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THERMAL CONDUCTIVITY STANDARD REFERENCE

MATERIALS FROM 4 TO 300K. I. ARMCO IRON

by

J. G. Hust

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THERMAL CONDUCTIVITY STANDARD REFERENCE

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J. G. Hust
Cryogenics Division
Institute for Basic Standards
National Bureau of Standards
Boulder, Colorado, 80302

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MATERIALS FROM 4 to 300 K. I. ARMCO IRON*

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ABSTRACT

Thermal conductivity, electrical resistivity, Lorenz ratio, and thermopower data are reported for several specimens of Armco iron for temperatures from 4 to 300 K. At low temperatures the electrical resistivity and thermal conductivity vary from specimen to specimen by more than 10%. However, the Lorenz ratios of these specimens differ by less than 1.5%; and the intrinsic resistivities calculated using Matthiessen's rule differ by less than 0.2% of the total resistivities. Thus, Armco iron specimens can be used as standards by measuring the residual resistivities and utilizing the Lorenz ratio reported here.

KEY WORDS
Cryogenics, electrical resistivity, iron, Lorenz ratio, Seebeck effect, thermal conductivity, transport properties.

* This work was carried out at the National Bureau of Standards under the sponsorship of the NASA-Space Nuclear Propulsion Office, Cleveland.
1. Introduction

Design and development engineers in the aerospace industry continue to have urgent need for thermal and mechanical property data for new materials. For most materials, especially new or uncommon alloys, measured values of thermal conductivity are not available and predictions cannot be made with adequate confidence. To help satisfy these needs, we have constructed an apparatus for the simultaneous measurement of thermal conductivity, electrical resistivity and thermopower. Measurements have been conducted on several aerospace alloys, Hust, et al.\textsuperscript{[1]} Another phase of this program, to establish standard reference data on several standard reference materials (or specimens), has begun. We intend to measure several specimens of materials which appear to be useful as standards. For some materials, material variability may be so great that only standard specimens (not standard materials) will be useful. Standard reference specimens or materials are useful for intercomparison of existing apparatus, for debugging new apparatus, and for calibration of comparative apparatus. The apparent large differences between the results of various investigators for a given material (50% is not unheard of) is evidence of the need for intercomparisons, calibrations, and standardization. The availability of standard reference materials will result in more accurate and more permanent transport property data for technically important solids.

This paper contains the results of our measurements on the transport properties of Armco iron.* Armco iron was investigated at low temperatures primarily because of its extensive use as a thermal conductivity standard at higher temperatures.\textsuperscript{[2]}

* The use in this paper of trade names of specific products is essential to the proper understanding of the work presented. Their use in no way implies any approval, endorsement, or recommendations by NBS. Armco iron is a registered trade name of a commercially pure iron produced by Armco Steel Corporation.
2. **Apparatus and Data Analysis**

The apparatus is based on the axial one-dimensional heat flow method. The specimen is a cylindrical rod 3.6 mm in diameter and 23 cm long with an electric heater at one end and a temperature controlled sink at the other. The specimen is surrounded by glass fiber and a temperature controlled shield. Eight thermocouples are mounted at equally spaced points along the length of the specimen to determine temperature gradients in the range 4 to 300 K.

The experimental data are represented by arbitrary functions over the entire range and smooth tables are generated from these functions. The number of terms used to represent each of the data sets is optimized, through the use of orthonormal functions, so that none of the precision of the data is lost by "underfitting" nor are any necessary oscillations introduced by "overfitting." A detailed description of this apparatus and the methods of data analysis is given by Hust, et al.[1] Further details are given in the Appendix of this report.

3. **Specimen Characterization**

An Armco iron rod (2.54 cm diameter and 35.6 cm long) was obtained from Battelle Memorial Institute. Typical composition of Armco iron in weight percent is: 0.015 C, 0.028 Mn, 0.005 P, 0.025 S, 0.003 Si, 0.04 Cu, and 99.9 Fe. This rod was annealed by the supplier as follows: \( \frac{1}{2} \) hour at 870°C in a gas-heated air muffle, and then in a quartz capsule at \( 1 \times 10^{-6} \) torr for \( 1 \frac{1}{2} \) hours at 875°C, furnace cooled to 150°C, held at 150°C for 24 hours, and furnace cooled to room temperature. We cut the rod into quarters along its axis and cut a 5 cm long piece from each end of each quadrant. These eight pieces were used for electrical residual resistivity ratio, hardness, and grain size measurements. Two of the center 25 cm sections were measured in the thermal conductivity apparatus. The division of the rod and the labeling of specimens is shown in figure 1.
The hardness of these specimens, after machining, was B-40.0. The specimens were subsequently reannealed using the same procedure indicated by the supplier. The hardness after anneal was B-37.1. The grain size approximated from ASTM Chart E112, plate 1 was 0.053 mm and 0.064 mm after machining and after reannealing respectively.

The electrical residual resistivity ratios, RRR, of the eight specimens (1A... 4A, 1B... 4B) after machining and of two of these specimens after reannealing are recorded in table 1. These ratios obtained from electrical resistance measurements at 273K and 4K in a specially fabricated dip probe, are estimated to be accurate to about 0.2%. Table 1 also contains the resistivity ratios of specimens 2C and 4C. The data marked with asterisks were obtained from the thermal conductivity apparatus.

