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## ELECTRICAL RESISTIVITY OF ALKALI ELEMENTS

By

T. C. CHI

CINDAS REPORT 40

January 1976

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## PREFACE

This technical report was prepared by the Electronic Properties Information Center (EPIC) of the Center for Information and Numerical Data Analysis and Synthesis (CINDAS), Purdue University, West Lafayette, Indiana, for the Defense Supply Agency, U.S. Department of Defense.

This report reviews the recorded world knowledge on the electrical resistivity of alkali elements in a most comprehensive and detailed form making it possible for all users of the subject to have access to the original data without having to duplicate the laborious and costly process of literature search and data extraction. It is quite appropriate at this point to mention that only original sources of data have been used for the critique of the data and that all cited documents are available at CINDAS. Also, for the active researchers in the field, a detailed discussion is presented for each material, reviewing the available information together with the considerations used by the author in arriving at the final recommended reference values.

It is hoped that this work will prove useful not only to the scientists in the field but also to other engineering research and development programs and for industrial applications, as it provides a wealth of knowledge heretofore unknown or inaccessible to many. In particular, it is felt that the critical evaluation, analysis and synthesis, and reference data generation constitute a unique aspect of this work.

While this work is prepared by the staff of CINDAS' Data Tables Division, it would not have been possible without the direct input of CINDAS' Scientific Documentation Division. Furthermore, valuable suggestions and guidance to this work have come from Dr. H. M. James and Dr. C. Y. Ho of CINDAS' senior staff.

West Lafayette, Indiana  
January 1976

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## ABSTRACT

This technical report presents and discusses the available data and information on the electrical resistivity of alkali elements (lithium, sodium, potassium, rubidium, cesium, and francium) and contains recommended reference values (or provisional or typical values). The compiled data include all the experimental data available from the literature and cover the temperature dependence, pressure dependence, and magnetic flux density dependence. The temperature range covered by the compiled data is from cryogenic temperatures to above the critical temperature of the elements. The recommended values are generated from critical evaluation, analysis, and synthesis of the available data and information and are given for both the total electrical resistivity and the intrinsic electrical resistivity. For most of the elements, the recommended values cover the temperature range from 1 K to 2000 K.

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## LIST OF SYMBOLS

a	Constant
A	Code for d. c. potentiometer method
b	Constant
B	Magnetic flux density; Code for d. c. bridge method
c	Constant
C	Code for a. c. potentiometer method
d	Constant
D	Code for a. c. bridge method
E	Code for eddy current method
G	Code for galvanometer amplifier method
I	Code for Induction method
$L_F$	Latent heat
M	Atomic weight
P	Pressure
Q	Code for Q-meter method
R	Resistance
T	Temperature
$T_k$	Knot temperature
$T_m$	Melting point
$T_c$	Critical temperature
$T'$	Reduced temperature
$\rho$	Electrical resistivity
$\rho_0$	Residual electrical resistivity
$\rho_i$	Intrinsic electrical resistivity
$\sigma$	Electrical conductivity
$\sigma'$	Reduced electrical conductivity
$\theta_D$	Debye temperature
$\theta_R$	Empirical temperature
-	Code for miscellaneous methods

## 1. INTRODUCTION

The purpose of this work is to present and discuss the available data and information on the electrical resistivity of alkali elements, to critically evaluate, analyze, and synthesize the data, and to make recommendations for the most probable values of the electrical resistivity over a wide temperature range. Experimental electrical resistivity data are available in the world literature for elements Li, Na, K, Rb, and Cs, and there exist estimated values for Fr. These elements are of much interest to both engineers and scientists since liquid alkali metals have excellent heat transfer characteristics. For instance, sodium has been used as a coolant for nuclear reactors and nuclear powered submarines.

Table 1 on the following page contains information on the crystal structures, transition temperatures, and certain other pertinent physical constants of the alkali elements. This information is very useful in data analysis and synthesis. For example, the electrical resistivity of a material generally changes abruptly when the material undergoes any transformation. One must, therefore, be extremely cautious in attempting to extrapolate the electrical resistivity value across any transition temperature. No attempt has been made to critically evaluate the temperatures and constants given in Table 1, and they should not be considered as recommended values.

This work is organized in six sections. In the theoretical background section, the elementary theory of electrical resistivity is discussed. In the section on data evaluation and generation of recommended values, the general procedures and methods for data evaluation and for the generation of recommended values are outlined.

In the data presentation section, the electrical resistivity of each of the alkali elements is presented separately in the order of increasing atomic number. Values of electrical resistivities are given for both the solid and liquid states. For an element at moderate and high temperatures the true electrical resistivity values for different high-purity (99.9<sup>+</sup>) samples at each temperature should be but little different; therefore, a set of recommended electrical resistivity values can be given for a high-purity element. At low temperatures, however, the electrical resistivity values for different samples with small differences in impurity and/or imperfection differ greatly, and a set of recommended or provisional values applies only to a sample with that particular amount of impurity and imperfection. Thus, the low-temperature electrical resistivity of an element may be presented as a family of curves, each of which is recommended for a sample with a particular amount of impurity and degree of imperfection, and hence a particular residual

TABLE 1. PHYSICAL CONSTANTS OF ALKALI ELEMENTS<sup>a</sup>

Name	Atomic No.	Atomic Weight	Density <sup>c</sup> $\text{Kg m}^{-3} \times 10^{-3}$	Crystal <sup>d</sup> Structure	Phase Transition	Debye <sup>e</sup> Temperature at 0 K	298 K	Melting Point, K	Normal Boiling Point, K	Critical Temp., K
Lithium (Li)	3	6.941	0.534	b. c. c.	Martensitic transformation at low temp.	352 ± 1.7	448	453.7	1617	3720
Sodium (Na)	11	22.989	0.9712	b. c. c.	Martensitic transformation at low temp.	157 ± 1	155 ± 5	371.0	1157	2733
Potassium (K)	19	39.098	0.871	b. c. c.		89.4 ± 0.5	100	336.35	1032	2280.8 ± 3
Rubidium (Rb)	37	85.4678	1.53	b. c. c.		54 ± 4	59	312.64	961	2.06 ± 5
Cesium (Cs)	55	132.9054	1.873	b. c. c.		40 ± 5	43	301.55	944	2051.1 ± 4.4
Francium (Fr)	87	(223)	2.14			39		300.2	950	

<sup>a</sup> Information taken from Ref. [1].

<sup>b</sup> Atomic weights based on  $^{12}\text{C} = 12$  as adopted by the International Union of Pure and Applied Chemistry in 1971. The number in parentheses is the mass number of the isotope of longest known half life.

<sup>c</sup> Density values given for 293 K.

<sup>d</sup> Structure at room temperature.

<sup>e</sup> Deduced from specific heat measurements.

resistivity,  $\rho_0$ . In this work, two well-defined curves are recommended for the full temperature range: one representing the intrinsic electrical resistivity,  $\rho_i$ , which is a unique function of temperature and is zero at absolute zero, and the other representing the total resistivity,  $\rho$ , for the purest form of each element on which measurements have been made. The latter curve at low temperatures is only applicable to the particularly characterized specimen with residual electrical resistivity clearly specified in the Remarks. These two curves come together at temperatures above about 100 K. Figure 1 shows the relationship between  $\rho_i$ ,  $\rho_0$ , and  $\rho$ .

The recommended or provisional electrical resistivities are tabulated with uniform but step-wise increasing increments in temperature as the temperature increases. The estimated accuracy of the recommended or provisional values for each element in each different temperature range is given in the discussion. The asterisked values in the tables are interpolated, extrapolated, or estimated in the temperature ranges where no experimental data are available.

From the recommended values of  $\rho$  and  $\rho_i$  which are tabulated in this report, the electrical resistivity of a particular sample at low temperatures could be predicted by either of the following two ways. One way is to find the difference between the measured resistivity value and the recommended  $\rho$  value at the same low temperature, then add this difference to the recommended  $\rho$  values at other temperatures. The second way is to compare the measured low temperature (i. e. below 100 K) value with  $\rho_i$  and get the difference which is the residual resistivity of this particular sample, then add this  $\rho_0$  to the recommended  $\rho_i$  at the other temperatures.

In the figure showing experimental data, a data set that consists of a single point is denoted by a number enclosed by a square, and a curve that connects a set of data points is denoted by a ringed number. These numbers correspond to those in the accompanying table on specimen characterization and measurement information and in the data table. When several sets of data are too close together to be distinguishable, some of the data sets or data points, those listed in the table, are omitted from the figure for the sake of clarity. For all elements except francium, both logarithmic plotting and linear plotting of electrical resistivity are used in order that details may be clearly shown for both the low and high temperature regions. The recommended values are presented in the same figure. The solid curve represents recommended values, and the dashed curves give provisional values in the temperature ranges where no or few experimental data are available. In the figure, the melting point (M. P.), normal boiling point (N. B. P.), and critical temperature (C. T.) of the elements are indicated. Some of these transition

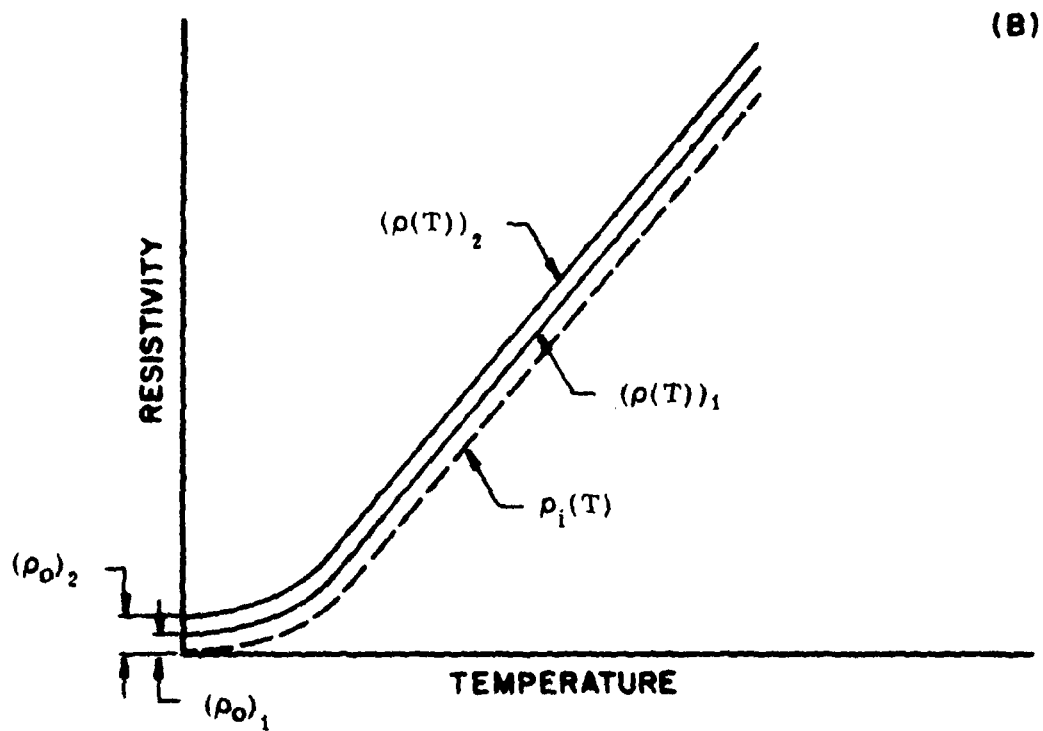
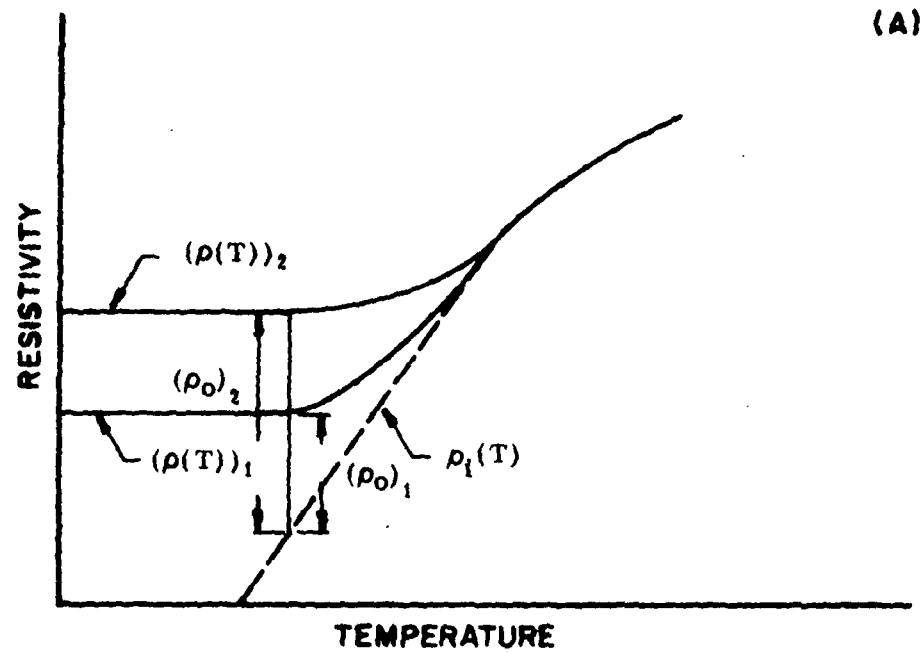


Figure 1. Relationship between intrinsic resistivity  $\rho_i(T)$ , residual resistivity,  $\rho_0$ , and total resistivity,  $\rho(T)$ . (A) in logarithm scale, (B) in linear scale.

points are also mentioned in the text. At the melting point the resistivity exhibits sharp discontinuity.

The tables on specimen characterization and measurement information give for each set of data the following information: the publication reference number, author's name, year of publication, experimental method used for the measurement, temperature range covered by the data, substance name and specimen designation, as well as the detailed description and characterization of the specimen and information on measurement conditions that are reported in the original paper. In these tables the code designations used for the experimental methods for electrical resistivity determination are as follows:

- A D. C. Potentiometer Method
- B D. C. Bridge Method
- C A. C. Potentiometer Method
- D A. C. Bridge Method
- E Eddy Current Method
- G Galvanometer Amplifier Method
- I Induction Method
- Q Q-Meter Method
- V Voltmeter and Ameter Direct Reading
- Other than above and described in the remarks

For a comprehensive yet concise review of all these methods, the reader is referred to the references of Appendix 7.1.

The available data and information for the pressure dependence and magnetic flux density dependence of the electrical resistivity are inadequate for performing detailed analysis and synthesis at this time. Consequently, no recommendations are made and only experimental data are presented in this report.

In the Thirteenth General Conference on Weights and Measures held in October 1967 in Paris, the unit "ohm-meter" (symbol:  $\Omega$  m) was adopted as the SI unit for electrical resistivity. In this work, the SI units are used. Table 2 gives conversion factors which may be used to convert the electrical resistivity values in  $\Omega$ m presented in this work to values in any of the several other units listed. Conversion tables for units of temperature, pressure, and magnetic flux density are listed in Appendix 7.2.

In the summary and conclusions section, figures are presented in which all the recommended curves on the intrinsic electrical resistivity are grouped together in order to facilitate a visual comparison.



TABLE 2. CONVERSION FACTORS FOR UNITS OF ELECTRICAL RESISTIVITY\*

MULTIPLY by appropriate factor to OBTAIN	ab $\Omega$ cm	$\mu\Omega$ cm	$\Omega$ cm	stat $\Omega$ cm	$\Omega$ m	$\Omega$ cir. mil ft <sup>-1</sup>	$\Omega$ in.	$\Omega$ ft.
	abohm-centimeter (emu)	1	0.001	10 <sup>-9</sup>	1.113 x 10 <sup>-21</sup>	10 <sup>-11</sup>	6.015 x 10 <sup>-3</sup>	3.937 x 10 <sup>-10</sup>
microohm- centimeter	1000	1	10 <sup>-6</sup>	1.113 x 10 <sup>-18</sup>	10 <sup>-6</sup>	6.015	3.937 x 10 <sup>-7</sup>	3.281 x 10 <sup>-6</sup>
ohm-centimeter	10 <sup>9</sup>	10 <sup>6</sup>	1	1.113 x 10 <sup>-12</sup>	0.01	6.015 x 10 <sup>6</sup>	0.3937	0.0328
statohm-centimeter (esu)	8.987 x 10 <sup>20</sup>	8.987 x 10 <sup>17</sup>	8.987 x 10 <sup>11</sup>	1	8.987 x 10 <sup>9</sup>	5.406 x 10 <sup>18</sup>	3.538 x 10 <sup>11</sup>	2.949 x 10 <sup>15</sup>
ohm-meter	10 <sup>11</sup>	10 <sup>8</sup>	100	1.113 x 10 <sup>-10</sup>	1	6.015 x 10 <sup>8</sup>	39.37	3.281
ohm-circular mil per foot	166.2	0.1662	1.662 x 10 <sup>-7</sup>	1.850 x 10 <sup>-19</sup>	1.662 x 10 <sup>-9</sup>	1	6.54 x 10 <sup>-8</sup>	5.45 x 10 <sup>-9</sup>
ohm-inch	2.54 x 10 <sup>9</sup>	2.54 x 10 <sup>6</sup>	2.54	2.827 x 10 <sup>-12</sup>	0.0254	1.528 x 10 <sup>7</sup>	1	0.083
ohm-foot	3.048 x 10 <sup>10</sup>	3.048 x 10 <sup>7</sup>	30.48	3.3924 x 10 <sup>-11</sup>	0.3048	1.833 x 10 <sup>8</sup>	12	1

\* This table is based on the universal constants from "The International System of Units (SI)," NBS Special Publication 330, National Bureau of Standards, U. S. Department of Commerce.

The complete bibliographic citation for the 129 references are given in the references section. Most of the references are available at CINDAS which are listed at the end of reference citations with numbers prefixed with the letter E or T.

## 2. THEORETICAL BACKGROUND

The electrical resistivity,  $\rho(T)$ , of a metal is often described approximately by the Matthiessen rule [2]

$$\rho(T) = \rho_0 + \rho_i(T), \quad (1)$$

where  $\rho_0$  is the residual resistivity at absolute zero and  $\rho_i(T)$ , the intrinsic resistivity, is the temperature-dependent resistivity of an ideally pure sample of the metal. The quantity  $\rho_0$  arises from the presence of impurities, defects, and strains in the metal lattice, while  $\rho_i(T)$  is caused by the interaction of the conduction electrons with the thermally induced vibrations of the lattice ions; that is, the phonons in the crystal. For a pure annealed sample at room temperature,  $\rho_0$  is only a small fraction of the total resistivity. There are a number of mechanisms that could produce deviation from the Matthiessen rule, i. e., a term  $\Delta\rho$  appearing on the right-hand side of equation (1). The first comprehensive survey of such deviation was made by J. Bass [128]. A more recent study by Cimberle, et al. [129] brings references up to date.

The intrinsic resistivity due to electron-phonon interactions may be approximated by the Grüneisen-Bloch relation [3]

$$\rho_i(T) = \frac{C}{M \theta_R} \left( \frac{T}{\theta_R} \right)^5 \int_0^{\theta_R/T} \frac{z^5 dz}{(e^z - 1)(1 - e^{-z})}, \quad (2)$$

where  $C$  is a constant,  $M$  is the atomic weight,  $T$  is the absolute temperature, and  $\theta_R$  is an empirical temperature characterizing the metal's ideal electrical resistivity in the same way that the Debye temperature,  $\theta_D$ , characterizes a solid's lattice specific heat. It is often true that  $\theta_R \approx \theta_D$ . Below about  $0.1 \theta_R$  this relation reduces to

$$\rho_i(T) \approx 124.4 \frac{C}{M} \frac{T^5}{\theta_R^6} \quad (3)$$

At high temperatures, as  $T \geq \theta_R$ ,

$$\rho_i(T) \approx \frac{C}{4M} \frac{T}{\theta_R^2}. \quad (4)$$

The Grüneisen-Bloch equation is derivable for idealized monovalent metals with Debye phonon spectra and spherical Fermi surfaces totally neglecting the effect of Umklapp processes. However, because of its comparative simplicity, the Grüneisen-Bloch equation provides a most valuable tool for analyzing and discussing experimental data.

The Grüneisen-Bloch equation never holds over the entire temperature range for the alkali metals. It is approximately valid only at low and high temperatures. By inverting the computation, one may intercompare the behavior of different metals by treating the experimental results as deviations from the Grüneisen-Bloch equation which is done by employing  $\theta_R$  as a variable parameter and computing the value that it must possess at any temperature in order that the Grüneisen-Bloch equation may agree with the experiment.

In all alkali metals the electrical resistivity increases abruptly on passing through the melting point and continues to rise in the liquid phase. The sudden change is due to the greater disorder of the liquid state and the disappearance of any definite crystal structure.

Mott [4] has presented a simple and fairly successful theory of liquid metals. He ignored the disordered positions and diffusive movements of the vibrating ions and assumed that near the melting point the ions of the liquid metal still maintain a more or less regular pattern. With an Einstein model, he obtained

$$\left(\frac{\rho_L}{\rho_S}\right)_{T_m} = \exp\left(\frac{80 L_F}{T_m}\right), \quad (5)$$

where  $\rho_L$  and  $\rho_S$  are the electrical resistivities of the liquid and solid phases,  $T_m$  is the melting point, and  $L_F$  is the latent heat of fusion in kilojoules per mole. The calculated values of  $(\rho_L/\rho_S)_{T_m}$  according to this formula compare moderately well with experimental data for alkali metals.

To estimate the electrical conductivity of molten alkali metals from the melting point to the critical point, Grosse [5] has proposed an empirical equation of the form of a simple equilateral hyperbola:

$$(\sigma' + b)(T' + b) = a \quad (6)$$

where  $\sigma' = \sigma/\sigma_m$  is the reduced electrical conductivity and  $T' = (T - T_m)/(T_c - T_m)$  is the reduced temperature,  $\sigma_m$  being the electrical conductivity of the liquid at the melting point and  $T_c$  the critical temperature; the quantities  $a$  and  $b$  are constants determined by the distances of the vertex of the hyperbola from the axes. The estimated values by Grosse's equation are valid for sodium, potassium, rubidium, and cesium, but not valid for lithium.

### 3. DATA EVALUATION AND GENERATION OF RECOMMENDED VALUES

The data analysis and synthesis are employed in this work whenever possible which included critical evaluation of available data and related information, reconciliation of disagreements in conflicting data, correlation of data in terms of various parameters, and curve fitting with theoretical or empirical equations. Besides critical evaluation and analysis of the existing data, semiempirical techniques have been employed to fill gaps and to extrapolate existing data so that the resulting recommended values are internally consistent and cover as wide a range of temperature as possible.

In the critical evaluation of the validity of electrical resistivity data, any unusual dependence or anomaly was carefully investigated, the experimental techniques were reviewed to see whether the actual boundary conditions in the experiment agreed with those assumed in the theory, and the author's estimations of uncertainty were checked to ensure that all the possible sources of errors were considered. The sources of errors may have included uncertainty in the measurement of specimen dimensions and of the distance between the potential probes, uncertainty due to the effects of thermal expansion, uncertainty in temperature measurements, uncertainty in the sensitivity of measuring circuits, and so on.

Many authors have included detailed error estimates in their published papers, and from these it is possible to evaluate the uncertainty for a particular method. However, experience has shown that the uncertainty estimates of most authors are unreliable. In many cases the difference between the results of two sets of data is much larger than the sum of their stated uncertainties.

Besides evaluating and analyzing individual data sets, correlating data in terms of various relevant parameters is a valuable technique and has frequently been used in data analysis. These parameters may include purity, density, residual electrical resistivity, and so on.

For meaningful data correlation, information on specimen characterization is very important. A full description of the specimen should include, wherever applicable, the following: purity or chemical composition, type of crystal, crystal axis orientation for a single crystal, microstructure, grain size, preferred grain orientation, inhomogeneity or additional phases for a polycrystalline specimen, specimen shape and dimensions, method and procedure of fabrication, sample history or treatment, test environment, and pertinent physical properties such as density, hardness, and transition temperature. Data on poorly characterized materials can hardly be analyzed or used for data correlation.

Besides specimen characterization, a full description of experimental details should be given by the author in order that his data can be meaningfully evaluated and fully utilized. Sometimes, as an initial method of evaluating the quality of a paper, consideration might be given to the amount of experimental detail reported in the paper; lack of experimental detail might lead to the results being given less weight.

Our preliminary recommended values for the electrical resistivity of the alkali elements were derived from experimental data that were considered reliable, using computer least square fits and graphing aid. These values are then corrected for thermal linear expansion and smoothing with a cubic spline function of variable knots in the form as the equation (7) and the final recommended values are obtained.

$$\log \rho_i = a + b(\log T - \log T_k) + c(\log T - \log T_k)^2 + d(\log T - \log T_k)^3 \quad (7)$$

where  $T$  = variable temperature in a given interval

$T_k$  = minimum temperature in the interval

In estimating the uncertainty of our recommended values, the accuracy that can be achieved by the various experimental technique, the scatter of data, and the purity of the materials, among other factors, were taken into consideration.

## 4. ELECTRICAL RESISTIVITY OF ALKALI ELEMENTS

### 4.1. LITHIUM

Lithium, with atomic number 3, is a silvery white, soft alkali metal. It is the lightest of all metals with a density of  $0.534 \text{ g cm}^{-3}$  at 293 K. Except at low temperatures, it has a body-centered cubic crystalline structure. It melts at 453.7 K and boils at about 1620 K. Its critical temperature has been estimated to be about 3720 K. Upon cooling through 75 K, body-centered cubic crystalline lithium undergoes a spontaneous martensitic transformation to a close-packed hexagonal structure. The transformation does not take place completely and stacking faults are usually present. At 4 K possibly as much as 90% has transformed to this second phase. On heating again, reversion to the body-centered crystalline structure does not begin until 90 K and will not complete until 160 K. Naturally occurring lithium is composed of two stable isotopes:  $\text{Li}^7$  (92.58%) and  $\text{Li}^6$  (7.42%). Three other radioactive isotopes are known to exist. Lithium ranks 32nd in the order of abundance of elements in the continental crust of the earth (0.002% by weight).

#### a. Temperature Dependence

There are 44 sets of experimental data available for the electrical resistivity of lithium. The information on specimen characterization and measurement conditions for each of the data sets is given in Table 4. The data are tabulated in Table 5 and shown in Figures 2 and 3. Determinations of the electrical resistivity of lithium for the solid and liquid phases cover continuously the temperature range from 1.2 to 1700 K.

There are 22 data sets obtained below 90 K. Among these, eight sets are single data points at liquid helium temperature. Dugdale, Gugan, and Okumura [6] reported the data for Li consisting of over 99%  $^6\text{Li}$  (curve 34). Krill [7] (curve 29) had the purest material (99.98% pure). There are seven sets of intrinsic resistivity values below 80 K, but these disagree by as much as a factor of 9. It is evident that these are large deviations from Matthiessen's Rule. The data of Krill and Lapiere [127] on dilute solutions of Ag in Li indicates that  $\rho - \rho_0$  may exceed  $\rho_1$  by a factor of 3 or more below 30 K, and that  $\rho - \rho_1$  may exceed  $\rho_0$  by a factor of 2 or more above 80 K; at intermediate T deviations from Matthiessen's Rule are of the order of 20% of the total resistivity. In addition, Li undergoes a martensitic transition (b.c.c.-h.c.p.) at low T, as a result of which electrical resistivity values depend somewhat on the thermal history of the

samples; see Dugdale and Gugan [21]. Because of these difficulties, Krill's data for  $\rho$  have been relied on at the lowest temperatures, since his material had the lowest  $\rho_0$ . In view of Krill's lack of attention to the martensitic transition, his values for  $\rho$  must be considered as provisional. In view of the deviations from Matthiessen's Rule, useful values of  $\rho_1$  at the lowest temperatures can be derived only by a more elaborate analysis, and are omitted here.

There are 21 data sets from 80 to 453.7 K. They agree with one another within 5%. Dugdale and Gugan [8] reported electrical resistivities at constant volume (curve 7), which are very close to those at zero pressure (curve 6). A least-mean-square error fit to the selected experimental data in this range was made with a Bloch-Grüneisen equation. The resulting values were corrected for thermal linear expansion, and then fitted with the cubic spline function equation (7) to obtain the final recommended values in this temperature range. The coefficients of equation (7) obtained are as follows:

Temperature Range, K	a	b	c	d
40 - 81.06	-1.173	3.193	7.549	-17.43
81.06 - 92.295	0.0139	2.904	-8.494	38.64
92.295 - 453.6	0.1575	2.314	-1.962	1.127

There are 17 data sets available for the liquid state. They agree with one another within about 10%. Freedman and Robertson [9] (curve 5) give the lowest values while Rigney et al. [10] (curve 11) give the highest values. Grosse [5] derived electrical resistivity values (curve 45) in the range from the melting point to his estimated critical temperature, 4150 K, by fitting the experimental data of Freedman and Robertson [9] (curve 5) and Kapelner et al. [11] (curve 38) to a hyperbola equation. All the experimental data except Rigney's data were used here for fitting the cubic spline function equation (7) to obtain the final recommended values. The coefficients of equation (7) are the following:

Temperature Range, K	a	b	c	d
453.7-1080.5	1.395	0.622	-0.228	0.430
1080.5-2200	1.620	0.634	0.258	0.314

The resistivity values represented by these equations are not corrected for thermal linear expansion of the container, which in most cases is not specified.

At the melting point (453.7 K), the electrical resistivity of Li in the liquid state is about 60% higher than that of the solid state.



The recommended values for the total and intrinsic electrical resistivities of lithium are listed in Table 3, and those for the total electrical resistivity are also shown in Figures 2 and 3. The recommended values for the total resistivity are for 99.98% pure lithium and those at temperatures below 50 K are applicable only to a specimen with residual resistivity of  $0.00724 \times 10^{-8} \Omega\text{m}$ . The recommended values for the liquid state are for the saturated liquid. The recommended values from 1 to 453.7 K are corrected for thermal linear expansion. The correction amounts to -0.79% at 1 K, -0.72% at 80 K, and 0.85% at 453.7 K. The uncertainty of the recommended values for the total electrical resistivity is believed to be within  $\pm 20\%$  from 1 K to 60 K, within  $\pm 5\%$  from 60 K to 1500 K and within  $\pm 10\%$  from 1500 K to 2000 K. Above 40 K the uncertainty of the recommended values for the intrinsic resistivity is a little higher than that of the total electrical resistivity; below 40 K, because of the deviations from Matthiessen's Rule, the uncertainty of  $\rho_i$  is so large that values are not listed in the table.

TABLE 3. RECOMMENDED ELECTRICAL RESISTIVITY OF LITHIUM  
(Temperature Dependence)

[Temperature, T, K; Total Resistivity,  $\rho$ ,  $10^{-8} \Omega m$ ; Intrinsic Resistivity,  $\rho_i$ ,  $10^{-8} \Omega m$ ]

Solid			Liquid			
T	$\rho$	T	$\rho$	$\rho_i^\dagger$	T	$\rho$
1	0.00724*	35	0.047*		453.7	24.80
2	0.00724*	40	0.074*	0.067*	500	26.33
3	0.00725*	45	0.109*	0.102*	600	29.34
4	0.00727*	50	0.162*	0.155*	700	32.10
5	0.00730*	60	0.345*	0.338*	800	34.71
6	0.00735*	70	0.636	0.629	900	37.22
7	0.00740*	80	1.000	0.993	1000	39.69
8	0.00745*	90	1.36	1.35	1100	42.13
9	0.00751*	100	1.73	1.72	1200	44.61
10	0.00760*	150	3.72	3.71	1300	47.41
11	0.00773*	200	5.71	5.70	1400	49.97
12	0.00792*	250	7.65	7.64	1500	53.00
13	0.00817*	273.15	8.53	8.52	1600	56.34*
14	0.00849*	293	9.28	9.27	1700	60.03*
15	0.00889*	300	9.55	9.54	1800	64.12*
16	0.00936*	350	11.45	11.44	1900	68.67*
18	0.0106*	400	13.40	13.39	2000	73.73*
20	0.0122*	450	15.44	15.43	2100	79.44*
25	0.0185*	453.7	15.59	15.58	2200	85.59*
30	0.0300*					

<sup>†</sup> At temperatures below 40 K, the uncertainty of  $\rho_i$  is so large that values are not listed.

\* Provisional values.

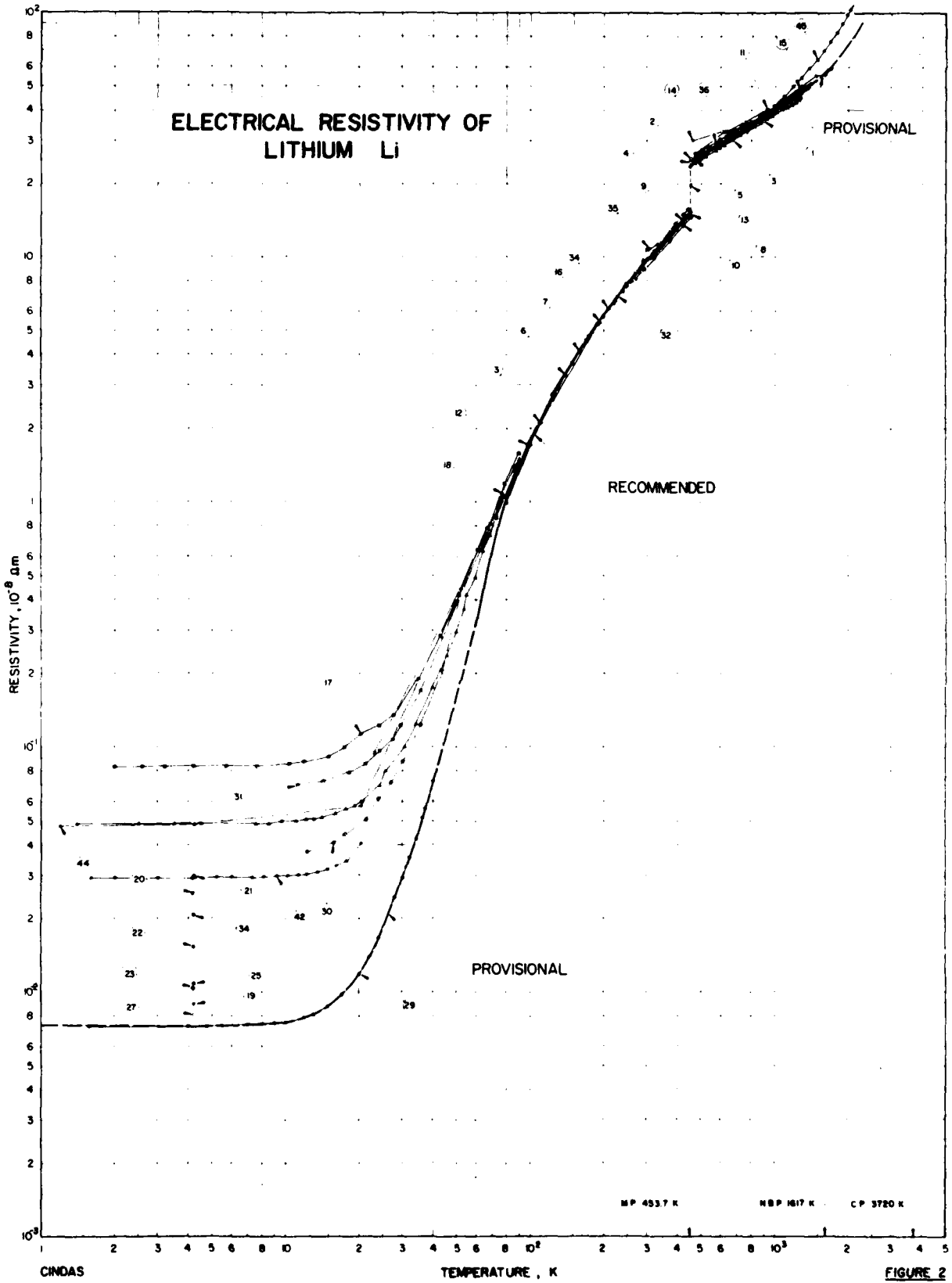


FIGURE 2

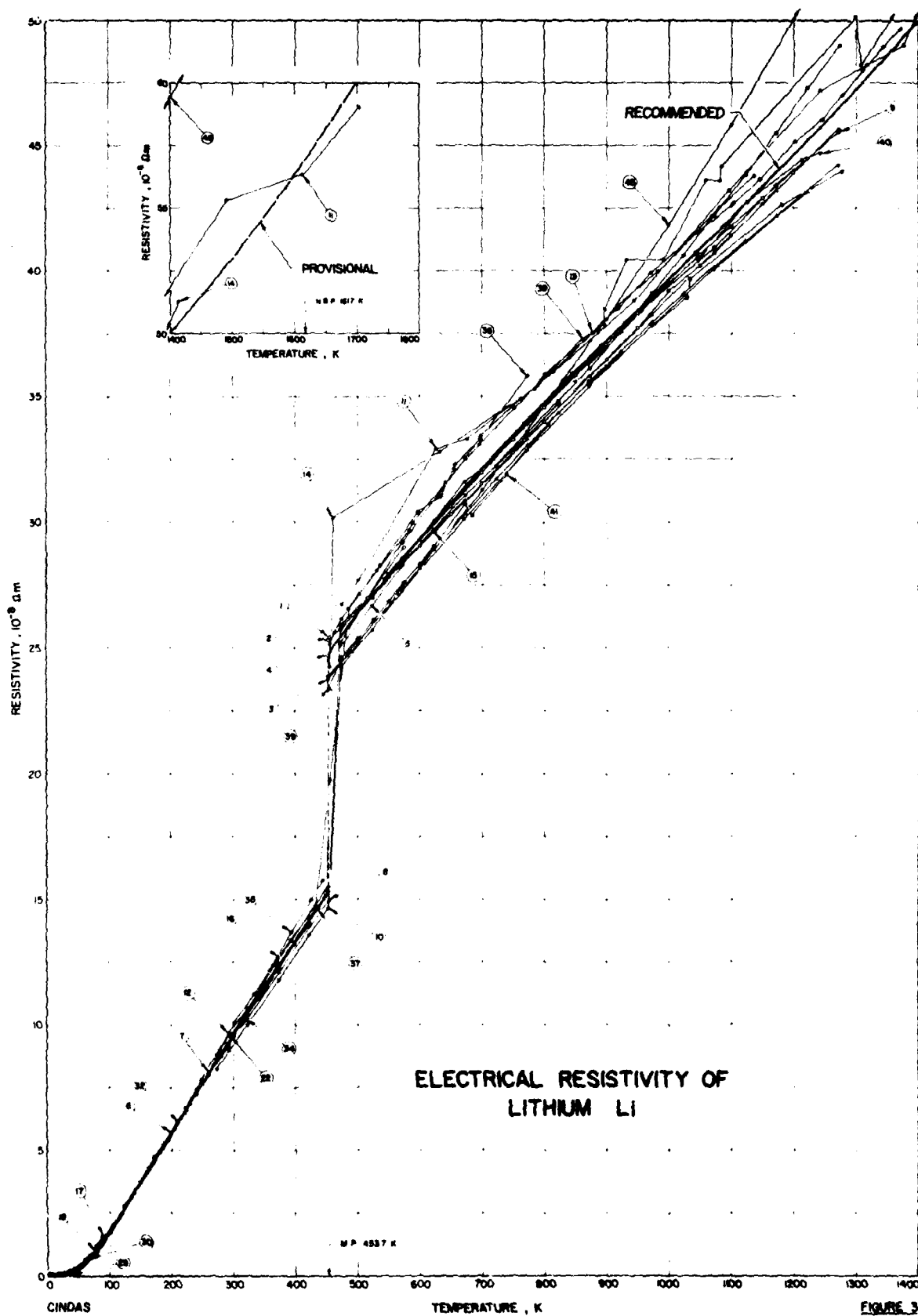


TABLE 4. MEASUREMENT INFORMATION ON THE ELECTRICAL RESISTIVITY OF LITHIUM Li (Temperature Dependence)

Cur. Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	12 Shpil'rain, E. E., Soldatenko, Yu. A., Yakimovich, K. A., Fomin, V. A., Savchenko, V. A., Belova, A. M., Kagan, D. N. and Krainova, L. F.	1965	A	454-1223	Li(I)	99.6 <sup>+</sup> Li, 0.26 Na, 0.0011 K, 0.0013 Ca and <0.015 other impurities; specimen was in liquid state which was enclosed in a stainless steel tube; specimen density = $10.5368 - 1.0208 \times 10^{-4} (T-273.15)$ g/cm <sup>3</sup> ; melting point = 453.65 K, boiling point = 1603 K; resistivity was measured in the insert atmosphere and the experiment results was presented as the following equation. $\rho = 20.96 + 2.4705 \times 10^{-2} (T-273.15)$ $\rho$ in units of $10^{-4} \Omega m$ , T in K.
2	12 Shpil'rain, E. E., et al.	1965	A	454-1223	Li(II)	99.8 <sup>+</sup> Li, 0.13 Na, 0.01 Ca, 0.001 K and <0.015 other impurities; specimen was in liquid state which was enclosed in a stainless steel tube; other specifications similarly as above specimen; $\rho = 19.82 + 3.053 \times 10^{-2} (T-273.15)$ (T-273.15) <sup>2</sup>
3	12 Shpil'rain, E. E., et al.	1965	A	454-1223	Li(III)	Similar to the above specimen; $\rho = 17.80 + 3.47 \times 10^{-2} (T-273.15)$ - $8.447 \times 10^{-4} (T-273.15)^2$
4	13 Faber, T. E.	1966	A	273-573		Nominally pure Li was supplied by A. D. Mackay Inc.; specimen was forced by dry helium gas into a clean stainless steel tube 2.5 mm inner diameter and 11.5 cm in length; for measurements at elevated temperature, the tube was enclosed in a furnace filled with helium.
5	9 Freedman, J. F. and Robertson, W. D.	1961	B	473-923		99.4 <sup>+</sup> Li, major impurity Na; vacuum distilled specimen was supplied by Nuclear Development Corp.; specimen was in liquid state and was enclosed in 304 stainless steel tube with 0.349" in diameter and 20" in length.
6	8 Dugdale, J. S. and Guggan, D.	1962	A	80-290		Pure Li specimen was obtained from the Lithium Corporation of America; 0.05 cm in diameter and 10 cm in length; resistivity was measured at zero pressure condition.
7	8 Dugdale, J. S. and Guggan, D.	1962	A	80-290		Similar to the above specimen; resistivity was calculated at constant density.
8	14 Shpil'rain, E. E., and Savchenko, V. A.	1968	A	273-1273	Li 1	0.8 Na, 0.0054 K, 0.003 Ca, <0.003 Al, 0.0018 Mg, 0.001 Si, <0.0003 Mn, 0.003 Fe, 0.0036 Ni, 0.0069 Cr, 0.03 Zr and 0.0005 C; specimen was filled in a 1Kh18N9T stainless steel test tube, 15 mm in diameter and 500 mm long with a wall thickness of 0.75 mm; data presented as smooth value by least squares method.
9	14 Shpil'rain, E. E., and Savchenko, V. A.	1968	A	273-1273	Li 2	0.1 Na, 0.0015 K, <0.002 Ca, <0.005 Al, 0.0012 Mg, <0.003 Si, 0.002 Mn, <0.13 Fe, 0.016 Ni, 0.024 Cr, <0.00025 Zr, 0.0012 N <sub>2</sub> and 0.096 O <sub>2</sub> ; other specifications similar to the above specimen.
10	14 Shpil'rain, E. E., and Savchenko, V. A.	1968		273-1273	Li 3	0.1 Na, 0.0015 K, <0.003 Ca, <0.005 Al, 0.006 Mg, 0.025 Si, 0.00082 Mn, <0.01 Fe, <0.01 Nb, <0.01 Cr, <0.01 Zr, 0.0012 N <sub>2</sub> and 0.045 O <sub>2</sub> ; other specifications similar to the above specimen.
11	10 Rigney, D. V., Kapelner, S. M., and Cleary, R. E.	1965	A	479-1703		0.24 O <sub>2</sub> , <0.003 N <sub>2</sub> , <0.0002 C, <0.001 Zr, <0.01 Nb, 0.013 Na, <0.01 Fe and <0.001 Ni; specimen was in liquid state and was filled in Nb-1 Zr capsule. Specimen 1.10 cm in diameter and 25 cm in length was produced by extrusion through a die.
12	15 Bidwell, C. C.	1926		73-423		Li specimen was filled in a Hyanes-25 Alloy cylindrical cell; density (g/cm <sup>3</sup> ) = 0.5345 - 0.30884 $\times 10^{-4} (T-305.15)$ ; T in K.
13	16 Tepper, F., Felensk, J., Roehlich, F. and May, V.	1965		308-1360		Liquid Li specimen placed in a Hyanes-25 Alloy cylindrical cell 0.5" outside diameter 0.043" in wall and 26" in length; data were extracted from the smooth curve.
14	17 Roehlich, F. and Tepper, F.	1965	A	463-1366		

TABLE 4. MEASUREMENT INFORMATION ON THE ELECTRICAL RESISTIVITY OF LITHIUM Li (Temperature Dependence) (continued)

Cur. Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
15 18	Semyachkin, B. E. and Solov'ev, A. N.	1964	A	483-1273		Li specimen TV8774-58 was placed in 1 kh 18N9T 0.8/0.5 mm capillary with 600 mm in length.
16 19	Guntz, A. and Broniewski, W.	1909		86-372		Pure
17 20	Rosenberg, H. M.	1956		2-293	Li 1	Pure Li was distilled into a stainless steel capillary 0.83 mm inside diameter, copper leads were in direct contact with the specimen.
18 20	Rosenberg, H. M.	1956		2-293	Li 2	Similar to the above specimen; except the copper contacts was soldered outside the capillary.
19 21	Dugdale, J. S. and Guggan, D.	1961	A	4.2, 80	Li 18C	Pure Li wire specimen 3 mm in diameter and 10 cm in length; specimen was obtained from the Lithium Corporation of America; it was heated at 423 K for 20 hrs.
20 21	Dugdale, J. S. and Guggan, D.	1961	A	4.2	Li 7A	Similar to the above specimen; except the diameter is 0.5 mm and no heat treatment.
21 21	Dugdale, J. S. and Guggan, D.	1961	A	4.2	Li 16A	Similar to the above specimen.
22 21	Dugdale, J. S. and Guggan, D.	1961	A	4.2	Li 8B	Similar to the above specimen.
23 21	Dugdale, J. S. and Guggan, D.	1961	A	4.2	Li 12C	Similar to the above specimen.
24*21	Dugdale, J. S. and Guggan, D.	1961	A	4.2	Li 13C	Similar to the above specimen.
25 21	Dugdale, J. S. and Guggan, D.	1961	A	4.2	Li 15C	Similar to the above specimen.
26 21	Dugdale, J. S. and Guggan, D.	1961	A	4.2	Li 19C	Similar to the above specimen.
27 21	Dugdale, J. S. and Guggan, D.	1961	A	4.2	Li 17C	Similar to the above specimen; except the diameter is 5 mm and specimen was heat treated for 24 hrs at 423 K.
28 22	Krautz, E.	1950	A	273		Pure.
29 7	Krill, G.	1971	A	1.3-40		99.98 pure; <0.0045 K, <0.004 Cl, <0.003 Na, <0.003 N, <0.001 Ce and <0.0003 Fe; specimen was 0.5 mm in diameter and 50 cm in length; $\rho/p_{300} = 7 \times 10^{-4}$ .
30 23	MacDonald, D. K. C., White, G. K., and Woods, S. B.	1955	A	12-295	Li 2	Pure Li specimen was obtained from Messers, A. D. Mackay, Inc.; specimen was extruded with a hydraulic press into a stainless steel tube with a film of Vaseline lubricating the inside wall of the tube; specimen diameter 1.4 mm.
31 23	MacDonald, D. K. C., et al.	1955	A	12-295	Li 3	Pure Li specimens were supplied by New Metals as Chemicals Ltd. (London); other specifications similar to the above specimen.
32 6	Dugdale, J. S., Guggan, D., and Okumura, K.	1961	A	4.2-320	Li 1	92.7% Li; 7.3% Li; 0.012 Al; 0.058 Ca; 0.017 Na; 0.011 K; 0.008 Fe, 0.004 Cu, 0.14 Mg and 0.04 N; the specimen was extruded into the form of wire about 0.5 mm in diameter and 100 cm in length; the results of electrical resistivity was taken from the ideal resistivity plus the residual resistivity.
33 6	Dugdale, J. S., et al.	1961	A	4.2-320	Li 2	0.043 Na, 0.011 K, 0.006 Cu and 0.0614 Mg; other specifications similar to the above specimen.
34 6	Dugdale, J. S., et al.	1961	A	4.2-320	Li 1	99.3% Li, 0.7% Li, 1.46 Ca, 0.066 Na, 0.4 Fe, 0.2 Cu, 0.035 Mg, 0.13 Sr, 0.2 Ba and trace Al, Cr and F; specimen was obtained from Oak Ridge National Lab.; specimen was extruded in the form of wire about 0.5 mm in diameter and 100 cm in length; electrical resistivity was taken from the ideal resistivity plus the residual resistivity.

