landolt-Börnstein tables deals with Crystal and Solid State Physics. Volume III/15, to which this subvolume 15a belongs, will cover data published up to 1981 on electrical transport in metals. Both experimental and theoretical results are included.

To hasten publication, the compilations in the subvolumes 15a and 15b are being printed as each author completes his manuscript. The order of the tables is thus chronological rather than thematic. A systematic survey is given on the inside cover.

This subvolume contains two main collections: one of electrical resistivity of pure metals and dilute alloys, and the other of electrical transport and thermodynamic properties of Kondo and spinfluctuation systems, and spin glasses. A brief contribution on size effects in the thermopower is also included.

In general, symbols and nomenclature are those used in the literature, but the reader is referred to the separate contributions for detailed information.

Our most grateful thanks are due to the authors for taking on the great and very laborious task of collecting the data and critically preparing the tables in this subvolume. We are confident that their contribution will be of great value to the physics community, and we hope that the authors will find in this their reward for their hard and careful work.

Thanks are also due to the editorial staff of Landolt-Börnstein, especially to Dr. H. See-müller who was in charge of the editorial preparation of this subvolume, and to Frau D. Dolle and Frau H. Weise, for their careful checking of the manuscripts and galleys.

We are also grateful to the Springer Verlag for their patient care and experienced help in the final preparation.

As in the case of other Landolt-Börnstein volumes, this subvolume is published without outside financial support to the publishers.

Darmstadt and Zürich, September 1982

The Editors

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1 Electrical resistivity of pure metals and dilute alloys

1.1 Introduction

1.1.1 General remarks

The electrical resistance R of a metallic wire is determined by passing a current I through the wire and measuring the potential difference U generated across a length l . R is then given by Ohm's law,

$$R = \frac{U}{I}. \quad (1)$$

The intrinsic resistivity ϱ of the metal is given by

$$\varrho = \frac{RA}{l}, \quad (2)$$

where A is the uniform cross-sectional area of the wire.

To determine the resistivity of a metal at temperature T it is thus necessary to know R , A , and l , all at T . A and l , however, are normally measured only at a reference temperature T_r , usually room temperature or 0°C (273.15 K). Two alternative "resistivities" can then be defined experimentally. These will be designated by the symbols

$$\varrho(T) = \frac{R(T)A(T_r)}{l(T_r)} = \frac{R(T)}{R(T_r)} \cdot \varrho(T_r), \quad (3a)$$

and

$$\varrho^+(T) = \frac{R(T)A(T)}{l(T)}. \quad (3b)$$

$\varrho^+(T)$ is determined by correcting the ratio $A(T_r)/l(T_r)$ to $A(T)/l(T)$ using the thermal expansion coefficient of the metal. In these tables, resistivities are listed in the form chosen by the original investigator; this is usually $\varrho(T)$.

At very low temperatures (e.g. $T \lesssim 4.2\text{ K}$), the resistivity of a metallic sample which does not become superconducting usually becomes independent of temperature. The magnitude of this resistivity is determined by the number of residual impurities in the metal, and the resistivity is thus called the "residual resistivity" and is designated by ϱ_0 , or by $\varrho_0(c)$, where c is a measure of the impurity concentration. For small impurity concentrations, the residual resistivity should be linearly proportional to the impurity concentration

$$\varrho_0(c) \propto c. \quad (4)$$

It is thus useful to know the values of $\varrho_0(c)/c$ (usually designated hereafter by the alternative symbol $\Delta\varrho/c$) for given impurities in given host metals. A table of such experimentally determined values is given below.

If a sample is sufficiently thin, sufficiently pure, and at sufficiently low temperature, then the mean-free-path of the electrons in the metal can become comparable to the sample thickness. In such a case, the residual resistivity will contain a contribution from surface scattering (size-effects). Information about such effects is also given below.

As the temperature of the metal is raised above the residual regime, the resistivity of the sample usually increases (exceptions include magnetic alloys such as Kondo alloys – see the article by K. H. Fischer, Chap. 2 in this volume), as entities other than just residual impurities and the sample surface begin to scatter the electrons.

At the lowest such temperatures, one expects to see a contribution from electron-electron scattering, which should vary as T^2 . Such contributions have definitely been observed in several transition metals, and very recently probably also in simple metals such as Al, the noble metals, and K.