C. F. Lucks of Battelle Memorial Institute performed similar measurements on another bar of Armco iron. The rms deviation of his results on six specimens is 6.5% of the mean while the rms deviation of our ten specimens is 3.6%. Lucks made his RRR measurements from 4K to 298K; in order to compare absolute values, I adjusted his values to $\rho_{273K}/\rho_{4K}$ by using $d\rho/dT = 0.05\mu \Omega \text{cm/K}$ at the ice point. This value of $d\rho/dT$ comes from my measurements in the thermal conductivity apparatus. The mean value of RRR (13.65) determined from my data is 5.5% below the mean value reported by Lucks. It is noted from table 1 that the RRR values are lower after annealing. This is an unexplained phenomena at this time, but probably is connected with diffusion of impurities from the grain boundaries upon heat treatment.
4. **Results**

The transport properties of specimens 2C and 4C were measured in the thermal conductivity apparatus. Specimen 2C was subsequently annealed (same annealing procedure as described before) and remeasured. These data are presented in tables 2 through 7. These specimens are referred to as 2 and 4 respectively in these tables. Specimen 2C after annealing is referred to as 2a.

The experimental data were functionally represented with the following equations:

\[ \ln \lambda = \sum_{i=1}^{n} a_i \left[ \ln T \right]^{i+1} \]  \hspace{1cm} \text{(1)}

\[ \rho = \sum_{i=1}^{m} b_i \left[ \ln T \right]^{i+1} \]  \hspace{1cm} \text{(2)}

\[ S = \sum_{i=1}^{\lambda} c_i \left[ \ln T' \right]^i / T'; T' = \frac{T}{10} + 1 \]  \hspace{1cm} \text{(3)}

where \( \lambda \) = thermal conductivity, \( \rho \) = electrical resistivity, \( S \) = thermopower, and \( T \) = temperature. Temperatures are based on the IPTS-68 scale above 20 K and the NBS P2-20 (1965) scale below 20 K. The parameters, \( a_i, b_i, \) and \( c_i, \) determined by least squares, are presented in tables 8, 9, and 10. Further details of this procedure are described by Hust, et al.\(^1\) The deviations of the experimental data from these equations are given in tables 11 through 19 and in figures 2 through 10. The "observed" thermal conductivities are computed from the mean temperature gradients indicated by adjacent thermocouples. Calculated values of \( \lambda, \rho, S, \) and \( L = \rho \lambda / T \) (Lorenz ratio) are presented in tables 20, 21, and 22 and in figures 11, 12, and 13.
A detailed error analysis for these measurements has been presented previously by Hust, et al.\textsuperscript{[1]} Based on this analysis of systematic and random errors the uncertainty estimates (with 95\% confidence) are as follows:

- **thermal conductivity:** 2.5\% at 300 K, decreasing as $T^4$ to 0.70\% at 200 K, 0.70\% from 200 K to 50 K, increasing inversely with temperature to 1.5\% at 4 K.
- **electrical resistivity:** 0.25\%
- **thermopower:** 0.5\% + 0.2\,\mu V/K at 4 K, 0.2\% + 0.05\,\mu V/K at 30 K, and 0.1\% + 0.03\,\mu V/K above 76 K.

The thermopower values given here are absolute values although our measurements were carried out with respect to normal silver wire. The absolute thermopowers of normal silver reported by Borelius, et al.\textsuperscript{[4]} were used to convert the experimental data to the absolute scale.

5. **Discussion**

The thermal conductivities of these specimens differ by as much as 10\% at low temperatures; the differences observed in electrical resistivity are similar. The thermal conductivity deviations of the three sets of values are shown in figure 14. These data would suggest that Armco iron is a poor thermal conductivity standard at low temperatures. However, upon further examination it is found that this conclusion is not valid. The Lorenz ratio for these measurements is much less variable at low temperatures than either $\rho$ or $\lambda$. Figure 15 illustrates the deviations of the Lorenz ratios for each specimen from the mean value.
Since these deviations are not appreciably larger than the uncertainty in the measured Lorenz ratio, the Lorenz ratio is assumed to be invariant from specimen to specimen. Thus one can obtain the electrical resistivity of a particular specimen of Armco iron and compute the thermal conductivity using the Lorenz ratio reported here.

In order for the above procedure to be practical one needs a relatively quick method of generating a $\rho$ vs $T$ curve for a particular specimen from relatively few measurements. Matthiessen's rule indicates that $\rho = \rho_0 + \rho_i$, where $\rho_0$ is the residual resistivity of the specimen and $\rho_i$ is the intrinsic resistivity of the material. It is known that this rule is not satisfied exactly and that a correction term $\Delta(\rho_0, \rho_i)$ exists. However, if this correction term is sufficiently small one can reconstruct a sufficiently accurate $\rho$ vs $T$ curve for a given specimen from knowledge of $\rho_i$ and measurement of $\rho_0$ (only one measurement). To investigate this possibility, $\rho_i$ was computed for each specimen using Matthiessen's rule. The relative deviations of the computed values of $\rho_i$ from the mean of three sets is shown in figure 16. This plot shows that $\rho_i$ values for specimens 2, 2a, and 4, as computed from Matthiessen's rule, differ from the mean by less than 0.3% of the resistivity. This deviation is only slightly larger than the estimated uncertainty of the measurements. It is not unreasonable to assume that this result can be extended to other specimens of Armco iron having similar values of $\rho_0$ and thus, Armco iron can be a useful low temperature standard reference material. This is especially significant, since Armco iron is already in extensive use as a high temperature standard reference material.\[2\] The thermal conductivity, $\lambda$, of standard reference specimen of Armco iron can be computed from
\[ \lambda = \frac{LT}{\rho} = \frac{LT}{\rho_i + \rho_o} \] (4)

where \( L \) and \( \rho_i \) are given in table 23 and \( \rho_o \) is determined by a relatively simple measurement.