\* Not shown in figure.

TABLE 4. MEASUREMENT INFORMATION ON THE ELECTRICAL RESISTIVITY OF LITHIUM LI (Temperature Dependence) (continued)

Cur. R.-f. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
35	Grube, G., Voestfläher, H., and	1932		273-443		99.0 pure, 0.62 K, 0.14 Na, 0.02 Fe <sub>2</sub> O <sub>3</sub> , 0.05 SiO <sub>2</sub> , 0.32 Li <sub>2</sub> N, and trace of Al <sub>2</sub> O <sub>3</sub> ; density 0.534 g cm <sup>-3</sup> . Pure; liquid state.
36	Ioannides, P., Nanyen, V.T., and Enderby, J.E.	1973		473-773		99.9% Li, 0.03 Na, 0.01 each K, Ca, N, Ni, 0.002 each Cl, Cr, 0.005 Fe; the specimen was purchased from Lithium Corp. of America; the specimen was purified by heating to 870°C for 2 hr over titanium sponge and was then maintained slightly above its melting point in intimate contact with the sponge prior to transfer to the dry box; the specimen container was type 347 stainless steel (0.75 in. O.D., 16 in. long), 0.085 in. wall thickness.
37	Kapelnier, S. and Bratton, W.	1961	A	299.9-452.6		Same as above specimen; in liquid state.
38	Kapelnier, S. and Bratton, W.	1961	A	454.6-1137.6		0.5 Na, 0.01 each O <sub>2</sub> , N <sub>2</sub> , Ba, 0.003 H <sub>2</sub> , 0.0001 Cr, 0.006 Ca, 0.03 Cr, 0.04 Si, and <0.003 other; liquid state specimen; electrical resistivity data were reported as the equation $\rho = 1.86 \times 10^{-4} + 2.98 \times 10^{-4} (T - 273 \text{ K})$ in units of 10 <sup>-3</sup> $\Omega$ m and T in K.
39	Arno'dov, M.N., Ivanovskii, M.N., Pleshivtsev, A.D., Subbotin, V.I., and Shmatko, B.A.	1970		454-623		0.1 Na, 0.05 Al, 0.0021 Ca, 0.001 C, 0.0001 Cr, 0.003 Fe, 0.0013 K, 0.0027 Mg, 0.0008 Mn, 0.0012 N <sub>2</sub> , 0.0001 Ni, 0.03 Si, 0.1 O <sub>2</sub> , and 0.0001 Zr; liquid state specimen.
40	Savchenko, V.A. and Shpil'rain, E'E'	1970		543.5-1243.9		0.1 Na, 0.055 Al, 0.0015 each Ca, K, 0.024 Cr, 0.13 Fe, 0.001 Mg, 0.002 Mn, 0.0012 N <sub>2</sub> , 0.016 Ni, 0.045 O <sub>2</sub> , 0.003 Si, and 0.00025 Zr; liquid state specimen.
41	Savchenko, V.A. and Shpil'rain, E'E'	1970		543.5-1243.9	Li + 0.1 Na	Pure; $R_0/R_{300} \sim 3.3 \times 10^{-4}$ ; specimen was obtained from Dr. R. A. Hull; relative electrical resistance data were reported; electrical resistivity were calculated by using the electrical resistivity at 290 K and the thermal expansion correction at the measuring temperature.
42	MacDonald, D.K.C. and Mendelsohn, K.	1950	G	1.6-20	Li 1	Pure; specimen was obtained from Kahlb.; sample dimension 0.5 mm in diameter and 50 mm in length; relative resistance data were reported; electrical resistivity were calculated by using the electrical resistivity at 273.16 K and the thermal expansion correction at the measuring temperature.
43*	Meissner, W. and Voigt, G.	1930		20.4-273.16	Li 1	Pure; sample dimension 1 x 3 x 28 mm; relative resistance were reported; electrical resistivity data were calculated by using the electrical resistivity at 273.16 K and the thermal expansion correction at the measuring temperature.
44	Meissner, W. and Voigt, G.	1930		1.19-273.16	Li 2	Electrical resistivity data were calculated from the semiempirical equation ( $\sigma' + 0.302$ ) ( $T' + 0.302$ ) = 0.392 where $\sigma' = \sigma/\sigma_m$ and $T' = T - T_m / (T_c - T_m)$ .
45	Gross, A.V.	1966		454-4150		

\* Not shown in figure.

TABLE 5. EXPERIMENTAL DATA ON THE ELECTRICAL RESISTIVITY OF LITHIUM LI (Temperature Dependence)

[Temperature, T, K; Resistivity,  $\rho$ ,  $10^{-1}\Omega\text{m}$ ]

T	$\rho$	T	$\rho$	T	$\rho$	T	$\rho$	T	$\rho$
CURVE 1									
454	25.43	873	34.33	80	0.993*	273	8.18	273	8.66*
500	26.57	873	35.58	100	1.710*	323	9.97	293	9.66
550	27.81	823	36.79	120	2.490*	373	11.76	323	10.59*
600	29.05	973	37.95	140	3.294*	423	13.55	348	11.49
650	30.29	1023	39.07	160	4.104	453	14.62	373	12.24
700	31.52	1073	40.15	180	4.91*	473	15.54	398	13.21
750	32.76	1123	41.19	200	5.710*	573	19.76	423	14.01
800	34.00	1173	42.18	220	6.503*	673	27.25		
850	35.24	1223	43.14	240	7.286*	773	30.11		
900	36.47			260	8.076	873	32.82		
950	37.71			273	8.591	973	35.38		
1000	38.95			273	8.591	1073	37.80		
1050	40.19			280	8.862	1173	40.08		
1100	41.42			290	9.257	1273	42.20*		
1150	42.66								
1200	43.90								
1223	44.47								
CURVE 2									
453.65	25.33	473.15	25.06	273	8.49*	475.6	26.73	453	25.3*
500	26.50	523.15	26.6	373	10.29	501.0	27.68	473	25.8*
550	27.90	573.15	28.24	423	13.90	626.2	32.91	523	27.0
600	29.29	623.15	29.70	453	14.97	676.0	33.28	573	28.3*
650	30.61	673.15	31.04	473	15.90	790.3	35.44	623	29.6
700	31.97	723.15	32.22	573	20.84	802.0	35.87	673	30.6*
750	33.29	773.15	33.44	773	33.31	896.4	37.86	723	32.2*
800	34.56	823.15	34.68	873	35.78	897.3	38.47	773	33.5
850	35.83			973	38.25	932.9	40.44	823	34.8
900	37.07			1073	40.72	991.4	40.41	873	36.1
950	38.28			1173	43.19	1060.5	43.62	973	37.6
1000	39.47			1273	45.16	1082.0	43.60	1023	39.1
1050	40.64							1073	40.6
1100	41.77							1123	42.2
1150	42.89							1173	43.8
1200	43.98							1223	45.5
1223	44.46*							1273	49.0
CURVE 3									
453	23.77	80	0.595	273	8.61*	1045.2	41.53	453	25.3*
473	24.40	100	1.714	323	10.62	1085.0	44.15	473	25.8*
523	25.95	120	2.497	373	12.43	1299.8	50.15	523	27.0
573	27.45	140	3.303	423	14.24	1308.4	48.24	573	28.3*
623	28.91	160	4.113	453	15.33	1491.3	55.31	623	29.6
673	30.33	180	4.910	473	16.43	1613.6	56.34	673	30.6*
723	31.70	200	5.704	573	25.74	1703.1	59.07	723	32.2*
773	33.04	220	6.472	773	33.88	182.0	48.03	773	33.5
823	34.37	240	7.231	873	36.41	186.0	48.21	823	34.8
873	35.70	260	7.995	973	38.94	188.5	48.66	873	36.1
923	37.03	273	8.495	1073	41.46	191.0	49.04	923	37.6
973	38.36	280	8.753	1173	43.40	193.5	49.51	973	39.1
1023	39.69	290	9.135	1273	45.54	196.0	50.00	1023	40.6
1073	41.02							1073	42.2
1123	42.35							1123	43.8
1173	43.68							1173	45.5
1223	45.01							1223	47.3
1273	46.34							1273	49.0
CURVE 4									
453	23.77	73	0.095	23	0.095	1103.5	42.68	453	25.3*
473	24.40	73	0.862	73	0.862	1146.5	43.64	473	25.8*
523	25.95	98	1.73	98	1.73	1203.1	45.13	523	27.0
573	27.45	123	2.77	123	2.77	1246.5	46.05	573	28.3*
623	28.91	148	3.72	148	3.72	1278.2	46.99	623	29.6
673	30.33	173	4.74	173	4.74	1312.0	48.03	673	30.6*
723	31.70	198	5.71*	198	5.71*	1318.7	48.21	723	32.2*
773	33.04	223	6.67	223	6.67	1342.0	48.96	773	33.5
823	34.37	248	7.78	248	7.78	1372.0	49.67	823	34.8
873	35.70							873	36.1
923	37.03							923	37.6
973	38.36							973	39.1
1023	39.69							1023	40.6
1073	41.02							1073	42.2
1123	42.35							1123	43.8
1173	43.68							1173	45.5
1223	45.01							1223	47.3
1273	46.34							1273	49.0
CURVE 5									
453	23.77	80	0.595	273	8.61*	1045.2	41.53	453	25.3*
473	24.40	100	1.714	323	10.62	1085.0	44.15	473	25.8*
523	25.95	120	2.497	373	12.43	1299.8	50.15	523	27.0
573	27.45	140	3.303	423	14.24	1308.4	48.24	573	28.3*
623	28.91	160	4.113	453	15.33	1491.3	55.31	623	29.6
673	30.33	180	4.910	473	16.43	1613.6	56.34	673	30.6*
723	31.70	200	5.704	573	25.74	1703.1	59.07	723	32.2*
773	33.04	220	6.472	773	33.88	182.0	48.03	773	33.5
823	34.37	240	7.231	873	36.41	186.0	48.21	823	34.8
873	35.70	260	7.995	973	38.94	188.5	48.66	873	36.1
923	37.03	273	8.495	1073	41.46	191.0	49.04	923	37.6
973	38.36	280	8.753	1173	43.40	193.5	49.51	973	39.1
1023	39.69	290	9.135	1273	45.54	196.0	50.00	1023	40.6
1073	41.02							1073	42.2
1123	42.35							1123	43.8
1173	43.68							1173	45.5
1223	45.01							1223	47.3
1273	46.34							1273	49.0

\* Not shown in figure.



TABLE 5. EXPERIMENTAL DATA ON THE ELECTRICAL RESISTIVITY OF LITHIUM Li (Temperature Dependence) (continued)

CURVE 17 (cont.)		CURVE 18 (cont.)		CURVE 25		CURVE 29 (cont.)		CURVE 31 (cont.)		CURVE 33 (cont.)		
T	$\rho$	T	$\rho$	T	$\rho$	T	$\rho$	T	$\rho$	T	$\rho$	
17.5	0.100	54.7	0.409	4.2	0.0109	15.91	0.00925*	29.51	0.124	190	5.322	
20.3	0.114	55.4	0.441*			16.94	0.00977	35.72	0.170	200	5.715*	
24.2	0.124	56.0	0.436	CURVE 26*		17.94	0.01042*	74.98	0.979	210	6.099*	
27.7	0.138	57.3	0.467*			18.86	0.01107*	295	9.25	220	6.482*	
34.9	0.190	58.2	0.516*	4.2	0.0106	19.95	0.01199	CURVE 32			230	6.864*
43.0	0.265	59.9	0.494			22.0	0.01407			240	7.243*	
51.2	0.419	62.8	0.661*	CURVE 27		24.0	0.01680	4.2	0.0264*	250	7.624	
61.2	0.646	63.9	0.634			26.04	0.02025*	80	1.021*	260	8.005*	
68.7	0.317	68.6	0.732	4.2	0.0082	27.92	0.02446	90	1.368	270	8.386*	
78.9	1.200	72.8	0.881*			29.95	0.02946	100	1.740*	280	8.765*	
89.7	1.564	76.8	1.045	CURVE 28		31.89	0.03567	110	2.127	290	9.145*	
293	8.98	79.6	1.144*	273	8.55*	36.0	0.04288	120	2.523*	300	9.521*	
		79.6	1.183*			37.92	0.0619	130	2.924	310	9.911	
		81.3	1.142*	CURVE 29				140	3.329*	320	10.291*	
		82.8	1.256*					150	3.734*			
1.4	0.049	83.8	1.308*			CURVE 30		160	4.139*	CURVE 34		
2.5	0.049	86.0	1.415	1.67	0.007311	12.27	0.0383	170	4.537	4.2	0.021	
3.5	0.049	87.3	1.415*	1.95	0.007312*	13.61	0.0392*	180	4.937*	80	1.016*	
4.5	0.049	89.9	1.517	2.45	0.007303	14.42	0.040*	190	5.334	90	1.363*	
5.6	0.049*	293	9.17	2.70	0.007318*	15.59	0.041	200	5.730*	100	1.733*	
6.1	0.049*			3.18	0.007308*	16.52	0.043*	210	6.114	110	2.122*	
7.5	0.049			3.45	0.007301*	17.50	0.0445	220	6.497*	120	2.514*	
8.5	0.049			3.77	0.007311*	19.77	0.049*	230	6.879	130	2.919	
8.6	0.049*			3.97	0.007300	21.43	0.052	240	7.258*	140	3.334*	
8.8	0.049*			4.34	0.007333*	23.22	0.057*	250	7.639	150	3.729*	
9.0	0.049*			4.45	0.007314*	23.93	0.062	260	8.020*	160	4.134*	
9.6	0.050			4.740	0.007367	27.04	0.072	270	8.401	170	4.532*	
10.1	0.049*			5.01	0.007330*	30.20	0.088	280	8.78*	180	4.932*	
10.3	0.050*			5.48	0.007359	35.72	0.124	290	9.160*	190	5.332*	
11.1	0.050			6.02	0.007385*	41.78	0.206	300	9.536	200	5.725*	
12.1	0.051			6.48	0.007401*	55.97	0.424	310	9.926	210	6.109	
13.0	0.051			6.99	0.007416	66.83	0.688	320	10.306	220	6.482*	
14.0	0.052			7.47	0.007431	78.16	1.028*			230	6.874*	
15.9	0.054			7.99	0.007456			CURVE 33			240	7.253*
16.6	0.054*			8.47	0.007479*	295	9.63*			250	7.634*	
17.6	0.056			8.99	0.00751			4.2	0.011*	260	8.015	
18.3	0.057*			9.48	0.00754*			80	1.006*	270	8.396*	
19.1	0.058			10	0.00759	11.32	0.0702	90	1.353*	280	8.775*	
20.2	0.060			6.78	0.007406*	12.73	0.071*	100	1.725*	290	9.155*	
20.3	0.061*			7.68	0.007442*	14.26	0.076*	110	2.112	300	9.53*	
24.3	0.070			8.83	0.007510*	16.67	0.076*	120	2.508*	310	9.92*	
25.5	0.080			9.75	0.00759*	18.11	0.079	130	2.909*	320	10.19*	
30.6	0.100			10.58	0.00768*	19.81	0.082*	140	3.314*			
34.1	0.125			11.92	0.00787	21.08	0.0854	150	3.719*	CURVE 35		
39.7	0.175			12.96	0.00812	22.18	0.089*	160	4.124*	273	8.75	
45.3	0.237			13.89	0.00844*	24.36	0.097	170	4.522*	303	10.08	
49.9	0.297			14.93	0.00882	27.16	0.1077	180	4.922*			
53.6	0.366											

\* Not shown in figure.

TABLE 5. EXPERIMENTAL DATA ON THE ELECTRICAL RESISTIVITY OF LITHIUM Li (Temperature Dependence) (continued)

T	$\rho$	T	$\rho$	T	$\rho$	T	$\rho$
<u>CURVE 35 (cont.)</u>		<u>CURVE 39</u>		<u>CURVE 42 (cont.)</u>		<u>CURVE 45 (cont.)</u>	
333	11.22	454	23.40	7.30	0.0295	2600.0	167.4*
363	12.35	475	24.52	8.10	0.0296	2800.0	204.1*
393	13.66	500	25.36	9.19	0.0297	3000.0	254.1*
423	14.96	525	26.11	10.20	0.0299	3200.0	325.3*
443	15.74	550	26.85	11.39	0.0301	3400.0	435.5*
<u>CURVE 36</u>		575	27.60	12.28	0.0304	3600.0	627.5*
473	25.2	600	28.34	13.51	0.0310	3800.0	1049.6*
573	29.2	623	29.03	14.78	0.0317	4000.0	2782.0*
673	32.5	<u>CURVE 40</u>		16.04	0.0328		
773	35.8	543.5	27.68	17.73	0.0345		
<u>CURVE 37</u>		621.5	29.62*	20.43	0.0405		
299.9	9.64	674.3	31.56	<u>CURVE 43*</u>			
316.5	10.26	714.2	32.35	20.42	0.060		
341.8	11.06	769.1	33.90	80.13	1.06		
372.1	12.19*	845.3	35.90	90.89	1.41		
421.5	14.05	851.3	35.55	273.16	8.55		
436.8	14.64	871.9	36.27	<u>CURVE 44</u>			
449.6	15.16	957.0	38.42	1.19	0.0475		
452.6	15.29*	1044.3	40.74	4.21	0.0485		
<u>CURVE 38</u>		1047.1	40.36	20.41	0.0578		
454.6	24.25	1127.9	42.75	77.74	1.04		
456.8	25.18	1214.6	44.44	86.32	1.28*		
463.8	25.61	1243.9	44.70	273.16	8.55*		
472.4	25.81*	<u>CURVE 41</u>		<u>CURVE 45</u>			
474.3	26.13	564.5	27.18	453.7	23.89		
476.8	26.19*	602.5	28.38*	500.0	25.23		
503.5	27.11	673.1	30.69	600.0	28.17		
531.3	28.09	682.6	30.26	700.0	31.28		
582.6	29.65	740.6	31.89	800.0	34.59*		
589.9	29.96	806.3	33.89	900.0	38.09		
642.6	31.55	899.3	36.17	1000.0	41.83		
696.8	33.10	1029.0	38.90	1100.0	45.80		
752.1	34.54	1034.4	39.67	1200.0	50.04		
806.3	35.86	1181.6	42.62	1300.0	54.56		
862.6	37.29	1279.4	43.96	1400.0	59.47		
917.4	38.49	<u>CURVE 42</u>		1500.0	64.72		
971.5	39.90	1.60	0.0293	1600.0	70.38		
1026.0	41.09	2.00	0.0293	1700.0	76.50		
1081.8	42.53	3.00	0.0293	1800.0	83.14		
1137.6	43.8	4.16	0.0294	1900.0	90.39		
		5.21	0.0295	2000.0	98.34		
		6.00	0.0295	2200.0	116.5*		
				2400.0	139.0*		

\* Not shown in figure.

#### b. Pressure Dependence

There are 10 sets of experimental data available for the electrical resistivity of lithium as a function of pressure. The information on specimen characterization and measurement condition for each of the data sets is given in Table 6. The data are tabulated in Table 7 and shown in Figure 4.

The available data and information for the pressure dependence of electrical resistivity of lithium are inadequate for performing detailed analysis and synthesis at this time. Consequently, no recommendations are made and only experimental data are presented here.

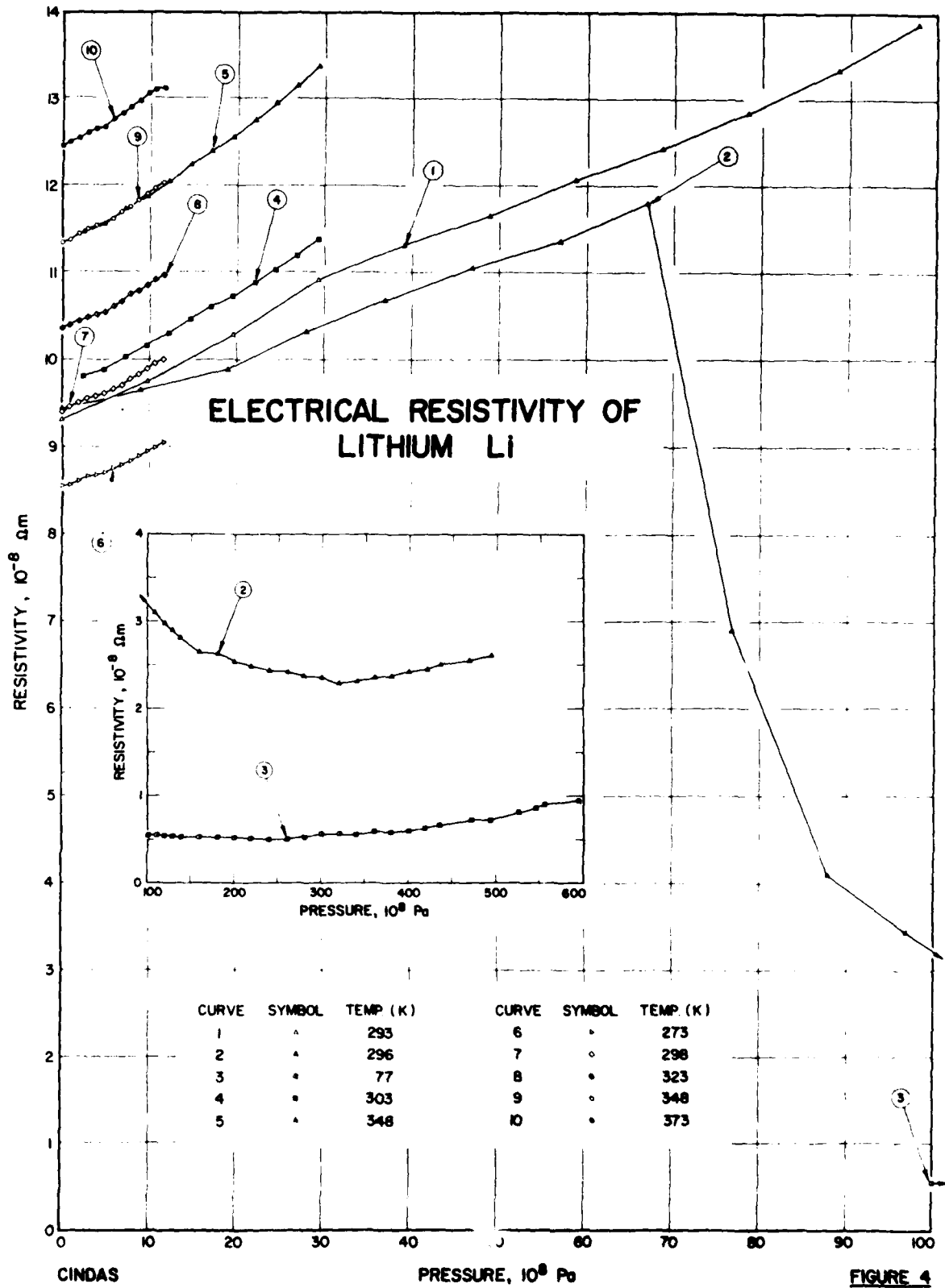


TABLE 6. MEASUREMENT INFORMATION ON THE ELECTRICAL RESISTIVITY OF LITHIUM Li (Pressure Dependence)

Cur. Ref. No.	Author(s)	Year	Method Used	Pressure Range, $10^6$ Pascal	Temperature Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1 30	Bridgman, P.W.	1952	A	0-98	~293		Pure; the specimen was squeezed and cut to final dimension under a heavy oil; the solid medium transmitting pressure within the cell is AgCl; relative resistance data were reported as a function of pressure; electrical resistivity data were obtained by using the compressibility and the recommended value of electrical resistivity at one atm pressure and 293 K.
2 31	Stager, R.A. and Drickamer, H.G.	1963	A	9-500	296		Commercial purity specimen; resistance as a function of pressure were reported; electrical resistivity data were obtained by using compressibility data and the recommended value of electrical resistivity at 296 K and one atm pressure.
3 31	Stager, R.A. and Drickamer, H.G.	1963	A	100-600	77		The above specimen; measured at 77 K after first pressing to $100 \times 10^6$ Pascal at 296 K and then cooling.
4 32	Bridgman, P.W.	1930	A	0-29.4	303		Pure; the specimen was obtained from Kahlbaum; it was extruded into a wire about 0.030 in. in diameter; the relative electrical resistance as a function of pressure data were reported.
5 32	Bridgman, P.W.	1930	A	0-29.4	348		The above specimen.
6 33	Bridgman, P.W.	1921	A	0-11.76	273		0.7 Al, trace of Fe; specimen was obtained from Merck; relative electrical resistance were reported.
7 33	Bridgman, P.W.	1921	A	0-11.76	298		The above specimen.
8 33	Bridgman, P.W.	1921	A	0-11.76	323		The above specimen.
9 33	Bridgman, P.W.	1921	A	0-11.76	348		The above specimen.
10 33	Bridgman, P.W.	1921	A	0-11.76	373		The above specimen.

TABLE 7. EXPERIMENTAL DATA ON THE ELECTRICAL RESISTIVITY OF LITHIUM L<sub>1</sub> (Pressure Dependence)  
 [Temperature, T, K; Pressure, P, 10<sup>8</sup> Pa; Resistivity,  $\rho$ , 10<sup>-3</sup>  $\Omega$ cm]

P	$\rho$	P	$\rho$	P	$\rho$	P	$\rho$	P	$\rho$	P	$\rho$						
CURVE 1 T = 293																	
0.0	9.326	466	2.56	24.5	11.03	4.90	9.62	0.00	12.46	0.00	12.46						
9.8	9.75	494	2.61	26.95	11.20	5.88	9.67	0.98	12.50	0.98	12.50						
19.6	10.29			29.4	11.39	6.86	9.71	1.96	12.56	1.96	12.56						
29.4	10.92	CURVE 3 T = 77															
39.2	11.32	100	0.554	CURVE 5 T = 348													
49.0	11.66	110	0.550	2.45	11.47	8.82	9.84	3.92	12.66	3.92	12.66						
58.8	12.06	119	0.548	4.9	11.56	9.80	9.90	4.90	12.68	4.90	12.68						
68.6	12.44	128	0.543	7.35	11.73	10.78	9.96	5.88	12.77	5.88	12.77						
78.4	12.85	138	0.539	9.8	11.88	11.72	10.01	6.86	12.84	6.86	12.84						
88.2	13.35	159	0.533	12.25	12.05	CURVE 8 T = 323											
98.0	13.89	180	0.528	14.7	12.24	0.00	10.36	7.84	12.91	7.84	12.91						
CURVE 2 T = 296																	
0	9.44	199	0.524	17.15	12.40	0.98	10.40	8.82	12.98	8.82	12.98						
9	9.65	218	0.518	19.6	12.56	1.96	10.45	9.80	13.07	9.80	13.07						
19	9.88	239	0.515	22.05	12.76	2.94	10.49	10.78	13.13	10.78	13.13						
28	10.32	260	0.510	24.5	12.95	3.92	10.53	11.76	13.21	11.76	13.21						
37	10.68	280	0.527	26.95	13.18	4.90	10.55	CURVE 9 T = 348									
47	11.06	299	0.564	29.4	13.38	5.88	10.62	0.00	11.35	0.00	11.35						
57	11.37	320	0.562	CURVE 6 T = 273													
67	11.81	339	0.559	0.00	8.55	6.86	10.68	0.98	11.38	0.98	11.38						
77	6.90	360	0.586	1.96	8.61	7.84	10.76	1.96	11.45	1.96	11.45						
86	4.09	379	0.585	2.94	8.66	8.82	10.80	2.94	11.50	2.94	11.50						
97	3.43	399	0.612	3.92	8.68	9.80	10.86	3.92	11.54	3.92	11.54						
108	3.10	418	0.640	4.90	8.70	10.78	10.92	4.90	11.56*	4.90	11.56*						
119	2.98	435	0.665	5.88	8.75	11.72	10.98	5.88	11.62	5.88	11.62						
128	2.90	471	0.723	6.86	8.79	6.86	11.70	6.86	11.70	6.86	11.70						
137	2.81	494	0.721	7.84	8.83	7.84	11.76	7.84	11.76	7.84	11.76						
159	2.65	526	0.806	8.82	8.89	8.82	11.83	8.82	11.83	8.82	11.83						
180	2.63	546	0.861	9.80	8.94	9.80	11.91	9.80	11.91	9.80	11.91						
199	2.54	567	0.918	10.78	8.99	10.78	11.97	10.78	11.97	10.78	11.97						
239	2.44	595	0.941	11.76	9.06	CURVE 7 T = 296											
260	2.42			0.00	9.42	0.00	9.42	0.00	9.42	0.00	9.42						
278	2.37	2.45	9.81	0.98	9.47	0.98	9.47	0.98	9.47	0.98	9.47						
298	2.36	4.9	9.88	1.96	9.52	1.96	9.52	1.96	9.52	1.96	9.52						
319	2.29	7.35	10.03	2.94	9.56	2.94	9.56	2.94	9.56	2.94	9.56						
340	2.31	9.8	10.16	3.92	9.59	3.92	9.59	3.92	9.59	3.92	9.59						
369	2.36	12.25	10.30	4.90	10.72	4.90	10.72	4.90	10.72	4.90	10.72						
379	2.36	14.7	10.46	5.88	10.88	5.88	10.88	5.88	10.88	5.88	10.88						
399	2.43	17.15	10.60	6.86		6.86		6.86		6.86							
420	2.45	19.6	10.72	7.84		7.84		7.84		7.84							
435	2.51	22.05	10.88	8.82		8.82		8.82		8.82							

\* Not shown in figure.

### c. Magnetic Flux Density Dependence

There are 9 sets of experimental data available for the electrical resistivity of lithium under the influence of magnetic field. The information on specimen characterization and measurement information for each of the data sets is given in Table 8. The data are tabulated in Table 9 and shown in Figure 5.

The available data and information for the magnetic flux density dependence of electrical resistivity of lithium are inadequate for performing detailed analysis and synthesis at this time. Consequently, no recommendations are made and only experimental data are presented here.

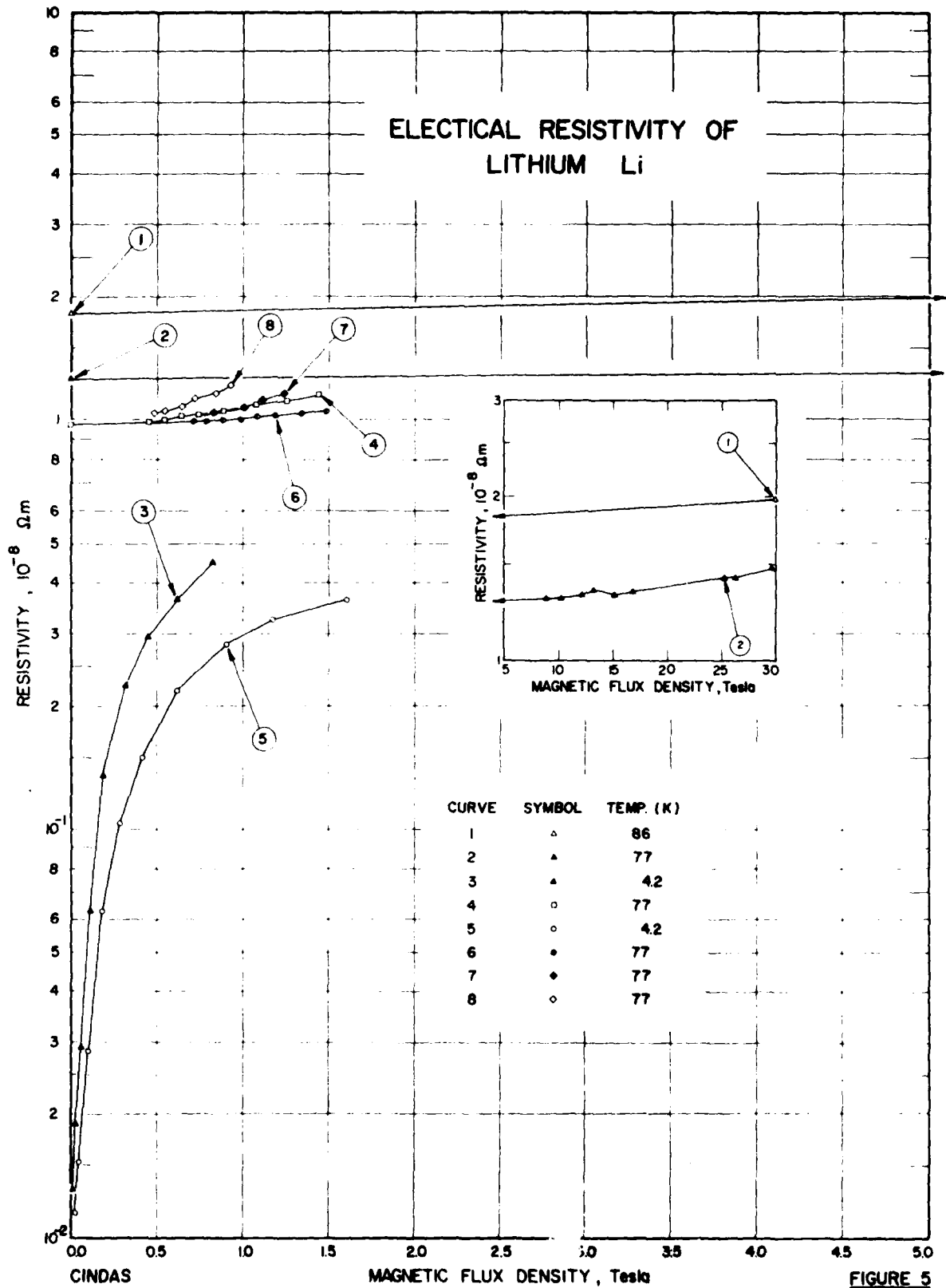


FIGURE 5



TABLE 8. MEASUREMENT INFORMATION ON THE ELECTRICAL RESISTIVITY OF LITHIUM Li (Magnetic Flux Density Dependence)

Cur. Ref. No.	Author(s)	Year	Method Used	Magnetic Flux Density Range, Tesla	Temperature Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1 34	Kapitza, P.	1929		0, 30	86	Li <sub>I</sub>	99.9 pure; specimen was obtained from Kahlbaum; magnetoresistance measurements were made in a transverse magnetic field; $R/R_r = 0.195$ , where $R_r$ is the resistance at room temperature.
2 34	Kapitza, P.	1929		0-30	77	Li <sub>II</sub>	99.9 pure; specimen was obtained from Kahlbaum; magnetoresistance measurements were made in a transverse magnetic field; $R/R_r = 0.137$ , where $R_r$ is the resistance at room temperature.
3 35	Gugan, D. and Jones, B.K.	1963	A	0-0.83	4.2		Pure; -phase mixture; specimen dimension 1.0 mm x 50 cm; the specimen was prepared from an ingot of low sodium content lithium originally obtained from the Lithium Corp. of America; the specimen was prepared by extrusion under liquid paraffin at room temperature, and they were rinsed with Analaar benzene; the specimen was annealed at room temperature for a week; the residual resistance ratio $R_{293 K}/R_4.2 K = 985$ ; the magnetoresistance measurement was in a transverse field; data were extracted from the smooth curve.
4 35	Gugan, D. and Jones, B.K.	1963	A	0-1.43	77		Same as the above specimen and conditions.
5 35	Gugan, D. and Jones, B.K.	1963	A	0-1.60	4.2		Same as the above specimen; similar conditions except it was measured in a longitudinal field.
6 35	Gugan, D. and Jones, B.K.	1963	A	0-1.49	77		Same as the above specimen and conditions.
7 35	Gugan, D. and Jones, B.K.	1963	A	0.5-1.24	77		Similar to the above specimen except it was pure bcc phase.
8 35	Gugan, D. and Jones, B.K.	1963	A	0.49-0.93	77		Same as the above specimen and similar conditions except it was measured in a transverse field.
9 36	Juntti, E.	1948	A	0, 3.04	20.4		Pure; resistance ratio $R_{20.4 K}/R_{273.15 K} = 0.0243$ ; measured in a transverse magnetic field.

TABLE 9. EXPERIMENTAL DATA ON THE ELECTRICAL RESISTIVITY OF LITHIUM Li (Magnetic Flux Density Dependence)  
 [Temperature, T, K; Magnetic Flux Density, B, Tesla; Electrical Resistivity,  $\rho$ ,  $10^{-8}$   $\Omega$ m]

B	$\rho$	B	$\rho$	B	$\rho$
<u>CURVE 1</u>					
$T = 86$					
0.0	1.9185	0.029	0.0117	0.840	1.169
30.0	1.9822	0.047	0.154	0.925	1.211
<u>CURVE 2</u>					
$T = 77$					
0.0	1.2777	0.090	0.0287	<u>CURVE 9</u>	
8.9	1.3033	0.178	0.0628	$T = 20.4$	
10.3	1.3033	0.285	0.104	0.00	0.2078
12.1	1.3384	0.404	0.150	3.04	0.2306
13.1	1.3567	0.623	0.219	<u>CURVE 5</u>	
15.1	1.3290	0.900	0.283	$T = 77$	
16.7	1.343	1.17	0.324	0.000	0.975*
25.3	1.4222	1.60	0.365	0.709	0.992
26.4	1.4222	<u>CURVE 6</u>			
29.6	1.4849	$T = 77$			
<u>CURVE 3</u>					
$T = 4.2$					
0.014	0.0109	0.788	0.996	0.944	1.001
0.023	0.0131	0.983	1.006	1.06	1.012
0.037	0.0190	1.18	1.021	1.33	1.034
0.052	0.0292	1.49	1.050	<u>CURVE 7</u>	
0.102	0.0633	$T = 77$			
0.187	0.131	0.459	0.999*	0.535	1.01*
0.323	0.225	0.623	1.02*	0.735	1.04*
0.445	0.296	0.821	1.05	1.00	1.08
0.615	0.367	1.10	1.11	1.24	1.16
0.829	0.451	<u>CURVE 8</u>			
$T = 77$					
0.000	0.975	0.492	1.037	0.535	1.050
0.455	0.994	0.584	1.066*	0.646	1.087
0.535	1.00	0.705	1.113	0.784	1.137*
0.640	1.01	<u>CURVE 8</u>			
0.742	1.02	$T = 77$			
0.894	1.05	<u>CURVE 8</u>			
1.06	1.08	$T = 77$			
1.25	1.11	<u>CURVE 8</u>			
1.43	1.16	$T = 77$			

\* Not shown in figure.