At slightly higher temperatures, the scattering of electrons by phonons (quantized lattice vibrations) begins to become important, and as the temperature rises above 10...20 K this contribution usually becomes dominant in relative pure metals. In fact, it is the electron-phonon contribution to $\varrho(T)$ which is normally meant when one refers to the intrinsic (or ideal) resistivity of a metal. At high temperatures, $\varrho_{\text{el-ph}}$, the electron-phonon contribution to $\varrho(T)$ increases approximately linearly with T for many metals. The simplest model which yields such behaviour is the Bloch-Grüneisen (B.G.) model. This model neglects electron-phonon Umklapp scattering (scattering in which a reciprocal lattice vector participates), and assumes a metal with a spherical Fermi surface and a Debye phonon spectrum characterized by a Debye temperature Θ_D . Experimentally, Θ_D ranges from about 40 K for Cs to about 1100 K for Be, with the values for most metals lying between 150 K and 450 K.

Because of the simplifying assumptions it contains, the B.G. model is not exact for any real metal. However, treating Θ_D as an adjustable parameter, it provides a useful equation for approximate fits to experimental data for many metals over a wide temperature range. The equation resulting from the B.G. model is

$$\varrho_{\text{B.G.}}(T) = K \left(\frac{T}{\Theta_D} \right)^5 \int_0^{\Theta_D/T} \frac{z^5 dz}{(e^z - 1)(1 - e^{-z})} = K \left(\frac{T}{\Theta_D} \right)^5 J_5 \left(\frac{\Theta_D}{T} \right), \quad (5)$$

where K is a constant for a given metal. A table of values for $J_5(\Theta_D/T)$ is given in Sect. 1.5. For $T \gtrsim \Theta_D$, $\varrho_{\text{B.G.}}$ varies approximately linearly with T , and as T approaches 0 K (i.e. $T \lesssim \Theta_D/20$) it varies as T^5 .

Because real metals do not have exactly spherical Fermi surfaces or Debye phonon spectra, and because Umklapp electron-phonon scattering is important, $\varrho_{\text{el-ph}}$ can vary as different powers of T at temperatures where $\varrho_{\text{B.G.}}$ would vary as T^5 . Thus, variations approximately as T^3 , T^4 , T^5 , and in the case of K even an exponential variation with T , have been reported and confirmed. In a given temperature range there is no general reason to expect $\varrho_{\text{el-ph}}$ to vary exactly as some power of T , and in many cases the approximate power of T observed can change with changes in sample purity.

This remark that the power of T in $\varrho_{\text{el-ph}}$ can depend upon the purity of the metal brings us to the subject of Matthiessen's rule, and deviations therefrom. If we imagine that an ideally pure metal (i.e. one containing no impurities and manifesting no size-effects) has a resistivity designated by $\varrho_p(T)$, then the question arises, "What happens to the temperature variation of the resistivity of this metal as impurities are added?". According to Matthiessen's rule, the answer is "Nothing". That is, Matthiessen's rule states that it is often not a bad approximation to envision the resistivity of a dilute alloy, $\varrho(c, T)$, as just the sum of the residual resistivity $\varrho_0(c)$ due to the impurity concentration c and the "ideal" resistivity of the host metal $\varrho_p(T)$.

Matthiessen's rule:

$$\varrho(c, T) = \varrho_0(c) + \varrho_p(T). \quad (6)$$

This rule is, however, essentially never exactly correct. It is thus useful to define a quantity called the Deviation from Matthiessen's rule, $\Delta(c, T)$ as

$$\Delta(c, T) = \varrho(c, T) - \varrho_p(T) - \varrho_0(c). \quad (7)$$

Strictly speaking, $\varrho_p(T)$ is only a hypothetical quantity, since it is impossible to produce a perfectly pure metal. $\varrho_p(T)$ is therefore approximated experimentally by inverting Matthiessen's rule to define a nominal pure metal resistivity

$$\varrho_i(T) = \varrho(c, T) - \varrho_0(c), \quad \text{for } c \text{ "very small"}. \quad (8)$$

At temperatures above about 10 K, currently available samples are usually sufficiently pure that the quantity defined in Eq. (8) becomes independent of c , and therefore, presumably, an excellent approximation to $\varrho_p(T)$. This article contains tables and figures of $\varrho_i(T)$ for all metals for which such data are available, using the purest samples available. It contains also figures of $\Delta(c, T)$ as defined by Eq. (7) for dilute alloys based on a number of host metals, so that the reader may see both the form and magnitudes of Deviations from Matthiessen's rule.