The absolute thermopowers of these three specimens are compared in figure 17. The deviations between specimens are only slightly larger than the uncertainty in the tabulated values; thus no significant difference between specimens can be detected from this property.

6. Acknowledgments

I wish to thank C. F. Luck of Battelle Memorial Institute for supplying the Armco iron rod and information regarding annealing. R. P. Reed and R. L. Durcholz of this laboratory did the hardness and grain size testing. This measurement program has been carried out under the helpful guidance of R. L. Powell.
7. References


3. C. F. Lucks, Private communication.

Table 1

Residual resistivity ratio ($\rho_{77K}/\rho_{4K}$) of Armco iron

<table>
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<tr>
<th>Specimen</th>
<th>After machining</th>
<th>After annealing</th>
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<tr>
<td>1A</td>
<td>14.12</td>
<td></td>
</tr>
<tr>
<td>2A</td>
<td>13.81</td>
<td></td>
</tr>
<tr>
<td>3A</td>
<td>14.13</td>
<td></td>
</tr>
<tr>
<td>4A</td>
<td>12.99</td>
<td></td>
</tr>
<tr>
<td>1B</td>
<td>13.81</td>
<td></td>
</tr>
<tr>
<td>2B</td>
<td>14.51</td>
<td>12.88</td>
</tr>
<tr>
<td>3B</td>
<td>14.09</td>
<td></td>
</tr>
<tr>
<td>4B</td>
<td>12.77</td>
<td>11.52</td>
</tr>
<tr>
<td>2C</td>
<td>13.86, 13.83*</td>
<td>12.58*</td>
</tr>
<tr>
<td>4C</td>
<td>12.44, 13.31*</td>
<td></td>
</tr>
</tbody>
</table>

* These values were determined from measurements using the thermal conductivity apparatus.
The data listed in tables 2 thru 7 are, in part, card images of experimental data as read into the computer for data processing. These data are not clearly labelled. The following is a line by line explanation of tables 2, 4, and 6.

1st line - Data identification.
2nd line - Sample heater voltage ($\mu V$), current (mA), platinum resistance thermometer voltage ($\mu V$), cryogenic bath pressure (mm of Hg), room temperature ($^\circ$C), platinum resistance thermometer current (mA), code indicating type of cryogenic bath (1 = liquid helium, 2 = liquid hydrogen, 3 = liquid nitrogen, 4 = dry ice-alcohol, 5 = ice-water).
3rd line - Thermocouple emfs ($\mu V$).
4th line - Seebeck emf ($\mu V$), specimen current (mA), specimen voltage drop ($\mu V$).
5th line - Thermocouple temperatures (K).
6th line - Heater power (W), reference temperature (K), specimen resistance ($\Omega$).
Table 2. Basic semi-processed temperature gradient data for Armco iron, specimen 2.