## 4.2. SODIUM

Sodium, with atomic number 11, is a soft, silver-white, lustrous alkali metal. It is a very reactive element and never found free in nature. Except at low temperatures it has a body-centered cubic crystalline structure, with a density of  $0.971 \text{ g cm}^{-3}$  at 293 K. It melts at 371.0 K and boils at about 1156 K. Its critical temperature has been estimated to be about 2733 K. Sodium contracts on freezing in a normal manner. The volume changes on melting is about 2.71% at one atmosphere. Sodium undergoes a partial martensitic transformation to hexagonal close-packed structures at about 36 K and therefore has a mixed phase below this temperature. Sodium has only one stable isotope,  $^{23}\text{Na}$ , but six other radioactive isotopes are known to exist. The metal is the sixth most abundant element in the continental crust of the earth (2.36% by weight).

Sodium is the metal which the quasi-free electron model describes the best. Its Fermi surface is not influenced by zone boundaries and therefore is spherical. Electrical resistivity measurements indicate that, despite the martensitic transformation, sodium retains its spherical Fermi surface.

### a. Temperature Dependence

There are 65 sets of experimental data available for the electrical resistivity of sodium. The information on specimen characterization and measurement conditions for each of the data sets is given in Table 11. The data are tabulated in Table 12 and shown in Figures 6 and 7. Determinations of the electrical resistivity of sodium for the solid and liquid phases cover continuously the temperature range from 1.8 to 1366 K.

There are 27 experimental data sets obtained below 100 K. Among these, White and Woods [37] (curve 38) give the lowest residual resistivity. There are 17 sets of intrinsic resistivity available. Dugdale and Guban [38] (curves 45 and 46) have reported the intrinsic resistivity of the separate bcc and hcp phases between 16 and 52 K. The resistivity of the hcp phase is lower than that of the bcc phase. In deriving the smoothed most probable values of intrinsic resistivity from the available data, the following overlapping temperature ranges were considered: below 14 K, 9-21 K, 14-30 K, 20-50 K, 30-100 K, 40-100 K, 50-100 K, etc. Within each range, a least-mean-square fraction error fit with the semiempirical equation  $\rho_1 = aT^b$  was made to all the available intrinsic resistivity data. The resulting values for adjacent ranges were intercompared and the values were corrected for thermal linear expansion. These preliminary values were then fitting with the cubic spline function equation (7) to generate the final recommended intrinsic resistivity values. The coefficients of equation (7) obtained are given in the following table:

Temperature Range, K	a	b	c	d
1 - 8.26	-8.523	5.582	-0.572	0.299
8.26- 11.04	-3.654	5.288	0.252	-10.15
11.04- 12.29	-3.003	4.874	-3.537	21.47
12.29- 36.71	-2.783	4.684	-0.546	-17.98
36.71- 65.89	-0.873	2.947	-3.109	3.606
65.89- 73.44	-0.265	2.066	-0.361	-10.52
73.44-100	-0.170	1.962	-1.849	1.554

Below 15 K, the intrinsic resistivity  $\rho_i$  approximately follows Bloch's  $T^5$  law. Because martensitic transformation effects of sodium affects the electrical resistivity values [38], the values below 40 K are provisional and are for a specimen of mixed phases.

There are 24 data sets in the temperature region from 100 K to the melting point 371 K. They agree with each other within 10%. Dugdale and Gugan [8] reported electrical resistivities at constant volume (curve 22), which are lower than those at zero pressure (curve 23). Only one set of data were measured on single crystals by Fritsch and Lüscher [39] (curve 30), and there is little difference in electrical resistivity values between the polycrystalline specimens and the single crystal specimen. A least-mean-square error fit to the totality of experimental data in this range was made with a third order polynomial. The resulting values were corrected for thermal linear expansion and then fitted with the cubic spline function equation (7) to obtain the final recommended values in this temperature range. The coefficients of equation (7) obtained are as follows:

Temperature Range, K	a	b	c	d
73.44-371	-0.170	1.962	-1.849	1.554

There are 27 data sets available for the liquid state. Endo [40] (curve 25), Lien and Silversten [41] (curve 18), and Swalin [42] (curve 48) have investigated the electrical resistivity at constant volume conditions and they agree with one another within 5%. The rest of the data are apparently measured at the saturated vapor pressure. At least nine sets of experimental values below 1300 K agree to within 10%. Semyachikin and Solov'ev [18] (curve 31) give the highest values while Freeman and Robertson [9] (curve 19) give the lowest values. Grosse [5] derived electrical resistivity (curve 65) values in the range from the melting point to his estimated critical temperature, 2800 K, by fitting the data of Kapelner and Bratton [43] (curve 17) to a hyperbolic equation. All the experimental data sets except those measured at constant volume were used here for the cubic spline function equation (7) to obtain the final recommended values. The coefficients of equation (7) are as follows:

Temperature Range, K	a	b	c	d
371 -1548.9	0.974	1.440	-0.365	1.041
1548.9-2000	1.996	2.219	1.602	24.77

The resistivity values represented by this equation are not corrected for thermal linear expansion of the container, which in most cases is not specified.

At the melting point (371 K), the electrical resistivity of sodium in the liquid state is about 40% higher than that of the solid state.

The recommended values for the total and intrinsic electrical resistivities are listed in Table 10, and those for the total electrical resistivity are also shown in Figures 5 and 6. The recommended values for the liquid state are for the saturated liquid. The recommended values for the total resistivity for the solid state are for a 99.99+ % pure sodium and those at temperatures below 40 K are applicable only to a specimen with residual resistivity  $\rho_0 = 0.000887 \times 10^{-8} \Omega\text{m}$ . The recommended values from 1 K to 371 K are corrected for thermal linear expansion. The correction amounts to -1.48% at 1 K, -1.2% at 100 K and 0.56% at 371 K. The uncertainty of the recommended total electrical resistivity is believed to be within  $\pm 20\%$  from 1 K to 40 K, within  $\pm 5\%$  from 40 K to 1500 K, and  $\pm 10\%$  from 1500 K to 2000 K. Above 50 K the uncertainty of the recommended values for the intrinsic resistivity is about the same as that of the total electrical resistivity; below 50 K this uncertainty is higher than that of the total electrical resistivity.

TABLE 10. RECOMMENDED ELECTRICAL RESISTIVITY OF SODIUM  
(Temperature Dependence)

[Temperature, T, K; Total Resistivity,  $\rho$ ,  $10^{-8} \Omega \text{ m}$ ; Intrinsic Resistivity,  $\rho_i$ ,  $10^{-8} \Omega \text{ m}$ ]

Solid					Liquid		
T	$\rho$	$\rho_i$	T	$\rho$	$\rho_i$	T	$\rho$
1	$8.87 \times 10^{-4*}$		35	0.117*	0.116*	371	9.43
2	$8.87 \times 10^{-4*}$	$1.3 \times 10^{-7*}$	40	0.172*	0.171*	400	10.50
3	$8.88 \times 10^{-4*}$	$1.1 \times 10^{-6*}$	45	0.233	0.232	500	14.36
4	$8.92 \times 10^{-4*}$	$5.0 \times 10^{-6*}$	50	0.300	0.299	600	18.56
5	$9.03 \times 10^{-4*}$	$1.59 \times 10^{-5*}$	60	0.447	0.446	700	23.20
6	$9.28 \times 10^{-4*}$	$4.12 \times 10^{-5*}$	70	0.615	0.614	800	28.38
7	$9.80 \times 10^{-4*}$	$9.26 \times 10^{-5*}$	80	0.796	0.795	900	34.19
8	0.00107*	$1.87 \times 10^{-4*}$	90	0.978	0.977	1000	40.73
9	0.00123*	$3.49 \times 10^{-4*}$	100	1.158	1.157	1100	48.12
10	0.00149*	$6.03 \times 10^{-4*}$	150	2.03	2.03	1200	56.45
11	0.00186*	0.00097*	200	2.89	2.89	1300	65.85
12	0.00237*	0.00048*	250	3.86	3.86	1400	76.44
13	0.00303*	0.00214*	273.15	4.33	4.33	1500	88.37
14	0.00391*	0.00302*	293	4.77	4.77	1600	101.8*
15	0.00503*	0.00414*	300	4.93	4.93	1700	117.1*
16	0.00644*	0.00555*	350	6.23	6.23	1800	135.1*
18	0.0102*	0.00934*	371	6.86	6.86	1900	157.1*
20	0.0156*	0.0147*				2000	184.4*
25	0.0370*	0.0361*					
30	0.0711*	0.0702*					

\* Provisional values.

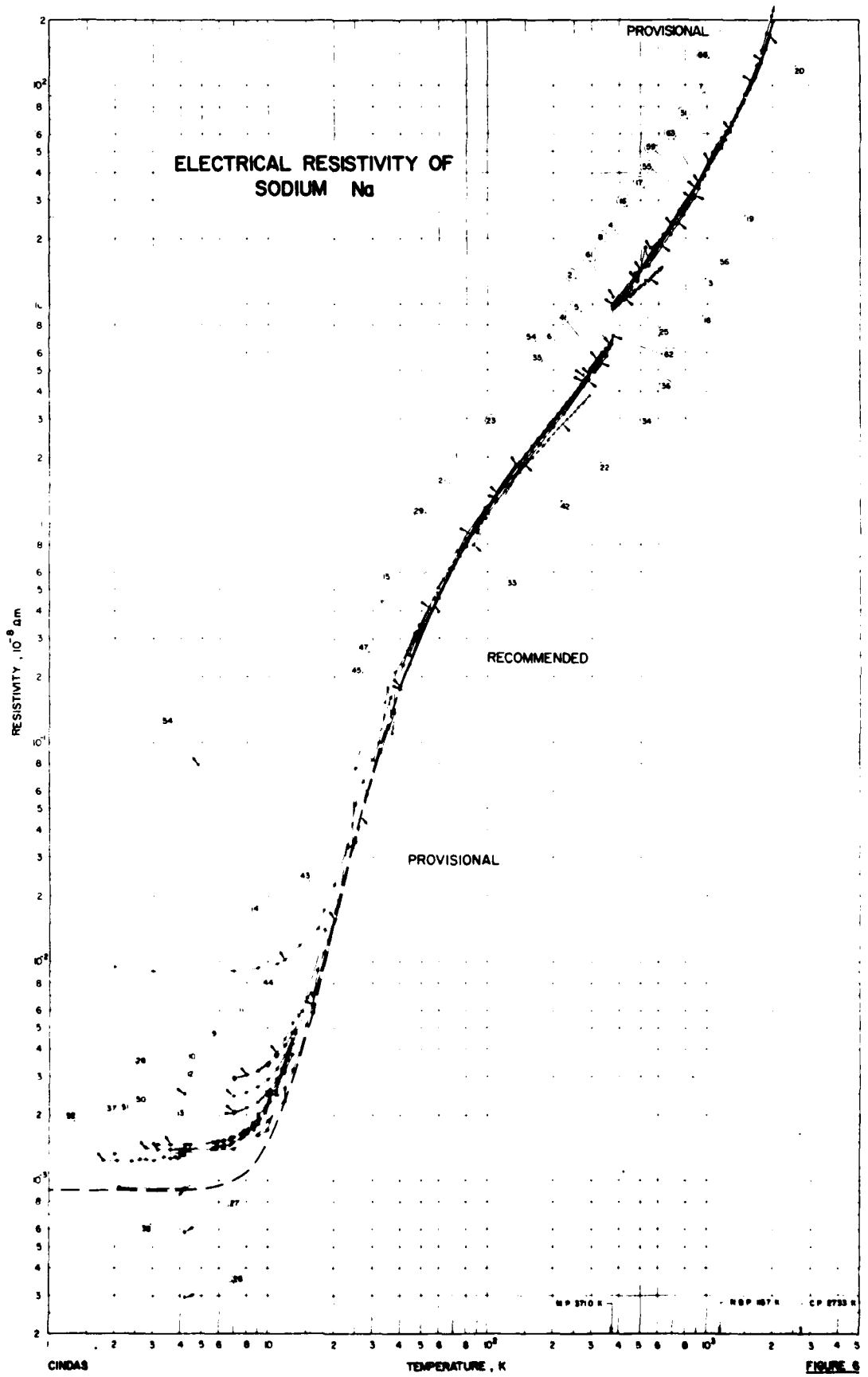


FIGURE 6

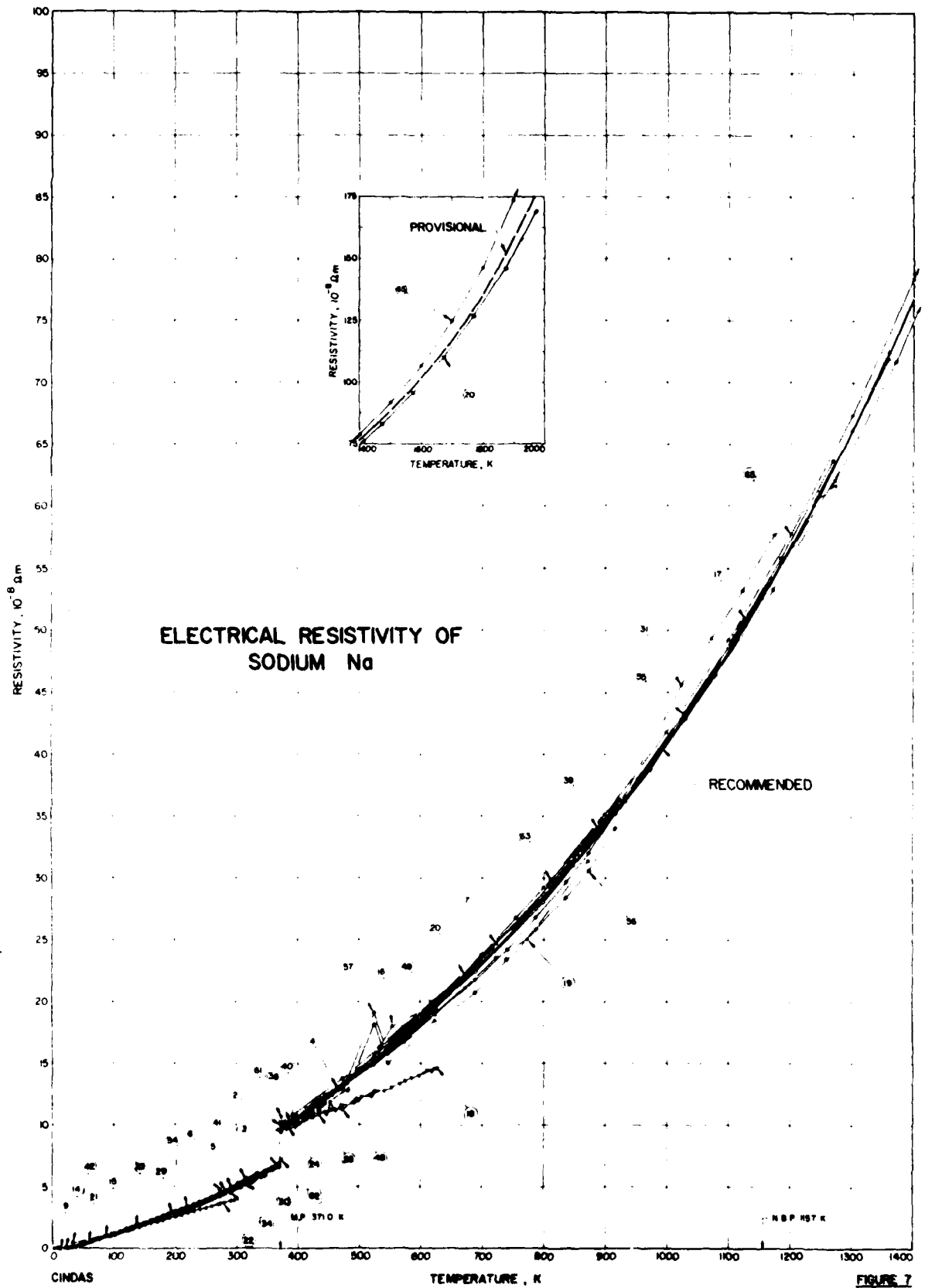




TABLE 11. MEASUREMENT INFORMATION ON THE ELECTRICAL RESISTIVITY OF SODIUM Na (Temperature Dependence)

Cur. Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1 44	Bradshaw, F. J. and Pearson, S.	1956	A	78-370		0.0025 K and < 0.0005 O; specimen was obtained from the Atomic Energy Research Establishment, Harwell; nickel tube 0.5 mm in diameter, 0.075 mm wall thickness and 16 mm long; was used to contain sodium.
2 45	Hennepf, J., Van Der Lugt, W., and Wright, G. W.	1971	B	373.15-398		99.95 pure specimen was supplied by Koch Light Co.; resistivity was a linear function of temperature from melting point to 125 C; described by $\rho_0/\Delta T = 0.034 \times 10^{-4} \Omega\text{m}/\text{K}$ . Pure; liquid state.
3 46	Bornemann, K. and Rauschenplatt, G.	1912		367-623		
4 47	Addison, C. C., Creffield, G. K., Rubberstey, P., and Fulham, R. J.	1969	B	371-570		Pure; < 0.04 Ca, < 0.001 O; liquid state; specimen was contained in AISA 321 stainless steel tubes 0.146 and 0.148 cm diameter, 11.249 and 12.427 cm long; density at 390.95 K is 0.927 g cm <sup>-3</sup> .
5 47	Addison, C. C., et al.	1969	B	292-370		Similar to above specimen except it was in solid state; density at 390.95 K is 0.9514 g cm <sup>-3</sup> .
6 48	Savenchenko, V. A. and Shpil'rain, E. E.	1969	A	283-357		0.006 H <sub>2</sub> , 0.0049 O <sub>2</sub> , 0.0042 Mn, 0.002 Fe, Ni, 0.0014 N <sub>2</sub> , 0.001 Ca, Si, Ti, V, 0.0064 Cr, 0.0003 Li, Mg, Cu, 0.0001 Al, Cd, Zr, 0.00001 Cs; the specimen was obtained from the Institute of the Chemistry and Technology of Rare Elements and Raw Minerals; measurements made in a stainless steel tube 10.5 cm in external diameter, 0.4 mm wall thickness. Similar to above specimen except liquid state.
7 48	Savenchenko, V. A. and Shpil'rain, E. E.	1969	A	384-1271		
8 49	Aksenova, L. I. and Belashchenko, D. K.	1971		363-473		
9 50	Holzhauser, W.	1970	G	7.0-13	1a	99.9 pure; liquid state; measurements made with capillary cell.
10 50	Holzhauser, W.	1970	G	7.0-13	1b	Specimen consisted of 41% hexagonal close packed crystal structure, the remainder being body center cubic; electrical resistivity data obtained from $\rho = \rho_0 + aT^3$ with $\rho_0 = 2.88 \times 10^{-11} \Omega\text{m}$ , $a = 5.13 \times 10^{-11} \Omega\text{m}/\text{K}^3$ .
11 50	Holzhauser, W.	1970	G	7.0-13	4a	Specimen consisted of 19% hexagonal close packed crystal structure, the remainder being body center cubic; electrical resistivity data obtained from $\rho = \rho_0 + aT^3$ with $\rho_0 = 2.35 \times 10^{-11} \Omega\text{m}$ , $a = 5.61 \times 10^{-11} \Omega\text{m}/\text{K}^3$ .
12 50	Holzhauser, W.	1970	G	7.0-13	3a	Specimen consisted of 8% hexagonal close packed crystal structure, the remainder being body center cubic; electrical resistivity data obtained from $\rho = \rho_0 + aT^3$ with $\rho_0 = 2.90 \times 10^{-11} \Omega\text{m}$ , $a = 6.63 \times 10^{-11} \Omega\text{m}/\text{K}^3$ .
13 50	Holzhauser, W.	1970	G	7.0-13	3b	Specimen consisted of 12% hexagonal close packed crystal structure, the remainder being body center cubic; electrical resistivity data obtained from $\rho = \rho_0 + aT^3$ with $\rho_0 = 2.00 \times 10^{-11} \Omega\text{m}$ , $a = 4.84 \times 10^{-11} \Omega\text{m}/\text{K}^3$ .
14 51	Berman, R. and MacDonald, D. K. C.	1951		2-46	Na I	Specimen consisted of 17% hexagonal close packed crystal structure, the remainder being body center cubic; electrical resistivity data obtained from $\rho = \rho_0 + aT^3$ with $\rho_0 = 1.95 \times 10^{-11} \Omega\text{m}$ , $a = 6.13 \times 10^{-11} \Omega\text{m}/\text{K}^3$ .
15 51	Berman, R. and MacDonald, D. K. C.	1951		2-80	Na II	Approximately 0.01 to 0.1 Al and Ca; supplied by British-Thomson-Houston Research Lab.; cast under vacuum in soft glass tubes. Trace of Ag; supplied by Messrs. Philips Ltd., Mitcham; cast under vacuum in soft glass tubes.
16 16	Tepper, F., Zelenk, J., Roehlich, F., and May, V.	1965	A	302-1360		Pure; density 0.8997, 0.8255, 0.8119, 0.7881, 0.7640, 0.7381 and 0.6967 g cm <sup>-3</sup> at 483.8, 804.1, 873.1, 972.7, 1085, 1189 and 1394 K, respectively.

TABLE 11. MEASUREMENT INFORMATION ON THE ELECTRICAL RESISTIVITY OF SODIUM Na (Temperature Dependence) (continued)

Cur. Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
17	Kapelnier, S. M. and Bratton, W. D.	1962	B	371-1126		<0.0375 Cs, K, < 0.015 Li, 0.0066 Fe, 0.0048 N <sub>2</sub> , 0.0032 O <sub>2</sub> , 0.0022 N <sub>2</sub> and <0.001 Cr; specimen was purchased from U. S. Industrial Chemical Co.; purified by melting and forcing molten liquid through a 20 $\mu$ stainless steel filter under purified argon; the tube was heated to about 550 C and then held for 2 hr prior to measurements.
18	Lien, S. Y. and Silverstein, J. M.	1969	A	373-623		99.95 pure; specimen was supplied by A. D. Mackay Inc.; the electrical resistivity specimen cell was made from precision quartz capillary open on one end, four tungsten current and potential leads were sealed into the capillary; measurements at constant volume.
19	Freedman, J. F. and Robertson, J. F.	1961	B	373-873		0.01 K, 0.003 Cl, 0.002 Li, Cs, 0.0125 others; sample was supplied by E. I. DuPont de Nemours Co.; specimen in liquid state; 304 stainless steel was the cell material, 0.349 in. diameter, 20 in. length.
20	Solov'ev, A. N.	1963		373-1973		Pure; density 0.928 g cm <sup>-3</sup> at 373 K, 0.706 g cm <sup>-3</sup> at 1273 K; data above 1293 K were extrapolated.
21	Dugdale, J. S. and Guggan, D.	1962	A	50-295	Na(6)	Pure; specimen was supplied by Messers A. D. Mackay and Co., New York; specimen was made in the form of base wire, 0.5 mm in diameter, 1 mm in length; $R_{4,2}/R_{300} = 3.0 \times 10^{-4}$ ; electrical resistivity was measured at zero pressure.
22	Dugdale, J. S. and Guggan, D.	1962	A	50-295	Na(6)	Same as the above specimen except the electrical resistivity was obtained at constant volume.
23	Dugdale, J. S. and Guggan, D.	1962	A	44-273.15	Na(4)	Pure; specimen was supplied by N. V. Phillips, Eindhoven Co.; specimen in glass capillary; $R_{4,2}/R_{300} = 2.0 \times 10^{-4}$ ; electrical resistivity was measured at zero pressure.
24	Endo, H.	1963	A	373-448		Pure; sample was supplied by A. D. Mackay Ltd.; specimen container was made of soft glass and consisted to a capillary tube (I.D. 0.7 mm) between two bulbs equipped with platinum electrode; electrical resistivity was measured at constant pressure condition.
25	Endo, H.	1963	A	373-448		Same as above specimen except electrical resistivity was obtained at constant volume.
26	Stern, R., Natale, G. G., and Rudnick, I.	1966	A	4.2-273	Na 1	High purity polycrystalline sample, vacuum distilled; annealed; 0.104 cm in diameter and 11.05 cm in length.
27	Stern, R., et al.	1966	A	4.2-273	Na 2	Similar to above specimen; 0.109 cm in diameter, 11.55 cm in length.
28	Stern, R., et al.	1966	A	4.2-273	Na 3	Similar to above specimen; unannealed.
29	McLennan, J. C. and Niven, C. D.	1927	B	20.6-273		Pure.
30	Fritsch, G. and Lüscher, E.	1969	B	308-371		99.99 pure; < 0.017 K, < 0.021 Mg, < 0.0012 Fe, and < 0.00087 Ca; single crystal specimen with crystal axis 7° to [100] direction; specimen was put in VZA steel tube 0.1 mm wall, 6 mm diameter; 12 cm long.
31	Semgachkin, B. E. and Solov'ev, A. N.	1964	A	373-1273		Pure; TU 1664-50 sample was placed in an 0.8/0.5 mm capillary, 600 mm long.
32*	Pachard, D. R. and Verhoeven, J. D.	1968	-	373-473		99.99 pure; electrical resistivity was measured by capillary-receiver technique.
33	Gumiz, A. and Bronieski, W.	1909		66-323		Pure; solid specimen.

\* Not shown in figure.

TABLE 11. MEASUREMENT INFORMATION ON THE ELECTRICAL RESISTIVITY OF SODIUM Na (Temperature Dependence) (continued)

Cur. Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
34	Hackspill, L.	1910	A	290-15	1	Pure; distilled sample was placed in a tube about 1-2 cm in diameter, 10-20 cm long.
35	Hackspill, L.	1910	A	273, 15, 291, 15	2	Similar to the above specimen.
36	Hackspill, L.	1910	A	93-389	3	Similar to the above specimen.
37	White, G. K. and Woods, S. B.	1956	A	2.1-18.6	Na 3	Pure; cast in soft glass; 0.13 mm in diameter, $\rho_0/\rho_{373} = 3 \times 10^{-4}$ .
38	White, G. K. and Woods, S. B.	1956	A	2.1-18.6	Na 4	Pure; cast in soft glass; 0.35 mm in diameter.
39	Roehlich, F. and Tepper, F.	1965	A	379-1366		Pure; specimen was placed in a Haynes-25 alloy cylindrical cell 0.5 in. O. D. with wall thickness 0.065 in. and 26 in. long.
40	Regel, A. R.	1958		273-473		Pure; data were extracted from the smooth curve.
41	Hornbeck, J. W.	1913		279-361		Pure; supplied by Eimer and Amend.
42	Bidwell, C. C.	1926		33-348		Pure; 0.2921 cm in diameter, 51.3 cm long, extruded bare wires.
43	Dugdale, J. S. and Gagan, D.	1960	A	16-37, 35	Na(7)	Pure; specimen was obtained from Messers A. D. Mackay and Co., New York; $R_{37}/R_{35} = 3.8 \times 10^{-4}$ ; by cooling the annealed sample to 4 K and measuring its resistance up to 40 K ideal electrical resistivity data were extracted from table.
44	Dugdale, J. S. and Gagan, D.	1960	A	16-37, 35	Na(7)	Same as above specimen, subsequently twice warming to 80 K and cooling to 4 K.
45	Dugdale, J. S. and Gagan, D.	1960	A	16-52	ideal B. C. C. Na	Pure; body center cubic phase; ideal electrical resistivity was calculated from 16 K to 40 K.
46*	Dugdale, J. S. and Gagan, D.	1960	A	16-52	ideal H. C. P. Na	Pure; hexagonal close packed phase; ideal resistivity was calculated from 16 to 52 K.
47	Cook, J. G., Van der Meer, M. P., and Laubitz, M. J.	1972		40-360	NRC 3	0.004 K, 0.0015 Si, < 0.001 Zr, Rb, 0.0005 Ca, < 0.0005 B, Co, Sn, Pb, Y, Ti, Mo, Bi, < 0.0003 Ba, 0.0003 Fe, Ba, 0.0002 Al, Cu, 0.0001 Mg, < 0.0001 Mn, Cr, Ni, V, Be, Ag, Sn, Li; specimen was obtained from Mine Safety Appliance Corp.
48	Swalin, R. A.	1967		371-623		Pure; liquid state electrical resistivity were calculated under constant volume condition.
49	Swalin, R. A.	1967		371-623		Pure; liquid state electrical resistivity were calculated under constant pressure (1 atm) condition.
50	MacDonald, D. K. C., White, G. K., and Woods, S. B.	1955, 1956	G	2.5-16	Na 1	Pure; specimen was cast in a fine soft glass capillary, 0.9 mm in diameter, 7 cm long continuous with a 50 cm long helically wound tube of about 0.2 mm I. D.; $\rho_0/\rho_{373} = 3.60 \times 10^{-4}$ .
51	MacDonald, D. K. C., et al.	1955, 1956	G	2.5-16	Na 2	Similar to the above specimen except the capillary was 0.5 mm in diameter, 7 cm in length and $\rho_0/\rho_{373} = 2.92 \times 10^{-4}$ .
52	Garland, J. C. and Bower, R.	1968, 1969	A	1.8-4.2		Pure; specimen was prepared by drawing molten sodium into a teflon tube, the voltage and current probes were then inserted through the side of tube; $\rho_{373}/\rho_0 = 3800$ , $\rho_0$ was obtained by using $\rho_{373} = 4.73 \times 10^{-4}$ Ohm.
53*	Greenfield, A. J.	1964	A	371		99.999% pure; liquid state; density 0.929 g cm <sup>-3</sup> .
54	Collman, R. R., Blewitt, T. H., Klambunde, C. E., Redman, J. K., and McDonald, D. L.	1961		4.8, 273		Pure; specimen was prepared by casting it under vacuum in a 0.125 in. O. D. and 0.004 in. wall and 1.50 in. long stainless steel tube.

\* Not shown in figure.

TABLE II. MEASUREMENT INFORMATION ON THE ELECTRICAL RESISTIVITY OF SODIUM Na (Temperature Dependence) (continued)

Cur. Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
55	Evangelisti, R. and Isaacchini, F.	1965	A	371-1273	Na	Pure; specimen in liquid state was placed in a type 316 stainless steel container.
56	Beisshchenko, D. K. and Vol'deit, A. V.	1972	A	393-917	1	0.005 Cd; specimen was placed in a molybdenum glass on 1 Kh18N9T stainless steel capillaries, the inner diameter was 1-2 mm, the length of the column was 40 mm; specimens were heat treated for the establishment of a steady state, at the end of heating treatment the sample was quenched in oil; electrical resistivity data were extracted from the smooth curve.
57	Beisshchenko, D. K. and Vol'deit, A. V.	1972	A	393-917	2	0.39 Cd; other specifications similar to the above specimen.
58*	Krautz, E.	1950	A	273	Na	Pure.
59*	Northrup, E. F.	1911	B	293.15, 373.15		Pure; specimen was supplied by Merck; sample was filled in a glass tube with platinum potential and current terminals; electrical resistivity data were obtained by comparing the electrical resistance of mercury and sodium.
60*	Van der Lugt, W., Devlin, J. F., Hemphof, J., and Leemstra, M. R.	1973	B	373.15, 473.15	Na	Pure.
61	Tamaki, S., Ross, R. G., Cusack, N. E., and Endo, H.	1973	A	373.15	Na	Pure; liquid state; the electrical resistivity was measured at pressure equal to 1 bar.
62	Tamaki, S., et al.	1973	A	373.15	Na	Same as above specimen; the electrical resistivity was measured at pressure equal to 4 kbar.
63	Bocilla, C. F., Lee, D., and Foley, P. J.	1965	V	533-922	Na	0.002 Na, 0.0015 Cl, 0.006 SO <sub>2</sub> , 0.0003 Fe, 0.0001 P <sub>2</sub> O <sub>5</sub> , and 0.0001 heavy metals; liquid state specimen was contained in a 316 stainless steel tube with O. D. of 7/16 in., wall of 0.018 in. and about 8 in. long; Chromel-Alumel thermocouples were used to measure the temperature.
64*	Savchenko, V. A. and Sapl'rain, E. E.	1974	A	373-556		Pure; 0.0002 H <sub>2</sub> ; experimental data can be fitted by the equation $\rho = 6.69 + 26.092 \times 10^{-3} (T-273) + 39.201 \times 10^{-5} (T-273)^2 - 39.962 \times 10^{-7} (T-273)^3 + 43.854 \times 10^{-11} (T-273)^4 - 12.634 \times 10^{-15} T^5$ (10 <sup>-6</sup> Ωm) where T is in units of K.
65	Grossee, A. V.	1966		372-2800		Calculated electrical resistivity; by fitting the data of Kapelner and Brazion to a hyperbolic equation ( $\sigma' + b$ ) / (T + b) = a, where $\sigma' = \rho_{m.p.} / \rho$ and T = (T - T <sub>m.p.</sub> ) / (T <sub>c.p. - T<sub>m.p.</sub>), a = 0.132 and b = 0.118.</sub>

\* Not shown in figure.

TABLE 12. EXPERIMENTAL DATA ON THE ELECTRICAL RESISTIVITY OF SODIUM Na (Temperature Dependence)  
 [Temperature, T, K; Resistivity,  $\rho$ ,  $10^{-4}$   $\Omega$ cm]

T	$\rho$	T	$\rho$	T	$\rho$	T	$\rho$	T	$\rho$		
<u>CURVE 1</u>											
70	0.676	371	9.79	11	0.00325	25	0.0769	525	15.61		
80	0.854	375	9.90*	12	0.00375	30	0.0833	542	16.25*		
90	1.033	379	9.98*	13	0.00443	32	0.10	554	18.01		
100	1.211	385	10.1	<u>CURVE 11</u>						630	20.09
110	1.388	397	10.5	7	0.00291	35	0.179	668	21.86		
120	1.567	405	10.7	8	0.00302*	38	0.212	688	24.76*		
130	1.743	409	11.0	9	0.00319*	43	0.263	726	24.76*		
140	1.919	414	11.3	10	0.00346	46.7	0.317	790	28.01		
150	2.095	425	11.7	<u>CURVE 15</u>						850	31.54
160	2.271	435	11.9	2	0.00132*	913	0.3531	913	35.31		
170	2.450	439	12.2	11	0.00387	<u>CURVE 16 (cont.)</u>			1009	41.76	
180	2.629	450	12.3	12	0.00445	4	0.00134	1079	46.44		
190	2.808	457	12.7	13	0.00526	7	0.00139	1108	48.94		
200	2.986	465	13.0	<u>CURVE 12</u>						1171	54.16
210	3.174	475	13.4	7	0.00208	10	0.00188	1238	60.10		
220	3.361	486	13.9	8	0.00216	12	0.00231	1300	66.17		
230	3.550	497	14.4	8	0.00216	12	0.00265	1334	69.59		
240	3.741	513	14.8	9	0.00229	13	0.00321	1360	72.48		
250	3.934	522	15.3	10	0.00248	14	0.00383	<u>CURVE 17</u>			
260	4.132	534	15.7	11	0.00278	15	0.00518	371.2	9.64		
270	4.333	544	16.1	12	0.00320	16	0.00613	424.5	11.44*		
273.15	4.386	559	16.7	13	0.00379	17	0.00919	482.5	13.78		
280	4.535	566	17.0	<u>CURVE 13</u>						585.7	17.98
290	4.739	570	17.1	7	0.00253	19	0.0129	693.9	23.16		
300	4.945	<u>CURVE 5</u>		8	0.00215	21	0.0192	804.4	28.68		
310	5.159	292	4.95	9	0.00231	23	0.034	908.7	34.91		
320	5.374	330	5.79	10	0.00256	25	0.0526	1012.8	41.86		
330	5.598	347	6.21	11	0.00293	27	0.067	1072.8	46.40		
340	5.830	359	6.51	12	0.00347	36	0.161	1126.0	51.00		
350	6.070	362	6.57	13	0.00423	44	0.270	<u>CURVE 18</u>			
360	6.319	362	6.57	7	0.00297	48	0.284	372.95	9.56		
370	6.571	366	6.61	8	0.00305	46	0.323	382.05	9.67		
<u>CURVE 2</u>											
373.2	10.00	367	6.67*	9	0.00318	2	0.00943	396.55	9.88		
398.2	10.85	370	6.84	10	0.00339	3	0.00943	403.35	10.16		
<u>CURVE 3</u>											
367	6.75	283.4	4.64	7	0.00943	7	0.00943	420.25	10.38		
371	9.60*	290.4	4.82	8	0.00954	9	0.00954	444.35	11.03		
373	9.65	291.0	4.80*	9	0.0098	11	0.0103	447.55	10.89		
423	11.4	291.0	4.82*	12	0.0119	12	0.0119	453.15	11.88		
473	13.18	291.9	4.85*	14	0.0143	14	0.0143	461.65	11.17		
523	14.90	293.2	4.88*	17	0.0172	17	0.0172	471.85	11.41		
573	16.70	318.0	5.43	20	0.0227	20	0.0227	471.85	11.61		
623	18.44	329.4	5.68*	23	0.0333	23	0.0333	492.75	11.79		
				24	0.0337	24	0.0337	499.45	11.95		
								505.05	12.27		

\* Not shown in figure.



TABLE 12. EXPERIMENTAL DATA ON THE ELECTRICAL RESISTIVITY OF SODIUM Na (Temperature Dependence) (continued)

CURVE 44 (cont.)		CURVE 47 (cont.)		CURVE 48 (cont.)		CURVE 50 (cont.)		CURVE 51 (cont.)		CURVE 55 (cont.)	
T	$\rho$	T	$\rho$	T	$\rho$	T	$\rho$	T	$\rho$	T	$\rho$
25.00	0.03702	70	0.6428	598.5	14.01*	7.89	0.0017	9.70	0.00206	689	22.4
28.55	0.06046	80	0.8109*	613.2	14.50*	8.15	0.00174*	9.82	0.00212*	751	25.7
32.35	0.09342	90	0.9806*	620.0	14.45	8.57	0.00185	10.21	0.00231	789	27.8
37.35	0.14137	100	1.115*			8.67	0.00181	10.37	0.00250	798	28.0
<u>CURVE 45</u>		<u>CURVE 49</u>									
140	1.491*	371.8	9.52*			9.08	0.00191	10.91	0.00249	848	31.0
160	2.181*	378.0	9.74*			9.08	0.00196	11.64	0.00286	885	33.7
180	2.534*	381.4	9.89*			9.70	0.00214	11.83	0.00329*	932	36.2
200	2.897*	387.6	10.04*			9.82	0.00220	12.25	0.00361	971	38.8*
220	3.270*	393.1	10.23*			10.21	0.00239	13.40	0.00478	1027	43.3
240	3.657*	405.1	10.60*			10.37	0.00258	13.83	0.00562*	1100	48.7
260	4.056*	403.1	10.71*			10.91	0.00257	14.39	0.00586*	1153	52.8
280	4.475*	416.8	11.03*			11.19	0.00294*	15.10	0.00682*	1204	56.8
300	4.915*	421.7	11.27*			11.64	0.00324	15.81	0.00711*	1280	62.9
320	5.365*	423.1	11.18*			11.83	0.00337*			<u>CURVE 56</u>	
340	5.849*	433.5	11.64*			12.33	0.00369			373	9.6*
360	6.359*	445.6	12.03*			13.40	0.00486			434	11.2*
<u>CURVE 46</u>		<u>CURVE 50</u>									
16	0.0035	367.1	9.60	476.4	13.29*	3.17	0.001391	1.79	0.001244	482	12.8
18	0.0064	369.3	9.50*	482.8	13.45	3.63	0.001392	2.06	0.001239	546	15.0
20	0.0103	370.3	9.62*	499.7	14.21	4.25	0.001395*	2.40	0.001238	525	18.1
22	0.0158	382.7	9.79	513.4	14.60	4.44	0.001394	2.62	0.001254	689	20.7
24	0.0232	394.8	9.94*	527.3	15.18	5.65	0.001417	2.80	0.001256	740	23.4
26	0.0329	397.0	10.19	548.7	15.95	5.74	0.001419	3.05	0.001249	787	25.8
28	0.0448	402.8	10.20*	571.2	17.07*	5.83	0.001423	3.38	0.001284	835	28.4
30	0.0583	412.7	10.32*	626.4	18.35	5.94	0.001441	3.62	0.001270	873	30.6
32	0.0738	416.0	10.44*			5.74	0.001419	3.80	0.001277	917	34.0
34	0.0909	429.3	10.84			5.83	0.001423	4.06	0.001310	<u>CURVE 57</u>	
36	0.1094	435.6	10.82*			5.83	0.001423	4.20	0.001315	373	9.6*
40	0.152	442.9	11.05*			5.94	0.001441			434	11.7*
42	0.1758	445.5	10.90*			6.28	0.001440			482	13.4*
44	0.2007	453.4	11.17			6.32	0.001442			546	15.8
46	0.2266	458.1	11.29			6.32	0.001451			525	19.1
48	0.254	469.3	11.47*			6.76	0.001472			689	21.8
50	0.282	472.7	11.28			6.76	0.00148			740	24.2
52	0.311	472.9	11.45*			6.86	0.00149			789	26.8
<u>CURVE 47</u>		<u>CURVE 53</u>									
40	0.1622	472.9	11.45*			371	9.57			373	9.6*
50	0.3217	522.0	12.54			5.83	0.001524			434	11.7*
60	0.4783	493.8	11.95			5.94	0.001523			482	13.4*
		486.1	12.08			6.28	0.001525			546	15.8
		498.5	11.97*			6.32	0.001524			525	19.1
		519.4	12.44			7.75	0.00160			689	21.8
		540.1	12.82*			7.83	0.00161			740	24.2
		555.4	12.98*			7.89	0.00162			789	26.8
		576.6	13.52*			8.15	0.00166			835	29.7
		587.5	13.86*			8.57	0.00177			873	32.0
						7.83	0.00161			917	35.2
						7.89	0.00162			<u>CURVE 58</u>	
						8.15	0.00166			273	4.34
						8.57	0.00177			<u>CURVE 59</u>	
						8.67	0.00173			293.15	4.875
						9.08	0.00183			373.15	9.705
						9.08	0.00188				
						9.08	0.00193*				

\* Not shown in figure.