We conclude this discussion by noting that magnetic metals contain an additional resistivity contribution, ϱ_{mag} , the form and temperature variation of which depend upon the temperature range and the nature of the ordered magnetic state (e.g. ferromagnetic, anti-ferromagnetic, spiral, etc.), and that changes in either $\varrho(T)$ itself, or its temperature derivative, $d\varrho/dT$, usually occur at structural phase transitions. Examples of these are contained in the tables and figures for $\varrho_i(T)$.

1.1.2 List of frequently used symbols and abbreviations

Symbols:

c	[at %] [wt %]	Impurity concentration; given in atomic percent unless weight percent is explicitly indicated
d	[mm]	diameter of round wires
l_b	[cm]	mean free path of electrons in bulk metal
p		scattering parameter ($p=1$: complete specular reflection; $p=0$: complete diffuse reflection)
t	[mm]	thickness of foils, films or square wires
R	[Ω]	electrical resistance
RRR		Residual Resistance Ratio = $R(273\text{ K})/R(4\text{ K})$, essentially equal to $\varrho(273\text{ K})/\varrho_0$, since thermal expansion between 273 K and 4 K is small. RRR is used as a rough measure of the purity of the sample; large RRR indicates high purity
T	[K] [$^{\circ}\text{C}$]	Temperature, given in Kelvins (absolute temperature) unless degrees Centigrade are explicitly indicated: $T(\text{K}) = T(^{\circ}\text{C}) + 273.15$
T_C	[K]	Curie temperature; temperature of ferromagnetic transition
T_N	[K]	Neel temperature; temperature of anti-ferromagnetic transition
T_M	[K]	Magnetic transition temperature other than simple ferromagnetic or anti-ferromagnetic transition; e.g. spiral phase, change in orientation of moments, etc. Superscript used when two or more such transitions occur
T_m	[K]	Melting temperature
T_c	[K]	Superconducting transition temperature
Z		Number of valence electrons, ΔZ difference in the number of valence electrons between the impurity and the host metal
$\alpha_0(T_1, T_2)$	[K^{-1}]	$\alpha_0(T_1, T_2) \equiv (1/\varrho(273.2\text{ K})) \left[\frac{\varrho(T_2) - \varrho(T_1)}{T_2 - T_1} \right]$. If $\varrho(T)$ varied strictly linearly with T in the vicinity of 273.2 K, then $\alpha_0(T_1, T_2)$ would be independent of T_1 and T_2 . For most simple metals, $\alpha_0(T_1, T_2)$ is approximately equal to $(1/273.2\text{ K}) \approx 0.004$
ϱ or $\varrho(T)$	[$\mu\Omega\text{cm}$]	The resistivity of a metal at temperature T ; <i>not</i> corrected for thermal expansion (see introduction)
ϱ^+ or $\varrho^+(T)$	[$\mu\Omega\text{cm}$]	The resistivity of a metal at temperature T ; <i>corrected</i> for thermal expansion (see introduction)
$\varrho(c, T)$	[$\mu\Omega\text{cm}$]	The resistivity at T of an alloy containing a known concentration c of a given impurity
$\varrho^b, \varrho^b(T)$	[$\mu\Omega\text{cm}$]	Temperature dependent part of bulk resistivity
$\varrho_f, \varrho_f(T)$	[$\mu\Omega\text{cm}$]	Temperature dependent part of thin foil (thin films or thin wires) resistivity
$\varrho_0(c)$	[$\mu\Omega\text{cm}$]	The residual resistivity of an alloy; nominally equal to $\varrho(c, 0)$, but usually measured at 4.2 K
$\varrho_p(T)$	[$\mu\Omega\text{cm}$]	The (hypothetical) resistivity of an ideally pure metal
$\varrho_i(c, T)$	[$\mu\Omega\text{cm}$]	$\varrho_i(c, T) \equiv \varrho(c, T) - \varrho_0(c)$ is the temperature dependent portion of the resistivity $\varrho(c, T)$. As $c \rightarrow 0$, $\varrho_i(c, T)$ should become independent of c and should approach $\varrho_p(T)$