<table>
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<tr>
<th>Thermal Conductivity Data for Armco Iron (2) 27Aug68 135pm</th>
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<tr>
<td>2901060  50.1000  3041.95  92.8  21.0  1.0  3.0</td>
</tr>
<tr>
<td>155.85  192.39  229.95  267.77  305.95  344.43  383.00  422.30</td>
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<th>Thermocouple Temperatures</th>
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<tr>
<td>77.251  79.254  81.302  83.354  85.418  87.487  89.555  91.649</td>
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<th>Specimen Resistance</th>
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<tr>
<td>8.7322-002</td>
<td>68.606</td>
<td>2.6227-004</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Thermal Conductivity Data for Armco Iron (2) 28Aug68 625 pm</th>
</tr>
</thead>
<tbody>
<tr>
<td>5856750  40.0000  4687.70  650.0  21.0  1.0  3.0</td>
</tr>
<tr>
<td>292.10  363.46  437.18  511.91  587.84  664.82  742.62  822.12</td>
</tr>
<tr>
<td>318.51  200.00  75.26</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Thermocouple Temperatures</th>
</tr>
</thead>
<tbody>
<tr>
<td>92.137  95.916  99.790 103.686 107.619 111.577 115.555 119.591</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Heater Power</th>
<th>Reference Temperature</th>
<th>Specimen Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5427-001</td>
<td>76.349</td>
<td>3.7630-004</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Thermal Conductivity Data for Armco Iron (2) 29Aug68 1145 am</th>
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</thead>
<tbody>
<tr>
<td>6754900  70.0000  4788.42  653.0  21.0  1.0  3.0</td>
</tr>
<tr>
<td>743.45  992.50  1254.80 1525.50 1804.70 2091.04 2384.58 2686.87</td>
</tr>
<tr>
<td>1343.50  200.00  150.26</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Thermocouple Temperatures</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Heater Power</th>
<th>Reference Temperature</th>
<th>Specimen Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.7284-001</td>
<td>76.811</td>
<td>7.5130-004</td>
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<table>
<thead>
<tr>
<th>Thermal Conductivity Data for Armco Iron (2) 30Aug68 100 am</th>
</tr>
</thead>
<tbody>
<tr>
<td>9614249  99.5800  4780.40  653.0  21.0  1.0  3.0</td>
</tr>
<tr>
<td>1661.95  2251.69 2878.90 3531.45 4208.12 4903.67 5616.50 6353.80</td>
</tr>
<tr>
<td>2724.50  200.00  315.78</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Thermocouple Temperatures</th>
</tr>
</thead>
<tbody>
<tr>
<td>161.685 189.651 216.693 248.594 278.803 309.855 341.683 374.600</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Heater Power</th>
<th>Reference Temperature</th>
<th>Specimen Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.5739-001</td>
<td>77.192</td>
<td>1.5789-003</td>
</tr>
<tr>
<td>THERMAL CONDUCTIVITY DATA FOR ARMCO IRON(2) 30AUG68 220PM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------------------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>399637</td>
<td>4.1500</td>
<td>-0.00</td>
</tr>
<tr>
<td>15.25</td>
<td>15.97</td>
<td>18.95</td>
</tr>
<tr>
<td>-0.03</td>
<td>100.00</td>
<td>11.66</td>
</tr>
<tr>
<td>THERMOCOUPLE TEMPERATURES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.010</td>
<td>5.229</td>
<td>5.446</td>
</tr>
<tr>
<td>HEATER POWER REFERENCE TEMPERATURE SPECIMEN RESISTANCE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.6585-005</td>
<td>4.073</td>
<td>1.1660-004</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>THERMAL CONDUCTIVITY DATA FOR ARMCO IRON(2) 30AUG68 330PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>827760</td>
</tr>
<tr>
<td>41.08</td>
</tr>
<tr>
<td>0.13</td>
</tr>
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<td>THERMOCOUPLE TEMPERATURES</td>
</tr>
<tr>
<td>HEATER POWER REFERENCE TEMPERATURE SPECIMEN RESISTANCE</td>
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<tr>
<td>7.1187-005</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>THERMAL CONDUCTIVITY DATA FOR ARMCO IRON(2) 30AUG68 630PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1265600</td>
</tr>
<tr>
<td>109.77</td>
</tr>
<tr>
<td>0.51</td>
</tr>
<tr>
<td>THERMOCOUPLE TEMPERATURES</td>
</tr>
<tr>
<td>HEATER POWER REFERENCE TEMPERATURE SPECIMEN RESISTANCE</td>
</tr>
<tr>
<td>1.6616-002</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>THERMAL CONDUCTIVITY DATA FOR ARMCO IRON(2) 30AUG68 710PM</th>
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<tbody>
<tr>
<td>2182120</td>
</tr>
<tr>
<td>216.53</td>
</tr>
<tr>
<td>3.60</td>
</tr>
<tr>
<td>THERMOCOUPLE TEMPERATURES</td>
</tr>
<tr>
<td>HEATER POWER REFERENCE TEMPERATURE SPECIMEN RESISTANCE</td>
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<tr>
<td>4.9469-002</td>
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</table>
Table 2 (Cont.)

<table>
<thead>
<tr>
<th>THERMAL CONDUCTIVITY DATA FOR ARMCO IRON(2) 3SEP68 347PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1195030</td>
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<tr>
<td>56.30</td>
</tr>
<tr>
<td>1.04</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>THERMOCOUPLE TEMPERATURES</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>HEATER POWER REFERENCE TEMPERATURE SPECIMEN RESISTANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.3860-002</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>THERMAL CONDUCTIVITY DATA FOR ARMCO IRON(2) 3SEP68 505PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>3480880</td>
</tr>
<tr>
<td>263.95</td>
</tr>
<tr>
<td>47.20</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>THERMOCOUPLE TEMPERATURES</th>
</tr>
</thead>
<tbody>
<tr>
<td>35.483</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>HEATER POWER REFERENCE TEMPERATURE SPECIMEN RESISTANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2576-001</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>THERMAL CONDUCTIVITY DATA FOR ARMCO IRON(2) 4SEP68 120PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>4860190</td>
</tr>
<tr>
<td>496.40</td>
</tr>
<tr>
<td>241.42</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>THERMOCOUPLE TEMPERATURES</th>
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</thead>
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<td>49.435</td>
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</table>