TABLE 12. EXPERIMENTAL DATA ON THE ELECTRICAL RESISTIVITY OF SODIUM Na (Temperature Dependence) (continued)

T	$\rho$	T	$\rho$
<u>CURVE 60*</u>			
373.15	9.6	1200	57.65
473.15	13.4	1300	67.24
		1400	78.26
<u>CURVE 61</u>			
373.15	10.7	1500	91.07
		1600	106.1
		1700	124.1
		1800	145.9
		1900	173.0
		2000	207.4
		2100	252.7*
		2200	314.9*
		2300	405.8*
		2400	551.0*
		2500	820.0*
		2600	1488.0*
		2700	6033.0*
<u>CURVE 62</u>			
373.15	7.2		
<u>CURVE 63</u>			
533	16.27		
589	18.41		
644	20.75		
700	23.80		
755	26.80		
811	29.84		
866.5	32.90		
922	36.31		
<u>CURVE 64*</u>			
372.4	9.64		
378.4	9.83		
399.4	10.15		
392.1	10.29		
440.5	11.97		
443.3	12.09		
452.1	12.44		
496.0	14.10		
515.3	14.93		
542.1	16.02		
567.4	17.08		
573.5	17.28		
656.2	20.96		
<u>CURVE 65</u>			
400	10.52*		
500	14.57*		
600	18.98		
700	23.65*		
800	29.22		
900	35.16		
1000	41.79		
1100	49.24		

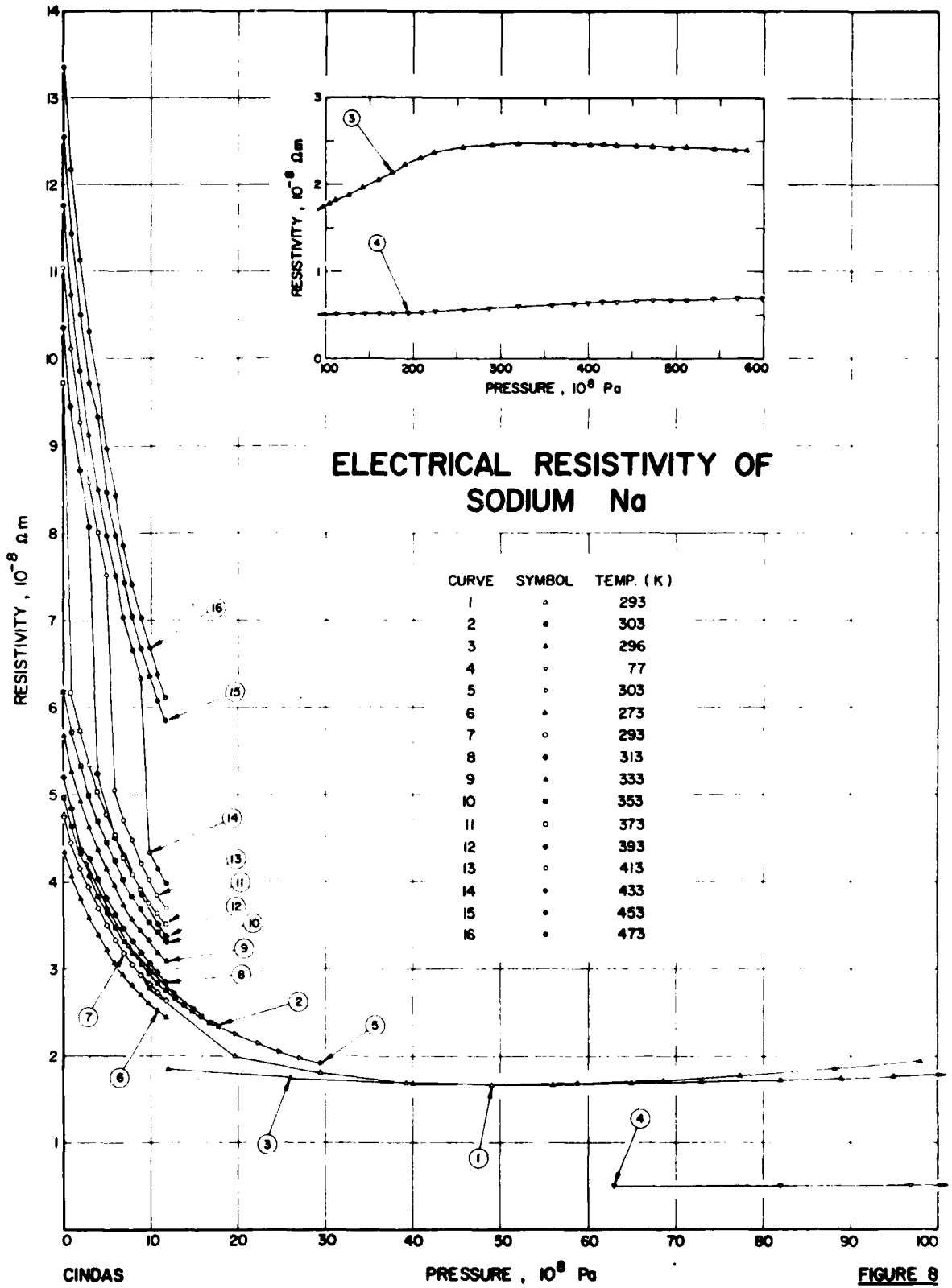
\* Not shown in figure.



#### b. Pressure Dependence

There are 16 sets of experimental data available for the electrical resistivity of sodium as a function of pressure. The information on specimen characterization and measurement conditions for each of the data sets is given in Table 13. The data are tabulated in Table 14 and shown in Figure 8.

The available data and information for the pressure dependence of electrical resistivity of sodium are inadequate for performing detailed analysis and synthesis at this time. Consequently, no recommendations are made and only experimental data are presented here.



CINDAS

PRESSURE,  $10^8$  Pa

FIGURE 8

TABLE 15. MEASUREMENT INFORMATION ON THE ELECTRICAL RESISTIVITY OF SODIUM Na (Magnetic Flux Density Dependence)

Cur. Ref. No.	Author(s)	Year	Method Used	Magnetic Flux Density Range, Tesla	Temperature Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	MacDonald, D. K. C.	1957		0-2.41	~4.2	Na, No. 1	Pure; the specimen was cast under high vacuum into a soft glass mold; platinum electrodes were used; $R_{4.2} K/R_{294} K = 2.85 \times 10^{-4}$ ; resistance was measured with the plane of specimen perpendicular to magnetic field H.
2	MacDonald, D. K. C.	1957		0-2.41	~4.2	Na, No. 1	Same as the above specimen; the resistance was measured with the plane of specimen parallel to magnetic field H.
3	MacDonald, D. K. C.	1957		0-2.54	~4.2	Na, No. 2	Pure; the specimen was cast under high vacuum into a soft glass mold; platinum electrodes were used; $R_{4.2} K/R_{294} K = 2.2 \times 10^{-4}$ ; resistance was measured with the plane of specimen perpendicular to magnetic field H.
4	MacDonald, D. K. C.	1957		0-2.65	~4.2	Na, No. 2	Same as the above specimen; the resistance was measured with the plane of specimen parallel to the magnetic field H.
5	Kapitza, P.	1929		0.30	86		Pure; specimen was obtained from Kahlbaum; magneto resistance measurements were made in a transverse magnetic field; $R/R_r = 0.2$ , where $R_r$ is the resistance at room temperature.
6	Justi, E.	1948	A	0-3.5	78.4	Na 4	Pure; $R_{78.4} K/R_{273.15} K = 0.1894$ ; measured in a transverse field.
7	Justi, E.	1948	A	0-3.51	20.4	Na 4	Same as the above specimen and conditions; $R_{20.4} K/R_{273.15} K = 0.00483$ .
8	Justi, E.	1948	A	0-3.51	14.0	Na 4	Same as the above specimen and conditions; $R_{14.0} K/R_{273.15} K = 0.00152$ .
9	Justi, E.	1948	A	0.1-65	78	Na 5	Similar to the above specimen and conditions; $R_{78} K/R_{273.15} K = 0.01893$ .
10	Justi, E.	1948	A	0-1.65	20.4	Na 5	Same as the above specimen and conditions; $R_{20.4} K/R_{273.15} K = 0.00435$ .
11	Justi, E.	1948	A	0-1.65	14.0	Na 5	Same as the above specimen and conditions; $R_{14.0} K/R_{273.15} K = 0.00117$ .
12*	Justi, E.	1948	A	0.1-65	78	Na 5	Same as the above specimen; it was measured in a longitudinal magnetic field.
13	Justi, E.	1948	A	0.1-65	20.4	Na 5	Same as the above specimen; it was measured in a longitudinal magnetic field.
14	Justi, E.	1948	A	0-3.51	20.4	Na 10	Similar to the above specimen; $R_{20.4} K/R_{273.15} K = 0.00875$ ; it was measured in a transverse field.
15	Justi, E.	1948	A	0-4.02	78	Na 11	Similar to the above specimen; $R_{78} K/R_{273.15} K = 0.186$ .
16	Justi, E.	1948	A	0-3.32	20.4	Na 11 milt.	Similar to the above specimen; $R_{20.4} K/R_{273.15} K = 0.00432$ .
17	Justi, E.	1948	A	0-3.95	20.4	Na 11 max	Similar to the above specimen and conditions.
18	Justi, E.	1948	A	0-3.32	20.4	Na 11 min	Similar to the above specimen and conditions.
19	Babistia, J. and Siebaumann, P. G.	1969		0-9	4.2		Pure; wire sample 1 to 1.5 in. long and were helically wound on a 3-in. diameter form; $R_{300} K/R_{4.2} K = 5000$ ; data were extracted from the smooth curve.

\* Not shown in figure.

TABLE 14. EXPERIMENTAL DATA ON THE ELECTRICAL RESISTIVITY OF SODIUM Na (Pressure Dependence)  
 [Temperature, T, K; Pressure, P, 10<sup>3</sup> Pa; Resistivity,  $\rho$ , 10<sup>-8</sup>  $\Omega$ m]

P	$\rho$	P	$\rho$	P	$\rho$	P	$\rho$	P	$\rho$	P	$\rho$	P	$\rho$
<u>CURVE 1</u> T = 293		<u>CURVE 3 (cont.)</u> T = 296		<u>CURVE 4 (cont.)</u> T = 77		<u>CURVE 7</u> T = 293		<u>CURVE 10</u> T = 350		<u>CURVE 12 (cont.)</u> T = 393			
0.0	4.789	89	1.738	384	0.639	0.00	4.763	0.00	6.189	10.78	3.523		
9.8	2.785	95	1.765	400	0.647	0.98	4.445	0.98	5.723	11.76	3.386		
19.6	2.001	104	1.784	416	0.651	1.96	4.166	1.96	5.330	<u>CURVE 13</u> T = 413			
29.4	1.818	111	1.823	433	0.653	2.94	3.955	2.94	4.994	0.00	11.05		
39.2	1.690	127	1.883	455	0.668	3.92	3.709	3.92	4.706	0.98	10.12		
49.0	1.662	142	1.971	474	0.671	4.90	3.518	4.90	4.469	1.96	9.27		
58.8	1.680	160	2.054	494	0.672	5.88	3.346	5.88	4.257	2.94	8.583		
68.6	1.715	176	2.147	512	0.675	6.86	3.194	6.86	4.023	3.92	8.003		
78.4	1.777	191	2.233	543	0.686	7.84	3.059	7.84	3.844	4.90	7.527		
88.2	1.848	208	2.312	570	0.694	8.82	2.942	8.82	3.692	5.88	5.053		
98.0	1.943	224	2.379	589	0.692	9.80	2.833	9.80	3.548	6.86	4.711		
<u>CURVE 2</u> T = 303		<u>CURVE 5</u> T = 303		<u>CURVE 8</u> T = 313		<u>CURVE 11</u> T = 373		<u>CURVE 14</u> T = 433					
0.00	4.972	257	2.434	285	0.692	10.78	2.735	10.78	3.420	0.00	11.770		
0.98	4.643	290	2.463	290	0.695	11.76	2.647	11.76	3.306	0.98	10.710		
1.96	4.330	320	2.482	290	0.695	11.76	2.647	11.76	3.306	1.96	9.860		
2.94	4.071	361	2.476	285	0.695	11.76	2.647	11.76	3.306	2.94	9.120		
3.92	3.848	384	2.471	285	0.695	11.76	2.647	11.76	3.306	3.92	8.501		
4.90	3.652	402	2.465	285	0.695	11.76	2.647	11.76	3.306	4.90	7.982		
5.88	3.480	418	2.463	285	0.695	11.76	2.647	11.76	3.306	5.88	7.527		
6.86	3.326	432	2.457	285	0.695	11.76	2.647	11.76	3.306	6.86	7.041		
7.84	3.187	455	2.450	285	0.695	11.76	2.647	11.76	3.306	7.84	6.665		
8.82	3.065	485	2.436	285	0.695	11.76	2.647	11.76	3.306	8.82	6.344		
9.80	2.950	544	2.401	285	0.695	11.76	2.647	11.76	3.306	9.80	6.040		
10.78	2.846	567	2.403	285	0.695	11.76	2.647	11.76	3.306	10.78	5.757		
11.76	2.750	581	2.403	285	0.695	11.76	2.647	11.76	3.306	11.76	5.494		
12.74	2.663	63	0.507	285	0.695	11.76	2.647	11.76	3.306	11.76	5.257		
13.72	2.587	82	0.504	285	0.695	11.76	2.647	11.76	3.306	11.76	5.035		
14.70	2.517	97	0.509	285	0.695	11.76	2.647	11.76	3.306	11.76	4.771		
15.68	2.453	112	0.510	285	0.695	11.76	2.647	11.76	3.306	11.76	4.542		
16.66	2.394	129	0.511	285	0.695	11.76	2.647	11.76	3.306	11.76	4.287		
17.64	2.341	145	0.523	285	0.695	11.76	2.647	11.76	3.306	11.76	4.036		
<u>CURVE 3</u> T = 296		<u>CURVE 6</u> T = 273		<u>CURVE 9</u> T = 333		<u>CURVE 12</u> T = 393		<u>CURVE 15</u> T = 453					
12	1.659	161	0.534	285	0.695	11.76	2.647	11.76	3.306	0.00	10.368		
26	1.753	177	0.532	285	0.695	11.76	2.647	11.76	3.306	0.98	9.472		
40	1.690	194	0.548	285	0.695	11.76	2.647	11.76	3.306	1.96	8.720		
56	1.675	210	0.548	285	0.695	11.76	2.647	11.76	3.306	2.94	8.075		
65	1.669	225	0.569	285	0.695	11.76	2.647	11.76	3.306	3.92	5.258		
73	1.700	257	0.569	285	0.695	11.76	2.647	11.76	3.306	4.90	4.781*		
82	1.728	287	0.584	285	0.695	11.76	2.647	11.76	3.306	5.88	4.620		
		320	0.600	285	0.695	11.76	2.647	11.76	3.306	6.86	4.309		
		359	0.613	285	0.695	11.76	2.647	11.76	3.306	7.84	4.072*		
				285	0.695	11.76	2.647	11.76	3.306	8.82	3.865		
				285	0.695	11.76	2.647	11.76	3.306	9.80	3.677*		

\* Not shown in figure.

TABLE 14. EXPERIMENTAL DATA ON THE ELECTRICAL RESISTIVITY OF SODIUM Na (Pressure Dependence) (continued)

P	P
<u>CURVE 15 (cont.)</u>	
<u>T = 453</u>	
4.90	8.471
5.88	7.982
6.86	7.448
7.84	7.041
8.82	6.694
9.80	6.375
10.78	6.095
11.76	5.857
<u>CURVE 16</u>	
<u>T = 473</u>	
0.00	13.360
0.98	12.180
1.96	11.140
2.94	10.312
3.92	9.722
4.90	8.973
5.88	8.441
6.86	7.968
7.84	7.426
8.82	7.039
9.80	6.694
10.78	6.388
11.76	6.120

### c. Magnetic Flux Density Dependence

There are 21 sets of experimental data available for the electrical resistivity of sodium under the influence of magnetic field. The information on specimen characterization and measurement information for each of the data sets is given in Table 15. The data are tabulated in Table 16 and shown in Figure 9.

The available data and information for the magnetic flux density dependence of electrical resistivity of sodium are inadequate for performing detailed analysis and synthesis at this time. Consequently, no recommendations are made and only experimental data are presented here.

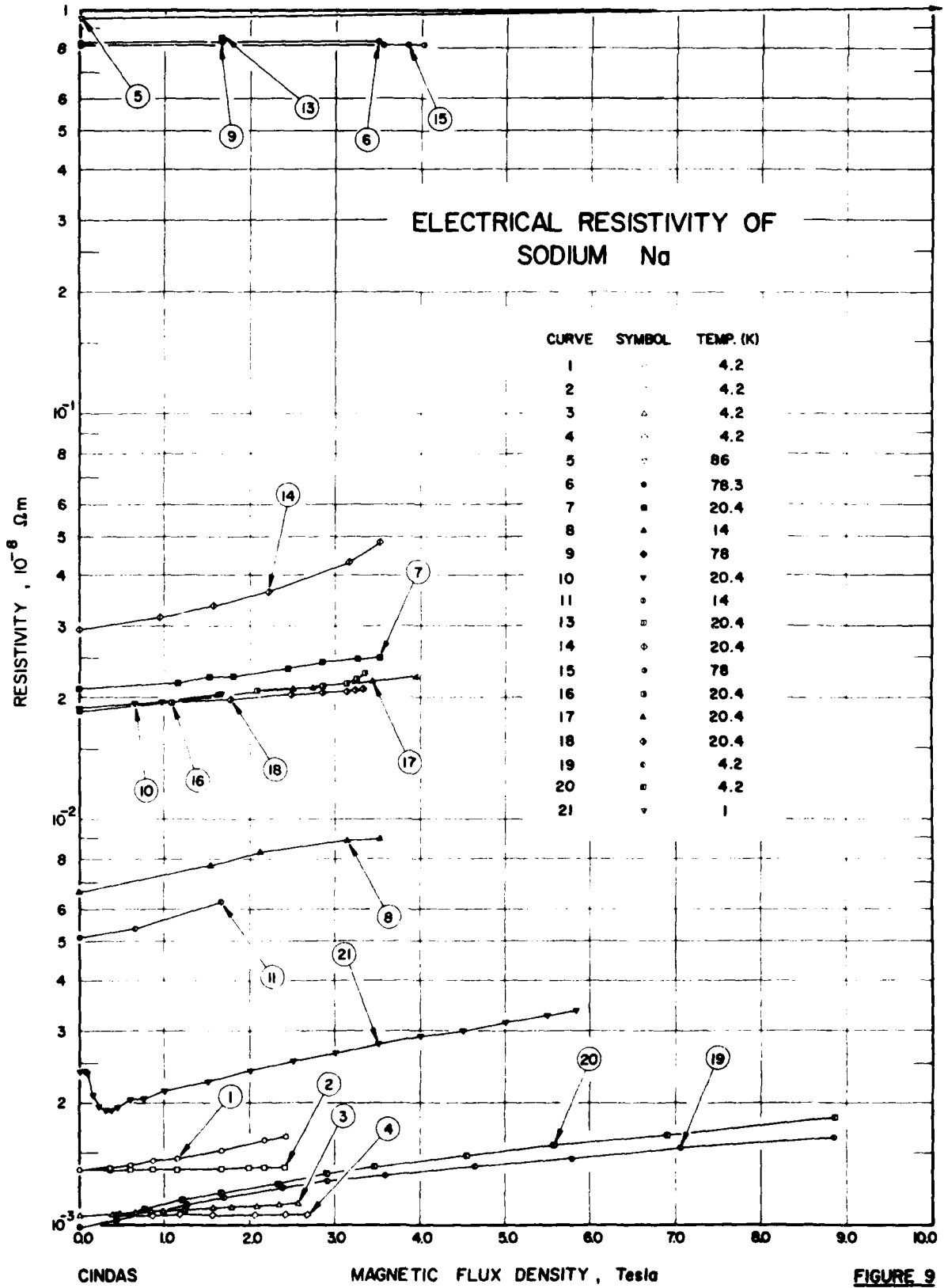


FIGURE 9

TABLE 15. MEASUREMENT INFORMATION ON THE ELECTRICAL RESISTIVITY OF SODIUM Na (Magnetic Flux Density Dependence)

Cur. Ref. No.	Author(s)	Year	Method Used	Magnetic Flux Density Range, Tesla	Temperature Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	MacDonald, D.K.C.	1957		0-2.41	~4.2	Na, No. 1	Pure; the specimen was cast under high vacuum into a soft glass mold; platinum electrodes were used; $R_4$ , $2 \text{ K}/R_{294} \text{ K} = 2.85 \times 10^{-4}$ ; resistance was measured with the plane of specimen perpendicular to magnetic field H.
2	MacDonald, D.K.C.	1957		0-2.41	~4.2	Na, No. 1	Same as the above specimen; the resistance was measured with the plane of specimen parallel to magnetic field H.
3	MacDonald, D.K.C.	1957		0-2.54	~4.2	Na, No. 2	Pure; the specimen was cast under high vacuum into a soft glass mold; platinum electrodes were used; $R_4$ , $2 \text{ K}/R_{284} \text{ K} = 2.2 \times 10^{-4}$ ; resistance was measured with the plane of specimen perpendicular to magnetic field H.
4	MacDonald, D.K.C.	1957		0-2.65	~4.2	Na, No. 2	Same as the above specimen; the resistance was measured with the plane of specimen parallel to the magnetic field H.
5	Kapitza, P.	1929		0, 30	86		Pure; specimen was obtained from Kahlbaum; magneto resistance measurements were made in a transverse magnetic field; $R/R_r = 0.2$ , where $R_r$ is the resistance at room temperature.
6	Justi, E.	1948	A	0, 3.5	78.4	Na 4	Pure; $R_{78.4} \text{ K}/R_{273.15} \text{ K} = 0.1894$ ; measured in a transverse field.
7	Justi, E.	1948	A	0-3.51	20.4	Na 4	Same as the above specimen and conditions; $R_{20.4} \text{ K}/R_{273.15} \text{ K} = 0.00483$ .
8	Justi, E.	1948	A	0-3.51	14.0	Na 4	Same as the above specimen and conditions; $R_{14.0} \text{ K}/R_{273.15} \text{ K} = 0.00152$ .
9	Justi, E.	1948	A	0, 1.65	78	Na 5	Similar to the above specimen and conditions; $R_{78} \text{ K}/R_{273.15} \text{ K} = 0.01893$ .
10	Justi, E.	1948	A	0-1.65	20.4	Na 5	Same as the above specimen and conditions; $R_{20.4} \text{ K}/R_{273.15} \text{ K} = 0.00435$ .
11	Justi, E.	1948	A	0-1.65	14.0	Na 5	Same as the above specimen and conditions; $R_{14.0} \text{ K}/R_{273.15} \text{ K} = 0.00117$ .
12	Justi, E.	1948	A	0, 1.65	78	Na 5	Same as the above specimen; it was measured in a longitudinal magnetic field.
13	Justi, E.	1948	A	0, 1.65	20.4	Na 5	Same as the above specimen; it was measured in a longitudinal magnetic field.
14	Justi, E.	1948	A	0-3.51	20.4	Na 10	Similar to the above specimen; $R_{20.4} \text{ K}/R_{273.15} \text{ K} = 0.00875$ ; it was measured in a transverse field.
15	Justi, E.	1948	A	0-4.02	78	Na 11	Similar to the above specimen; $R_{78} \text{ K}/R_{273.15} \text{ K} = 0.186$ .
16	Justi, E.	1948	A	0-3.32	20.4	Na 11 mitt.	Similar to the above specimen; $R_{20.4} \text{ K}/R_{273.15} \text{ K} = 0.00432$ .
17	Justi, E.	1948	A	0-3.95	20.4	Na 11 max	Similar to the above specimen and conditions.
18	Justi, E.	1948	A	0-3.32	20.4	Na 11 min	Similar to the above specimen and conditions.
19	Babitskin, J. and Siebenmann, P. G.	1969		0-9	4.2		Pure; wire sample 1 to 1.5 in. long and were helically wound on a 3-in. diameter form; $R_{300} \text{ K}/R_4$ , $2 \text{ K} = 5000$ ; data were extracted from the smooth curve.



TABLE 15. MEASUREMENT INFORMATION ON THE ELECTRICAL RESISTIVITY OF SODIUM Na (Magnetic Flux Density Dependence) (continued)

Cur. Ref. No.	Author(s)	Year	Method Used	Magnetic Flux Density Range, Tesla	Temperature Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
20	Babickin, J. and Siebenmann, P. G.	1949		0-9	4.2		Similar to the above specimen except it was distorted, i. e., about 25% of the total length.
21	Babickin, J. and Siebenmann, P. G.	1957		0-5.8	1		Pure Na; the sodium was contained in a soft-glass capillary with bulbous ends through which two currents and two potential probes of platinum were sealed; the sodium capillary was 80 $\mu$ (microns) in diameter and 1.1 cm long; since the sodium solidified slowly from one end during its preparation, it is to be a single crystal or nearly so; the sodium specimen was obtained through S. B. Woods of National Research Council of Canada; the magnetic field was produced by a Bitter Solenoid and it was known to 1% and uniform over the specimen to better than 0.1%; the specimen length was aligned perpendicular to H to within 1°.

TABLE 16. EXPERIMENTAL DATA ON THE ELECTRICAL RESISTIVITY OF SODIUM Na (Magnetic Flux Density Dependence)  
 (Temperature, T, K; Magnetic Flux Density, B, Tesla; Resistivity,  $\rho$ ,  $10^{-8} \Omega\text{m}$ )

B	$\rho$	B	$\rho$	B	$\rho$	B	$\rho$	B	$\rho$
CURVE 1									
$T = 4.2$									
0.00	0.001371	2.03	0.001065	0.00	0.01892	1.08	0.01950	0.00	0.009898*
0.35	0.001385	2.40	0.001066	0.65	0.01940	2.08	0.02087	0.41	0.001050*
0.60	0.001408	2.65	0.001067	0.97	0.01957	2.83	0.02137	0.76	0.001098
0.87	0.001440	CURVE 5		1.65	0.02046	3.12	0.02161	1.20	0.001151
1.13	0.001469	$T = 56$		3.24	0.02225	3.24	0.02225	1.65	0.001203
1.65	0.001539	0.0	0.9578	3.32	0.02307	2.31	0.02307	2.90	0.001273
2.15	0.001613	30.0	1.0248*	CURVE 11		2.90	0.001333	3.47	0.001393
2.41	0.001659	CURVE 6		0.00	0.00509	3.47	0.001488	4.54	0.001488
$T = 4.2$									
CURVE 2									
0.00	0.001371*	CURVE 6		0.65	0.00538	5.59	0.001571	5.59	0.001571
0.35	0.001372	$T = 78.3$		1.65	0.00623	6.90	0.001678	6.90	0.001678
0.60	0.001373	0.00	0.8239	CURVE 12*		8.86	0.001835	8.86	0.001835
0.87	0.001375	3.50	0.8290	$T = 78$		0.00	0.01879*	0.00	0.01879*
1.13	0.001376	CURVE 7		1.60	0.02027	1.60	0.02027	1.60	0.02027
1.65	0.001379	$T = 20.4$		2.50	0.02100	2.50	0.02100	2.50	0.02100
1.98	0.001381	0.00	0.0210	3.11	0.02118	3.11	0.02118	3.11	0.02118
2.15	0.001382	1.15	0.02188	3.43	0.02195	3.43	0.02195	3.43	0.02195
2.40	0.001383	1.52	0.02262	3.95	0.02251	3.95	0.02251	3.95	0.02251
CURVE 3									
$T = 4.2$									
0.00	0.001059	0.00	0.0210	CURVE 13		0.00	0.01879*	0.00	0.002394
0.38	0.001066	1.15	0.02188	$T = 20.4$		0.05	0.01937*	0.05	0.002394
0.46	0.001066	1.52	0.02262	0.00	0.8235*	0.07	0.01963	0.07	0.002391
0.65	0.001073	1.80	0.02268	1.65	0.8474	0.14	0.01965	0.14	0.002068
0.83	0.001078	2.43	0.0236	0.00	0.8235*	0.21	0.01965	0.21	0.001965
0.98	0.001082	2.83	0.0243	1.65	0.8240	0.30	0.01910	0.30	0.001910
1.21	0.001089	3.26	0.0248	0.00	0.8235*	0.37	0.001910	0.37	0.001910
1.55	0.001100	3.51	0.0250	0.00	0.8235*	0.45	0.001942	0.45	0.001942
1.77	0.001107	CURVE 8		0.00	0.02936	0.60	0.002029	0.60	0.002029
2.08	0.001118	$T = 14.0$		0.936	0.03155	0.76	0.002038	0.76	0.002038
2.32	0.001126	0.00	0.00661	1.56	0.03378	1.00	0.002134	1.00	0.002134
2.54	0.001135	1.52	0.00771	2.20	0.03629	1.50	0.002267	1.50	0.002267
CURVE 4									
$T = 4.2$									
0.00	0.001059	0.00	0.00661	3.15	0.04163	2.00	0.002404	2.00	0.002404
0.43	0.001059*	1.52	0.00771	3.51	0.04413	2.50	0.002532	2.50	0.002532
0.85	0.001060	2.10	0.00832	CURVE 15		3.00	0.002658	3.00	0.002658
1.17	0.001061	3.13	0.00888	$T = 78$		3.50	0.002797	3.50	0.002797
1.51	0.001063	3.51	0.00937	0.00	0.8090	4.00	0.002915	4.00	0.002915
CURVE 9									
$T = 70$									
0.00	0.8235*	0.00	0.8235*	3.54	0.8119	4.50	0.003043	4.50	0.003043
1.65	0.8246	3.84	0.8123	4.02	0.8124	5.00	0.003167	5.00	0.003167
CURVE 16 (cont.)									
$T = 20.4$									
0.00	0.009898	0.00	0.009898	1.69	0.001178	4.50	0.003381	4.50	0.003381
0.41	0.001050*	0.42	0.001044	2.37	0.001233	5.50	0.003299	5.50	0.003299
0.76	0.001098	0.81	0.001088	2.90	0.001281	7.06	0.001538	7.06	0.001538
1.20	0.001151	1.25	0.001129	3.58	0.001327	8.84	0.001647	8.84	0.001647
1.65	0.001203	1.69	0.001178	4.65	0.001397	0.00	0.01879	0.00	0.01879
2.31	0.001273	2.37	0.001233	5.79	0.001464	0.00	0.01879	0.00	0.01879
2.90	0.001333	2.90	0.001281	7.06	0.001538	0.00	0.01879	0.00	0.01879
3.47	0.001393	3.58	0.001327	8.84	0.001647	0.00	0.01879	0.00	0.01879
4.54	0.001488	4.65	0.001397	0.00	0.01879	0.00	0.01879	0.00	0.01879
5.59	0.001571	5.79	0.001464	0.00	0.01879	0.00	0.01879	0.00	0.01879
6.90	0.001678	7.06	0.001538	0.00	0.01879	0.00	0.01879	0.00	0.01879
8.86	0.001835	8.84	0.001647	0.00	0.01879	0.00	0.01879	0.00	0.01879

\* Not shown in figure.

### 4.3. POTASSIUM

Potassium, with atomic number 19, is a silvery, soft, very reactive alkali metal, easily cut with a knife. Next to lithium, it is the second lightest known metal. It has a body-centered cubic crystalline structure with a density of  $0.862 \text{ g cm}^{-3}$  at 293 K. It melts at 336.35 K and boils at about 1047 K. Its critical temperature has been determined to be  $2280.8 \pm 3 \text{ K}$ . Naturally occurring potassium is composed of two stable isotopes,  $^{39}\text{K}$  (93.10%) and  $^{41}\text{K}$  (6.88%), and one radioactive isotope  $^{40}\text{K}$  (0.00118%), which has a half-life of  $1.28 \times 10^9$  years. The radioactivity of  $^{40}\text{K}$  presents no appreciable hazard. Potassium has six other radioactive isotopes known to exist. The metal is the eighth most abundant element in the continental crust of the earth (2.09% by weight).

#### a. Temperature Dependence

There are 49 sets of experimental data available for the temperature dependence on the electrical resistivity of potassium. The information on specimen characterization and measurement conditions for each of the data sets is given in Table 18. The data are tabulated in Table 19 and shown in Figures 10 and 11. Determinations of the electrical resistivity of potassium for the solid, liquid, and gas phases cover the continuous temperature range from 1 to 2366 K.

There are 21 data sets obtained below 100 K. Among these, three sets are single data points at liquid helium temperature. Dugdale [76] (curve 1) gave the lowest residual resistivity,  $\rho_0 = 0.00087 \times 10^{-8} \Omega\text{m}$ . Dugdale and Guban [8] tabulated electrical resistivities at constant volume (curve 17), which are lower than those at zero pressure (curve 18). Thirteen sets of intrinsic electrical resistivity values are obtained by subtraction of residual resistivity  $\rho_0$  from the measured resistivity. In deriving the smoothed most probable values of intrinsic resistivity from the available data, the following overlapping temperature ranges were considered: below 10 K; 5-20 K; 10-40 K; 20-80 K; 30-150 K; etc. Within each range, a least-mean-square fraction error fit of the equation  $\rho_i = aT^b$  was made to all the available intrinsic resistivity data. The resulting values for adjacent ranges were intercompared and the values were corrected for thermal linear expansion. These preliminary values were then fitting with the cubic spline function equation (7) to generate the final recommended values. The coefficients of equation (7) obtained in the fitting are given in the following table:

Temperature Range, K	a	b	c	d
1 - 2.86	-6.796	5.219	0.164	-0.186
2.86- 6.42	-4.391	5.252	-0.092	0.442
6.42- 7.14	-2.547	5.350	0.372	-182.8
7.14- 8.00	-2.316	4.193	-25.19	198.8
8.00- 10.50	-2.147	3.157	4.027	-16.89
10.50-100	-1.745	3.399	-1.978	0.603

Below 7 K, the intrinsic resistivity  $\rho_i$  approximately follows Bloch's  $T^5$  law.

There are 16 data sets in the temperature region from 100 K to the melting point, 336.35 K. Dugdale and Gugan [8] also tabulated electrical resistivities at constant volume (curve 17), which are lower than those at zero pressure (curve 18). A least-mean-square-error fit to the totality of experimental data except those measured at constant volume in this range was made with a third order polynomial. The resulting values were corrected for thermal linear expansion, and then fitted the cubic spline function for equation (7) to obtain the final recommended values in this temperature range. The coefficients of equation (7) obtained are as follows:

Temperature Range, K	a	b	c	d
10.5 -270.65	-1.745	3.399	-1.978	0.603
270.65-336.35	-0.807	1.418	0.574	22.28

There are 23 data sets available for the liquid state. Endo [40] (curve 29), and Lien and Silversten [41] (curve 30) also tabulated the electrical resistivities at constant volume. Freyland and Hansel [77] (curves 41 to 44) have measured the electrical resistivity at several constant pressure conditions from the melting point up to the critical temperature and above. The rest of the data are apparently measured at the saturated vapor pressure. Below 1000 K they agree with one another within 10%; the error may be somewhat higher above 1000 K. Roehlich and Tepper [17] (curve 26) give the highest value while Solov'ev [52] (curve 31) gives the lowest values. Below 1300 K, all the experimental data except those measured at constant volume and at constant pressure were fitted by a logarithmic third order polynomials. Above 1300 K, the resistivity values were obtained by extrapolating the fitted values and following the experimental trend. These values were then fitting with the cubic spline function equation (7) to generate the final recommended values. The coefficients of equation (7) obtained are as follows:

Temperature Range, K	a	b	c	d
336.35-1090.3	1.146	1.154	0.494	0.287
1090.3 -2000	1.901	1.882	0.933	13.67

At the melting point (336.35 K), the electrical resistivity of potassium in the liquid state increases to about 50% higher than that of the solid state.

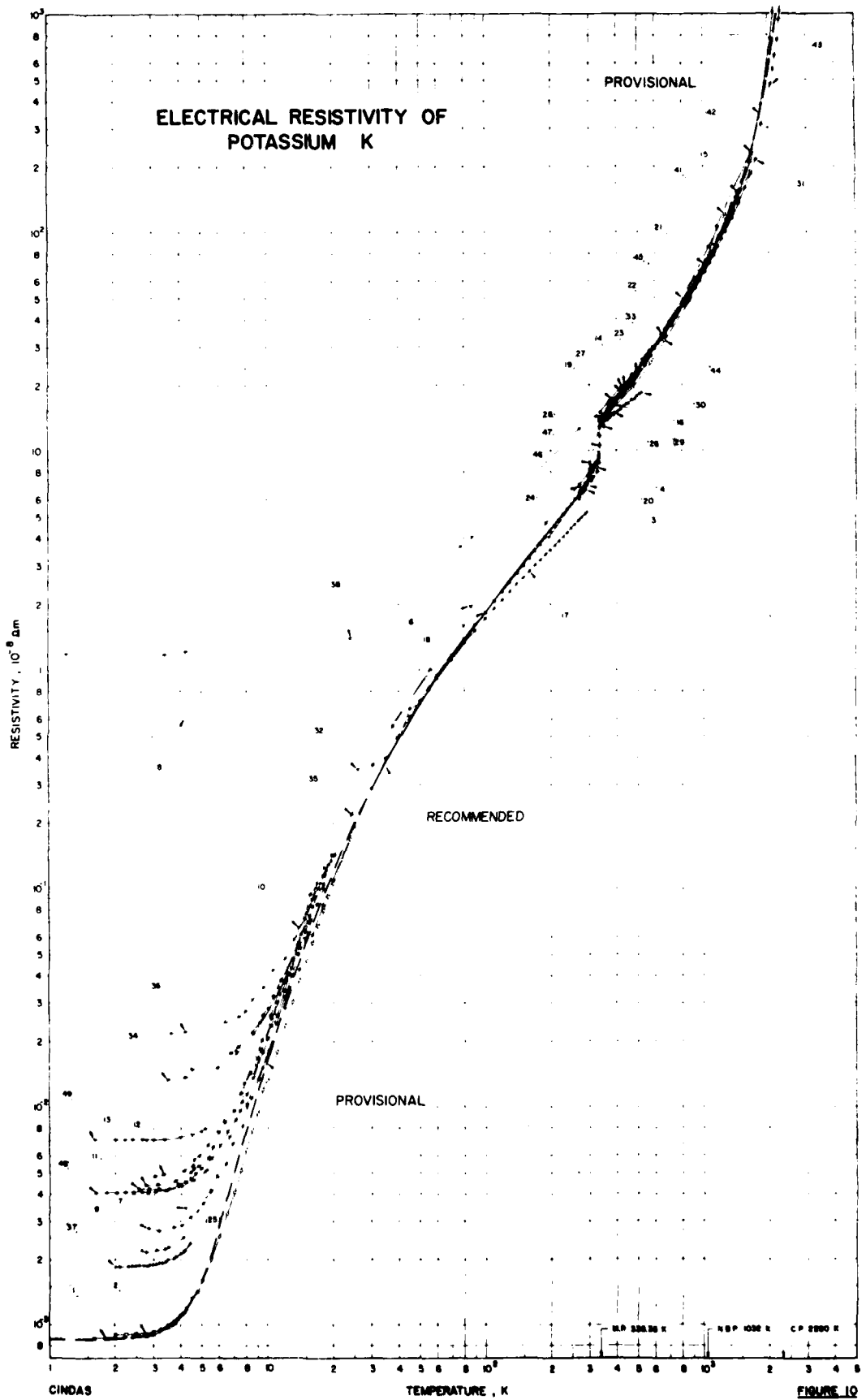
The recommended values for the total and intrinsic electrical resistivity are listed in Table 17, and those for the total electrical resistivity are also shown in Figures 9 and 10. The recommended values for the liquid state are for the saturated liquid. The recommended values of the total resistivities for the solid state are for a 99.99% pure potassium and those at temperatures below 40 K are only applicable to a specimen with residual resistivity  $\rho_0 = 0.00085 \times 10^{-8} \Omega\text{m}$ . The recommended values from 1 K to 336.8 K are corrected for thermal linear expansion. The correction amounts to -1.74% at 1 K, -1.1% at 135 K, and 0.35% at 336.35 K. Because there is a strong indication for deviation from the Matthiessen's rule for the electrical resistivity of potassium [128], the values of  $\rho$  and  $\rho_i$  below 30 K are considered provisional. The uncertainty of the recommended total electrical resistivity is believed to be within  $\pm 20\%$  from 1 K to 30 K, within  $\pm 50\%$  from 40 K to 1500 K and within  $\pm 10\%$  from 1500 K to 2000 K. Above 30 K the uncertainty of the recommended values for the intrinsic resistivity is about the same as that of the total electrical resistivity; below 30 K this uncertainty is higher than that of the total electrical resistivity.

TABLE 17. RECOMMENDED ELECTRICAL RESISTIVITY OF POTASSIUM  
(Temperature Dependence)

[Temperature, T, K; Total Resistivity,  $\rho$ ,  $10^{-8} \Omega m$ ; Intrinsic Resistivity,  $\rho_i$ ,  $10^{-8} \Omega m$ ]

Solid						Liquid	
T	$\rho$	$\rho_i$	T	$\rho$	$\rho_i$	T	$\rho$
1	0.00085*		35	0.379	0.378	336.35	13.95
2	0.00086*	$6.1 \times 10^{-6}$ *	40	0.480	0.479	350	14.64
3	0.00091*	$5.1 \times 10^{-5}$ *	45	0.583	0.582	400	17.18
4	0.00109*	$2.3 \times 10^{-4}$ *	50	0.689	0.658	500	22.91
5	0.00161*	0.00076*	60	0.905	0.904	600	29.58
6	0.00284*	0.00199*	70	1.12	1.12	700	37.31
7	0.00523*	0.00437*	80	1.34	1.34	800	46.20
8	0.00804*	0.00719*	90	1.56	1.56	900	56.36
9	0.0114*	0.0106*	100	1.79	1.79	1000	67.94
10	0.0160*	0.0152*	150	2.99	2.99	1100	81.05
11	0.0218*	0.0209*	200	4.26	4.26	1200	96.04
12	0.0286*	0.0278*	250	5.74	5.74	1300	114.0
13	0.0366*	0.0357*	273.15	6.49	6.49	1400	136.3
14	0.0455*	0.0446*	293	7.20	7.20	1500	164.6
15	0.0554*	0.0545*	300	7.47	7.47	1600	201.4*
16	0.0661*	0.0652*	336.35	9.22	9.22	1700	249.7*
18	0.0900*	0.0891*				1800	313.8*
20	0.117*	0.116*				1900	399.6*
25	0.195*	0.194*				2000	575.3*
30	0.283*	0.282*					

\* Provisional values.