$\rho_i, \rho_i(T)$ or $\rho_M(T)$	$[\mu\Omega\text{cm}]$	For a high purity metal ($c \ll 1$ at %), the symbol $\rho_i(T)$ will be used instead of $\rho_i(c, T)$ to indicate that the measured quantity is to be viewed as an approximation to $\rho_p(T)$. In some cases, to avoid confusion, $\rho_i(T)$ will be replaced by the symbol $\rho_M(T)$, where M will be the symbol of the host metal; e.g. $\rho_{Fe}(T)$
$\Delta\rho, \Delta\rho(T)$ or $\Delta\rho(c, T)$	$[\mu\Omega\text{cm}]$	$\Delta\rho(T) \equiv \rho(c, T) - \rho_i(T)$, where $\rho(c, T)$ is measured on an alloy of interest and $\rho_i(T)$ is measured on the purest sample of the host metal available to the investigator. $\Delta\rho(T)$ is often designated the "impurity resistivity" of the alloy
$\rho_{\parallel}(T)$ and $\rho_{\perp}(T)$ $\rho_{\parallel}, \rho_{\perp}$ $\rho_{\parallel}, \rho_{\perp}$	$[\mu\Omega\text{cm}]$	For a single crystal of an anisotropic metal, more than one resistivity is necessary to characterize the specimen. Where two resistivities are needed, $\rho_{\parallel}(T)$ designates the resistivity parallel to the principal axis (c-axis), and $\rho_{\perp}(T)$ designates the resistivity perpendicular to this axis. Where three are needed, subscripts designate the crystal direction: e.g. ρ_{100}
Δ or $\Delta(c, T)$	$[\mu\Omega\text{cm}]$	$\Delta(c, T) \equiv \rho(c, T) - \rho_i(T) - \rho_0(c) = \Delta\rho(c, T) - \rho_0(c)$. Δ is often called the Deviation from Matthiessen's rule (see introduction), since if Matthiessen's rule were exactly obeyed, $\Delta(c, T)$ would be identically zero

Abbreviations:

ASE	Anomalous size effect
DMR	Deviations from Matthiessen's rule
calc	calculated
est	estimated
expt	experimental
extrap	extrapolated
interp	interpolated
pc	polycrystalline
sc	single crystal
sm	smoothed

Crystal structures:

fcc	face centred cubic
bcc	body centred cubic
hcp	hexagonal closest packed
dhcp	hexagonal closest packed with a double sized unit cell
ortho	orthorhombic
rhomb	rhombohedral
tetr	tetragonal
mono	monoclinic

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1.2 Pure metals

1.2.1 Pure metal resistivities at $T=273.2\text{ K}$

Table 1. Contents: 1. $\varrho_i(273.2\text{ K})$, the resistivities of pure metals at $T=273.2\text{ K}$; and 2. $\alpha_0(T_1, T_2)=(1/\varrho_i(273.2\text{ K})[(\varrho_i(T_2)-\varrho_i(T_1))/(T_2-T_1)]$, the temperature coefficient of resistivity for the metal at 273.2 K. The only exceptions are metals for which $\varrho(T)$ is given when it was not possible to determine $\varrho_i(T)$ reliably, and metals for which ϱ_i is given at a nearby temperature other than 273.2 K (e.g. 293 K) when it was not possible to reliably convert the data to 273.2 K.

Each metal is specified by its chemical symbol, and the table contains the temperature in [K] for which the resistivity is given (normally 273.2 K), the crystal structure of the metal, whether the sample was a single crystal sc or polycrystalline pc, the residual resistance ratio RRR of the sample where available, the temperature coefficient $\alpha_0(T_1, T_2)$, T_1 and T_2 are given in [K], and the reference to the original data.

Generally, several independently measured values are listed for samples of differing purities, so that the reader may ascertain the range of variation to be found in the literature. Where many alternative values have been published, a representative set of the best values has been chosen. In each case the first value listed is that preferred by the present author; this is normally either the lowest value or the value obtained on the highest purity sample. Other values are then listed in no particular order. Where both single crystal and polycrystalline values are of comparable accuracy for anisotropic metals, the single crystal values are listed first and polycrystalline values are listed only where they appear to provide useful additional information. For brevity, we do not distinguish between 273.15 K and 273.2 K, since the data are not accurate enough to warrant this distinction.

* An asterisk indicates that this number is calculated by the present author from data given in the original paper.

sc: single crystal; pc: polycrystalline. For further abbreviations, see list of symbols.