<table>
<thead>
<tr>
<th>HEATER POWER REFERENCE TEMPERATURE SPECIMEN RESISTANCE</th>
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</thead>
<tbody>
<tr>
<td>2.4050-001</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>THERMAL CONDUCTIVITY DATA FOR ARMCO IRON(2) 4SEP68 430PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>2335100</td>
</tr>
<tr>
<td>106.20</td>
</tr>
<tr>
<td>8.19</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>THERMOCOUPLE TEMPERATURES</th>
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</thead>
<tbody>
<tr>
<td>26.074</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>HEATER POWER REFERENCE TEMPERATURE SPECIMEN RESISTANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.6629-002</td>
</tr>
<tr>
<td>THERMAL CONDUCTIVITY DATA FOR ARMCO IRON (2) 6SEP76 1130AM</td>
</tr>
<tr>
<td>---------------</td>
</tr>
<tr>
<td>4149000</td>
</tr>
<tr>
<td>239.86</td>
</tr>
<tr>
<td>544.20</td>
</tr>
<tr>
<td>THERMOCOUPLE TEMPERATURES</td>
</tr>
<tr>
<td>204.212</td>
</tr>
<tr>
<td>HEATER POWER</td>
</tr>
<tr>
<td>1.7840-001</td>
</tr>
</tbody>
</table>

| THERMAL CONDUCTIVITY DATA FOR ARMCO IRON (2) 7SEP76 430 PM |
|---------------|-----------|-----------|----------|---------|--------|--------|
| 6270555       | 60.9600   | 17299.40  | 627.4    | 22.0    | 1.0    | 4.0    |
| 733.74        | 1001.22   | 1277.22   | 1556.20  | 1841.25 | 2129.90| 2422.95| 2722.05 |
| 1174.06       | 100.00    | 160.62    |          |         |        |        |
| THERMOCOUPLE TEMPERATURES |
| 227.472       | 239.645   | 252.132   | 264.687  | 277.470 | 290.357| 303.441| 316.795 |
| HEATER POWER | REFERENCE TEMPERATURE | SPECIMEN RESISTANCE |
| 4.0734-001    | 193.620   | 1.6062-003 |

---
The data listed in tables 2 thru 7 are, in part, card images of experimental data as read into the computer for data processing. These data are not labelled clearly. The following is a line by line explanation of tables 3, 5, and 7.

1st line - Data identification.
2nd line - Platinum resistance thermometer voltage (\(\mu V\)), cryogenic bath pressure (mm of Hg), room temperature (\(^\circ C\)), platinum resistance thermometer current (mA), code indicating type of cryogenic bath (1 = liquid helium, 2 = liquid hydrogen, 3 = liquid nitrogen, 4 = dry ice-alcohol, 5 = ice-water), specimen current (mA), specimen voltage (\(\mu V\)), mean emf of eight thermocouples (\(\mu V\)).

3rd line - Reference temperature (K), specimen resistance (\(\Omega\)), specimen temperature (K).
<table>
<thead>
<tr>
<th>Temperature</th>
<th>Resistance</th>
<th>Temperature</th>
<th>Resistivity</th>
<th>Date/Time</th>
<th>Data Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>840 AM</td>
<td>3242.83</td>
<td>93.20</td>
<td>21.00</td>
<td>1.00</td>
<td>3.00</td>
</tr>
<tr>
<td>950 AM</td>
<td>3243.31</td>
<td>93.20</td>
<td>21.00</td>
<td>1.00</td>
<td>3.00</td>
</tr>
<tr>
<td>950 AM</td>
<td>3775.15</td>
<td>92.80</td>
<td>21.00</td>
<td>1.00</td>
<td>3.00</td>
</tr>
<tr>
<td>950 AM</td>
<td>4689.61</td>
<td>651.60</td>
<td>21.00</td>
<td>1.00</td>
<td>3.00</td>
</tr>
<tr>
<td>110 PM</td>
<td>4737.00</td>
<td>653.00</td>
<td>20.00</td>
<td>1.00</td>
<td>3.00</td>
</tr>
<tr>
<td>1200 PM</td>
<td>4815.05</td>
<td>652.50</td>
<td>21.00</td>
<td>1.00</td>
<td>3.00</td>
</tr>
<tr>
<td>845 PM</td>
<td>17246.80</td>
<td>631.50</td>
<td>20.00</td>
<td>1.00</td>
<td>4.00</td>
</tr>
<tr>
<td>1125 PM</td>
<td>17316.50</td>
<td>628.60</td>
<td>21.00</td>
<td>1.00</td>
<td>4.00</td>
</tr>
</tbody>
</table>

Table 3. Basic semi-processed isothermal electrical resistivity data for Armco iron, specimen 2.
<table>
<thead>
<tr>
<th>Isothermal Resistivity Data for Armco Iron (2)</th>
<th>30Aug68 150pm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference Temperature</td>
<td>Specimen Resistance</td>
</tr>
<tr>
<td>4.075</td>
<td>1.1660-004</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Isothermal Resistivity Data for Armco Iron (2)</th>
<th>30Aug68 420pm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference Temperature</td>
<td>Specimen Resistance</td>
</tr>
<tr>
<td>4.055</td>
<td>1.1670-004</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Isothermal Resistivity Data for Armco Iron (2)</th>
<th>30Aug68 520pm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference Temperature</td>
<td>Specimen Resistance</td>
</tr>
<tr>
<td>4.055</td>
<td>1.1685-004</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Isothermal Resistivity Data for Armco Iron (2)</th>
<th>30Aug68 650pm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference Temperature</td>
<td>Specimen Resistance</td>
</tr>
<tr>
<td>4.055</td>
<td>1.1740-004</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Isothermal Resistivity Data for Armco Iron (2)</th>
<th>3Sep68 205pm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference Temperature</td>
<td>Specimen Resistance</td>
</tr>
<tr>
<td>19.851</td>
<td>1.1795-004</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Isothermal Resistivity Data for Armco Iron (2)</th>
<th>3Sep68 255pm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference Temperature</td>
<td>Specimen Resistance</td>
</tr>
<tr>
<td>19.873</td>
<td>1.1860-004</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Isothermal Resistivity Data for Armco Iron (2)</th>
<th>4Sep68 1115am</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference Temperature</td>
<td>Specimen Resistance</td>
</tr>
<tr>
<td>19.983</td>
<td>1.3815-004</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Isothermal Resistivity Data for Armco Iron (2)</th>
<th>4Sep68 255pm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference Temperature</td>
<td>Specimen Resistance</td>
</tr>
<tr>
<td>19.881</td>
<td>1.1890-004</td>
</tr>
</tbody>
</table>
Table 4. Basic semi-processed temperature gradient data for Armco iron, specimen 2a.