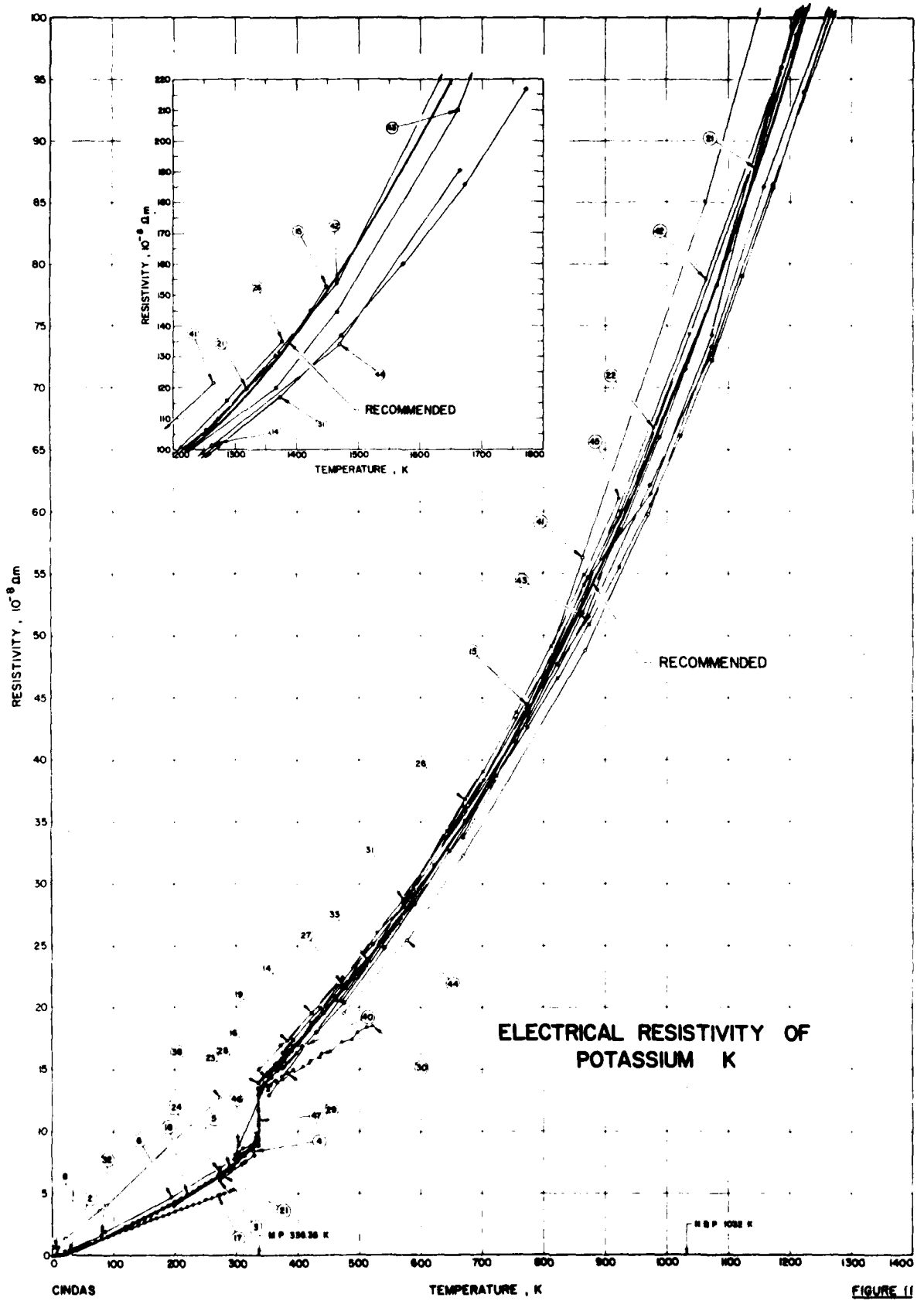




TABLE 18. MEASUREMENT INFORMATION ON THE ELECTRICAL RESISTIVITY OF POTASSIUM K (Temperature Dependence)

Cur. Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1 76	Gugan, D.	1971		1.2-4.2	K3(c)	Pure; low sodium grade material was supplied by Mine Safety Appliance Co.; polycrystalline wire specimen 1 mm in diameter and 20 cm long; sample was fully annealed at 250 K.
2 78	Eklin, J. W. and Maxfield, B. W.	1971	C	1-25		High purity polycrystalline wire specimen was extruded from the potassium obtained from Mine Safety Appliance, Ltd.
3 56	Hackspill, L.	1910	A	273, 291	1	Pure.
4 56	Hackspill, L.	1910	A	292, 328	2	Pure.
5 56	Hackspill, L.	1910	A	198, 289	3	Pure.
6 19	Gatz, A. and Bronieski, W.	1909		86-323		Pure.
7 79	Natale, G. G. and Rudnick, I.	1968	A	4.2	K1	99.98 pure; specimen was obtained from M. S. R. Research Corp.; sample 0.208 cm in diameter and 10.4 cm in length; unannealed; $\rho_{273}/\rho_{4.2} = 1790$ .
8 79	Natale, G. G. and Rudnick, I.	1968	A	4.2	K11	Similar to the above specimen except the length was 10.3 cm; $\rho_{273}/\rho_{4.2} = 10$ .
9 79	Natale, G. G. and Rudnick, I.	1968	A	2.5-20	K1B	Similar to the above specimen; sample length 10.9 cm and was annealed at 105 K for 1 hr; $\rho_{273}/\rho_{4.2} = 1708$ .
10 79	Natale, G. G. and Rudnick, I.	1968	A	2.5-20	K12	Similar to the above specimen; sample length 9.8 cm; $\rho_{273}/\rho_{4.2} = 2440$ .
11 79	Natale, G. G. and Rudnick, I.	1968	A	2.5-20	K13	Similar to the above specimen; sample length 9.6 cm; unannealed; $\rho_{273}/\rho_{4.2} = 1342$ .
12 79	Natale, G. G. and Rudnick, I.	1968	A	2.5-20	K18	Similar to the above specimen; sample length 10.0 cm; $\rho_{273}/\rho_{4.2} = 1187$ .
13 79	Natale, G. G. and Rudnick, I.	1968	A	2.5-20	K19	Similar to the above specimen; $\rho_{273}/\rho_{4.2} = 1276$ .
14 18	Semyachkin, B. E. and Solov'ev, A. N.	1964	A	338-1273		Pure; TUMK HP 2010-5 sample was placed in an 0.8/0.5 mm 1Kh 18Ng T steel capillary, 60 mm in length.
15 80, 81	Lezmon, A. W. Jr., Deem, H. W., Eldridge, E. A., Hall, E. H., Matolich, J. Jr., and Walling, J. F.	1963		301-1448		0.1 Na, 0.0053 O <sub>2</sub> , 0.003 Li, 0.005 Rb, 0.001 Cs, Zr, Fe, Co.
16 45	Hennepf, J., Van der Lugt, W., and Wright, G. W.	1971	B	373.2-398		Pure; resistivity was a linear function of temperature from melting point up to 125 C; described by $\rho_p/dT = 0.053 \times 10^{-8} \Omega \text{m K}^{-1}$ .
17 8	Dugdale, J. S. and Gagan, D.	1962	A	8-295.1	K(3), K(4)	Pure; specimens were obtained from Mine Safety Appliance Ltd., Toronto; the specimens were made in the form of bare wires about 100 cm long and 0.5 mm in diameter; electrical resistivity was obtained at constant density condition; $\rho(0)/\rho(293) = 8 \cdot 10^{-4}$ .
18 8	Dugdale, J. S. and Gagan, D.	1962	A	8-295.1	K(3), K(4)	Similar to the above specimens except the electrical resistivity was measured at zero pressure condition.
19 49	Akenova, L. I. and Belachenko, D. K.	1971		383-473		99.9 pure; measurements made in capillary cell; liquid state specimen.
20 58	Hornbeck, J. W.	1913		278-331		Pure; trace of Na; supplied by Elmer and Amend.
21 16	Tepper, F., Zelenak, J., Roehllich, F., and May, V.	1965	A	296-1365		Pure; liquid state specimen; density 0.7651, 0.7434, 0.7161, 0.6889, 0.6664, 0.6276, 0.6024, and 0.5861 g cm <sup>-3</sup> at 520.5, 701.3, 827.7, 944.3, 1048, 1206, 1302, and 1374 K respectively.

TABLE 18. MEASUREMENT INFORMATION ON THE ELECTRICAL RESISTIVITY OF POTASSIUM K (Temperature Dependence) (continued)

Cur. Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
22	Kaplaner, S. M. and Bratton, W. D.	1962	B	298-1037		0.32 Nb, 0.02 Fe, and 0.04 O <sub>2</sub> ; molten specimen contained in 317 stainless steel tube; specimen was supplied by Fisher Scientific Co. Pure; data were extracted from the smooth curve.
23	Regel, A. R.	1958		273-433		
24	Krautz, E.	1950	A	273		Pure.
25	Archibald, M. A., Dumick, J. E., and Jericho, M. H.	1967		4.2		99.9% pure; specimen was supplied by J. T. Baker Chemical Co.; sample was placed in a nylon tube with 1 mm bore.
26	Roehlich, F. and Tepper, F.	1965	A	341-1366		Pure; specimen was placed in a Hayne-25 alloy cylindrical cell 0.5" in O. D., 0.063" in wall thickness, and 26" in length.
27	Bornemann, K. and Rauschenplat, G.	1912		337-623		Pure potassium; liquid state.
28	Endo, H.	1963	A	330-390		Pure; sample was supplied by A. D. Mackay Ltd.; specimen container was made of soft glass capillary tube (I. D. 0.3 mm); electrical resistivity was measured at constant pressure condition.
29	Endo, H.	1963	A	330-390		Same as above specimen except the electrical resistivity was obtained at constant volume.
30	Lien, S. Y. and Silverstein, J. M.	1969	A	373-623		99.95 pure; sample was supplied by A. D. Mackay Inc.; specimen cell was made from precision quartz capillary open on one end; constant volume.
31	Solov'ev, A. N.	1963		373-1773		Pure; liquid state specimen; density 0.829 g cm <sup>-3</sup> at 337 K, 0.676 g cm <sup>-3</sup> at 973 K; electrical resistivity data above 973 K were extrapolated.
32	McLennan, J. C. and Niven, C. D.	1927	B	20.6-273		Pure.
33	Itami, T. and Shimoji, M.	1970	A	373-533		99.99 pure; the measuring cell was made of halo glass and four tungsten wires were sealed as the current and potential probes.
34	MacDonald, D. K. C., White, G. K., and Woods, S. B.	1955	A	3.5-12.6	K1	Pure; specimen was obtained from the Pure Metals Research Committee of the United Kingdom; specimen was melted in vacuo and run into soft-glass tubes with platinum leads sealed in; sample effective diameter 1.3 mm; $\rho/\rho_{293} = 1.88 \times 10^{-2}$ .
35	MacDonald, D. K. C., et al.	1955	A	4.5-56.4	K2	Similar to the above specimen except the effective diameter was 2.1 mm and $\rho/\rho_{293} = 1.95 \times 10^{-2}$ .
36	MacDonald, D. K. C., et al.	1955	A	3.6-17.6	K4	Similar to the above specimen except the effective diameter was 1.3 mm and $\rho/\rho_{293} = 3.08 \times 10^{-2}$ .
37	Gorland, J. C. and Bower, R.	1968	A	2-4.2		Pure; specimen was prepared by cold-extruding vacuum distilled potassium under oil; copper wire current and voltage probes were then inserted into the extruded wire; residual resistivity was obtained by using $\rho_{293} = 7.10 \times 10^{-6} \Omega\text{m}$ .
38	Meissner, W. and Voigt, B.	1930	-	1.22-273	K2	Pure; specimen was obtained by melting in vacuum; sample diameter 4.8 mm and 123 mm long; the resistance was measured by compensation method with a mirror galvanometer.
39*	Northup, E. F.	1911	B	293.15, 373.15		Pure; specimen was supplied by Merck; sample was filled in a glass tube supplied with platinum potential and current terminals; the electrical resistivity data were obtained by comparison with the electric resistance data of mercury and potassium.

\* Not shown in figure.

TABLE 18. MEASUREMENT INFORMATION ON THE ELECTRICAL RESISTIVITY OF POTASSIUM K (Temperature Dependence) (continued)

Cur. Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
40	Van der Lugt, W., Devin, J. F., Hemphof, J., and Leemstra, M. R.	1972	B	338.15, 408.15	Pure.	Pure.
41	Freyland, W. F. and Hanel, F.	1972		337-1265		Pure; liquid potassium was filled in a cylindrical tungsten-rhenium container with thin wall; the electrical resistivity of the fluid metal within the cell is measured parallel to the known resistance of the surrounding metallic container; measurement was taken at pressure equal to 10 bar.
42	Freyland, W. F. and Hanel, F.	1972		471-2173		Same as the above specimen; the electrical resistivity was measured at pressure equal to 160 bar.
43	Freyland, W. F. and Hanel, F.	1972		670-2366		Same as the above specimen; the electrical resistivity was measured at pressure equal to 230 bar.
44	Freyland, W. F. and Hanel, F.	1972		475-1665		Same as the above specimen; the electrical resistivity was measured at pressure equal to 310 bar.
45	Boettia, C. F., Lee, D. I., and Foley, P. J.	1965	V	533-922		99.97 pure, 0.005 each Na, O <sub>2</sub> ; specimen was obtained from MSA Research Corp; liquid state specimen was contained in a 316 type stainless steel tube with 7/16 in. O. D., wall 0.018 in. and about 8 in. long; chromel-alumel thermocouples were used to measure the temperature.
46	Kurnakow, N. S. and Nikitinsky, A. J.	1914	B	273-373		Pure; Thomson double bridge was used for measuring the electrical resistivity; the specimen was filled in a glass tube and immersed in Vaslin thermostat; mercury was filled in the test tube for calibration.
47	Addison, C. C., Creffield, G. K., and Pulham, R. J.	1971		302-569		99.9 purity specimen (Koch-Light) was washed free of protective oil with light petroleum and purified before use by filtration at just above the melting point through a sintered glass pad; the specimen was contained in a steel capillary of known cross-sectional area and length.
48	Aleksandrov, B. N., Lomacov, O. I., and Semanova, E. D.	1973	A	1.6-5.2	K1	99.99 purity specimen was contained in glass capillaries of diameter 1.2 mm and length 45 mm, into which were sealed potential and current leads in the form of platinum or molybdenum wire; relative resistivity data were reported; data were extracted from figure.
49	Aleksandrov, B. N., et al.	1973	A	1.6-5.2	K2	Similar to the above specimen.

TABLE 19. EXPERIMENTAL DATA ON THE ELECTRICAL RESISTIVITY OF POTASSIUM K (Temperature Dependence)  
 [Temperature, T, K; Resistivity,  $\rho$ ,  $10^{-8}$   $\Omega$ m]

T	$\rho$	T	$\rho$	T	$\rho$	T	$\rho$	T	$\rho$	T	$\rho$	T	$\rho$
<u>CURVE 1</u>													
0.0	0.00087*	13.00	0.0302	3.74	0.0028	4.18	0.0045*	2.80	0.00438*	301	7.52	301	7.52
1.6	0.0007018	14.00	0.0379	4.04	0.00285	4.44	0.0047	3.12	0.0044	373	15.4	373	15.4
1.8	0.00087044	15.00	0.0467	4.43	0.0031	4.69	0.00495	3.78	0.00457	473	21.5	473	21.5
2.0	0.0008711	16.00	0.0566	5.08	0.0036	4.98	0.00522	4.46	0.0050	573	28.4*	573	28.4*
2.2	0.00087253	17.00	0.0676	5.50	0.0041	5.55	0.00582	4.59	0.0052	673	35.8*	673	35.8*
2.4	0.0008754	18.00	0.0795	6.47	0.0055	6.05	0.00665	4.83	0.00532	773	44.4	773	44.4
2.6	0.0008804	19.00	0.0925	6.93	0.0068	6.55	0.00776	5.37	0.00583	873	54.3	873	54.3
2.8	0.000989	20.00	0.1069	7.67	0.0082	7.11	0.00873	5.61	0.00652	973	66.4	973	66.4
3.0	0.00093019	22.00	0.1369	8.04	0.0100	7.50	0.00966	5.98	0.00764	1033	74.2	1033	74.2
3.2	0.0009326	24.00	0.1699	8.45	0.0110	8.05	0.01159	6.38	0.00859	1173	93.8	1173	93.8
3.3	0.0009467	<u>CURVE 3</u>											
3.4	0.0009667	9.48	0.0152	8.85	0.01538*	8.85	0.01538*	7.67	0.0106	1273	110.0	1273	110.0
3.5	0.0009728	10.05	0.0183	9.44	0.01791	9.44	0.01791	7.83	0.0128	1373	131.0	1373	131.0
3.6	0.0009813	10.94	0.0243	10.94	0.02065	10.00	0.02065	8.38	0.0143	1423	145.0	1423	145.0
3.7	0.0010025	12.00	0.0320	11.09	0.02649	9.00	0.0168	9.00	0.0185	1448	153.0	1448	153.0
3.8	0.0010263	12.94	0.040	12.00	0.03412	12.00	0.03412	9.27	0.0185	<u>CURVE 16</u>			
3.9	0.0010624	13.80	0.050	12.82	0.04335	10.47	0.0236	10.47	0.0236	373.2	15.0	373.2	15.0
4.0	0.0010913*	14.69	0.059	13.96	0.0537	13.96	0.0537	11.12	0.0302	398.0	16.3	398.0	16.3
4.1	0.0011232	15.74	0.072	15.74	0.0638	14.93	0.0638	12.08	0.0378	<u>CURVE 17</u>			
4.2	0.0011577	16.98	0.085	15.87	0.0752	15.87	0.0752	13.06	0.0474	8	0.0103	8	0.0103
<u>CURVE 2</u>													
2.00	0.0009016	292	8.7*	18.03	0.100	16.63	0.092	13.80	0.0568	10	0.0177	10	0.0177
2.25	0.0009041	328	8.4	18.49	0.117	18.07	0.105	15.38	0.0705	12	0.0284	12	0.0284
2.50	0.0009085	<u>CURVE 5</u>											
2.75	0.000917	198	4.0	2.60	0.00218	3.02	0.0048	338	15.0	14	0.0428	14	0.0428
3.00	0.00093	273	6.3	2.78	0.00216	3.33	0.0049	373	16.9	16	0.0618	16	0.0618
3.25	0.00095	289	7.1	3.10	0.00222	4.14	0.0051	423	19.5	18	0.0849	18	0.0849
3.50	0.00099	<u>CURVE 6</u>											
3.75	0.001042	3.40	0.00223	4.56	0.00538	5.23	0.00538	523	25.1	20	0.110	20	0.110
4.00	0.001108	4.12	0.0025	4.59	0.00574	4.59	0.00574	573	28.2	25	0.193	25	0.193
4.25	0.001194	5.86	0.0048	4.86	0.00587	4.86	0.00587	623	31.5	30	0.239	30	0.239
4.50	0.001303	6.71	0.0073	5.33	0.0067	5.33	0.0067	673	35.1	35	0.389	35	0.389
4.75	0.001436	8.93	0.0155	7.87	0.0116	7.87	0.0116	723	38.7	40	0.494	40	0.494
5.00	0.001585	10.45	0.0256	9.40	0.0203	9.40	0.0203	773	42.6	45	0.668	45	0.668
5.50	0.002	13.84	0.0664	10.35	0.0264	10.35	0.0264	823	46.6	55	0.817	55	0.817
6.00	0.00255	15.07	0.0771	11.05	0.0333	11.05	0.0333	873	50.9	60	0.925	60	0.925
6.50	0.00324	16.79	0.1078	12.26	0.0415	12.26	0.0415	923	55.5	70	1.114	70	1.114
7.00	0.00408	18.28	0.1266	14.22	0.062	14.22	0.062	973	60.5	80	1.334	80	1.334
7.50	0.00511	<u>CURVE 7</u>											
8.00	0.00632	4.2	0.00341	16.07	0.080	16.07	0.080	1023	66.1	90	1.524	90	1.524
8.50	0.00772	<u>CURVE 8</u>											
9.00	0.00933	4.2	0.061	17.02	0.101	17.02	0.101	1073	72.2*	100	1.724	100	1.724
9.50	0.00121	<u>CURVE 9</u>											
10.00	0.0132	2.56	0.0042	18.03	0.116	18.03	0.116	1123	79.0	110	1.914	110	1.914
11.00	0.0179	3.17	0.0042	19.10	0.130	19.10	0.130	1173	86.2*	120	2.094	120	2.094
12.00	0.0236	2.85	0.00277	2.76	0.00437	2.76	0.00437	1223	94.0	130	2.284	130	2.284
		3.18	0.0027	3.88	0.0044	3.88	0.0044	1273	102.3	140	2.464	140	2.464
										150	2.644	150	2.644
										160	2.824	160	2.824
										170	3.004	170	3.004

\* Not shown in figure.



TABLE 19. EXPERIMENTAL DATA ON THE ELECTRICAL RESISTIVITY OF POTASSIUM K (Temperature Dependence) (continued)

CURVE 37 (cont.)		CURVE 42		CURVE 45 (cont.)		CURVE 48 (cont.)	
T	ρ	T	ρ	T	ρ	T	ρ
3.39	0.00195	471	20.46	755	43.8	2.80	0.004094
3.45	0.00196*	563	26.98	811	49.1	3.00	0.004108
3.49	0.00198	670	33.96	866.5	54.9	3.19	0.004150*
3.54	0.00198*	864	52.94	922	61.1	3.40	0.004189
3.60	0.00199*	1064	78.88	CURVE 46		3.59	0.004203*
3.64	0.00201*	1281	107.15	273	6.60*	3.81	0.004258*
3.70	0.00202	1468	153.81	298	7.71	4.00	0.004317
3.73	0.00203*	1667	233.88	298	8.82	4.21	0.004402*
3.74	0.00203*	1865	388.15	303	8.82	4.31	0.004466*
3.80	0.00205	2070	788.85	348	14.43	4.43	0.004503*
3.84	0.00206*	2122	1185.75*	373	15.80	4.49	0.004575*
3.86	0.00206*	2173	3104.60*	CURVE 47		4.57	0.004620
3.95	0.00211*	CURVE 43		4.66	0.004681*	4.66	0.004681*
4.00	0.00212	670	33.8	4.71	0.004721*	4.71	0.004721*
4.04	0.00213*	869	51.4	4.82	0.004768*	4.82	0.004768*
4.07	0.00215*	1367	120.2	4.90	0.004831*	4.90	0.004831*
4.11	0.00216	1466	144.5	4.97	0.004870*	4.97	0.004870*
4.15	0.00219*	1662	210.4	5.04	0.004929	5.04	0.004929
4.18	0.0022*	1862	311.1	5.10	0.004965*	5.10	0.004965*
CURVE 38		2065	480.8	5.18	0.0050035	CURVE 49	
1.22	1.182	2126	563.6	CURVE 44		1.62	0.007012
3.44	1.182	2169	653.1	475	19.50	2.00	0.007027
4.21	1.202	2222	772.5	578	25.47	2.21	0.007028
20.42	1.409	2267	959.4	669	32.28	2.42	0.007027
77.60	3.653	2327	1224.0*	867	48.86	2.53	0.007028
87.61	4.075	2366	1496.0*	1072	73.28	2.79	0.007043
273.16	12.75	CURVE 44		1157	96.30	3.00	0.007050
CURVE 39*		1469	135.2	1469	135.2	3.20	0.007068*
293.15	7.118	1665	190.9	418	18.04*	3.37	0.007120
373.15	15.275	CURVE 45		443	19.51	3.56	0.007119*
CURVE 40		533	25.2	464	20.69	3.78	0.007193*
338.15	13.1*	580	29.6	479	21.64	4.00	0.007242
408.15	16.8	644	34.2	491	22.35	4.21	0.007336*
CURVE 41		700	39.0	512	23.67	4.35	0.007390*
336.8	12.98	CURVE 46		534	25.11*	4.43	0.007424*
670	35.65	1.61	0.004045	549	25.97	4.51	0.007489*
771	42.76	1.82	0.004045	569	27.28	4.58	0.007526
864	58.23	2.02	0.004045	CURVE 48		4.67	0.007564*
1062	85.11	2.21	0.004044	1.61	0.004045	4.77	0.007606*
1265	121.61	2.40	0.004063	1.82	0.004045	4.83	0.007676*
		2.62	0.004077	4.91	0.007738*	4.97	0.007779*
				5.03	0.007828	5.03	0.007828
				5.11	0.007907*	5.11	0.007907*
				5.17	0.007969	5.17	0.007969

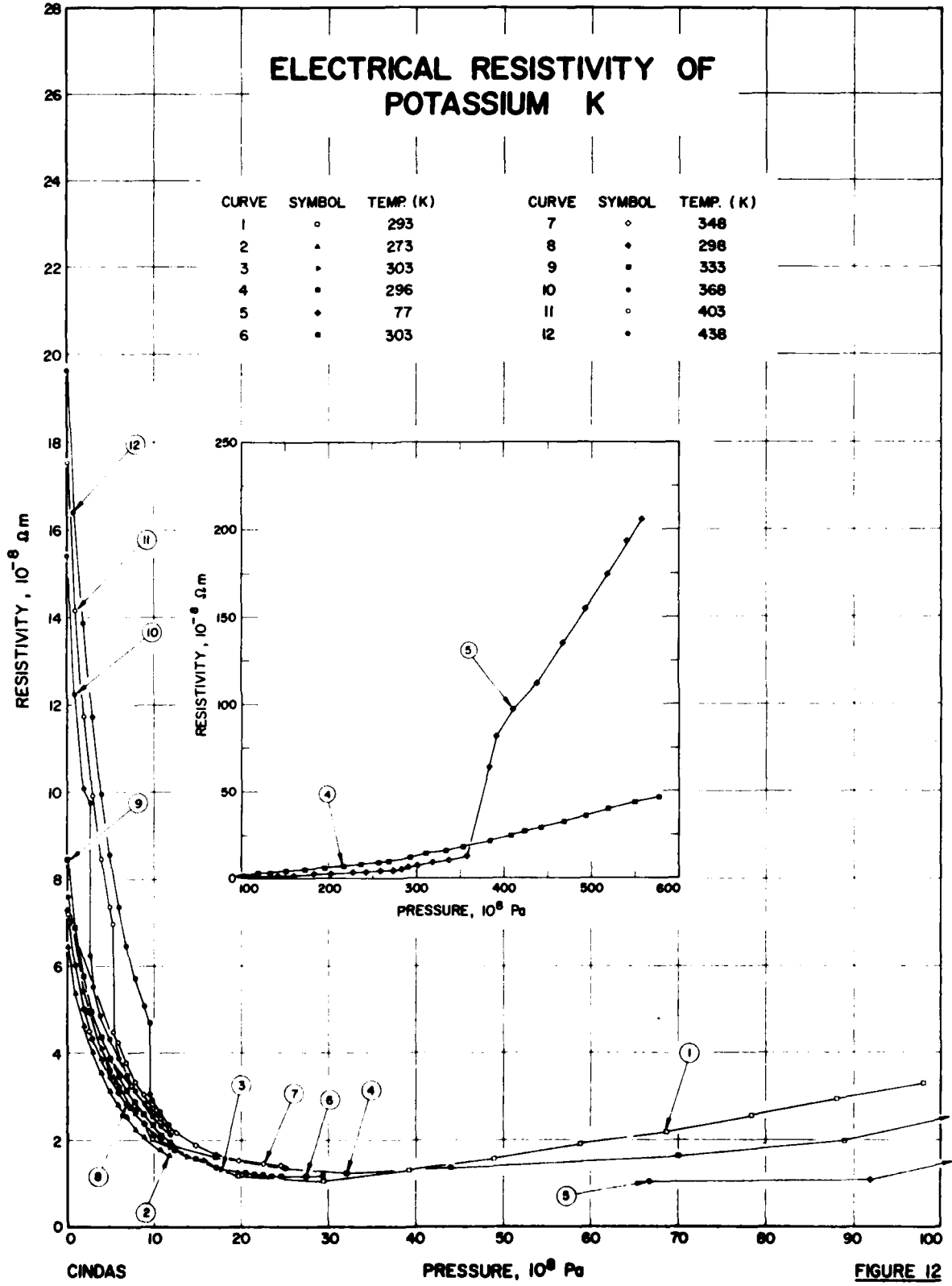
\* Not shown in figure.

### b. Pressure Dependence

There are 12 sets of experimental data available for the electrical resistivity of potassium as a function of pressure. The information on specimen characterization and measurement conditions for each of the data sets is given in Table 20. The data are tabulated in Table 21 and shown in Figure 12.

The available data and information for the pressure dependence of electrical resistivity of potassium are inadequate for performing detailed analysis and synthesis at this time. Consequently, no recommendations are made and only experimental data are presented here.

### ELECTRICAL RESISTIVITY OF POTASSIUM K



CINDAS

PRESSURE, 10<sup>8</sup> Pa

FIGURE 12



TABLE 20. MEASUREMENT INFORMATION ON THE ELECTRICAL RESISTIVITY OF POTASSIUM K (Pressure Dependence)

Cur. Ref. No.	Author(s)	Year	Method Used	Pressure Range, 10 <sup>4</sup> Pa	Temperature Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1 20	Bridgman, P. W.	1952	A	0-98	293		Pure; AgCl is the material to transmit pressure; the relative resistance data were reported; the electrical resistivity data were obtained by using the recommended value of electrical resistivity at 293 K and one atm pressure, the compressibility data and the relative resistance data.
2 86	Bridgman, P. W.	1925	A	0-11.76	273		Pure; solid, 1.5 mm diameter bare wire sample was extruded under Nijol.
3 72	Bridgman, P. W.	1930	A	0-19.60	303		Pure; solid, bare wires.
4 31	Stager, R. A. and Drickamer, H. G.	1963	A	12-578	296		Commercial purity specimen; the resistance as function of pressure was reported.
5 31	Stager, R. A. and Drickamer, H. G.	1963	A	67-558	77		Same as the above specimen.
6 32	Bridgman, P. W.	1938		0-29.4	303		Pure; specimen was obtained from Kahlbaum; it was extruded to bare wire; the relative electrical resistance as a function of pressure data were reported.
7 32	Bridgman, P. W.	1938		0-24.5	348		Same as the above specimen.
8 33	Bridgman, P. W.	1921		0-11.76	298		Pure; specimen was contained in a glass capillary; relative electrical resistance were reported.
9 33	Bridgman, P. W.	1921		0-11.76	333		Same as the above specimen.
10 33	Bridgman, P. W.	1921		0-11.76	368		Same as the above specimen.
11 33	Bridgman, P. W.	1921		0-11.76	403		Same as the above specimen.
12 33	Bridgman, P. W.	1921		0-11.76	438		Same as the above specimen.



### c. Magnetic Flux Density Dependence

There are 35 sets of experimental data available for the electrical resistivity of potassium under the influence of magnetic field. The information on specimen characterization and measurement information for each of the data sets is given in Table 22. The data are tabulated in Table 23 and shown in Figure 13.

The available data and information for the magnetic flux density dependence of electrical resistivity of potassium are inadequate for performing detailed analysis and synthesis at this time. Consequently, no recommendations are made and only experimental data are presented here.

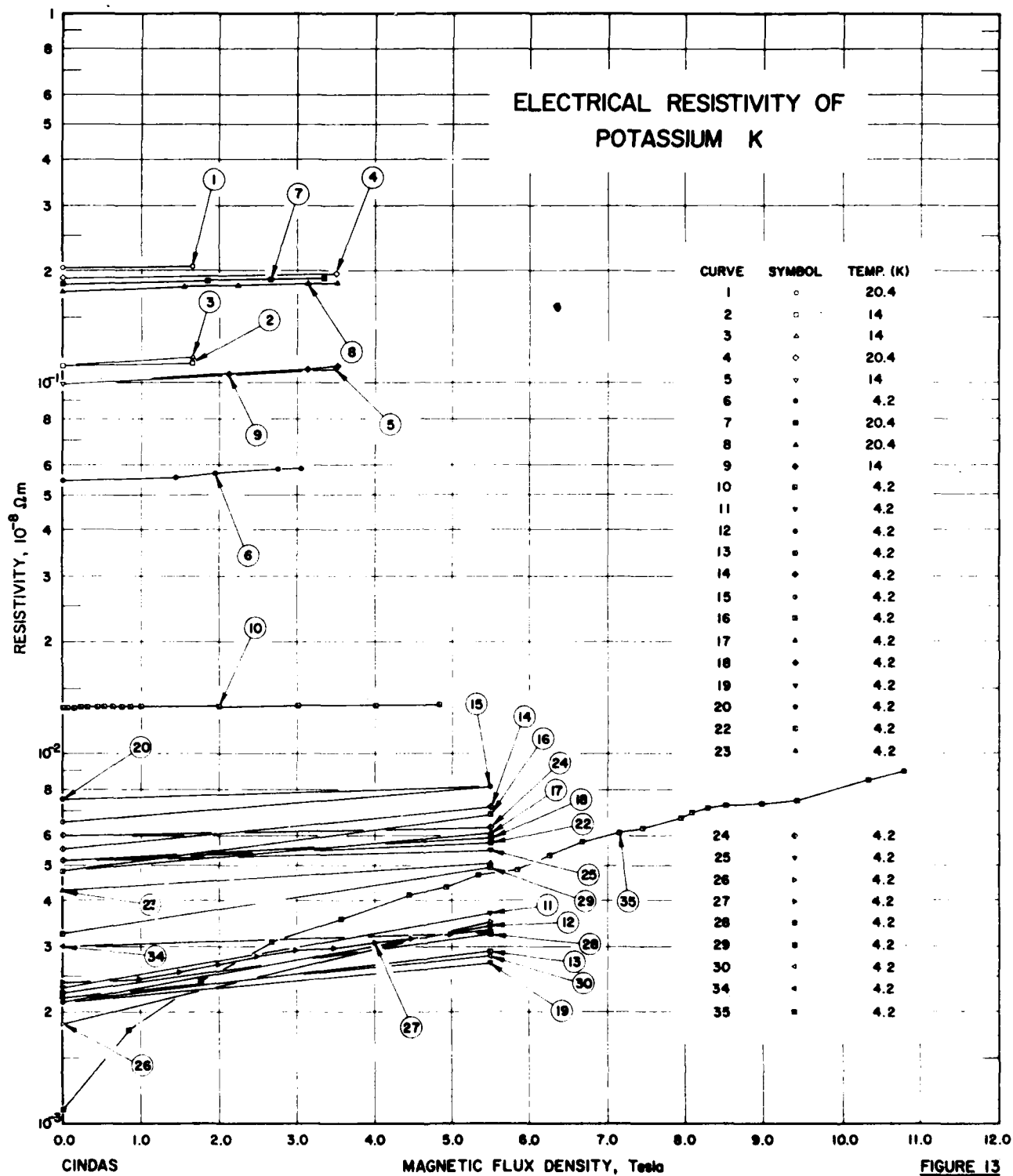


TABLE 22. MEASUREMENT INFORMATION ON THE ELECTRICAL RESISTIVITY OF POTASSIUM K (Magnetic Flux Density Dependence)

Cur. Ref. No.	Author(s)	Year	Method Used	Magnetic Flux Density Range, Tesla	Temperature Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	Justi, E.	1948	A	0, 1.65	20.4	K5	Pure; 1 mm width, 40 mm long; R <sub>20.4 K/R<sub>273.15 K</sub></sub> = 0.02835; measured in a transverse magnetic field.
2	Justi, E.	1948	A	0, 1.65	14.0	K5	Same as the above specimen; R <sub>14 K/R<sub>273.15 K</sub></sub> = 0.0155.
3	Justi, E.	1948	A	0, 1.65	14.0	K5	Same as the above specimen except measured in a longitudinal magnetic field.
4	Justi, E.	1948	A	0, 3.5	20.4	K6	Pure; R <sub>20.4 K/R<sub>273.15 K</sub></sub> = 0.02673; measured in a transverse magnetic field.
5	Justi, E.	1948	A	0, 3.5	14.0	K6	Same as the above specimen; R <sub>14 K/R<sub>273.15 K</sub></sub> = 0.0138.
6	Justi, E.	1948	A	0-3.05	4, 22	K6	Same as the above specimen; R <sub>4, 22 K/R<sub>273.15 K</sub></sub> = 0.00756.
7	Justi, E.	1948	A	0-3.33	20.4	K6	Same as the above specimen; R <sub>20.4 K/R<sub>273.15 K</sub></sub> = 0.02604.
8	Justi, E.	1948	A	0-3.51	20.4	K11	Pure; R <sub>20.4 K/R<sub>273.15 K</sub></sub> = 0.0247; measured in a transverse magnetic field.
9	Justi, E.	1948	A	0-3.51	14.0	K11	Same as the above specimen; R <sub>14, 0 K/R<sub>273.15 K</sub></sub> = 0.0138.
10	Babiskin, J. and Stebennann, P. G.	1969		0-5	4.2		Pure; 1 mm in diameter and 1 mm long wire specimen; R <sub>300 K/R<sub>4.2 K</sub></sub> = 560; $r$ measured in a transverse magnetic field; data were extracted from the smooth curve.
11	Penz, P. A. and Bowers, R.	1968	-	0, 5.5	4.2	1	99.95 pure; single crystal specimen; 1 mm thickness and elliptical surface with 4 mm semiminor axes; the specimen was obtained from Mine Safety Appliance Co.; the disk normal and magnetic field was in [100] direction; residual resistance ratio RRR = $3.1 \times 10^3$ ; the magnetic resistance was deduced from helicon resonance.
12	Penz, P. A. and Bowers, R.	1968	-	0, 5.5	4.2	2	Similar to the above specimen and conditions except RRR = $3.4 \times 10^3$ .
13	Penz, P. A. and Bowers, R.	1968	-	0, 5.5	4.2	3	Similar to the above specimen and conditions.
14	Penz, P. A. and Bowers, R.	1968	-	0, 5.5	4.2	4	Similar to the above specimen and conditions except RRR = $1.3 \times 10^3$ .
15	Penz, P. A. and Bowers, R.	1968	-	0, 5.5	4.2	5	Similar to the above specimen and conditions except RRR = $1.1 \times 10^3$ .
16	Penz, P. A. and Bowers, R.	1968	-	0, 5.5	4.2	6	Similar to the above specimen and conditions except RRR = $1.5 \times 10^3$ .
17	Penz, P. A. and Bowers, R.	1968	-	0, 5.5	4.2	7	Similar to the above specimen and conditions.
18	Penz, P. A. and Bowers, R.	1968	-	0, 5.5	4.2	8	Similar to the above specimen and conditions except RRR = $1.4 \times 10^3$ .
19	Penz, P. A. and Bowers, R.	1968	-	0, 5.5	4.2	9	Similar to the above specimen and conditions except RRR = $3.4 \times 10^3$ and the magnetic field and specimen normal was in the [110] direction.
20	Penz, P. A. and Bowers, R.	1968	-	0, 5.5	4.2	10	Similar to the above specimen and conditions except RRR = $0.9 \times 10^3$ .

TABLE 22. MEASUREMENT INFORMATION ON THE ELECTRICAL RESISTIVITY OF POTASSIUM K (Magnetic Flux Density Dependence) (continued)

Cur. Ref. No.	Author(s)	Year	Method Used	Magnetic Flux Density Range, Tesla	Temperature Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
21*	Penz, P. A. and Bowers, R.	1968	-	0, 5.5	4.2	11	Similar to the above specimen and conditions except RRR = $1.3 \times 10^3$ .
22	Penz, P. A. and Bowers, R.	1968	-	0, 5.5	4.2	12	Similar to the above specimen and conditions except RRR = $1.4 \times 10^3$ .
23	Penz, P. A. and Bowers, R.	1968	-	0, 5.5	4.2	13	Similar to the above specimen and conditions except RRR = $1.7 \times 10^3$ .
24	Penz, P. A. and Bowers, R.	1968	-	0, 5.5	4.2	14	Similar to the above specimen and conditions except RRR = $1.2 \times 10^3$ .
25	Penz, P. A. and Bowers, R.	1968	-	0, 5.5	4.2	15	Similar to the above specimen and conditions except RRR = $1.4 \times 10^3$ .
26	Penz, P. A. and Bowers, R.	1968	-	0, 5.5	4.2	16	Similar to the above specimen and conditions except RRR = $3.9 \times 10^3$ and the specimen normal and the magnetic field was in [111] direction.
27	Penz, P. A. and Bowers, R.	1968	-	0-5.5	4.2	17	Similar to the above specimen and conditions except RRR = $3.0 \times 10^3$ .
28	Penz, P. A. and Bowers, R.	1968	-	0, 5.5	4.2	18	Similar to the above specimen and conditions except RRR = $3.2 \times 10^3$ .
29	Penz, P. A. and Bowers, R.	1968	-	0, 5.5	4.2	19	Similar to the above specimen and conditions except RRR = $2.2 \times 10^3$ and the specimen normal and the magnetic field was in [123] direction.
30	Penz, P. A. and Bowers, R.	1968	-	0, 5.5	4.2	20	Similar to the above specimen and conditions except RRR = $3.3 \times 10^3$ .
31*	Penz, P. A. and Bowers, R.	1968	-	0, 5.5	4.2	21	Similar to the above specimen and conditions except RRR = $3.9 \times 10^3$ .
32*	Penz, P. A. and Bowers, R.	1968	-	0, 5.5	4.2	22	Similar to the above specimen and conditions except RRR = $1.4 \times 10^3$ .
33*	Penz, P. A. and Bowers, R.	1968	-	0, 5.5	4.2	23	Similar to the above specimen and conditions except RRR = $1.2 \times 10^3$ .
34*	Penz, P. A. and Bowers, R.	1968	-	0, 5.5	4.2	24	Similar to the above specimen and conditions except RRR = $2.4 \times 10^3$ .
35	Penz, P. A. and Bowers, R.	1968	-	0-11	4.2		99.95 pure; polycrystalline specimen about 1 mm thick was used; the magnetic resistance was measured in a Bitter solenoid at the NML.

\* Not shown in figure.

TABLE 23. EXPERIMENTAL DATA ON THE ELECTRICAL RESISTIVITY OF POTASSIUM K (Magnetic Flux Density Dependence)  
 [Temperature, T, K; Magnetic Flux Density, B, Tesla; Electrical Resistivity,  $\rho$ ,  $10^{-4}$  (cm)]

B	$\rho$	B	$\rho$	B	$\rho$	B	$\rho$	B	$\rho$	B	$\rho$	B	$\rho$	B	$\rho$	B	$\rho$
CURVE 1 $T = 20.4$		CURVE 8 $T = 20.4$		CURVE 13 $T = 4.2$		CURVE 21* $T = 4.2$		CURVE 27 (cont.) $T = 4.2$		CURVE 35 $T = 24.0$							
0.00	0.2040	0.00	0.1779	0.0	0.00212*	0.0	0.00554	4.97	0.00324	0.00	0.00109						
1.65	0.2060	1.545	0.1812	5.5	0.00292	5.5	0.00610	5.50	0.00336	0.85	0.00179						
CURVE 2 $T = 14.0$		CURVE 9 $T = 14.0$		CURVE 14 $T = 4.2$		CURVE 22 $T = 4.2$		CURVE 28 $T = 4.2$		1.76	0.00242						
0.00	0.1117	0.00	0.0954	0.0	0.00554	0.0	0.00515*	0.0	0.00225	2.67	0.00310						
1.65	0.1138	2.22	0.1831	5.5	0.00720	5.5	0.00577	5.5	0.00326	3.57	0.00358						
CURVE 3 $T = 14.0$		CURVE 10 $T = 4.2$		CURVE 15 $T = 4.2$		CURVE 23 $T = 4.2$		CURVE 29 $T = 4.2$		4.46	0.00414						
0.00	0.1117*	0.00	0.09942*	0.0	0.00655	0.0	0.00424	0.0	0.00327	4.92	0.00436						
1.65	0.1167	2.10	0.1057	5.5	0.00819	5.5	0.00504	5.5	0.00494	5.33	0.00470						
CURVE 4 $T = 22.4$		CURVE 16 $T = 4.2$		CURVE 17 $T = 4.2$		CURVE 24 $T = 4.2$		CURVE 30 $T = 4.2$		5.83	0.00484						
0.00	0.1926	0.00	0.1336	0.0	0.00682	0.0	0.00600	0.0	0.00218	6.27	0.00531						
3.50	0.1977	0.05	0.1337	5.5	0.00682	5.5	0.00630	5.5	0.00284	6.68	0.00579						
CURVE 5 $T = 14.0$		CURVE 17 $T = 4.2$		CURVE 18 $T = 4.2$		CURVE 25 $T = 4.2$		CURVE 31* $T = 4.2$		7.17	0.00608						
0.00	0.09842	0.21	0.1341	0.0	0.00480*	0.0	0.00515*	0.0	0.00185	7.46	0.00627						
3.50	0.1089	0.30	0.1343	5.5	0.00610	5.5	0.00545	5.5	0.00327	7.93	0.00667						
CURVE 6 $T = 4.22$		CURVE 18 $T = 4.2$		CURVE 19 $T = 4.2$		CURVE 26 $T = 4.2$		CURVE 32* $T = 4.2$		8.10	0.00694						
0.00	0.05446	0.43	0.1344	0.0	0.00515	0.0	0.00185	0.0	0.00185	8.30	0.00716						
1.43	0.05589	0.52	0.1345	5.5	0.00592	5.5	0.00351	5.5	0.00581	8.52	0.00723						
1.93	0.05690	0.64	0.1345	0.0	0.00515	0.0	0.00185	0.0	0.00515	8.99	0.00735						
2.75	0.05830	0.75	0.1346	5.5	0.00592	5.5	0.00351	5.5	0.00581	10.32	0.00853						
3.05	0.05849	0.86	0.1345	0.0	0.00592	0.0	0.00351	0.0	0.00581	10.79	0.00893						
CURVE 7 $T = 20.4$		CURVE 19 $T = 4.2$		CURVE 20 $T = 4.2$		CURVE 27 $T = 4.2$		CURVE 33* $T = 4.2$									
0.00	0.1876	0.00	0.00232	0.0	0.00212*	0.00	0.00240	0.0	0.0060								
1.83	0.1899	5.5	0.00370	5.5	0.00271	0.99	0.00243	5.5	0.006305								
2.64	0.1904	CURVE 12 $T = 4.2$		CURVE 20 $T = 4.2$		1.48	0.00256	CURVE 34 $T = 4.2$									
3.33	0.1918	0.0	0.00212	0.0	0.00753	1.99	0.00269	0.0	0.00515								
		5.5	0.00343	5.5	0.00806*	2.49	0.00281	5.5	0.00581								
						2.89	0.00293										
						3.47	0.00297										
						4.00	0.00308										
						4.47	0.00313										

\* Not shown in figure.