Metal (T) K	ϱ_i $\mu\Omega\text{ cm}$	RRR	$\alpha_0(T_1, T_2)$ K^{-1}	Ref.
Ac	No data found for this metal.			
Ag (273...)	1.467	1850	0.0040* (260, 295)	70Se1
pc, fcc	1.471	1850		70Se1
	1.468	1050	0.0040* (273)	70Ma1
	1.466(1)	600	0.0040* (273)	69La1
	1.468	2100	0.0041* (235, 295)	73Ko1
	1.466	1850		73Ko1
	1.463	1650		73Ko1
	1.468	650		73Ko1
	1.48	≥ 1000	0.0041* (250, 295)	59Wh1
Al (273.2)	2.429	3450	0.0046* (252, 297)	70Se1
pc, fcc	2.460	2250		66Pa1
	2.44			52Br1
Am (273)	62.2	25	0.0026* (260, 300)	77Sc1
pc, dhcp	64* (extrap)			74br1
As (293)	ϱ_0 not subtracted			
sc, rhomb(II)	32.1(9)			69Je1
	35.6(18)		0.0045(6) (293, 373)	65Ta1
(I)	25.2(8)			69Je1
	25.5(5)		0.0040* (293, 373)	65Ta1
	26			30Me1
Au (273.2)	2.03 ₁	100	0.0040* (260, 280)	70Co1
pc, fcc	2.023(40)	250	0.0040* (260, 280)	68Da1
	2.04	150	0.0041* (273)	69La1
	2.04		0.0040* (260, 280)	74My1
	2.01	300	0.0041* (250, 295)	59Wh1

continued

Table 1 (continued)

Metal (T) K	ρ_i $\mu\Omega \text{ cm}$	RRR	$\alpha_0(T_1, T_2)$ K^{-1}	Ref.
Ba (273.2)	29.8 ₂	220	0.0049* (260, 280)	78Co1
pc, bcc	30.7	22		78Co1
	29.4			71Ra1
Be (273.2)	2.71	80	0.0090 (250, 295)	63Re1
pc	2.7* (extrap)			53Po1
sc, hcp ()	3.56			42Er1
	3.58			38Gr1
	3.8 (interp)		0.0093* (250, 300)	75Mi1
($\perp$)	3.12			40Gr1
	2.8 (interp)		0.0082* (250, 300)	75Mi1
Bi (273.2)				
sc, rhomb ()	127		0.0044 ₅ (273, 373)	25Br1
	130		0.0042 (273, 423)	39Ka1
	135		0.0040* (273, 318)	56Ok1
($\perp$)	100		0.0044 ₅ (273, 373)	25Br1
	102		0.0048 (273, 423)	39Ka1
	105.5		0.0043* (273, 318)	56Ok1
Ca (273.2)	3.08	41	0.0040 (273)	67Ka1
pc, fcc	3.11* (interp)	60	0.0039 (255, 291)	75Co1
Cd (273.2)				
sc, hcp ()	7.81(3)	8000	0.0040* (256, 298)	78Ro1
	7.78	≥ 8000	0.0043* (261, 289)	75Al1
	7.73		0.0041 (273, 293)	32Go1
	7.59			33Br2
($\perp$)	6.30(3)	8000	0.0041* (256, 298)	78Ro1
	6.36	≥ 8000	0.0044* (261, 289)	75Al1
	6.35		0.0040 ₅ (273, 293)	32Go1
	6.29			33Br2
Ce (273.2)				
pc, β -Ce, dhcp	77* (extrap)	19	0.0009* (100, 300) (est from graph)	76Bu1
	83* (extrap)	19		76Bu1
γ -Ce, fcc	70* (extrap)	27	0.0009* (100, 300) (est from graph)	76Bu1
Cm (273)	≈ 82 (extrap from $T \leq 160 \text{ K}$)	2	0.0007* (240, 300) (est)	77Sc2
pc, dhcp				
Co (273.2)				
sc, hcp ()	9.2* (extrap)			66Ma1 (see 74hu1)
($\perp$)	5.0* (extrap)			66Ma1 (see 74hu1)
pc	5.1 ₅	170	0.0056* (250, 295)	59Wh1
	5.21	140	0.0056* (250, 300)	73La1
	5.25		0.0057* (223, 323)	67Ki1
Cr (273.2)	11.8* (extrap)	380	0.003 ₀ * (280, 300)	77Mo1
pc, bcc	12.1	250	0.003 ₆ * (250, 295)	59Wh1
	12.5 (interp)			69Mo1
Cs (273.2)	18.0	≥ 250	0.0048* (260, 280)	65Du1
pc, bcc	18.1		0.0050 (273, 298) [25 Br 1]	10Ha1