<table>
<thead>
<tr>
<th>THERMAL CONDUCTIVITY DATA FOR ARMCO IRON(2A)</th>
<th>9 MAR 69 900 AM</th>
</tr>
</thead>
<tbody>
<tr>
<td>385760</td>
<td>40.0000</td>
</tr>
<tr>
<td>4707.44</td>
<td>647.0</td>
</tr>
<tr>
<td>176.41</td>
<td>246.46</td>
</tr>
<tr>
<td>318.77</td>
<td>392.55</td>
</tr>
<tr>
<td>467.41</td>
<td>643.60</td>
</tr>
<tr>
<td>543.60</td>
<td>620.64</td>
</tr>
<tr>
<td>699.16</td>
<td>3.0</td>
</tr>
<tr>
<td>1.0</td>
<td>300.24</td>
</tr>
<tr>
<td>70.64</td>
<td>200.00</td>
</tr>
</tbody>
</table>

THERMOCOUPLE TEMPERATURES

| 86.123                                      | 89.880          |
| 93.726                                      | 97.617          |
| 101.539                                     | 105.499         |
| 109.478                                     | 113.503         |

HEATER POWER REFERENCE TEMPERATURE SPECIMEN RESISTANCE

| 1.5430-001                                  | 76.529          |
| 3.5320-004                                  |                 |

<table>
<thead>
<tr>
<th>THERMAL CONDUCTIVITY DATA FOR ARMCO IRON(2A)</th>
<th>10 MAR 69 1020 AM</th>
</tr>
</thead>
<tbody>
<tr>
<td>5788935</td>
<td>60.0000</td>
</tr>
<tr>
<td>4703.45</td>
<td>648.0</td>
</tr>
<tr>
<td>222.71</td>
<td>304.56</td>
</tr>
<tr>
<td>555.17</td>
<td>732.56</td>
</tr>
<tr>
<td>915.93</td>
<td>1104.85</td>
</tr>
<tr>
<td>1298.58</td>
<td>1497.87</td>
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<tr>
<td>815.92</td>
<td>200.00</td>
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<tr>
<td>95.86</td>
<td></td>
</tr>
</tbody>
</table>

THERMOCOUPLE TEMPERATURES

| 88.574                                      | 97.165          |
| 106.066                                     | 115.174         |
| 124.455                                     | 133.888         |
| 143.444                                     | 153.156         |

HEATER POWER REFERENCE TEMPERATURE SPECIMEN RESISTANCE

| 3.4734-001                                  | 76.493          |
| 4.7950-004                                  |                 |

<table>
<thead>
<tr>
<th>THERMAL CONDUCTIVITY DATA FOR ARMCO IRON(2A)</th>
<th>10 MAR 69 500 PM</th>
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</thead>
<tbody>
<tr>
<td>806700</td>
<td>85.5700</td>
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<tr>
<td>4767.78</td>
<td>648.0</td>
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<td>560.81</td>
<td>909.22</td>
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<tr>
<td>1282.68</td>
<td>1675.24</td>
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<tr>
<td>2083.94</td>
<td>2507.94</td>
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<td>2946.02</td>
<td>3399.18</td>
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<td>1922.56</td>
<td>200.00</td>
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<tr>
<td>169.05</td>
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</tbody>
</table>

THERMOCOUPLE TEMPERATURES

| 106.908                                     | 124.653         |
| 143.186                                     | 162.222         |
| 181.652                                     | 201.478         |
| 221.674                                     | 242.513         |

HEATER POWER REFERENCE TEMPERATURE SPECIMEN RESISTANCE

| 6.7416-001                                  | 77.078          |
| 8.4525-004                                  |                 |

<table>
<thead>
<tr>
<th>THERMAL CONDUCTIVITY DATA FOR ARMCO IRON(2A)</th>
<th>11 MAR 69 440 PM</th>
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<tbody>
<tr>
<td>3860100</td>
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<td>4859.08</td>
<td>667.0</td>
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<tr>
<td>1077.97</td>
<td>1163.31</td>
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<td>1251.43</td>
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<td>1540.05</td>
<td>1428.79</td>
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<tr>
<td>1518.60</td>
<td>1608.94</td>
</tr>
<tr>
<td>1700.87</td>
<td>133.58</td>
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</tbody>
</table>

THERMOCOUPLE TEMPERATURES

| 133.853                                     | 138.057         |
| 142.394                                     | 146.730         |
| 151.054                                     | 155.405         |
| 159.763                                     | 164.175         |

HEATER POWER REFERENCE TEMPERATURE SPECIMEN RESISTANCE

| 1.5400-001                                  | 77.907          |
| 6.6690-004                                  |                 |
Table 4 (Cont.)