#### 4.4. RUBIDIUM

Rubidium, with atomic number 37, is a silvery-white soft alkali metal. It has a body-centered cubic crystalline structure with a density of  $1.532 \text{ g cm}^{-3}$  at 293 K. It melts at 312.64 K and boils at about 959 K. Its critical temperature has been determined to be 2106 K at a pressure of 408.2 atm and the density at the critical temperature was  $0.1818 \text{ g cm}^{-3}$ . Naturally-occurring rubidium is composed of one stable isotope,  $^{85}\text{Rb}$  (72.15%), and one unstable isotope,  $^{87}\text{Rb}$  (27.85%), which is radioactive and has a half-life of  $5 \times 10^{11}$  years. Ordinary rubidium is sufficiently radioactive to expose a photographic film in about one to two months. Fifteen other radioactive isotopes of rubidium are known to exist. Rubidium ranks 22nd in the order of abundance of elements in the continental crust of the earth (0.009% by weight).

##### a. Temperature Dependence

There are 33 sets of experimental data available for the temperature dependence on the electrical resistivity of rubidium. The information on specimen characterization and measurement conditions for each of the data sets is given in Table 25. The data are tabulated in Table 26 and shown in Figures 14 and 15. Determination of the electrical resistivity of rubidium for the solid and liquid phase cover the continuous temperature range from 1.13 to 1866 K.

There are 15 sets of experimental data obtained below 100 K. Among these, 4 sets (curves 10, 12, 13, and 14) are at constant volume under various pressures and 2 sets are for thin films (curves 5 and 6). Aleksandrov, Lemonos, and Semenova [85] (curve 32) gave the lowest residual resistivity,  $\rho_0 = 0.0134 \times 10^{-8} \Omega\text{m}$ . Four sets of the intrinsic electrical resistivity at zero pressure are obtained by subtraction of the residual resistivity  $\rho_0$  from the measured resistivity. In deriving the smoothed most probable values of intrinsic resistivity from the available data, the following overlapping temperature ranges were considered: below 8 K; 5-20 K; 10-40 K; 20-80 K; 30-150 K; etc. Within each range, a least-mean-square fraction error fit of the semiempirical equation  $\rho_i = aT^b$  was made to all available intrinsic resistivity data. The resulting values for adjacent ranges were intercompared and the values were corrected for thermal linear expansion. These preliminary values were then fitting with the equation (7) to generate the final recommended values. The coefficients of equation (7) obtained in the fitted are given in the following table:



Temperature Range, K	a	b	c	d
1.97- 7.16	-3.322	3.325	1.970	-3.042
7.16- 10.72	-1.375	2.671	-3.140	10.75
10.72- 12.10	-0.945	2.561	2.514	-40.51
12.10- 14.46	-0.810	2.491	-3.851	10.85
14.46- 50.04	-0.635	2.089	-1.327	0.576
50.04-100	0.196	1.161	-0.396	0.562

There are 19 data sets in the temperature region from 100 K to the melting point, 312.64 K. Among these, 4 sets (curves 10, 12, 13, 14) are at constant volume under various pressures and 1 set (curve 1) is a single data point at 273 K. Messiner and Voigt [29] (curve 26) give the highest value, which is about 60% higher than all the other data; therefore, this data set and those sets measured at constant volume are excluded for the computer fitting. A least-mean-square fractional error fit to the totality of experimental data in this range was made with  $\rho_1 = aT^b$ . The resulting values were corrected for thermal linear expansion, and then fitted with the cubic spline function equation (7) to obtain the final recommended values in this temperature range. The coefficients of equation (7) obtained are as follows:

Temperature Range, K	a	b	c	d
50.04-312.64	0.196	1.161	-0.396	0.562

There are 11 data sets measured in the liquid state. Endo [40] (curve 22) and Lien and Silvertsen [41] (curve 2) have tabulated the electrical resistivity at constant volume up to 470 K. The rest of the data are apparently measured at the saturated vapor pressure. Solov'ev [52] (curve 3) gives the lowest values while Kapelner and Bratton [43] (curve 8) give the highest values. Grosse [5] derived electrical resistivity values (curve 34) from the melting point to his estimated critical temperature, 2106 K, by fitting the data of Kapelner and Bratton [43] (curve 8) to a hyperbola. Below 1000 K, all the experimental data except those measured at constant volume were fitted by a logarithmic third order polynomials. Above 1000 K, the electrical resistivity values are obtained by extrapolating the fitted values and following the experimental trend. The resulting values are fitted with the cubic spline function equation (7) to obtain the final recommended values. The coefficients of equation (7) obtained from fitting are as follows:

Temperature Range, K	a	b	c	d
312.64- 611.74	1.353	1.051	0.485	-0.498
611.74-1087.7	1.689	1.207	0.049	4.138
1087.7 -2000	2.057	2.007	3.153	-0.531

At the melting point (312.64 K), the electrical resistivity of rubidium in the liquid state is about 63% higher than that of the solid state. Mott's formula (Eq. 5) gives the electrical resistivity about 75% higher than that of the solid state.

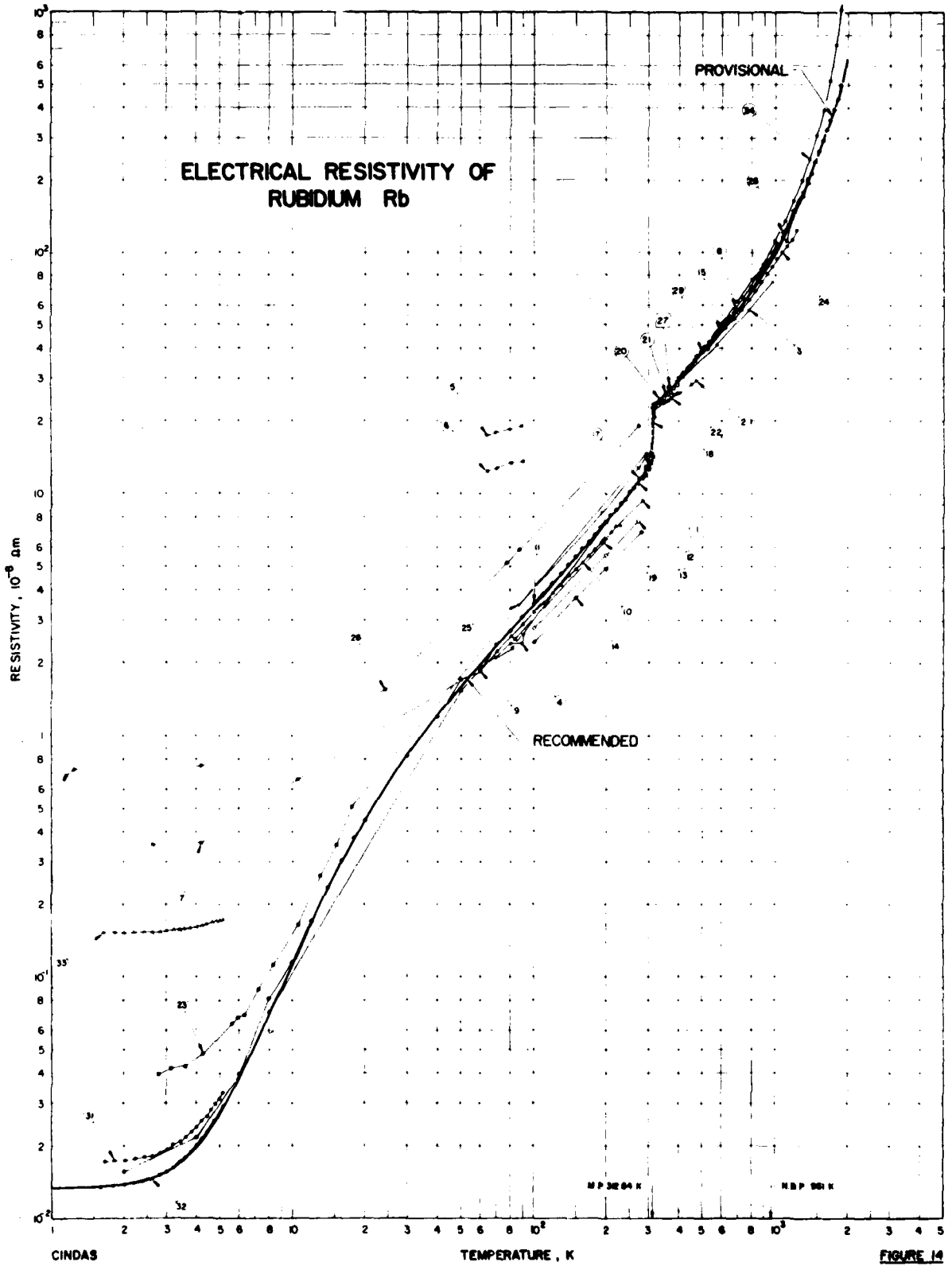
The recommended values for the total and intrinsic electrical resistivity are listed in Table 24, and those for the total electrical resistivity are also shown in Figures 11 and 12. The recommended values for the liquid state are for the saturated liquid. The recommended values of the total resistivities for the solid state are for a 99.99+ % pure rubidium and those at temperatures below 50 K are only applicable for a specimen with residual resistivity  $\rho_0 = 0.0131 \times 10^{-8} \Omega\text{m}$ . The recommended values from 1 K to 312.64 K are corrected for thermal linear expansion. The correction amounts to -1.77% at 1 K, -0.9% at 160 K, and 0.2% at 312.64 K. The uncertainty of the recommended total electrical resistivity is believed to be within  $\pm 5\%$  from 1 to 1500 K and within  $\pm 10\%$  from 1500 K to 2000 K. Above 20 K the uncertainty of the intrinsic resistivity is about the same as that of the total electrical resistivity; below 20 K this uncertainty is higher than that of the total electrical resistivity.

TABLE 24. RECOMMENDED ELECTRICAL RESISTIVITY OF RUBIDIUM  
(Temperature Dependence)

[Temperature, T, K; Total Resistivity,  $\rho$ ,  $10^{-8} \Omega m$ ; Intrinsic Resistivity,  $\rho_i$ ,  $10^{-8} \Omega m$ ]

Solid						Liquid	
T	$\rho$	$\rho_i$	T	$\rho$	$\rho_i$	T	$\rho$
1	0.0131		35	1.02	1.01	312.64	22.52
2	0.0136	0.00050*	40	1.21	1.20	350	25.42
3	0.0153	0.0022*	45	1.40	1.39	400	29.51
4	0.0194	0.0063*	50	1.58	1.57	500	38.27
5	0.0270	0.0139*	60	1.94	1.93	600	47.61
6	0.0384	0.0253*	70	2.29	2.28	700	57.48
7	0.0528	0.0397*	80	2.65	2.64	800	68.50
8	0.0691	0.0560*	90	3.00	2.99	900	81.50
9	0.0872	0.0741*	100	3.36	3.35	1000	97.26
10	0.109	0.0954*	150	5.27	5.26	1100	116.7
11	0.134	0.121*	200	7.49	7.48	1200	140.8
12	0.165	0.152*	250	10.14	10.13	1300	170.3
13	0.197	0.184*	273.15	11.54	11.53	1400	206.3
14	0.229	0.216*	293	12.84	12.83	1500	249.7
15	0.263	0.250*	300	13.32	13.31	1600	301.8*
16	0.298	0.285*	312.64	14.21	14.20	1700	364.1*
18	0.370	0.357*				1800	438.2*
20	0.444	0.431				1900	525.9*
25	0.636	0.623				2000	629.4*
30	0.830	0.817					

\* Provisional values.



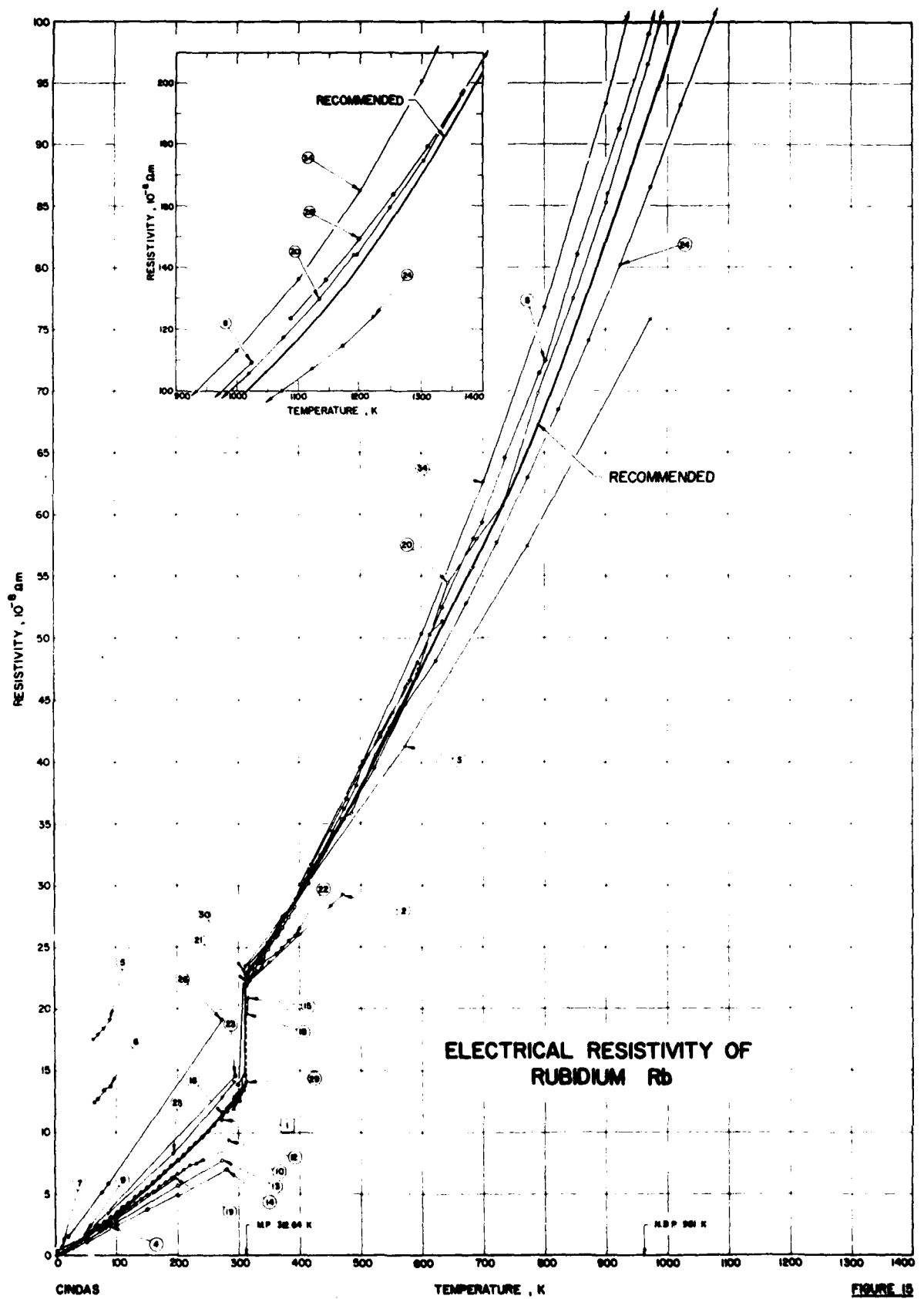


TABLE 25. MEASUREMENT INFORMATION ON THE ELECTRICAL RESISTIVITY OF RUBIDIUM Rb (Temperature Dependence)

Cat. Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1 22	Krausz, E.	1950	A	273	Pure.	
2 41	Lien, S. Y. and Silvertsen, J. M.	1969	A	312-470		99.9 pure rubidium was supplied by A. D. Mackay Inc.; the specimen cells were made from precision quartz capillaries open on one end; four tungsten current and potential leads were sealed into the capillary; measurements at constant volume; data represented by $\rho = 22.0 + (80/\delta T)$ ( $T = 312$ ), $312 < T < 470$ K, $\rho$ in units of $10^{-4}$ $\Omega$ cm.
3 52, 88	Solov'ev, A. N.	1963, 1967		312-973		Pure; liquid state specimen; density $1.475 \text{ g cm}^{-3}$ at 312 K, $1.179 \text{ g cm}^{-3}$ at 973 K.
4 89	Lovell, A. C. B.	1936	A	60-90		0.03 Na, 0.8 K, 0.2 Cs, 0.2 B, trace of Ca, Si; the specimen was prepared by the reduction of rubidium chloride with calcium metal in high vacuum apparatus.
5 89	Lovell, A. C. B.	1936	A	60-90	Rb(Film)	The above specimen was deposited on pyrex glass surface $1.35 \text{ cm}$ width, $1.55 \text{ cm}$ long; film thickness $43.7 \text{ \AA}$ .
6 89	Lovell, A. C. B.	1936	A	60-90	Rb(Film)	Similar to the above specimen with film thickness $87.4 \text{ \AA}$ .
7 54	McLernan, J. C. and Niven, C. D.	1927	B	2.63-293		Pure; specimen was filled in a U-shaped capillary.
8 43	Kapelner, S. M. and Bratton, W. D.	1962	B	299-1025		99.5 pure; 0.32 Ca, 0.05 Na, and 0.06 K; specimen was obtained from American Potash and Chemical Corp.; liquid specimen was loaded into a type 307 stainless steel tube heated at $550 \text{ C}$ for 2 hr.
9 90	Dugdale, J. S. and Phillips, D.	1965	A	2-300	6, 7, 8	Pure; specimens were obtained from L. Light and Co. Ltd.; wire specimens about $2 \text{ mm}$ in diameter were extruded under distilled paraffin oil; $R_{293}/R_{4.2} = 580$ ; electrical resistivity was measured under zero pressure.
10 90	Dugdale, J. S. and Phillips, D.	1965	A	2-280	6, 7, 8	Same as above specimen except the electrical resistivity was obtained under constant volume.
11 90	Dugdale, J. S. and Phillips, D.	1965	A	0-240		Similar to the above specimen; ideal resistivity as function of temperature at constant pressure ( $p = 0$ ); data were extracted from the smooth curve.
12 90	Dugdale, J. S. and Phillips, D.	1965	A	0-284		Similar to the above specimen; ideal resistivity as function of temperature at constant density as at 0 K at zero pressure; data were extracted from the smooth curve.
13 90	Dugdale, J. S. and Phillips, D.	1965	A	0-273		Similar to the above specimen; at constant density as at 0 K at 1000 atm.
14 90	Dugdale, J. S. and Phillips, D.	1965	A	0-280		Similar to the above specimen; at constant density as at 0 K at 4,200 atm; data above 150 K were interpolation between present results and a point based on Bridgman's data at ice point.
15 56	Hackspill, L.	1910	A	291-316	1	Pure; specimen was filled in a U-shaped capillary.
16 56	Hackspill, L.	1910	A	273-293	2	Similar to the above specimen.
17 56	Hackspill, L.	1910	A	273-291	3	Similar to the above specimen.
18 56	Hackspill, L.	1910	A	293-313	4	Similar to the above specimen.
19 56	Hackspill, L.	1910	A	83-313	5	Similar to the above specimen.
20 17, 91, 92	Tepper, F., Murchison, A., Zelnak, J., and Roehlich, F.	63-1965	A	367-1370		99.5 pure; specimen was placed in a Haynes-25 alloy cylindrical cell $0.5''$ in O. D., $0.065''$ wall, and $26''$ in length.

TABLE 26. MEASUREMENT INFORMATION ON THE ELECTRICAL RESISTIVITY OF RUBIDIUM Rb (Temperature Dependence) (continued)

Cur. Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
21	Eudo, H.	1963	A	313-393		Pure; specimen was supplied by A. D. Mackay Ltd.; specimen was contained in a soft glass capillary tube (I. D. 0.7 mm); electrical resistivity was measured at constant pressure condition.
22	Eudo, H.	1963	A	313-393		Same as above specimen; electrical resistivity was obtained at constant volume.
23	MacDonald, D.K.C., White, G.K., and Woods, S.B.	1955		2.5-293	Rb 1	Pure; specimen was obtained from Messers A. D. Mackay (New York); specimen was melted in vacuo and run into soft glass tubes with platinum leads sealed in; 1.65 mm in diameter; $\rho_0/\rho_{300} = 2.63 \times 10^{-2}$ .
24	Semyachkin, B. E. and Solov'ev, A. N.	1964	A	313-1223		Pure; specimen was obtained from RETV 118-69; specimen was placed in a (0.6/0.5 mm) 1 Kh 18 NgT 60 mm long capillary.
25	Gunka, A. and Broniewski, W.	1909		86-292		Pure.
26	Melzer, W. and Voigt, B.	1930		1.13-273.16	Rb 1	Pure; specimen was distilled in glass tube; specimen diameter was 4.8 mm and 35 mm long.
27	Van der Lugt, W., Devlin, J. F., Hemphof, J., and Leenstra, M. R.	1972	B	373.15		Pure; data was extracted from graph.
28	Hochman, J. M., Silver, I. L., and Bonilla, C. F.	1964	A	1088-1868		Commercial purity (99.7-99.9 Rb); specimen was provided by Penn Rare Metals; liquid phase specimen was partially filled in a 90 Ta, 8 W, 2 Hf alloy capsule 1 in. O. D., 1/16 in. wall, and 12 in. long; it was surrounded by a molybdenum wire heater on an alumina core and radiation shields, all contained in a vessel pressurized with argon of extreme purity; temperature was obtained by W/W-26Re thermocouple; the electrical resistivity data were corrected for thermal expansion; critical point about 2111 K was determined by comparing the "pseudoreduced" electrical resistivity with mercury and cesium.
29	Semyachkin, B. E. and Solov'ev, A. N.	1970	A	293-623		99.97 pure; the specimen was placed in a stainless steel tube in a copper block; the temperature was measured by a Pt-PtRh (10%) thermocouple; the measurements were carried out during both heating and cooling at ~0.0/min. rate and with current in both directions; $\rho_{\text{liquid}}/\rho_{\text{solid}} = 1.562$ , $(1/\rho) (d\rho/dT)_{\text{solid}} = 45.5 \times 10^{-4}/\text{K}$ and $(1/\rho) (d\rho/dT)_{\text{liquid}} = 37.2 \times 10^{-4}/\text{K}$ at melting point.
30	Kurnakov, N. S. and Nikitinskiy, A. J.	1914	B	273-373		Pure; Thomson double bridge was used for measurements; the specimen was filled in a glass tube and immersed in a Vasilin thermostat; mercury was filled in the tube for calibration.
31	Aleksandrov, B. N., Lomonosov, O. I., and Semenov, E. D.	1973	A	1.6-5.2	Rb 1	99.99 purity specimen was contained in glass capillaries of diameter 0.5 mm and length 22 mm; into which were sealed potential and current leads in the form of platinum or molybdenum wire; $R_0/R_{290} = 1.35 \times 10^{-2}$ ; resistive electrical resistivity data were reported.
32	Aleksandrov, B. N., et al.	1973	A	1.6-5.2	Rb 4	Similar to the above specimen except $R_0/R_{290} = 1.085 \times 10^{-2}$ .
33	Aleksandrov, B. N., et al.	1973	A	1.6-5.2	Rb 5	Similar to the above specimen except $R_0/R_{290} = 1.21 \times 10^{-2}$ .
34	Groose, A. V.	1966		312.6-2100		Electrical resistivity data were derived by fitting the data of Kaplaner and Bratton to a hyperbolic equation ( $\sigma' + b$ ) ( $T' + b$ ) = a from 312.64 K to 2106 K; where $\sigma' = \rho_{\text{m.p.}}/\rho$ and $T' = (T - T_{\text{m.p.}})/(T_{\text{c.p.}} - T_{\text{m.p.}})$ ; $b = 0.186$ and $a = 0.141$ .

TABLE 26. EXPERIMENTAL DATA ON THE ELECTRICAL RESISTIVITY OF RUBIDIUM Rb (Temperature Dependence)

[Temperature, T, K; Resistivity, $\rho$ , $10^{-8}$ (cm)]							
T	$\rho$	T	$\rho$	T	$\rho$	T	$\rho$
<u>CURVE 1</u>							
273	11.0	298.7	13.85	160	5.900	210	6.953
<u>CURVE 2</u>							
312	22.00	310.6	14.67	170	6.327	220	7.334
350	23.75	312.3	22.84	180	6.758	230	7.376
400	26.05	314.8	22.93*	190	7.203	<u>CURVE 11</u>	
450	28.35	319.5	23.35	200	7.663	273	11.6
470	29.27	364.8	25.96	210	8.129	291	12.1
<u>CURVE 3</u>							
312	23.5	419.8	31.62	220	8.604	<u>CURVE 16</u>	
373	27.5	477.3	37.06	230	9.089	273	11.6
573	41.3	583.4	42.30	240	9.581	<u>CURVE 17</u>	
773	57.5	581.4	46.59	250	10.025	273	11.6
973	75.8	582.5	46.61*	260	10.602	<u>CURVE 18</u>	
<u>CURVE 4</u>							
60.0	1.9	634.8	52.45	270	11.125	293	12.3*
68.9	2.1	685.6	58.01	280	11.657	303	13.1
80.0	2.4	699.2	59.37	290	12.218	313	19.6
89.6	2.4	736.2	64.61	300	12.867	<u>CURVE 19</u>	
<u>CURVE 5</u>							
63.9	17.5	802.0	72.49	3	0.00	83	2.5
69.8	17.9	854.8	81.06	20	0.43	195	6.3
79.9	18.4	923.2	91.29	50	1.57	273	11.6*
89.8	19.1	970.3	99.05	100	3.23	290	12.0*
<u>CURVE 6</u>							
64.2	12.4	1024.8	109.31	284	9.33	300	12.6*
70.3	12.7	<u>CURVE 10</u>					
80.3	13.4	2	0.01568*	3	0.00	<u>CURVE 20</u> (cont.)	
90.2	13.7	4	0.02172	20	0.43	1190.92	144.17
<u>CURVE 7</u>							
2.63	0.353	6	0.03966	50	1.57	1195.37	144.27
4.2	0.357	8	0.08172	100	3.23	1249.81	159.55
10.6	0.658	10	0.1155	200	6.55	1803.70	174.96
82.0	2.30	12	0.1703	400	11.657	1367.55	186.97
293.0	12.6	14	0.2352	800	12.867	1369.81	197.36
<u>CURVE 8</u>							
2	0.01572	16	0.3051*	6	0.00	<u>CURVE 21</u>	
4	0.02172	18	0.3755*	20	0.39	312.65	22.00*
6	0.03966	20	0.4475*	50	1.57	314.95	22.15
8	0.08172	30	0.8135*	100	3.23	319.35	22.54
10	0.1155	40	1.1835*	200	6.55	327.55	23.16
12	0.1703	50	1.542	284	9.33	336.35	23.74
14	0.2352	60	1.867*	3	0.00	341.85	24.22
16	0.3045	70	2.228	20	0.43	340.25	24.84
18	0.3762	80	2.562	50	1.57	361.65	25.74
20	0.4485	90	2.882	100	3.23	372.35	26.58
30	0.8219	100	3.218	200	6.55	383.25	27.43
40	1.2059	120	3.869	400	11.657	392.95	28.24
50	1.7195	150	4.197	600	15.65	<u>CURVE 22</u>	
60	1.867	180	4.587	800	19.6	319.65	22.32
70	2.338	200	4.857	9	0.00	327.95	22.82
80	2.715	220	5.191	20	0.28	339.95	23.35
90	3.095	240	5.570	50	1.13	341.65	23.85
100	3.476	260	6.222	100	2.42	362.05	24.44
110	3.865	280	6.585	150	3.70	372.65	24.94
120	4.261	300	6.96	200	4.89	383.35	25.53
130	4.661	316	7.34	280	6.96	<u>CURVE 23</u>	
150	5.481	291	11.9	9	0.00	2.76	0.0394
<u>CURVE 9</u> (cont.)							
160	6.327	300	12.9	20	0.28	3.13	0.0409
170	6.758	308	13.4	50	1.13	3.60	0.0427
180	7.203	316	13.9	100	2.42	4.28	0.0474
190	7.663	316	14.4	200	4.89	5.69	0.0641
200	8.129	316	14.9	400	11.657	5.94	0.0678
210	8.604	316	15.4	600	15.65	6.34	0.0695
220	9.089	316	15.9	800	19.6	7.23	0.0867
230	9.581	316	16.4	903.70	86.05	969.26	96.59
240	9.581	316	16.9	1020.92	105.82	1052	0.169
250	10.025	316	17.4	1076.48	117.59	13.06	0.281
260	10.602	316	17.9	1135.37	129.96	15.17	0.353
270	11.125	316	18.4				
280	11.657	316	18.9				
290	12.218	316	19.4				
300	12.867	316	19.9				

\* Not shown in figure.



TABLE 26. EXPERIMENTAL DATA ON THE ELECTRICAL RESISTIVITY OF RUBIDIUM Rb (Temperature Dependence) (continued)

T	$\rho$	T	$\rho$	T	$\rho$	T	$\rho$
<u>CURVE 23 (cont.)</u>							
18.79	0.5214	1088.7	123.5	1.66	0.01721	1.64	0.1523
293.00	14.6	1144.3	130.0	1.84	0.01741	1.84	0.1525
<u>CURVE 24</u>							
313	22.5	1199.8	149.2	2.03	0.01745	2.00	0.1529
323	23.3	1255.4	163.6	2.24	0.01767	2.20	0.1530
373	27.4*	1310.9	179.4	2.43	0.01782	2.42	0.1534
423	31.4	1366.5	196.6	2.63	0.01824	2.61	0.1538
473	35.4	1422.1	215.8	2.82	0.01868	2.81	0.1545
523	39.5	1477.6	239.1	3.01	0.01920	3.00	0.1551
573	44.6	1533.2	265.0	3.20	0.02002	3.21	0.1560
623	48.1	1588.7	294.0	3.42	0.02076	3.40	0.1566
673	52.3	1644.3	325.6	3.62	0.02179	3.58	0.1580
723	57.7	1699.8	359.6	3.82	0.02275	3.78	0.1593
773	63.0	1755.4	396.6	4.00	0.02392	4.00	0.1607
823	68.5	1810.9	438.8	4.21	0.02526	4.21	0.1627
873	74.1	1866.5	500.6	4.34	0.02596	4.34	0.1636*
<u>CURVE 25</u>							
923	80.2	293.2	12.83	4.44	0.02649	4.40	0.1652
973	86.5	312	14.03	4.52	0.02729*	4.50	0.1659*
1023	93.2	312	21.91	4.69	0.02863*	4.58	0.1663*
1073	100.0	313.2	22.06*	4.81	0.02985	4.87	0.1675
1123	107.2	333.2	23.72	4.90	0.03056*	4.74	0.1683*
1173	114.5	353.2	25.42	5.00	0.03126	4.81	0.1695*
1223	124.0	373.2	27.14	5.03	0.03187	4.87	0.1704
<u>CURVE 26</u>							
86.15	3.45	393.2	28.89	5.10	0.03248	4.94	0.1710*
154.85	8.25	413.2	30.67	5.17	0.03311	5.00	0.1717
273.15	12.80	433.2	32.48	<u>CURVE 27</u>			
292.35	14.08	453.2	34.32	273	11.29*	2000	2376*
<u>CURVE 27</u>							
1.13	0.664	473.2	36.20	298	13.16	2100	67800*
1.15	0.6893	493.2	38.10	308	23.15		
1.25	0.7296	513.2	40.04	348	25.32		
4.20	0.7507	533.2	42.01	373	27.47		
20.42	1.569	553.2	44.01	<u>CURVE 28</u>			
77.60	5.166	573.2	46.05	1088.7	123.5		
87.81	5.842	593.2	48.13	1144.3	130.0		
273.16	19.2	613.2	50.24	1199.8	149.2		
<u>CURVE 28</u>							
373.15	27.5	633.2	51.32	1255.4	163.6		
<u>CURVE 29</u>							
293.2	12.83	1310.9	179.4	1310.9	179.4		
312	14.03	1366.5	196.6	1366.5	196.6		
312	21.91	1422.1	215.8	1422.1	215.8		
313.2	22.06*	1477.6	239.1	1477.6	239.1		
333.2	23.72	1533.2	265.0	1533.2	265.0		
353.2	25.42	1588.7	294.0	1588.7	294.0		
373.2	27.14	1644.3	325.6	1644.3	325.6		
393.2	28.89	1699.8	359.6	1699.8	359.6		
413.2	30.67	1755.4	396.6	1755.4	396.6		
433.2	32.48	1810.9	438.8	1810.9	438.8		
453.2	34.32	1866.5	500.6	1866.5	500.6		
473.2	36.20	<u>CURVE 29</u>					
493.2	38.10	293.2	12.83	4.60	0.02802		
513.2	40.04	312	14.03	4.69	0.02863*		
533.2	42.01	312	21.91	4.75	0.02918*		
553.2	44.01	313.2	22.06*	4.81	0.02985		
573.2	46.05	333.2	23.72	4.90	0.03056*		
593.2	48.13	353.2	25.42	5.00	0.03126		
613.2	50.24	373.2	27.14	5.03	0.03187		
633.2	51.32	393.2	28.89	5.10	0.03248		
<u>CURVE 30</u>							
273	11.29*	413.2	30.67	5.17	0.03311		
298	13.16	433.2	32.48	<u>CURVE 31</u>			
308	23.15	453.2	34.32	1.66	0.01721		
348	25.32	473.2	36.20	1.84	0.01741		
373	27.47	493.2	38.10	2.03	0.01745		
<u>CURVE 31</u>							
373.15	27.5	513.2	40.04	2.24	0.01767		
<u>CURVE 32</u>							
400	30.06	533.2	42.01	2.43	0.01782		
500	39.56	553.2	44.01	2.63	0.01824		
600	50.31	573.2	46.05	2.82	0.01868		
700	62.60	593.2	48.13	3.01	0.01920		
800	76.78	613.2	50.24	3.20	0.02002		
900	93.31	633.2	51.32	3.42	0.02076		
1000	112.8	1088.7	123.5	3.62	0.02179		
1100	136.2	1144.3	130.0	3.82	0.02275		
1200	164.8	1199.8	149.2	4.00	0.02392		
1300	200.5	1255.4	163.6	4.21	0.02526		
1400	246.4	1310.9	179.4	4.34	0.02596		
1500	307.4	1366.5	196.6	4.44	0.02649		
1600	392.7	1422.1	215.8	4.52	0.02729*		
1700	520.2	1477.6	239.1	4.60	0.02802		
1800	731.7	1533.2	265.0	4.69	0.02863*		
1900	1150*	1588.7	294.0	4.75	0.02918*		
2000	2376*	1644.3	325.6	4.81	0.02985		
2100	67800*	1699.8	359.6	4.90	0.03056*		
<u>CURVE 32</u>							
400	30.06	1755.4	396.6	4.90	0.03056*		
500	39.56	1810.9	438.8	5.00	0.03126		
600	50.31	1866.5	500.6	5.03	0.03187		
700	62.60	<u>CURVE 33</u>					
800	76.78	1.64	0.1523				
900	93.31	1.84	0.1525				
1000	112.8	2.00	0.1529				
1100	136.2	2.20	0.1530				
1200	164.8	2.42	0.1534				
1300	200.5	2.61	0.1538				
1400	246.4	2.81	0.1545				
1500	307.4	3.00	0.1551				
1600	392.7	3.21	0.1560				
1700	520.2	3.40	0.1566				
1800	731.7	3.58	0.1580				
1900	1150*	3.78	0.1593				
2000	2376*	4.00	0.1607				
2100	67800*	4.21	0.1627				
<u>CURVE 33</u>							
400	30.06	4.34	0.1636*				
500	39.56	4.40	0.1652				
600	50.31	4.44	0.1659*				
700	62.60	4.50	0.1659*				
800	76.78	4.58	0.1663*				
900	93.31	4.67	0.1675				
1000	112.8	4.74	0.1683*				
1100	136.2	4.81	0.1695*				
1200	164.8	4.87	0.1704				
1300	200.5	4.94	0.1710*				
1400	246.4	5.00	0.1717				
1500	307.4	5.10	0.1723*				
1600	392.7	5.14	0.1736				
1700	520.2	<u>CURVE 34</u>					
1800	731.7	1.6	0.01356				
1900	1150*	1.8	0.01368				
2000	2376*	2.0	0.01380				
2100	67800*	2.2	0.01405				
<u>CURVE 34</u>							
400	30.06	2.4	0.01429				
500	39.56	2.6	0.01466				
600	50.31	2.8	0.01516				
700	62.60	3.0	0.01555				
800	76.78	3.2	0.01627				
900	93.31	3.4	0.01713				
1000	112.8	3.6	0.01799				
1100	136.2	3.8	0.01898				
1200	164.8	4.0	0.02009				
1300	200.5	4.22	0.02144				
1400	246.4	4.41	0.02267				
1500	307.4	4.59	0.02403*				
1600	392.7	4.75	0.02526				
1700	520.2	4.895	0.02662*				
1800	731.7	5.035	0.02896*				
1900	1150*	5.16	0.02933				
2000	2376*	<u>CURVE 35</u>					
2100	67800*	1.6	0.01356				

\* Not shown in figure.

#### b. Pressure Dependence

There are 10 sets of experimental data available for the electrical resistivity of rubidium as a function of pressure. The information on specimen characterization and measurement conditions for each of the data sets is given in Table 27. The data are tabulated in Table 28 and shown in Figure 16.

The available data and information for the pressure dependence of electrical resistivity of rubidium are inadequate for performing detailed analysis and synthesis at this time. Consequently, no recommendations are made and only experimental data are presented here.

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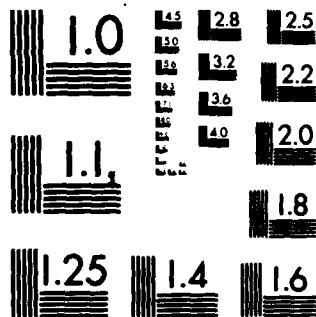
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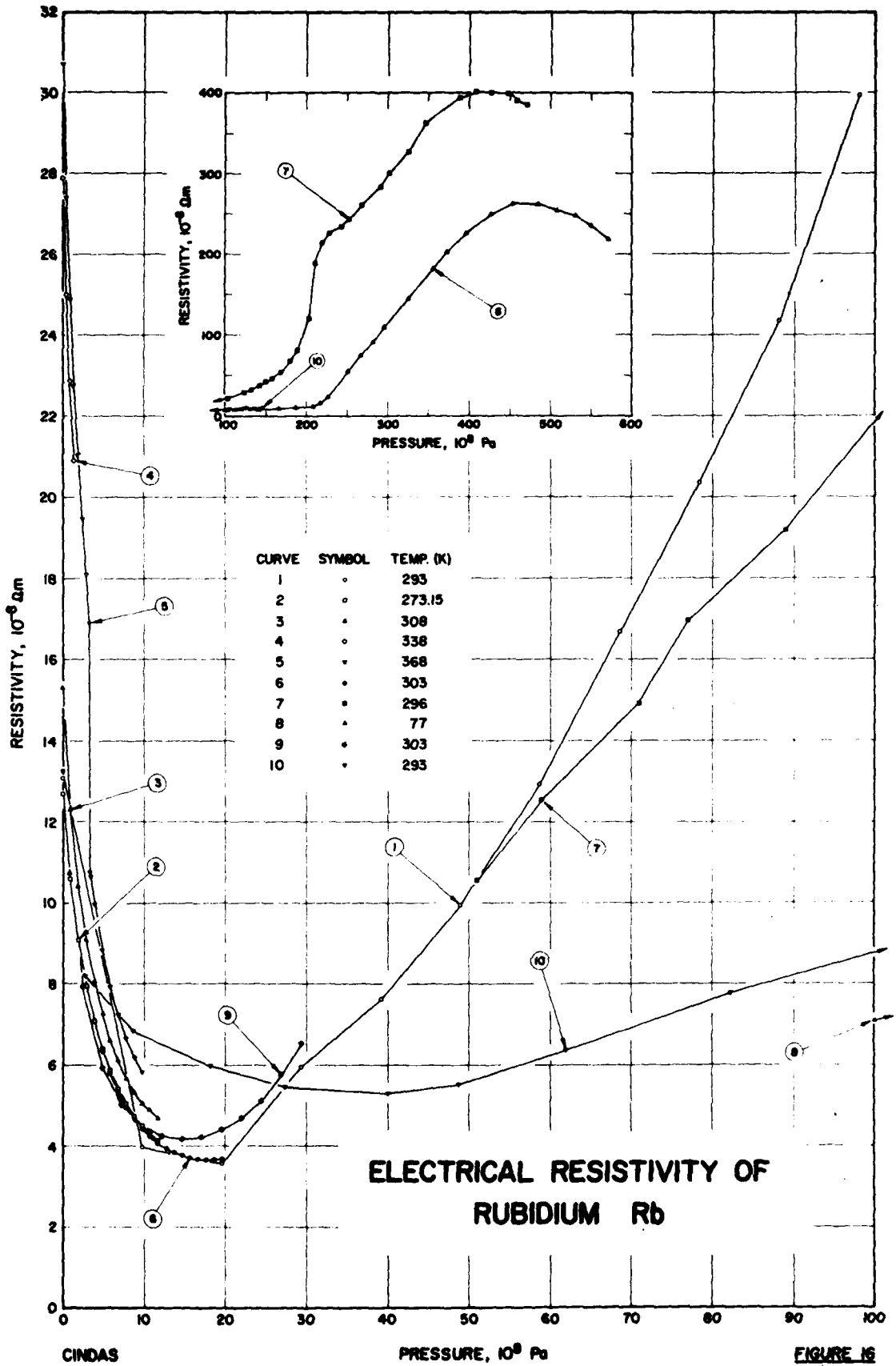


TABLE 27. MEASUREMENT INFORMATION ON THE ELECTRICAL RESISTIVITY OF RUBIDIUM Rb (Pressure Dependence)

Cur. Ref. No.	Author(s)	Year	Method Used	Pressure Range, $10^4$ Pa	Temperature Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1 30	Bridgman, P. W.	1952	A	0-98	~293		Pure; 0.013 in. diameter wire specimen was squeezed flat to about 0.004 in. thick; AgCl was used to transmit the pressure; relative electrical resistance were reported; the electrical resistivity data were obtained by using the recommended value of electrical resistivity at 293 K, compressibility data with the relative resistance data.
2 86	Bridgman, P. W.	1925	A	0-11.76	273		Pure; solid, bare wires.
3 86	Bridgman, P. W.	1925	A	0-11.76	308		Pure; solid, bare wires.
4 86	Bridgman, P. W.	1925	A	0-1.47	328		Pure; liquid, in glass capillary, 0.5 mm inside diameter, 4 or 5 cm long.
5 86	Bridgman, P. W.	1925	A	0-9.8	368		Pure; specimen in glass capillary, 0.5 mm inside diameter, 4 or 5 cm long.
6 72	Bridgman, P. W.	1930	A	0-19.6	303		Pure; solid, bare wires; it was extruded to a diameter about 1.6 mm and bent into a harpin 5 or 6 cm on a side.
7 31	Stager, R. A. and Drickamer, H. G.	1963	A	50-472	296		Commercial purity specimen; the resistance as function of pressure data were reported.
8 31	Stager, R. A. and Drickamer, H. G.	1963	A	100-571	77		Same as the above specimen.
9 32	Bridgman, P. W.	1938	A	0-29.4	303		Pure; specimen was enclosed in a U shape glass envelope, the lower part was about 2 mm inside diameter and 2 cm long; the relative electrical resistance data were reported.
10 95	Bundy, F. P.	1959	A	2-150	293		Pure; the specimen was triply vacuum distilled; the specimen was enclosed in a very thin walled glass capillary tube; the silver chloride sleeve around the specimen core served as an approximate hydrostatic medium; resistance data were reported.