continued

Table 1 (continued)				
Metal (T) K	ρ_1 $\mu\Omega \text{ cm}$	RRR	$\alpha_0(T_1, T_2)$ K^{-1}	Ref.
Cu (273.2) pc, fcc	1.54 ₀	3400	0.0043* (250, 298)	65 Du 1
	1.54 ₁	2200	0.0043* (251, 298)	65 Du 1
	1.546		0.0043* (250, 300)	67 Mo 1
		850	0.0044* (250, 293)	
	1.544(2)	1530		59 Po 1
	1.55	620		59 Wh 1
	1.55			15 Me 1
Dy (273.2) sc, hcp ($\parallel$)	69.1* (interp)	12	0.0012* (240, 299)	68 Bo 1
	70* (est from graph)	12		71 Vo 1
	75* (extrap)			60 Ha 1
	($\perp$) 103.2* (interp)	22	0.0014* (240, 299)	68 Bo 1
	105* (est from graph)	16		71 Vo 1
	99* (extrap)			60 Ha 1
	pc 88* (extrap)	38		60 Ha 1
	81* (est from graph)	8		64 Co 1
	$\frac{1}{3}(\rho_{\parallel} + 2\rho_{\perp})$ 92*			68 Bo 1
Er (273.2) sc, hcp ($\parallel$)	39.5* (interp)	15	0.0027 ₅ * (273.2)	76 Sp 1
	39.9* (interp)	8	0.0029* (260, 299)	68 Bo 1
	40* (est from graph)		0.0030* (150, 300)	61 Gr 1
	($\perp$) 76.9* (interp)	30	0.0024* (273.2)	76 Sp 1
	78.7* (interp)	15	0.0024 ₅ * (260, 299)	68 Bo 1
	70* (est from graph)		0.0026* (150, 300)	61 Gr 1
	pc 65* (est from graph)			61 Gr 1
	73* (est from graph)	13		65 Ar 1
	$\frac{1}{3}(\rho_{\parallel} + 2\rho_{\perp})$ 64*			76 Sp 1
Eu (298) pc, bcc	81.3			58 Sp 1
	89.6	220	0.0016* (280, 318)	60 Cu 1
	86.8		0.0016* (297, 373)	80 Te 1
	86.4* (extrap)	20		69 Me 1
Fe (273.2) pc, bcc	8.64	35		66 Fu 1
	8.6	250		64 Ar 1 (see 66 Fu 1)
	8.7	100	0.0058* (250, 295)	59 Wh 1
	8.57			41 Ro 1
Fr No data for this metal.				
Ga (273.2) sc, ortho ($\parallel$)	50.3	14000	0.003 ₈ * (273, 293)	51 Po 1
	52.2	15000	0.003 ₅ * (273, 293)	64 Re 1
	($\perp, a$) 16.0 ₅	8000	0.004* (273, 293)	51 Po 1
	($\perp, b$) 7.5	9000	0.004* (273, 293)	51 Po 1
	7.65	10500	0.0037* (273, 293)	64 Re 1
Gd (273.2) sc, hcp ($\parallel$)	118.4* (interp)	45	0.0019* (270, 275)	69 Ne 2
	125* (est from graph)	42		77 Ma 1
	117* (est from graph)	37		63 Ni 1
	($\perp$) 127.1* (interp)	29	0.0019* (270, 275)	69 Ne 2
	128* (est from graph)	21		77 Ma 1
	123* (est from graph)			63 Ni 1
	pc 127.5* (est from graph)	50		64 Co 2
	130* (est from graph)			74 Gu 1

continued

Table 1 (continued)