<table>
<thead>
<tr>
<th>THERMAL CONDUCTIVITY DATA FOR ARMCO IRON(2A) 12 MAR 69 1007 AM</th>
</tr>
</thead>
<tbody>
<tr>
<td>THERMAL CONDUCTIVITY</td>
</tr>
<tr>
<td>THERMOCOUPLE TEMPERATURES</td>
</tr>
<tr>
<td>HEATER POWER</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>THERMAL CONDUCTIVITY DATA FOR ARMCO IRON(2A) 25 MAR 69 1345 PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>THERMAL CONDUCTIVITY</td>
</tr>
<tr>
<td>THERMOCOUPLE TEMPERATURES</td>
</tr>
<tr>
<td>HEATER POWER</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>THERMAL CONDUCTIVITY DATA FOR ARMCO IRON(2A) 26 MAR 69 1200 NOON</th>
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<tbody>
<tr>
<td>THERMAL CONDUCTIVITY</td>
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<tr>
<td>THERMOCOUPLE TEMPERATURES</td>
</tr>
<tr>
<td>HEATER POWER</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>THERMAL CONDUCTIVITY DATA FOR ARMCO IRON(2A) 26 MAR 69 1705 PM</th>
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</thead>
<tbody>
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<td>THERMAL CONDUCTIVITY</td>
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<td>THERMOCOUPLE TEMPERATURES</td>
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<tr>
<td>HEATER POWER</td>
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<table>
<thead>
<tr>
<th>THERMAL CONDUCTIVITY DATA FOR ARMCO IRON(2A) 26 MAR 69 2200 PM</th>
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<td>THERMAL CONDUCTIVITY</td>
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Table 4 (Cont.)

<table>
<thead>
<tr>
<th>THERMAL CONDUCTIVITY DATA FOR ARMCO IRON(2A) 13 MAR 69 1215 PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>3485400  36.1700  119.35  649.0  23.0  1.0  2.0</td>
</tr>
<tr>
<td>121.95   179.47   233.65  285.60  334.52  382.52  429.04  474.74</td>
</tr>
<tr>
<td>35.68    200.00   28.20</td>
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<table>
<thead>
<tr>
<th>THERMOCOUPLE TEMPERATURES</th>
</tr>
</thead>
<tbody>
<tr>
<td>27.118  30.535  35.761  36.867  39.815  42.691  45.459  48.185</td>
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<table>
<thead>
<tr>
<th>HEATER POWER  REFERENCE TEMPERATURE  SPECIMEN RESISTANCE</th>
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<tbody>
<tr>
<td>1.2607-001  20.016  1.4100-004</td>
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<table>
<thead>
<tr>
<th>THERMAL CONDUCTIVITY DATA FOR ARMCO IRON(2A) 13 MAR 69 300 PM</th>
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<tbody>
<tr>
<td>5068460  52.5700  115.82  649.0  25.0  1.0  2.0</td>
</tr>
<tr>
<td>219.36   324.85   426.15  526.76  627.07  729.72  834.48  943.00</td>
</tr>
<tr>
<td>175.46   200.00   34.37</td>
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<table>
<thead>
<tr>
<th>THERMOCOUPLE TEMPERATURES</th>
</tr>
</thead>
<tbody>
<tr>
<td>33.034  39.367  45.427  51.371  57.226  63.110  69.019  75.068</td>
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<table>
<thead>
<tr>
<th>HEATER POWER  REFERENCE TEMPERATURE  SPECIMEN RESISTANCE</th>
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</thead>
<tbody>
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<td>2.6645-001  20.147  1.7105-004</td>
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<table>
<thead>
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<th>THERMAL CONDUCTIVITY DATA FOR ARMCO IRON(2A) 13 MAR 69 520 PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>5634400  58.4200  120.00  649.0  25.0  1.0  2.0</td>
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<tr>
<td>415.50   534.85   660.15  790.32  925.50  1066.90  1213.85  1367.52</td>
</tr>
<tr>
<td>368.80   200.00   44.98</td>
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<table>
<thead>
<tr>
<th>THERMOCOUPLE TEMPERATURES</th>
</tr>
</thead>
<tbody>
<tr>
<td>44.888  52.075  59.343  66.746  74.305  82.053  89.959  98.108</td>
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<table>
<thead>
<tr>
<th>HEATER POWER  REFERENCE TEMPERATURE  SPECIMEN RESISTANCE</th>
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</thead>
<tbody>
<tr>
<td>3.2916-001  20.364  2.2490-004</td>
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<table>
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<tr>
<th>THERMAL CONDUCTIVITY DATA FOR ARMCO IRON(2A) 7 MAR 69 500 PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>2404575  24.9400  4655.48  643.0  24.0  1.0  3.0</td>
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<tr>
<td>39.78    65.57    91.85   118.38  145.02  171.87  198.65  225.74</td>
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<tr>
<td>89.71    200.00   52.60</td>
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<table>
<thead>
<tr>
<th>THERMOCOUPLE TEMPERATURES</th>
</tr>
</thead>
<tbody>
<tr>
<td>78.236  79.648  81.081  82.521  83.965  85.414  86.858  88.310</td>
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<table>
<thead>
<tr>
<th>HEATER POWER  REFERENCE TEMPERATURE  SPECIMEN RESISTANCE</th>
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</thead>
<tbody>
<tr>
<td>5.9970-002  76.056  2.6800-004</td>
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Table 4 (Cont.)