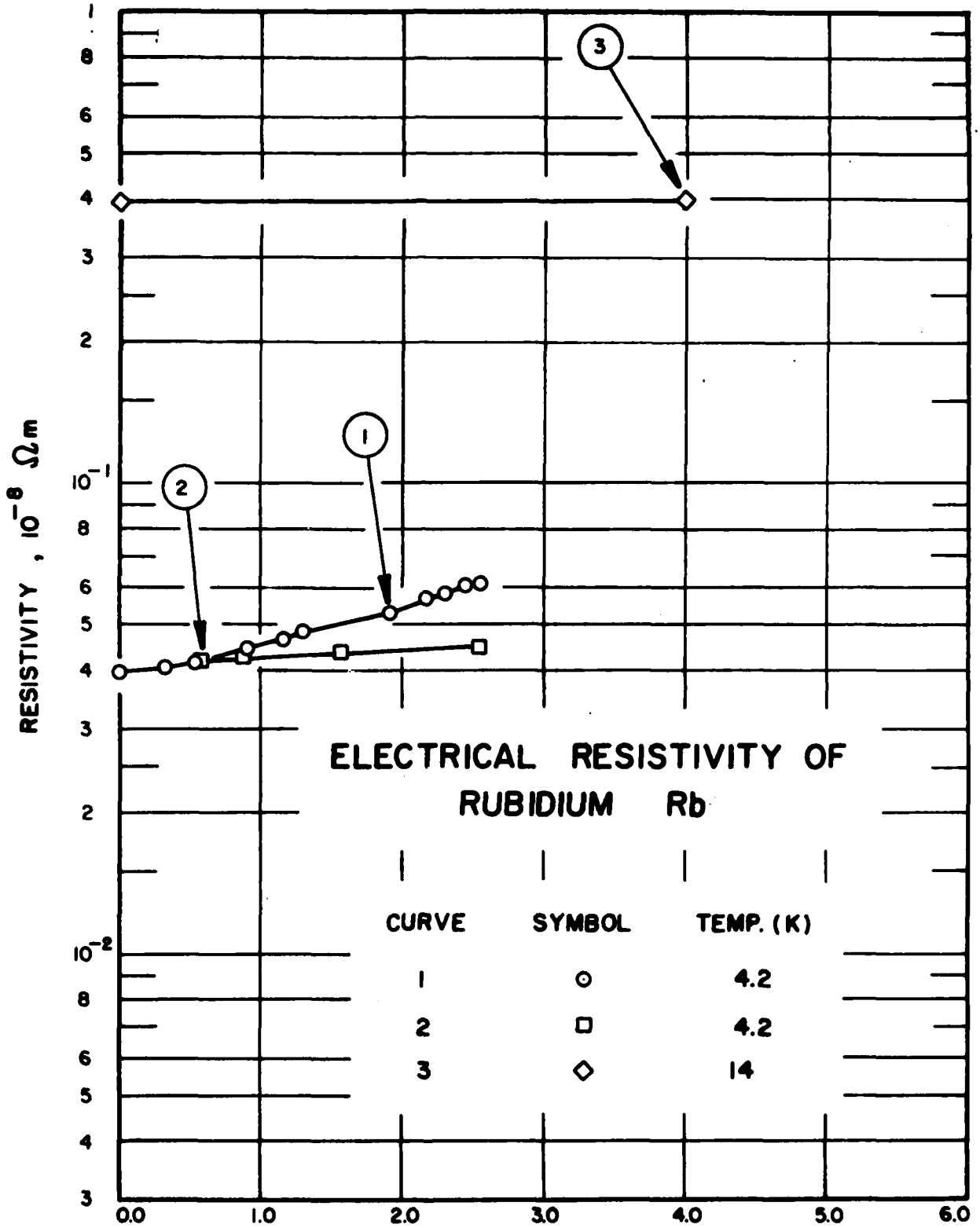


### c. Magnetic Flux Density Dependence

There are three sets of experimental data available for the electrical resistivity of rubidium under the influence of magnetic field. The information on specimen characterization and measurement information for each of the data sets is given in Table 29. The data are tabulated in Table 30 and shown in Figure 17.

The available data and information for the magnetic flux density dependence of electrical resistivity of rubidium are inadequate for performing detailed analysis and synthesis at this time. Consequently, no recommendations are made and only experimental data are presented here.





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MAGNETIC FLUX DENSITY, Tesla

FIGURE 17

TABLE 29. MEASUREMENT INFORMATION ON THE ELECTRICAL RESISTIVITY OF RUBIDIUM Rb (Magnetic Flux Density Dependence)

Cur. Ref. No.	Author(s)	Year	Method Used	Magnetic Flux Density Range, Tesla	Temperature Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1 73	MacDonald, D. K. C.	1957		0-2.55	~4.2		Pure, plate specimen; 0.5-0.6 mm thickness, 7 mm width, and 4.2 cm in length; $R_4, 2 \text{ K}/R_{294 \text{ K}} = 3.10^{-4}$ ; resistance was measured with the plane of specimen perpendicular to the magnetic field.
2 73	MacDonald, D. K. C.	1957		0-2.55	~4.2		Same as the above specimen; the resistance was measured with the plane of specimen parallel to the magnetic field.
3 36	Justi, E.	1948		0.4-0	14	Rb 4	Pure; $R_{14, 0 \text{ K}}/R_{273, 15 \text{ K}} = 0.0339$ ; it was measured in a transverse magnetic field.

TABLE 30. EXPERIMENTAL DATA ON THE ELECTRICAL RESISTIVITY OF RUBIDIUM Rb (Magnetic Flux Density Dependence)

[Temperature, T, K; Magnetic Flux Density, B, Tesla; Resistivity,  $\rho$ ,  $10^{-9} \text{ Ohm}$ ]

B	CURVE 1		CURVE 2 (cont.)	
	$\frac{\rho}{T=4.2}$	$\rho$	$\frac{\rho}{T=4.2}$	$\rho$
0.00	0.0393		0.58	0.0418
0.31	0.0407		0.88	0.0426
0.54	0.0417		1.58	0.0433
0.91	0.0446		2.55	0.0445
1.17	0.0464		CURVE 3	
1.30	0.0487		$\frac{\rho}{T=14}$	
1.91	0.0530		0.0	0.3922
2.18	0.0566		4.0	0.3938
2.31	0.0581			
2.45	0.0601			
2.48	0.0605*			
2.55	0.0615			
	CURVE 2			
	$\frac{\rho}{T=4.2}$			
0.00	0.0393*			
0.34	0.0405*			

\* Not shown in figure.

#### 4.5. CESIUM

Cesium, with atomic number 55, is a silvery-white, soft, ductile, alkali metal. It has a body-centered cubic crystalline structure with a density of  $1.873 \text{ g cm}^{-3}$  at 293 K. It melts at 301.55 K and boils at about 944 K. Its critical temperature has been measured to be  $2051 \pm 4 \text{ K}$ . Cesium has only one stable isotope,  $^{133}\text{Cs}$ , though twenty other radioactive isotopes are known to exist. It ranks 45th in the order of abundance of elements in the continental crust of the earth (0.003% by weight).

##### a. Temperature Dependence

There are 56 sets of experimental data available for the temperature dependence on the electrical resistivity of cesium. The information on specimen characterization and measurement conditions for each of the data sets is given in Table 32. The data are tabulated in Table 33 and shown in Figures 17 and 18. Determinations of the electrical resistivity of cesium for the solid, liquid, and gas phases cover the temperature region from 1.5 to 8800 K.

There are 18 data sets obtained below 100 K. Among these, Aleksandrov, Lomonos, Ignatév, and Gromov [96] (curve 49) gave the lowest residual resistivity  $\rho_0 = 0.00236 \times 10^{-8} \Omega\text{m}$  for 99.995 pure specimen. Dugdale and Phillips [90] reported the electrical resistivities for several constant volumes (curves 10, 12, 13, and 14). Appleyard [97] tabulated the electrical resistivity of Cs thin film (495 Å) on pyrex glass (curve 24). McWhan and Stevens [98] tabulated the electrical resistivity data for several constant pressures (curves 50-52). Eight sets of intrinsic electrical resistivity are obtained by subtraction of residual resistivity  $\rho_0$  from the measured resistivity. In deriving the smoothed most probable values of the intrinsic resistivity from the available data, the following overlapping temperatures were considered: below 10 K, 5-20 K, 10-40 K, 20-80 K, 30-150 K, etc. Within each range, a least-mean-square fraction error fit with the semiempirical equation  $\rho_i = aT^b$  was made to all available intrinsic resistivity data. The resulting values for adjacent ranges were intercompared and the values were corrected for thermal linear expansion. The preliminary values were then fitted with the cubic spline function equation (7) to generate the final recommended values. The coefficients of equation (7) obtained in the fitting are given in the following table:

Temperature Range, K	a	b	c	d
1 - 9.11	-3.551	2.829	1.293	-1.192
9.11- 11.10	-0.698	2.019	-2.137	20.63
11.10- 12.55	-0.529	2.105	3.149	-36.25
12.55- 22.14	-0.413	2.131	-2.670	2.793
22.14-100	-0.00765	1.323	-0.603	0.436

There are 17 data sets in the temperature region from 100 K to the melting point 301.55 K. Among these, four sets (curves 10, 12, 13, and 14) are for constant volume and three sets (curves 50-52) are for constant pressure. For the rest of the data, excluding curve 30, after subtracting the residual resistivity, they agree with one another within 5%. A least-mean-square fraction error fit of the totality of experimental data except those measured at constant volume in this range was made with  $\rho_i = aT^b$ . The resulting values were corrected for thermal linear expansion, and then fitted with the cubic spline function equation (7) to obtain the final recommended values in this temperature range. The coefficients of equation (7) obtained are as follows:

Temperature Range, K	a	b	c	d
22.14-202.68	-0.00765	1.323	-0.603	0.436
202.68-301.55	1.095	1.373	0.655	-5.028

There are 32 data sets available for the liquid state. Endo [40] also tabulated the electrical resistivities at constant volume (curve 27). Pfeifer, Freyland, and Hensel [99] (curves 32-39), Renkert, Hensel, and Franck [100] (curves 40-45), Tamski, Ross, Cusak, and Endo [69] (curves 46 and 47), and Barol'skii, Ermokhin, Kulik, and Mel'mikov [101] (curve 53) have investigated the electrical resistivities at various constant pressure. The rest of the data are apparently measured at the saturated vapor pressure. Below 1000 K they agree with one another within 10% and somewhat higher above 1000 K. Below 1000 K, all the experimental data except those measured at constant volume and at constant pressure were fitted by a logarithm third order polynomial. Above 1000 K, the electrical resistivity values are obtained by extrapolating the fitted values and following the experimental trend. The resulting values are fitted with the cubic spline function equation (7) to obtain the final recommended values. The coefficients of equation (7) obtained from fitting are as follows:

Temperature Range, K	a	b	c	d
301.55- 532.3	1.567	0.880	-0.030	0.739
532.3 - 652.4	1.794	1.000	0.516	-0.652
652.4 -2000	1.886	1.076	0.343	4.426

At the melting point (301.55 K), the electrical resistivity of cesium in the liquid state increases to about 73% higher than that of solid state. Using Mott's formula (Eq. 5), it gives  $(\rho_L/\rho_L)_{T_m} = 75\%$ .

Borol'skii, Ermoklin, Kulik, and Mel'nikov [101] (curves 53-56) have investigated the electrical resistivity of dense nonideal plasma at various pressures up to 8800 K.

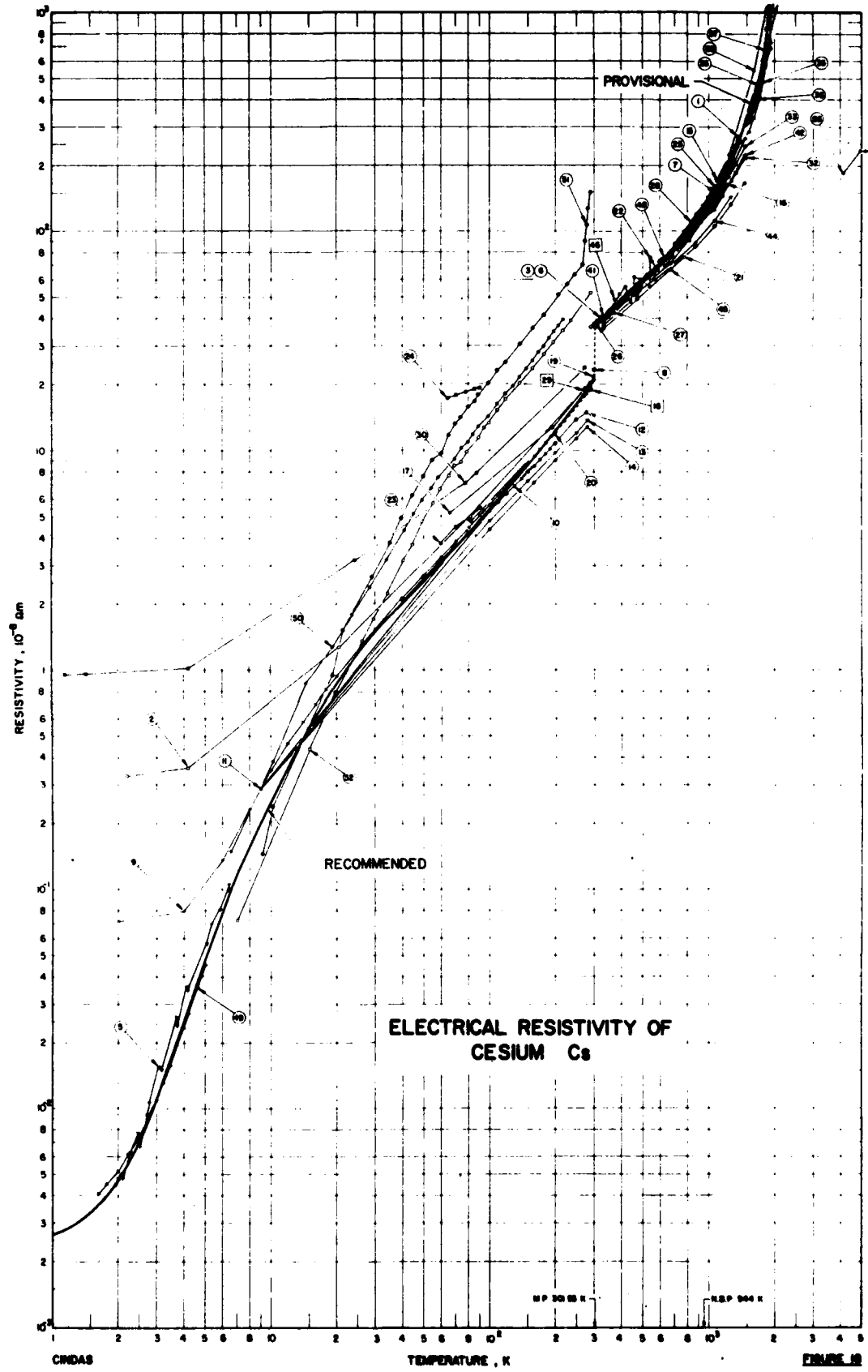
The recommended values for the total and intrinsic electrical resistivity are listed in Table 31, and those for the total electrical resistivity are also shown in Figures 17 and 18. The recommended values for the liquid state are for the saturated liquid. The recommended values of the total electrical resistivities for the solid state are for a 99.99% pure cesium and those at temperatures below 50 K are applicable only to a specimen with residual resistivity  $\rho_0 = 0.00232 \times 10^{-8} \Omega\text{m}$ . The recommended values are corrected for thermal linear expansion from 1 K to 301.55 K. The correction amounts to -1.8% at 1 K, -1.1% at 140 K, and 0.06% at 301.55 K. The uncertainty of the recommended values for the total electrical resistivity is believed to be within  $\pm 5\%$  from 1 K to 1500 K and  $\pm 10\%$  from within 1500 K to 2000 K. Above 20 K the uncertainty of the intrinsic resistivity is about the same as that of the total electrical resistivity; below 20 K this uncertainty is higher than that of the total electrical resistivity.

TABLE 31. RECOMMENDED ELECTRICAL RESISTIVITY OF CESIUM  
(Temperature Dependence)

[Temperature, T, K; Total Resistivity,  $\rho$ ,  $10^{-8} \Omega m$ ; Intrinsic Resistivity,  $\rho_i$ ,  $10^{-8} \Omega m$ ]

Solid						Liquid	
T	$\rho$	$\rho_i$	T	$\rho$	$\rho_i$	T	$\rho$
1	0.0026		35	1.72	1.72	301.55	36.93
2	0.0048	0.0024*	40	1.99	1.99	350	42.11
3	0.0118	0.0092*	45	2.27	2.27	400	47.45
4	0.0255	0.0229*	50	2.54	2.54	500	58.46
5	0.0474	0.0448*	60	3.07	3.07	600	70.30
6	0.0771	0.0745*	70	3.61	3.61	700	82.97
7	0.114	0.111*	80	4.16	4.16	800	96.97
8	0.155	0.152*	90	4.71	4.71	900	113.4
9	0.198	0.195*	100	5.28	5.28	1000	133.4
10	0.243	0.240*	150	8.43	8.43	1100	158.1
11	0.294	0.291*	200	12.22	12.22	1200	189.0
12	0.354	0.351*	250	16.66	16.66	1300	227.6
13	0.419	0.416*	273.15	18.75	18.75	1400	276.3
14	0.485	0.482*	293	20.46	20.46	1500	337.8
15	0.550	0.547*	300	21.04	21.04	1600	415.5*
16	0.614	0.611*	301.55	21.16	21.16	1700	513.9*
18	0.738	0.735*				1800	638.8*
20	0.859	0.856*				1900	797.6*
25	1.15	1.15				2000	1000.0*
30	1.44	1.44					

\* Provisional values.



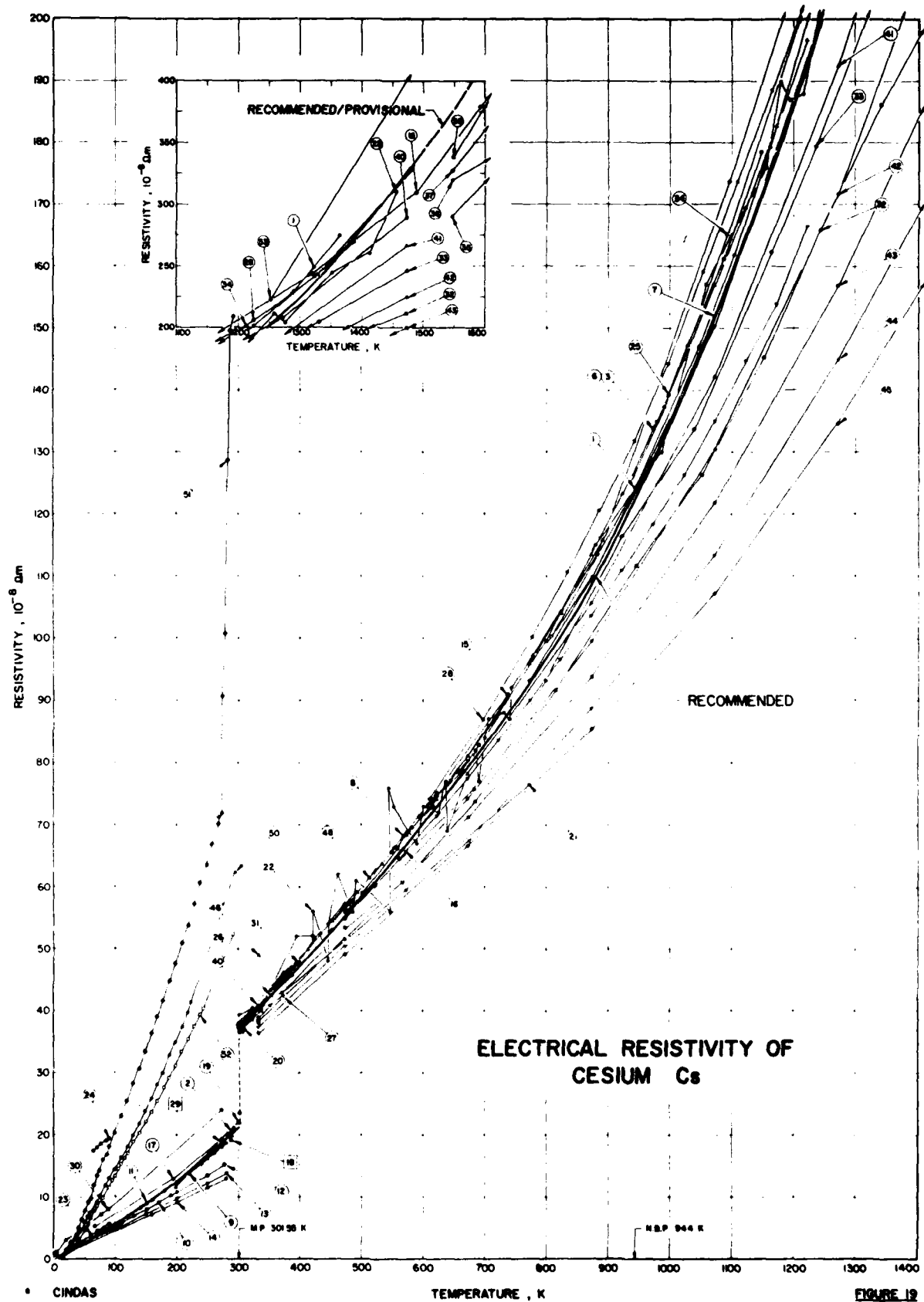




TABLE 32. MEASUREMENT INFORMATION ON THE ELECTRICAL RESISTIVITY OF CESIUM Cs (Temperature Dependence)

Cur. Ref. No. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1 17, 91, 92	Tepper, F., Murchison, A., Zelenak, J., and Roehlrich, F.	1963-1965	A	302-1360		Pure; specimen was placed in a Haynes-25 alloy cylindrical cell, 0.5 in. O.D. with wall thickness 0.065 in., and 2.6 in. long.
2 102	McLennan, J. C., Niven, C. D., and Wilhelm, J. O.	1928		2.2-290		Pure; specimen was run into a fine capillary tube.
3 12	Shpil'rain, E. E., Soldatenko, Yu. A., Yakimovich, K. A., Fomin, V. A., Savchenko V. A., Belova, A. M., Kagan, D. N., and Krainova, J. F.	1965	A	300-1223	Cs (I)	Pure; 0.4 Rb, 0.05 K, and 0.04 Na; specimen in liquid state; measured in insert gas atmosphere; the liquid metal was enclosed in a stainless steel tube; density = $1.853 - 5.71 \times 10^{-4} (T-273.15)$ g cm <sup>-3</sup> , melting point = 300.45 K; boiling point = 963.15 K; data were presented by $\rho = 34.98 + 11.233 \times 10^{-4} (T-273.15) 10^{-4}$ $\Omega$ m (from M. P. to 623 K), $\rho = 49.66 + 2.318 \times 10^{-4} (T-273.15) + 1.386 \times 10^{-4} (T-273.15)^2$ (from 623-1223 K), T in K units.
4* 12	Shpil'rain, E. E., et al.	1965	A	300-1223	Cs (II)	Pure; 0.003 Rb, 0.005 Na, and 0.00013 K; melting point = 301.25 K; other specifications similar to the above specimen; data were presented by $\rho = 34.089 + 9.816 \times 10^{-4} (T-273.15) + 0.383 \times 10^{-4} (T-273.15)^2$ (from M. P. to 723 K), $\rho = 63.98 + 2.724 \times 10^{-4} (T-273.15) + 1.712 \times 10^{-4} (T-273.15)^2$ (723-1223 K), where $\rho$ in $10^{-4}$ $\Omega$ m, T in K units.
5 23, 103	MacDonald, D. K. C., White, G. K., 1955, and Woods, S. B.	1955, 1956	A	2-6.5	Cs 3	Pure; specimen was obtained from Messrs A. D. Mackay (New York); specimen was melted in vacuo and run into soft glass tube with platinum leads sealed in; sample diameter 1.6 mm; $\rho_0/\rho_{295} = 2.08 \times 10^{-3}$ .
6 14	Shpil'rain, E. E. and Savchenko, V. A.	1968	A	303-1173	Cs 1	Pure; 0.4 Na, 0.05 K, and 0.03 Rb; specimen was obtained by reduction of CsCl and distillation of the cesium at pressure of $1 \times 10^{-3}$ ton and at temperature about 700 C; specimen was filled in a 1 Kh 18 NgT stainless steel test tube, 15 mm in diameter and 50 cm long with a wall thickness 0.75 mm.
7 14	White, G. K., et al.	1968	A	303-1173	Cs 2	Pure; 0.005 Na, 0.00013 K, and 0.003 Rb; other specifications similar to the above specimen.
8 104	Hyman, J. Jr.	1961	A	302-692		Pure; specimen was placed in a type 321 stainless steel tube 0.125 in. in diameter, 0.012 in. wall, 3 in. long; fitted with two copper current electrodes; two 30 gauge electrodes were spot welded along the tube with 1 in. separation.
9 90	Dugdale, J. S. and Phillips, D.	1965	A	1.5-300	Cs 4, 5, 6	Pure; specimens were obtained from L. Light and Co. Ltd., Colnbrook, England; wire specimens were extruded under distilled paraffin; 3 mm diameter; $I_{295}/I_{4.2} = 250$ ; the electrical resistivity was measured under zero pressure.
10 90	Dugdale, J. S. and Phillips, D.	1965	A	2-200	Cs 4, 5, 6	Same as above specimen; electrical resistivity was measured at constant volume condition.
11 90	Dugdale, J. S. and Phillips, D.	1965	A	0-274		Similar to the above specimen; ideal electrical resistivity were reported as function of temperature at constant pressure ( $p = 0$ ); data were extracted from smooth curve.
12 90	Dugdale, J. S. and Phillips, D.	1965	A	0-277		Similar to the above specimen; ideal electrical resistivity were reported as function of temperature at constant density as at 0 K at zero pressure; data were extracted from smooth curve.
13 90	Dugdale, J. S. and Phillips, D.	1965	A	0-281		Similar to the above specimen; at constant density as at 0 K at 1000 atm.
14 90	Dugdale, J. S. and Phillips, D.	1965	A	0-280		Similar to the above specimen; at constant density as at 0 K at 42,000 atm; data above 150 K were interpolated between present results and a point based on Bridgman's data at ice point.

\* Not shown in figure.

TABLE 32. MEASUREMENT INFORMATION ON THE ELECTRICAL RESISTIVITY OF CESIUM Cs (Temperature Dependence) (continued)

Cur. Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
15	Hochman, J.M. and Bosalla, C.F.	1965	A	589-1922		99.97 pure; 0.0154 O <sub>2</sub> , 0.0145 Rb, 0.004 Na, 0.0023 Ca, 0.0018 Fe, 0.0013 S, 0.0016 B, 0.0006 K, 0.0003 each Mg, Cr, and Ni; specimen was obtained from Dow Chemical Co.; liquid specimen was placed in a 90 Ts/10 W alloy capsule, 1 in. O.D., 1/10 in. wall, and 12 in. long; thermal expansion corrected.
16	Semyachkin, B.E. and Solov'ev, A.N.	1964		303-1223		Pure; specimen was placed in a Haynes-25 alloy cylindrical cell, 0.5 in. O.D., with wall thickness 0.065 in., and 26 in. in length.
17	Gunz, A. and Broniewski, W.	1909		86-293		Pure.
18	Hackspill, L.	1910	A	289	1	Pure.
19	Hackspill, L.	1910	A	198-307	2	Pure.
20	Hackspill, L.	1910	A	83-310	3	Pure.
21	Solov'ev, A.N.	1963, 1967		302-773		Pure; liquid state specimen; density 1.83, 1.80, 1.69, 1.58 g cm <sup>-3</sup> at 302, 373, 573, and 793 K.
22	Lezmon, A.W. Jr., Deem, H.W., Eldridge, E.A., Hall, E.H., Matulich, J., and Walling, J.F.	1964		333-1456		Pure; 0.0002 each Al, Fe, 0.0001 each Ag, Mo, 0.0003 Ca, 0.001 each Cs, Si, 0.0005 Ni, 0.002 Na, Rb, and 0.0015 K.
23	Appleyard, E.T.S.	1937		60-90		Pure; bulk material.
24	Appleyard, E.T.S.	1937		64.8-90	Cs (Film)	Pure; Cs film was deposited on Pyrex glass at 64 K; film thickness 49.5 Å.
25	Kapelaer, S.M. and Bratton, W.D.	1962	B	301.5-1150		99.9 pure; 0.0001 each O <sub>2</sub> , N <sub>2</sub> , 0.00045 C, and 0.0004 Rb; specimen was obtained from MSA Research Corp.; liquid specimen was loaded into a type 347 stainless steel tube welded and sealed and it was heated at 823 K for 2 hr prior to measurements.
26	Embo, H.	1963	A	302-374		Pure; specimen was supplied by A. D. Mackey Ltd.; specimen was placed in an 0.7 mm I.D. soft glass capillary tube; electrical resistivity was measured at constant pressure condition.
27	Embo, H.	1963	A	302-374		Same as above specimen; electrical resistivity was obtained at constant volume.
28	Hoffman, H.W. and Robin, T.T. Jr.	1967		600-1388		Pure.
29	Krautz, E.	1950		273		Pure.
30	Metsaer, W. and Voigt, B.	1930		1.15-273	Cs 1	Pure; specimen was distilled in a glass tube; sample diameter was 3 mm and about 33 mm in length.
31	Van der Lug, W., Devlin, J.F., Hensebof, J., and Leenstra, M.R.	1973	B	373.15-398.15		Pure; $dp/dT = 0.1005 \times 10^{-4} \Omega\text{m/K}$ .
32	Pfeifer, H.P., Freyland, W.F., and Hensel, F.	1973		473-1473		Pure; fluid cesium was placed in a metallic tungsten-26% rhenium tube as container, at the ends of the tube two thermocouples (97% W, 3% Re-74% W, 26% Re) were fixed; electrical resistivity was measured at pressure equal to 90 bar; data were extracted from smooth curve.
33	Pfeifer, H.P., et al.	1973		473-1473		Similar to the above specimen; electrical resistivity was measured at pressure equal to 300 bar.
34	Pfeifer, H.P., et al.	1973		473-1482		Similar to the above specimen; electrical resistivity was measured at pressure equal to 100 bar.

TABLE 32. MEASUREMENT INFORMATION ON THE ELECTRICAL RESISTIVITY OF CESIUM Cs (Temperature Dependence) (continued)

Cur. Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
35	Pfeifer, H. P., Freyland, W. F., and Hensel, F.	1973		1546-2103		Similar to the above specimen; electrical resistivity was measured at pressure equal to 200 bar.
36	Pfeifer, H. P., et al.	1973		1547-2104		Similar to the above specimen; electrical resistivity was measured at pressure equal to 175 bar.
37	Pfeifer, H. P., et al.	1973		1547-2100		Similar to the above specimen; electrical resistivity was measured at pressure equal to 150 bar.
38	Pfeifer, H. P., et al.	1973		1548-2093		Similar to the above specimen; electrical resistivity was measured at pressure equal to 130 bar.
39*	Pfeifer, H. P., et al.	1973		1548-2007		Similar to the above specimen; electrical resistivity was measured at pressure equal to 115 bar.
40	Renkert, H., Hensel, F., and Franck, E. U.	1971		333-1473		Pure; liquid cesium was placed in the cell of pure molybdenum, the vessel was filled with purified argon and the argon pressure balanced the cesium pressure inside the cell; critical point $T_c = 2023$ K and $p_c = 110$ bar; electrical resistivity was measured at $p = 100$ bar.
41	Renkert, H., et al.	1971		333-1473		Similar to the above specimen; electrical resistivity was measured at $p = 200$ bar.
42	Renkert, H., et al.	1971		333-1473		Similar to the above specimen; electrical resistivity was measured at $p = 400$ bar.
43	Renkert, H., et al.	1971		333-1473		Similar to the above specimen; electrical resistivity was measured at $p = 600$ bar.
44	Renkert, H., et al.	1971		333-1473		Similar to the above specimen; electrical resistivity was measured at $p = 800$ bar.
45	Renkert, H., et al.	1971		333-1473		Similar to the above specimen; electrical resistivity was measured at $p = 1000$ bar.
46	Tamaki, S., Ross, R. G., Cusack, N. E., and Endo, H.	1973	A	373.15		Pure; liquid state; electrical resistivity was measured at pressure 1 bar.
47*	Tamaki, S., et al.	1973	A	373.15		Pure; liquid state; electrical resistivity was measured at pressure 4 kbar.
48	Semyachkin, B. E. and Solov'ev, A. N.	1970	A	293-623		99.97 pure; the specimen was placed in a stainless steel tube in a copper block; temperature was measured by a Pt-PtRh(10%) thermocouple; the measurements were carried out during both heating and cooling at 0.1 C/min. rate and with current in both directions; $\rho_{\text{liquid}}/\rho_{\text{solid}} = 1.704$ , $(1/\rho) dp/dT_{\text{solid}} = 49.2 \times 10^{-4}/\text{K}$ , $(1/\rho) dp/dT_{\text{liquid}} = 31.4 \times 10^{-4}/\text{K}$ .
49	Aleksandrov, B. N., Lomonosov, O. I., Ignat'ev, O. S., and Gromov, O. G.	1969	A	1.6-5		99.995 pure; 0.004 Rb, 0.002 Na, 0.0004 K, and traces of Si, Ca, Mg, Fe, and Al; the resistance of cesium was measured in thick walled cylindrical glass capillaries; platinum wires were used as potential and current leads; relative resistivity $\rho_{\text{w}}/\rho_{\text{cs}} = 1.13 \times 10^{-4}$ ; relative resistance data were reported.
50	McWhan, D. B. and Stevens, A. L.	1969		3-300		99.97 pure, $\rho_{\text{w}}/\rho_{\text{cs}} = 450$ ; electrical resistivity were measured at $P = 30$ Kbar.
51	McWhan, D. B. and Stevens, A. L.	1969		3-300		Same as the above specimen except $P = 43$ Kbar.
52	McWhan, D. B. and Stevens, A. L.	1969		3-300		Same as the above specimen except $P = 60$ Kbar.

\* Not shown in figure.

TABLE 32. MEASUREMENT INFORMATION ON THE ELECTRICAL RESISTIVITY OF CESIUM Cs (Temperature Dependence) (continued)

Cur. Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
53	Barol'skii, S. G., Ermokhin, N. V., Kulk, P. P., and Mel'nikov, V. M.	1972	A	1253-2473		Dense strong nonideal plasma; a stationary set up of the "chamber oven" type at pressure $p = 150$ atm.
54*	Barol'skii, S. G., et al.	1972	A	7050-7750		Dense strong nonideal plasma; a pulse set up with the plasma stabilized by a solid transparent wall; measured at $p = 130$ atm.
55*	Barol'skii, S. G., et al.	1972	A	7150-8600		Same as the above specimen except measured at $p = 170$ atm.
56*	Barol'skii, S. G., et al.	1972	A	4150-5780		Same as the above specimen except measured at $p = 350$ atm.

\* Not shown in figure.

TABLE 33. EXPERIMENTAL DATA ON THE ELECTRICAL RESISTIVITY OF CESIUM Cs (Temperature Dependence)

[Temperature, T, K; Resistivity, $\rho$ , $10^{-4}$ $\Omega$ m]	
T	$\rho$
<u>CURVE 1</u>	
308.6	38.6
480.2	57.4
643.5	76.96
808.0	100.33
944.6	124.2
1048.5	147.06
1104.1	161.8
1162.4	174.32
1225.7	201.16
1290.2	229.1
1323.0	248.92
1365.8	274.57
<u>CURVE 2</u>	
2.2	0.324
4.2	0.350
20.6	1.28
82.0	5.04
290.0	20.5
<u>CURVE 3</u>	
300.3	37.94
323	46.11
423	51.72
473	57.34
523	62.96
573	68.57
623	74.19
673	79.81
723	85.43
773	91.05
823	96.67
873	102.29
923	107.91
1073	145.90
1123	169.50
1173	183.78
1223	196.76
<u>CURVE 4*</u>	
291.1	32.8
323	39.09
373	44.29
423	49.67
473	55.25
523	61.02
573	66.98
623	73.13
673	79.48
723	86.02
773	92.78
823	99.7
873	106.8
923	114.1
1023	139.8
1073	151.8
1123	164.6
1173	178.1
1223	192.6
<u>CURVE 5</u>	
1.9635	0.0045
2.000	0.0048
2.070	0.0050
2.1088	0.0048
2.275	0.0063
2.478	0.0077
2.530	0.0067
2.716	0.0093
2.774	0.0106
3.076	0.0155
3.141	0.015
3.707	0.0239
4.12	0.0360
4.188	0.0347
5.105	0.0566
5.383	0.0693
5.875	0.0809
6.457	0.0988
6.457	0.1063
<u>CURVE 6</u>	
303	36.25
323	40.50
373	46.12
473	57.35
573	68.58
673	81.12
773	95.92
873	113.5
973	133.8
1073	156.9
1173	182.8
<u>CURVE 7</u>	
303	37.07
323	39.09*
373	44.29*
473	55.25*
573	66.98*
673	79.48*
773	93.16
873	109.3
973	128.8
1073	151.8
1173	178.1
<u>CURVE 8</u>	
302	23.5
323	29.05*
387	45.8
452	63.1
494	57.6
503	59.0
560	66.3
568	68.4
617	73.0
617	74.2
661	78.3
692	85.9
<u>CURVE 9</u>	
2	0.0719
4	0.0796
6	0.1365
<u>CURVE 9 (cont.)</u>	
8	0.233*
10	0.349
12	0.464*
14	0.578*
16	0.693*
18	0.812*
<u>CURVE 10 (cont.)</u>	
8	0.233*
10	0.350
12	0.465
14	0.578
16	0.693
18	0.812
20	0.937
30	1.535
40	2.121
50	2.709
60	3.298
70	3.883
80	4.478
90	5.062
100	5.651
110	6.240
120	6.827
130	7.416
140	8.002
150	8.589
160	9.178
170	9.768
180	10.358
190	10.948
200	11.538
210	12.128
220	12.718
230	13.308
240	13.898
250	14.488
260	15.078
270	15.668
280	16.258
290	16.848
<u>CURVE 10</u>	
9	0.29
100	5.70
150	8.97
200	12.35
250	16.14
274	18.26
<u>CURVE 11</u>	
9	0.29
100	5.70
150	8.97
200	12.35
250	16.14
274	18.26
<u>CURVE 12</u>	
9	0.29*
100	5.38
150	8.06
200	10.77
249	13.48
277	15.08
<u>CURVE 13</u>	
9	0.29*
100	4.79
150	7.28
200	9.71
250	12.08
281	13.75
<u>CURVE 14</u>	
9	0.29*
100	4.42
159	7.18
200	9.07
250	11.41
280	12.85
<u>CURVE 15</u>	
582	69.77
737	90.97
863	113.5
1097	173.8
1321	243.5
1488	309.1
1592	379.1
1706	445.6
1818	567.4
1911	690.7
1959	1000 $\pm$ 8000*
<u>CURVE 16</u>	
303	37.9
323	39.9
373	44.9
423	49.8*
473	55.0*
523	60.3
573	65.8
623	71.5
673	77.5
723	83.7
773	90.0
823	96.6
873	103.6
923	110.9
973	118.5
1023	126.2
1073	134.9
1123	144.6
1173	154.6
1223	166.4

\* Not shown in figure.