Metal (T) K	ρ_i $\mu\Omega\text{ cm}$	RRR	$\alpha_0(T_1, T_2)$ K^{-1}	Ref.
Hf (273.2)				
sc, hcp ()	32.7	20	0.0043 ₅ (273, 473)	52Ad 1
($\perp$)	32.0		0.0045 (273, 473)	52Ad 1
pc	28.0		0.0042* (250, 295)	59Wh 1
	29.7		0.0042 (273, 373)	53Br 1
	26.5		0.0038	51Li 1
Hg (227.65)				
sc, rhomb ()	17.8			45gr 1
($\perp$)	23.5			45gr 1
(Hg is liquid at 273.2 K)				
Ho (273.2)				
sc, hcp ()	54.6* (interp)	17	0.0021* (259, 298)	69Ne 1
	51* (est from graph)	16		62St 1
($\perp$)	93.4* (interp)	34	0.0020* (260, 300)	69Ne 1
	86* (est from graph)	25		62St 1
pc	71* (est from graph)			62St 1
$\frac{1}{3}(\rho_{ } + 2\rho_{\perp})$	80			69Ne 1
In (273.2)				
sc, bc tetr ()	7.851* (interp)	10000	0.0047* (260, 300)	68Ba 1
	7.9			62ol 1
($\perp$)	8.132	10000	0.0048* (260, 300)	68Ba 1
	8.3			62ol 1
pc	7.986* (interp)		0.0048* (260, 300)	68Ba 1
	8.0		0.0047* (223, 323)	62Po 1
	8.19			32Me 1
	8.21		0.0048 (260, 273)	67Ka 2
Ir (273.2)	4.6 ₅	50	0.0042* (250, 295)	59Wh 1
pc, fcc	4.7 ₅ * interp	86	0.0044* (200, 300)	67Po 2
K (273.15)	6.196(60)	2150	0.0051* (260, 280)	79Co 1
pc, bcc	6.447	1300	0.0050* (260, 280)	62Du 1
La (273.2)				
α -La, dhpc,	59.2* (interp)	240	0.0022* (260, 300)	77Le 1
pc	47*			70Pa 1
	40* (est from graph)			75Kr 2
β -La, (fcc, stable with 0.2 at % Gd), pc	56.6	44		77Le 1
Li (273.2)				
Li, natural,	8.495	770	0.0044 ₅ * (260, 300)	61Du 1
pc, bcc				
^6Li	8.337	400	0.0046* (260, 300)	61Du 1
Lu (273.2)				
sc, hcp ()	30.5* (interp)	40	0.0049* (263, 299)	68Bo 1
($\perp$)	67.9* (interp)	26	0.0036* (258, 298)	68Bo 1
pc	48* (est from graph)	10		60Co 1 (65me 1)
$\frac{1}{3}(\rho_{ } + 2\rho_{\perp})$	55*			68Bo 1

continued

Table 1 (continued)

Metal (T) K	ρ_i $\mu\Omega\text{ cm}$	RRR	$\alpha_0(T_1, T_2)$ K^{-1}	Ref.
Mg (273.2)				
sc, hcp ($\parallel$)	3.48* (extrap)		0.0041 (273, 465)	55 Ni 1
	3.48		0.0043 (273, 373)	31 Go 1
	3.52		0.0042 (273, 373)	31 Br 1
	3.42 (extrap)	350	0.0043* (250, 289)	75 Al 1
($\perp$)	4.18* (extrap)		0.0039 (273, 465)	55 Ni 1
	4.18		0.0042 (273, 373)	31 Go 1
	4.25 (extrap)	500	0.0043* (250, 289)	75 Al 1
	4.69		0.0044 (273, 373)	31 Br 1
pc	4.10	630	0.0042 ₅ * (260, 295)	70 Se 1
$\frac{1}{3}(\rho_{\parallel} + 2\rho_{\perp})$	3.95*			55 Ni 1
α-Mn (273.2)	136.6	20	0.0002* (250, 295)	65 Me 1
pc, simple cubic	136	12	0.0005* (250, 295)	59 Wh 1
Mo (273.2)	4.87 ₉	8000	0.0047 (250, 300)	74 Mo 1
pc, bcc	4.8 ₄	22	0.0046 (250, 295)	59 Wh 1
	5.0 ₃			25 Ge 1
	5.00			65 Ho 1
Na (273.2)	4.289	5000	0.0048 ₅ (260, 295)	60 Du 1, 62 Du 1
pc, bcc	4.325	800	0.0048 ₅ (260, 280)	72 Co 1
Nb (273.2)	13.27	213	0.0037 (260, 280)	72 Ab 1
pc, bcc	13.5	33	0.0036 (250, 295)	59 Wh 1
	13.47 (inferred)			78 Pe 1
Nd (273.2)				
sc, hex ($\parallel$)	48.0* (interp)	21	0.0026* (256, 289)	79 Pe 1
($\perp$)	63.9* (interp)	14	0.0022* (256, 301)	79 Pe 1
pc,	57 (est from graph)	11		61 Al 1
$\frac{1}{3}(\rho_{\parallel} + 2\rho_{\perp})$	58.6			79 Pe 1
Ni (273.2)	6.24 ₄ (interp)	270	0.0059 (250, 300)	76 La 1
pc, bcc	6.2 ₀	300	0.0059 (250, 295)	59 Wh 1
	6.14			37 Wi 1
Np (273)	116* (est from graph)	40		63 Me 1
pc, ortho	97* (est from graph)	15		70 Me 1
	85* (est from graph)	7		65 Ol 1
	[impurities in Np appear to reduce ρ (273 K)]			
Os (273.2)				
sc, hcp ($\parallel$)	5.7* (extrap; Θ and T)	320		68 Sc 1
($\perp$)	9.0* (extrap; Θ and T)	400		68 Sc 1
pc	8.3 ₅	100	0.0043* (250, 295)	59 Wh 1
	8.1 (interp)	22	0.0043* (200, 300)	67 Po 2
Pa (273)	15.88 $\pm$ 20% (interp)	9.3	0.0037 (251, 298)	77 Ha 1
pc, bc tetr				
Pb (273.2)	19.20	> 980	0.0040 ₆ (273 K)	74 Co 1
pc, fcc	19.22	100000	0.0041 (260, 280)	73 Mo 1
	19.28	> 1040		70 Lu 1
	19.33	> 400		70 Lu 1
	19.3			67 Po 1
	19.3* (extrap)	14000		63 Al 1
	19.2			00 Ja 1

continued

Table 1 (continued)

Metal (T) K	ρ_i $\mu\Omega\text{ cm}$	RRR	$\alpha_o(T_1, T_2)$ K^{-1}	Ref.
Pd (273.2)	9.74 ₃	250	0.0039* (250, 300)	72La 1
pc, fcc	9.71	570	0.0040* (250, 295)	59Wh 1
	9.7 ₇			34Gr 1
Pm (300)	54(3)			66Wi 1
pc, hcp				
Po (273)	42(10)			49Ma 1
pc, film, simple cubic				
Pr (273)	51* (est from graph)	110		72Kr 1
pc, dhcp	65.5* (interp)	30	0.0018 ₅ * (250, 300)	67Ar 1
	64* (est from graph)			61Al 1
Pt (273.2)	9.76(5)	5000	0.0040* (273 K)	67Ma 1
pc, fcc	9.83(5)	900	0.0040* (273 K)	67Ma 1
	9.80	600	0.0040* (273 K)	66La 1
	9.60	600	0.0040* (250, 295)	59Wh 1
	9.85			62Po 2
	9.81			15Me 1
Pu (273)	128...145* (est from graph; varied with current relative to oriented grain axes)	19		64El 1
pc, monocl	126* (est from graph)	6.3		63Ki 1
	130* (est from graph)	8.7	-0.0004 ₅ * (200, 300) (est from graph)	76Jo 1
	128*	6.4	-0.0002* (250, 300)	63Me 1
Ra	No data found for this metal.			
Rb (273.2)	11.24 ₄	450	0.0051* (260, 290)	79Co 2
pc, bcc	11.26* (interp)	615	0.0051* (260, 300)	65Du 2
Re (273.2)				
sc, hcp ($\parallel$)	12.7* (est from graph)	25000		78Vo 1
($\perp$)	17.6* (est from graph)	19000		78Vo 1
$\frac{1}{3}(\rho_{\parallel} + 2\rho_{\perp})$	16.0*			78Vo 1
pc	16.7* (extrap)			72Pe 1
	16.9	1000	0.0045* (250, 295)	59Wh 1
	17.2	220		63Po 1
Rh (273.2)	4.3 ₆	570	0.0045* (250, 295)	59Wh 1
pc, fcc	4.35			33Br 1
	4.33	180		62Po 2
Ru (273.2)				
sc, hcp ($\parallel$)	5.14	1000		76Az 1
	5.1 ₅ (from graph)	20000		78Vo 1
	5.2 (interp)		0.0045* (200, 300)	67Po 2
($\perp$)	6.61	1000		76Az 1
	6.6 ₅ (from graph)	25000		78Vo 1
	6.7 (interp)		0.0045* (200, 300)	67Po 2
pc	6.6 ₉	450	0.004 ₇ * (250, 295 K)	59Wh 1 (65me 1)

continued