TABLE 33. EXPERIMENTAL DATA ON THE ELECTRICAL RESISTIVITY OF CESIUM Cs (Temperature Dependence) (continued)

T	$\rho$	T	$\rho$	T	$\rho$	T	$\rho$	T	$\rho$
<u>CURVE 17</u>									
66	5.25	553	73	1.15	0.950	1548	289.7	1919	1458*
194.7	12.81	580	67	1.43	0.960	1622	331.1	1958	2032*
273	19.3	601	73	717.2	87.35	1704	414.9	1976	2666*
292.4	21.1	626	72	4.21	1.027	1773	489.7	2002	3908*
<u>CURVE 18</u>									
		637	77	90.2	99.68	1836	583.4	2021	6426*
		640	69	923.0	123.63*	1913	737.5	2042	9772*
		686	68	979.4	134.84	1994	937.5	2056	12820*
289	19.2	691	77	998.8	139.29	2036	1056*	2068	17140*
<u>CURVE 19</u>									
		701	84	1029.9	147.20	2064	1253*	2080	23330*
		706	87	1088.3	161.26	2103	1458*	2093	34670*
		731	88	1149.7	178.63	<u>CURVE 38</u>			
198	11.5	740	87	373.15	45.3	1547	319.1	1548	337.2
273	18.0	743	92	398.15	47.8	1610	337.3*	1619	392.6
290	19.9	824	104	<u>CURVE 32</u>				1678	474.2
300	22.1	880	115	302.1	36.74*	1682	403.6	1748	619.4
307	36.6	987	130	311.1	37.95	1763	492.0*	1794	731.1
<u>CURVE 20</u>									
		1059	157	473	53.45	1833	602.5	1820	851.1
		1156	176	567	60.81	1890	701.4	1852	1037
		1180	190	685	73.79	1939	851.1	1886	1282
83	4.8	1195	187	815	91.65	1987	1081*	1915	1828
198	12.0	1217	188	946	111.7	2034	1294*	1950	3311
273	18.2*	1259	211	1052	125.3	2104	2511*	1968	4385
290	20.1*	1277	204	1152	145.2	<u>CURVE 37</u>			
303	36.6	1353	244	1244	165.9	1547	326.6	1990	11160
310	37.0	1414	260	1343	186.2	1626	378.4*	1997	21280
		1456	310	1473	211.8	1701	459.1	2006	35310
<u>CURVE 21</u>									
		<u>CURVE 26</u>				1839	688.6	2007	47640
302	39.3	302.1	36.74*	473	54.95	<u>CURVE 40</u>			
373	42.9	311.1	37.95	561	64.56	333	40.82	473	50.56
573	59.6	325.7	39.44	683	75.64	473	80.26	673	80.26
773	76.5	337.8	40.62	799	93.32	673	109.9	873	109.9
<u>CURVE 22</u>									
		354.7	42.68	822	116.4	1073	150.15	1073	150.15
		374.3	44.76*	1038	133.6	1273	208.33	1273	208.33
		<u>CURVE 27</u>				1896	893.5	1473	289.85
		306.2	37.22	1164	162.2	<u>CURVE 41</u>			
		323.1	38.52	1237	179.5	1548	337.2	333	40.16
		338.6	40.04	1331	204.1	1613	392.6	473	55.31*
		351.6	40.95	1473	245.4	1686	476.4	473	78.13
		373.2	42.42	<u>CURVE 28</u>				673	80.26
		611.1	74.2	473	54.95	873	109.9	1073	150.15
		698.4	86.9	561	64.56	1273	208.33	1273	208.33
		777.3	100.2	683	75.64	1896	893.5	1473	289.85
		835.0	110.7	799	93.32	<u>CURVE 39</u>			
		896.1	120.6	822	116.4	1547	326.6	1990	11160
		942.8	131.9	1038	133.6	1626	378.4*	1997	21280
		997.8	144.3	1164	162.2	1701	459.1	2006	35310
		1055.6	159.1	1237	179.5	1753	517.6	2007	47640
		1110.0	173.8	1331	204.1	<u>CURVE 40</u>			
		1166.7	188.7	1473	245.4	333	40.82	473	50.56
		1222.3	205.9	<u>CURVE 34</u>				673	80.26
		1260.0	217.1	473	54.95	873	109.9	1073	150.15
		1288.9	227.9	559	64.86	1273	208.33	1273	208.33
		1325.0	241.4	559	64.86	1896	893.5	1473	289.85
		1357.8	254.4	666	76.71	<u>CURVE 41</u>			
		1388.9	267.4	778	97.27	1548	337.2	333	40.16
		<u>CURVE 29</u>				1613	392.6	473	55.31*
		301.3	37.42	881	115.8	1686	476.4	473	78.13
		308.8	38.32*	990	137.4	1709	616.6	673	80.26
		321.6	39.80*	1094	165.2	1813	737.9	873	109.9
		374.4	45.77	1213	201.4	1847	947.2	1073	150.15
		483.8	57.71	1327	242.1	1881	1047*	1273	208.33
		273	19.0	1482	326.0	<u>CURVE 42</u>			

\* Not shown in figure.

TABLE 33. EXPERIMENTAL DATA ON THE ELECTRICAL RESISTIVITY OF CESIUM Cs (Temperature Dependence) (continued)

T	$\rho$	T	$\rho$	T	$\rho$	T	$\rho$	T	$\rho$
<b>CURVE 42</b>									
333	38.91	301.5	37.24*	49.7	5.958	159.2	36.34	188.6	29.28
473	53.22	313.2	38.57	54.8	6.784	168.1	39.11	198.5	31.21
673	74.18	333.2	40.88	58.8	7.511	178.9	41.73	208.8	33.45
873	99.50	353.2	43.17	69.3	9.191	188.9	44.81	218.5	35.44
1073	130.04	373.2	45.45*	74.7	10.13	198.5	47.68	228.9	37.58
1273	171.82	393.2	47.72	80.6	10.92	208.2	51.09	238.9	39.46
1473	224.20	413.2	49.99	84.6	11.80	219.1	53.84	243.6	40.48
<b>CURVE 43</b>									
333	36.17	433.2	52.26	89.2	12.89	229.3	57.37	292.7	52.44
473	51.60	453.2	54.55	99.1	14.31	238.6	60.65	<b>CURVE 53</b>	
673	71.13	473.2	56.86	109.1	16.30	248.7	63.71	1253	223
873	93.72	493.2	59.20	119.2	18.16	257.4	66.87	1623	549
1073	121.60	513.2	61.59	128.6	19.98	268.1	70.29	1953	1348*
1273	156.96	533.2	63.99	138.6	21.80	269.8	76.40	2353	1736*
1473	199.20	553.2	66.46	148.9	23.87	273.2	71.90	2473	6896*
<b>CURVE 44</b>									
333	37.17	573.2	68.90	159.2	25.83	275.5	90.66	<b>CURVE 54*</b>	
473	50.40	593.2	71.46	168.8	28.06	280.8	108.99	7050	512.8
673	67.75	613.2	73.98	178.3	30.00	284.1	128.7	7300	370.3
873	88.73	633.2	75.25	188.5	32.84	287.8	149.4	7750	308.6
1073	113.38	653.2	77.98	198.7	35.02	292.2	151.7	<b>CURVE 55*</b>	
1273	144.93	673.2	80.66	209.2	37.49	<b>CURVE 52</b>		7.1	0.072
1473	183.48	693.2	83.48	218.1	39.74	7.1	0.439	20.3	0.794
<b>CURVE 45</b>									
333	36.23	1.64	0.00406	223.6	41.41	26.3	1.358	7150	288.8
473	49.09	1.78	0.00449	233.6	44.41	29.6	1.701	8050	250.0
673	65.79	2.01	0.00516	235.9	46.48	34.3	2.239	8900	217.4
873	85.40	2.24	0.00617	<b>CURVE 51</b>		40.4	3.154	<b>CURVE 56*</b>	
1073	107.07	2.48	0.00718	9.2	0.145	44.8	3.717	4150	185.2
1273	134.59	2.75	0.00906	10.3	0.239	48.8	4.725	4960	232.5
1473	168.92	3.00	0.01091	15.1	0.542	56.3	5.795	8780	232.5
<b>CURVE 46</b>									
373.15	49.0	3.23	0.01318	19.3	0.950	65.4	7.685	<b>CURVE 57</b>	
<b>CURVE 47*</b>									
373.15	37.3	3.49	0.01597	21.5	1.827	69.9	8.501	<b>CURVE 58*</b>	
<b>CURVE 48</b>									
293.2	20.96	3.74	0.01955	29.1	2.662	74.3	9.885	<b>CURVE 59*</b>	
301.5	21.86	4.00	0.02342	35.2	3.845	79.6	9.834	<b>CURVE 60*</b>	
<b>CURVE 49</b>									
373.15	49.0	4.22	0.02748	44.7	6.257	84.5	12.71	<b>CURVE 61*</b>	
<b>CURVE 50</b>									
373.15	37.3	4.48	0.03317	50.0	7.693	89.5	11.41	<b>CURVE 62*</b>	
<b>CURVE 51 (cont.)</b>									
293.2	20.96	4.87	0.03589	55.4	9.018	94.5	12.71	<b>CURVE 63*</b>	
301.5	21.86	5.04	0.04565	60.1	9.780	99.6	13.39	<b>CURVE 64*</b>	
<b>CURVE 52 (cont.)</b>									
373.15	49.0	6.6	0.149	65.5	11.83	104.8	14.51	<b>CURVE 65*</b>	
<b>CURVE 53 (cont.)</b>									
373.15	37.3	10.3	0.383	70.2	13.38	109.6	15.31	<b>CURVE 66*</b>	
<b>CURVE 54* (cont.)</b>									
293.2	20.96	14.7	0.867	74.4	14.18	115.1	16.27	<b>CURVE 67*</b>	
301.5	21.86	19.1	1.285	80.9	15.98	119.7	17.16	<b>CURVE 68*</b>	
<b>CURVE 55* (cont.)</b>									
373.15	49.0	23.8	1.781	86.1	16.75	129.3	18.79	<b>CURVE 69*</b>	
<b>CURVE 56* (cont.)</b>									
373.15	37.3	28.5	2.380	89.8	18.00	139.1	20.35	<b>CURVE 70*</b>	
<b>CURVE 57* (cont.)</b>									
293.2	20.96	34.0	3.205	109.9	23.12	149.1	22.26	<b>CURVE 71*</b>	
301.5	21.86	41.0	4.348	119.1	25.41	159.0	23.73	<b>CURVE 72*</b>	
<b>CURVE 58* (cont.)</b>									
373.15	49.0	45.0	5.173	129.8	28.34	169.3	25.44	<b>CURVE 73*</b>	
<b>CURVE 59* (cont.)</b>									
373.15	37.3	149.0	33.87	149.0	33.87	179.0	27.61	<b>CURVE 74*</b>	

\* Not shown in figure.

### b. Pressure Dependence

There are 17 sets of experimental data available for the electrical resistivity of cesium as a function of pressure. The information on specimen characterization and measurement conditions for each of the data sets is given in Table 34. The data are tabulated in Table 35 and shown in Figure 20.

The available data and information for the pressure dependence of electrical resistivity of cesium are inadequate for performing detailed analysis and synthesis at this time. Consequently, no recommendations are made and only experimental data are presented here.



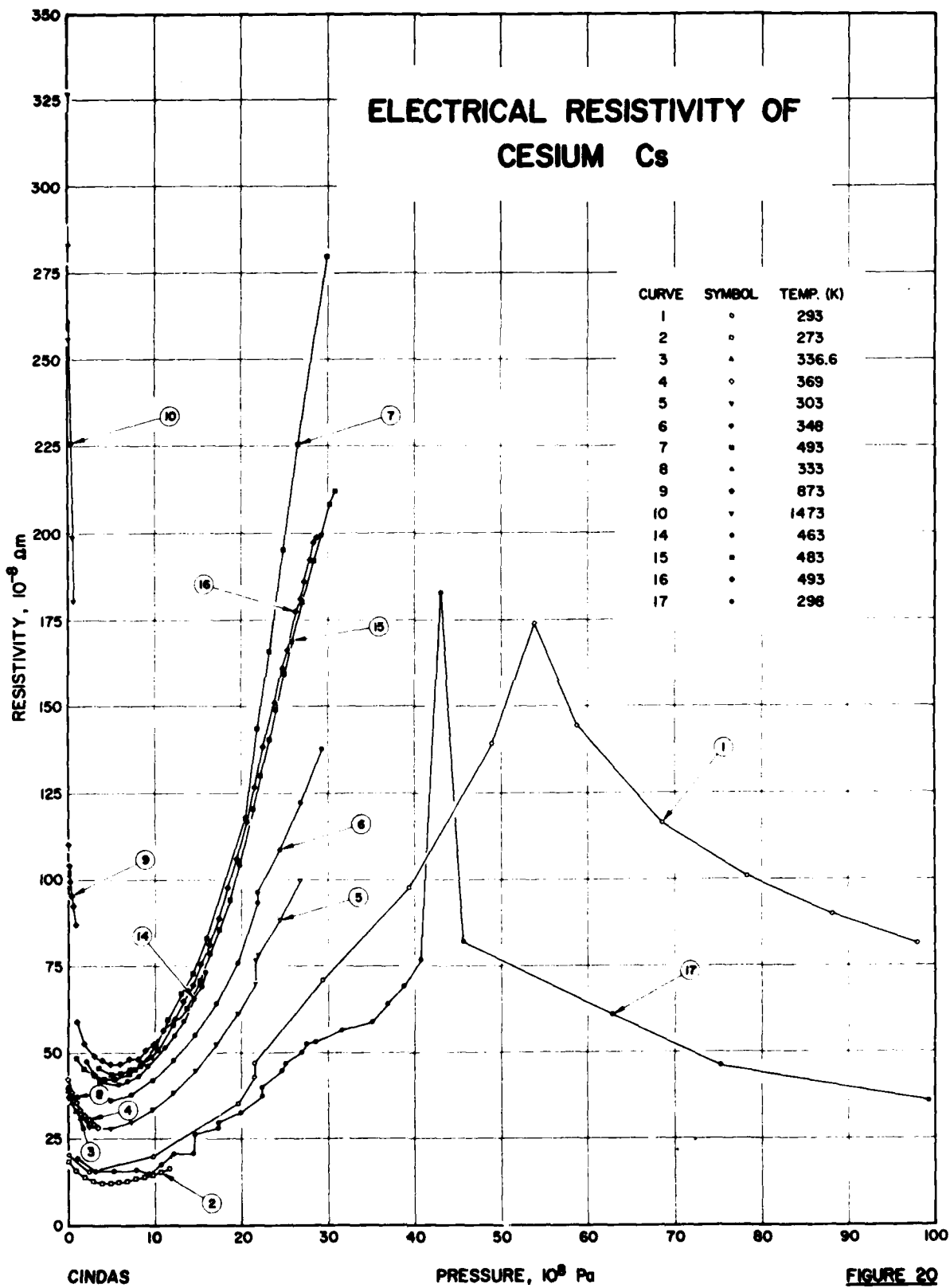


FIGURE 20

TABLE 34. MEASUREMENT INFORMATION ON THE ELECTRICAL RESISTIVITY OF CESIUM Cs (Pressure Dependence)

Cur. Ref. No.	Author(s)	Year	Method Used	Pressure Range, $10^6$ Pa	Temperature Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	30 Bridgman, P. W.	1952		0-98	~298		Pure; extruded wire specimen; AgCl was used as the material for transmitting pressure; relative resistance data were reported; combine this with the recommended value of electrical resistivity at 293 K and compressibility data, the electrical resistivity data were obtained.
2	86 Bridgman, P. W.	1925	A	0-11.76	273		Pure; solid, bare wires.
3	86 Bridgman, P. W.	1925	A	0-1.47	338.6		Pure; liquid; in glass capillary.
4	86 Bridgman, P. W.	1925	A	0-3.43	369		Pure; liquid; in glass capillary; $R_{\text{liquid}}/R_{\text{solid}} = 1.695$ at $p = 3780$ kg/cm <sup>2</sup> .
5	32 Bridgman, P. W.	1938		0-29.4	303		Pure; specimen was obtained from Mackay; provided sealed in glass; relative electrical resistance as a function of pressure data were reported.
6	32 Bridgman, P. W.	1938		0-29.4	348		Same as the above specimen.
7	109 Oshima, R., Endo, H., Shimomura, O., and Minomura, S.	1974		0-30	493		99.9 pure; liquid state specimen was filled in a glass capillary with inner diameter of 1.5 mm and length of 12 mm; silicon oil was used as a pressure transmitted medium.
8	100 Renkert, H., Hensel, F., and Franck, E. U.	1971		0.025-1.0	333		Pure; liquid specimen was placed in the cell of pure molybdenum; the vessel was filled with purified argon and the argon pressure balanced the cesium pressure inside the cell; critical point $T_c = 2023$ K and $P_c = 110$ bar.
9	100 Renkert, H., et al.	1971		0.025-1.0	873		Same as the above specimen.
10	100 Renkert, H., et al.	1971		0.025-0.79	1473		Same as the above specimen.
11*	100 Renkert, H., et al.	1971		0.02-0.145	2073		Same as the above specimen.
12*	100 Renkert, H., et al.	1971		0.03-0.133	2173		Same as the above specimen.
13*	100 Renkert, H., et al.	1971		0.02-0.175	2273		Same as the above specimen.
14	110 Makarenko, I. N.	1968		2-16	463		Pure; liquid state; data were extracted from the figure.
15	110 Stibov, S. M. and Makarenko, I. N.	1968		3.6-30	483		Same as the above specimen.
16	110 Stibov, S. M. and Makarenko, I. N.	1968		1-29	493		Same as the above specimen.
17	96 McWhan, D. B. and Stevens, A. L.	1969		0-100	298		99.97 pure; $\rho_{298 \text{ K}}/\rho_{4.2 \text{ K}} = 45^\circ$ .

\* Not shown in figure.



TABLE 35. EXPERIMENTAL DATA ON THE ELECTRICAL RESISTIVITY OF CESIUM Cs (Pressure Dependence) (continued)

CURVE 15 (cont.) T = 483		CURVE 17 T = 298	
P	$\rho$	P	$\rho$
25.9	168.8	1.00	19.50
27.1	180.2	3.18	15.80
28.4	191.8	5.25	15.80
29.3	199.4	7.93	16.10
30.2	208.2	9.35	15.1
30.9	212.4	10.70	17.6
		12.20	20.9
		14.45	20.9
		14.67	26.4
		17.32	28.1
		17.35	29.9
		19.99	32.6
		22.43	37.4
		22.43	40.0
		24.74	44.6
		25.17	46.6
		27.05	50.0
		27.52	52.5
		28.65	53.0
		31.68	56.3
		35.14	58.6
		36.90	63.9
		38.75	68.9
		40.70	76.9
		43.00	182.7
		45.69	81.9
		62.85	60.9
		75.26	46.0
		99.31	35.8

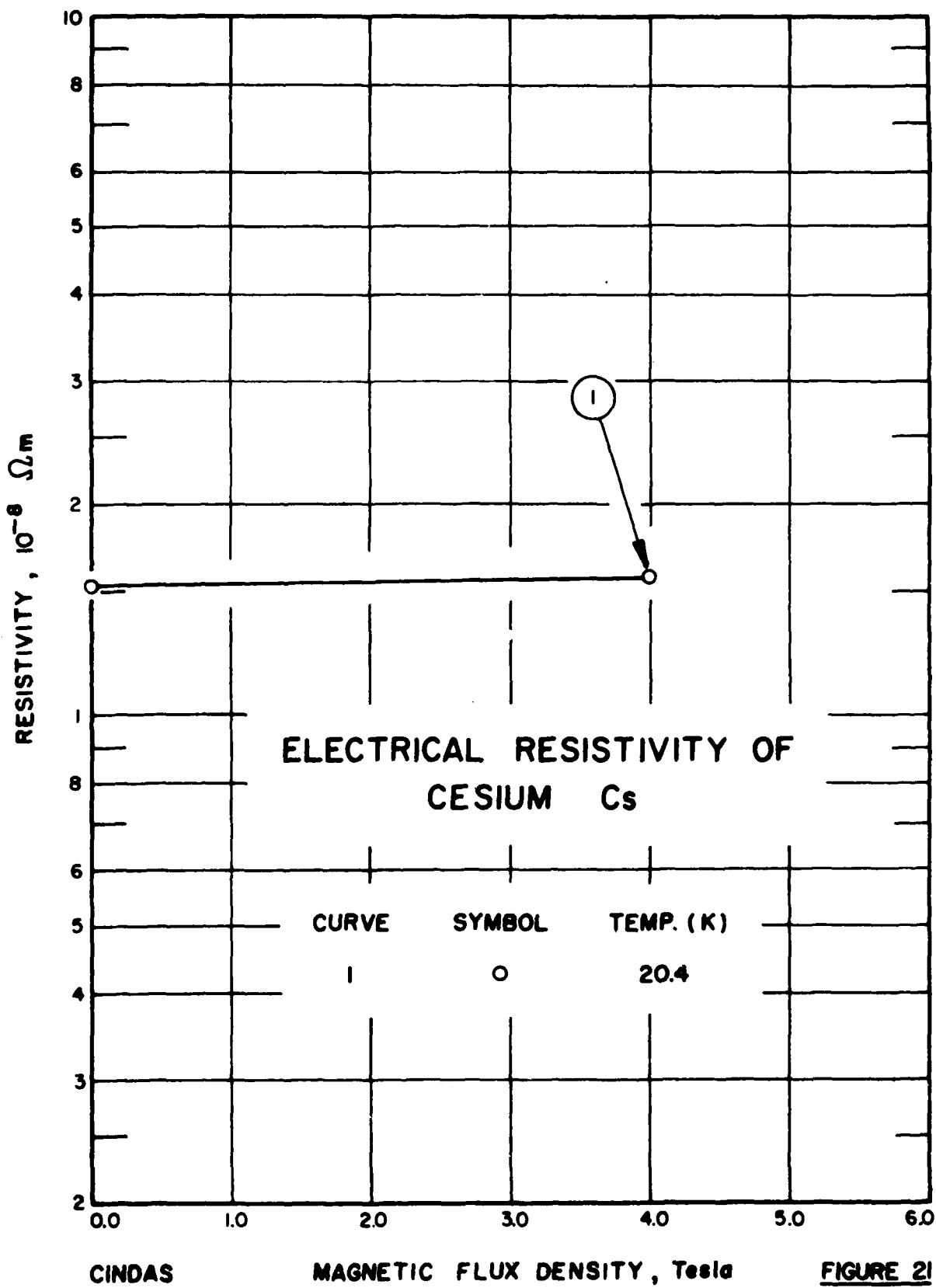
  

CURVE 16 T = 493	
P	$\rho$
1.0	59.0
1.9	52.7
3.0	49.0
3.9	48.0
4.9	46.7
6.0	46.7
7.1	48.1
8.1	48.1
9.0	50.8
9.9	52.2
11.1	56.5
12.3	59.7
13.3	64.7
14.4	69.5
15.3	75.4
16.3	81.1
17.4	88.8
18.4	97.5
19.5	105.9
20.7	116.8
21.6	126.7
22.5	138.3
23.9	151.0
24.8	160.9
25.3	166.1
26.3	177.1
26.9	181.0
27.3	185.8
28.0	192.1
28.4	197.2
28.8	198.6

### c. Magnetic Flux Density Dependence

There is only one set of experimental data available for the electrical resistivity of cesium under the influence of magnetic field. The information on specimen characterization and measurement information for each of the data sets is given in Table 36. The data are tabulated in Table 37 and shown in Figure 21.

The available data and information for the magnetic flux density dependence of electrical resistivity of cesium are inadequate for performing detailed analysis and synthesis at this time. Consequently, no recommendations are made and only experimental data are presented here.



**FIGURE 21**

TABLE 36. MEASUREMENT INFORMATION ON THE ELECTRICAL RESISTIVITY OF CESIUM Cs (Magnetic Flux Density Dependence)

Cur. Ref. No.	Author(s)	Year	Method Used	Magnetic Flux Density Range, Tesla	Temperature Range, K	Name and Designation	Composition (weight percent), Specifications, and Remarks
1	Justi, E.	1948	A	0, 4.0	20.4	Cs ?	Pure; $R_{20.4 K}/R_{273.15 K} = 0.0746$ ; it was measured in a transverse magnetic field.

TABLE 37. EXPERIMENTAL DATA ON THE ELECTRICAL RESISTIVITY OF CESIUM Cs (Magnetic Flux Density Dependence)  
[Temperature, T, K; Magnetic Flux Density, B, Tesla; Resistivity,  $\rho$ ,  $10^{-9}$  Ohm]

B	$\rho$
CURVE 1 $T = 20.4$	
0.0	1.531
4.0	1.575

#### 4.6. FRANCIUM

Francium, with atomic number 87, is the last member of the alkali metal series and is unstable and radioactive. Its chemical properties closely resemble those of cesium. It is a solid at room temperature having a melting point of 300.2 K and a boiling point of 950 K. Francium has no stable isotope, but twenty short-lived radioactive isotopes are known to exist, with half-lives ranging from far less than 1 millisecond ( $^{215}\text{Fr}$ ) to 22 min. ( $^{223}\text{Fr}$ ). The longest-lived isotope ( $^{233}\text{Fr}$ ) exists in nature in uranium minerals, but the total amount of it in the crust of the earth at any time is probably less than an ounce.

##### a. Temperature Dependence

There is no experimental determination of electrical resistivity on francium. Solov'ev [52] calculated the electrical resistivity from 293.15 to 1273.15 K by assuming that the atomic electrical resistances of alkali metals are all the same.

On the basis of the expected similarities between francium and the other alkali metals, we have roughly estimated the electrical resistivity values from 100 K to 1500 K by extrapolation to the atomic number 87 of a curve drawn through the values for sodium, potassium, rubidium, and cesium in a graph of electrical resistivity versus atomic number with temperature as a parameter. The change of resistivity at the melting point was obtained by using Mott's formula, Eq. (5), with a latent heat of 0.4 K cal/mole, which was also obtained by extrapolating the data of latent heat versus atomic number of lithium, sodium, potassium, rubidium, and cesium to 87 (Fr).

The provisional values for the intrinsic electrical resistivity are smoothed by the cubic spline function Eq. (7). The four term coefficients for the function Eq. (7) are given in the following:

<u>Temperature Range, K</u>	<u>a</u>	<u>b</u>	<u>c</u>	<u>d</u>
100-300.2	0.934	0.952	0.0137	1.286
300.2-881	1.74	0.907	-0.276	0.820
881-1500	2.19	1.186	0.874	1.522

These values are listed in Table 38 and shown in Figure 22 with the data of Solov'ev. The uncertainty of the provisional values is believed to be within  $\pm 50\%$ .



TABLE 38. PROVISIONAL ELECTRICAL RESISTIVITY OF FRANCIUM  
(Temperature Dependence)

[Temperature, T, K; Intrinsic Resistivity,  $\rho_i$ ,  $10^{-8} \Omega\text{m}$ ]

Solid		Liquid	
T	$\rho_i$	T	$\rho_i$
100	8.6	300.2	55
150	12.9	400	71
200	18.0	500	86
250	25.0	600	102
273.15	28.9	700	119
293	32.6	800	138
300.2	34.0	900	158
		1000	181
		1100	211
		1200	251
		1300	307
		1400	385
		1500	497

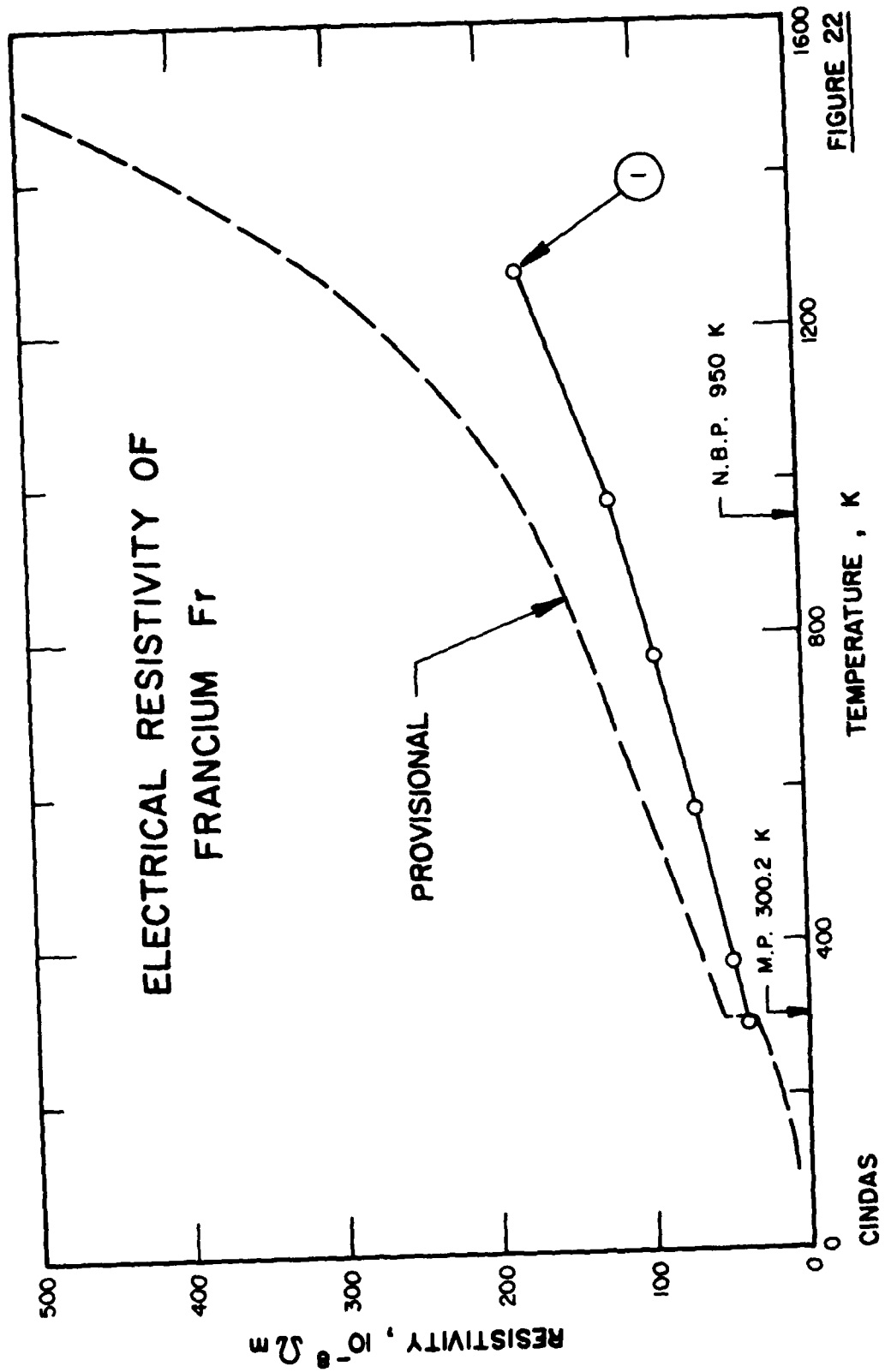


FIGURE 22

TABLE 39. CALCULATED INFORMATION ON THE ELECTRICAL RESISTIVITY OF FRANCIUM Fr (Temperature Dependence)

Cur. Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1 52	Solov'ev, A. N.	1963		293-1273		Electrical resistivity data were calculated by assuming the atomic electrical resistances of alkali metals are all the same; the data necessary for the calculation, i. e., the melting point and the density at $T = 0$ K and $T = T_{\text{melt}}$ were found by extrapolation of the straight lines for alkali metals in coordinates of properties vs atomic number.

TABLE 40. CALCULATED DATA ON THE ELECTRICAL RESISTIVITY OF FRANCIUM Fr (Temperature Dependence)

[Temperature, T, K; Resistivity,  $\rho$ ,  $10^{-6}$   $\Omega\text{m}$ ]

T	$\rho$
<u>CURVE 1</u>	
293.15	39.0
373.15	47.5
573.15	70.2
773.15	95.5
973.15	122.0
1273.15	178.0

## 5. SUMMARY AND CONCLUSION

The electrical resistivities of the alkali elements have been surveyed and studied from time to time by a number of investigators, including Meaden [111], Kaye & Laby [112], Grosse [5], and Shpil'rain, et al. [113], to name just a few. Electrical Resistivity data are compiled in a number of handbooks such as those sponsored by Landolt-Börnstein [114], AIP [115], CRC [116], and Liquid-Metals Handbook [117], etc. However, their main concern is to provide a general picture through only one or a few particular sets of data, and only a limited temperature range is covered. The purpose of the present work is quite different from that of the above mentioned works. There are two major aims: (1) to exhaustively search the open literature so that all the available experimental data are comprehensively compiled, and (2) to generate recommended reference values by critical evaluation, analysis, and synthesis of the existing experimental data.

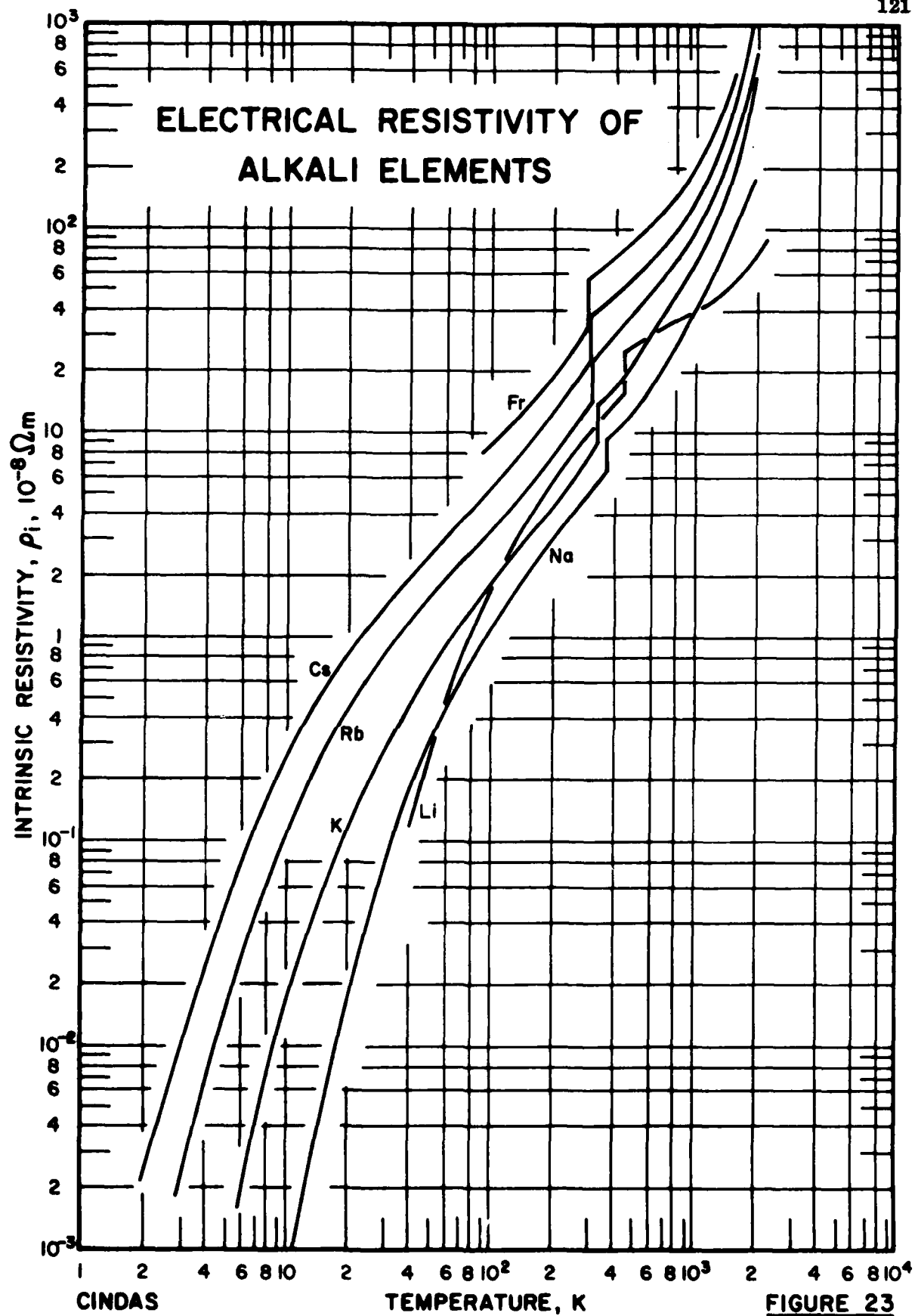
The above aims are now achieved. The recommended values were obtained by least squares fitting of the selected experimental data, or by correlating the related properties, and by smoothing with a cubic spline function. The comparison of electrical resistivity data from the literature with the present recommended values are shown in Table 41. The values from AIP [115] are taken from the book by Meaden [111] so that they are identical.

With a view to bring out any similarities or differences between the recommended values for the alkali elements, the recommended values of the intrinsic resistivities are plotted together from 2 to 2000 K and shown in Fig. 23.

TABLE 41. COMPARISON OF ELECTRICAL RESISTIVITY DATA FROM THE LITERATURE WITH THE PRESENT RECOMMENDED VALUES

Element	Temperature K	Total Resistivity, $\rho$ , $10^8 \Omega \text{ m}$									
		Present work (1976)	CRC (1974)	AIP (1972)	Shpil'rain, et al. (1970)	Grosse (1966)	Kaye & Laby (1966)	Meaden (1965)	Börnstein (1960)	Landolt & Börnstein (1960)	L. M. H. (1954)
Li	20	0.0129	-	-	-	-	-	0.035	-	-	-
	273.15	8.53	8.55	8.51	8.12	-	8.55	8.51	8.55, 8.9	-	
	1000	39.69	-	-	39.00	41.83	-	-	-	45.25 (503K)	
	2000	73.73	-	-	-	98.34	-	-	-	-	
Na	20	0.0156	-	-	-	-	-	0.0175	-	-	
	273.15	4.33	4.20	4.29	4.29	-	4.2	4.29	4.28-5.09	-	
	1000	40.73	-	-	39.80	41.79	-	-	-	18.44 (623K)	
	2000	184.4	-	-	-	207.4	-	-	-	-	
K	20	0.117	-	-	-	-	-	0.112	-	-	
	273.15	6.49	6.15	6.45	6.23	-	6.1	6.45	6.1-7.03	-	
	1000	67.94	-	-	67.91	78.8	-	-	-	31.4 (623K)	
	2000	575.3	-	-	-	746	-	-	-	-	
Rb	20	0.431	-	-	-	-	-	0.443	-	-	
	273.15	11.54	11.28	11.26	11.25	-	11.0	11.26	11.29-12.8	-	
	1000	97.26	-	-	102.6	112.8	-	-	-	27.47 (373K)	
	2000	629.4	-	-	-	2376	-	-	-	-	
Cs	20	0.859	-	-	-	-	-	0.922	-	-	
	273.15	18.75	20 (293K)	18.04	18.30	-	18.8	18.04	18.1-19.3	-	
	1000	133.4	-	-	-	153.0	-	-	-	37.0 (310K)	
	2000	1000	-	-	-	5731	-	-	-	-	
Fr	100	8.6*	-	-	-	-	-	-	-	-	
	273.15	28.9*	-	-	-	-	-	-	-	-	
	1500	497*	-	-	-	-	-	-	-	-	

 \* Intrinsic Resistivity,  $\rho_i$ .



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## 7. APPENDIX

## 7.1. Methods of Measuring Electrical Resistivity

## A. Steady State Methods

1. Voltmeter and ammeter direct reading (V) [118\* p. 159; 119, pp. 244-5]
2. DC Potentiometric Method (A) [111,\* pp. 151-8]
  - a. 4-probe potentiometric method
3. DC Bridge Method (B) [111, pp. 144-51]
  - a. Kelvin Double Bridge
  - b. Mueller Bridge
  - c. Wheatstone Bridge
4. van der Pauw Method (P), [120]\*
5. Galvanometer Amplifier Method (G), [121,\* pp. 159-62]

## B. Non-steady State Methods

1. Periodic currents involved
  - a. Direct connection to sample
    - (1) AC Potentiometric Method (C) [111, pp. 161-2]
    - (2) AC Bridge Method (D) [111, p. 162]
    - (3) Q-Meter Method (Q)
  - b. No connection to sample
    - (1) Mutual Inductance Method (M) [122] \*
    - (2) Self-inductance Method (S) [123] \*
    - (3) Rotating Field Method (R) [124] \*
2. Non-periodic currents involved
  - a. Direct connection to sample
    - (1) Transient (subsecond) technique (T) [125] \*
  - b. No connection to sample
    - (1) Eddy current decay method (E) [126;\*111, p. 103]

## C. General Comments

## 1. Code "I" means Induction Method

This is a combination of Items B.1.b. and B.2.b. above. Subsumed under I is M, R, S, or E. Used only if author indicates induction method used and does not report which specific one.

## 2. The symbol "→" used if method described by the author is not sufficient to assign a specific code presently used. Example:

---

\* References are given in Section 6.

- a. If the author says an "AC Method" was used, the following wording would be used under the item "Measuring conditions" in the column Composition, Specifications, and Remarks: "Experimental Method described as an AC Method." Note this "Method" corresponds to the heading B. 1. above. In the column for Method Used on the Specification Table the following symbol would appear:
- .

7.2 Conversion Tables for Units of Temperature, Pressure, and  
Magnetic Flux Density

TABLE 42. CONVERSION TABLES BETWEEN THE KELVIN, CELSIUS,  
FAHRENHEIT, AND RANKINE TEMPERATURE SCALES\*

K	°C	°F	°R
0	-273.15	-459.67	0
50	-223.15	-369.67	90
100	-173.15	-279.67	180
150	-123.15	-189.67	270
200	-73.15	-99.67	360
250	-23.15	-9.67	450
273.15	0	32	491.67
293	19.85	67.73	527.4
300	26.85	80.33	540
350	76.85	170.33	630
400	126.85	260.33	720
450	176.85	350.33	810
500	226.85	440.33	900
1000	726.85	1340.33	1800
1500	1226.85	2240.33	2700
2000	1726.85	3140.33	3600
3000	2726.85	4940.33	5400
4000	3726.85	6740.33	7200

\* This table is based on the universal constants from "The International System of Units (SI)," NBS Special Publication 330, National Bureau of Standards, U.S. Department of Commerce.

TABLE 43. CONVERSION FACTORS ON UNITS OF PRESSURE\*

	atm	dyne/ cm <sup>2</sup>	inch of water	cm Hg	PASCAL	lb/in. <sup>2</sup>	lb/ft <sup>2</sup>
1 atmosphere =	1	1.013 x 10 <sup>6</sup>	406.8	76	1.013 x 10 <sup>5</sup>	14.70	2116
1 dyne per cm <sup>2</sup> =	9.869 x 10 <sup>-7</sup>	1	4.015 x 10 <sup>-4</sup>	7.501 x 10 <sup>-5</sup>	0.1	1.450 x 10 <sup>-5</sup>	2.089 x 10 <sup>-3</sup>
1 inch of water at 4° C <sup>a</sup> =	2.458 x 10 <sup>-3</sup>	2491	1	0.1868	249.1	3.613 x 10 <sup>-2</sup>	5.202
1 centimeter of mer- cury at 0° C <sup>a</sup> =	1.316 x 10 <sup>-2</sup>	1.333 x 10 <sup>4</sup>	5.353	1	1333	0.1934	27.85
1 NEWTON per METER <sup>2</sup> =1 PASCAL=	9.869 x 10 <sup>-6</sup>	10	4.015 x 10 <sup>-3</sup>	7.501 x 10 <sup>-4</sup>	1	1.450 x 10 <sup>-4</sup>	2.089 x 10 <sup>-2</sup>
1 pound per in. <sup>2</sup> =	6.805 x 10 <sup>-2</sup>	6.895 x 10 <sup>4</sup>	27.68	5.171	6.895 x 10 <sup>3</sup>	1	144
1 pound per ft <sup>2</sup> =	4.725 x 10 <sup>-4</sup>	478.8	0.1922	3.591 x 10 <sup>-2</sup>	47.88	6.944 x 10 <sup>-3</sup>	1

<sup>a</sup> Where the acceleration of gravity has the standard value 9.80665 meters/sec<sup>2</sup>.

1 bar = 10<sup>5</sup> Pa

1 Kbar = 10<sup>8</sup> Pa

TABLE 44. CONVERSION FACTORS ON UNITS OF MAGNETIC FLUX DENSITY\*

	gauss	kiloline/ in <sup>2</sup>	TESLA	milli- gauss	gamma
1 gauss (line per cm <sup>2</sup> ) =	1	6.452 x 10 <sup>-3</sup>	10 <sup>-4</sup>	1000	10 <sup>5</sup>
1 kiloline per in. <sup>2</sup> =	155.0	1	1.550 x 10 <sup>-2</sup>	1.550 x 10 <sup>5</sup>	1.550 x 10 <sup>7</sup>
1 WEBER per METER <sup>2</sup> = 1 TESLA =	10 <sup>4</sup>	64.52	1	10 <sup>7</sup>	10 <sup>9</sup>
1 milligauss =	0.001	6.452 x 10 <sup>-6</sup>	10 <sup>-7</sup>	1	100
1 gamma =	10 <sup>-5</sup>	6.452 x 10 <sup>-6</sup>	10 <sup>-9</sup>	0.01	1

\* This table is based on the universal constants from "The International System of Units (SI)," NBS Special Publication 330, National Bureau of Standards, U.S. Department of Commerce.

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