<table>
<thead>
<tr>
<th>THERMAL CONDUCTIVITY DATA FOR ARMCO IRON(2A) 19 MAR 69 435PM</th>
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<tr>
<td>456750</td>
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<tr>
<td>11.55</td>
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<td>0.01</td>
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<tr>
<td>HEATER POWER</td>
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<tr>
<td>2.1658-003</td>
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<tr>
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</thead>
<tbody>
<tr>
<td>696128</td>
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<td>27.32</td>
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<tr>
<td>HEATER POWER</td>
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<tr>
<td>5.0330-003</td>
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<table>
<thead>
<tr>
<th>THERMAL CONDUCTIVITY DATA FOR ARMCO IRON(2A) 19 MAR 69 715 PM</th>
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</thead>
<tbody>
<tr>
<td>1151310</td>
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<tr>
<td>49.97</td>
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<tr>
<td>0.43</td>
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<tr>
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<tr>
<td>HEATER POWER</td>
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<tr>
<td>1.3770-002</td>
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<table>
<thead>
<tr>
<th>THERMAL CONDUCTIVITY DATA FOR ARMCO IRON(2A) 19 MAR 69 810 PM</th>
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</thead>
<tbody>
<tr>
<td>1908125</td>
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<tr>
<td>100.81</td>
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<tr>
<td>1.99</td>
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<td>THERMOCOUPLE TEMPERATURES</td>
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<td>HEATER POWER</td>
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<td>3.7819-002</td>
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Table 4 (Cont.)

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Thermal Conductivity Data for Armco Iron(2A)</th>
<th>Thermocouple Temperatures</th>
<th>Heater Power</th>
<th>Reference Temperature</th>
<th>Specimen Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 Mar 69</td>
<td>10:45 AM</td>
<td>2325375 24.1500 -0.00 673.0 24.0 -0.0 1.0</td>
<td>13.124 15.930 18.345 20.525 22.462 24.271 25.929 27.501</td>
<td>5.6158-002</td>
<td>4.083</td>
<td>1.3090-004</td>
</tr>
<tr>
<td></td>
<td>12 Noon</td>
<td>1263105 15.1210 -0.00 675.0 24.0 -0.0 1.0</td>
<td>15.983 16.725 17.436 18.139 18.796 19.438 20.043 20.627</td>
<td>1.6573-002</td>
<td>4.083</td>
<td>1.3025-004</td>
</tr>
<tr>
<td>THERMAL CONDUCTIVITY DATA FOR ARMCO IRON(2A) 27 MAR 69 445 PM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------------------------------------------</td>
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<td>--------</td>
<td>--------</td>
<td>------</td>
<td>--------</td>
<td></td>
</tr>
<tr>
<td>2896500 30.0000 17492.50 624.0 24.0 1.0</td>
<td>4.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>836.10 894.12 953.57 1012.84 1071.74 1130.78 1190.16 1250.63</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>263.21 100.00 137.56</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>THERMOCOUPLE TEMPERATURES</th>
</tr>
</thead>
<tbody>
<tr>
<td>235.947 256.585 259.285 241.973 244.641 247.312 249.995 252.724</td>
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<table>
<thead>
<tr>
<th>HEATER POWER REFERENCE TEMPERATURE SPECIMEN RESISTANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.6895-002 195.475 1.3756-003</td>
</tr>
</tbody>
</table>

| THERMAL CONDUCTIVITY DATA FOR ARMCO IRON(2A) 3 APR 69 430 PM |
|-----------------------------------------------|--------|--------|--------|------|--------|
| 2878800 29.8200 25486.20 620.0 23.0 1.0 | 5.0    |
| 60.32 121.19 182.76 244.43 306.20 368.06 430.24 492.86 |
| 245.31 100.00 175.34 |

<table>
<thead>
<tr>
<th>THERMOCOUPLE TEMPERATURES</th>
</tr>
</thead>
<tbody>
<tr>
<td>275.998 278.715 281.464 284.218 286.975 289.737 292.513 295.309</td>
</tr>
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<table>
<thead>
<tr>
<th>HEATER POWER REFERENCE TEMPERATURE SPECIMEN RESISTANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.5846-002 275.288 1.7534-003</td>
</tr>
</tbody>
</table>

| THERMAL CONDUCTIVITY DATA FOR ARMCO IRON(2A) 4 APR 69 920 AM |
|-----------------------------------------------|--------|--------|--------|------|--------|
| 2896200 30.0000 25510.00 628.0 23.0 1.0 | 5.0    |
| 60.90 122.44 184.73 247.11 309.60 372.20 435.15 498.55 |
| 247.90 100.00 173.69 |

<table>
<thead>
<tr>
<th>THERMOCOUPLE TEMPERATURES</th>
</tr>
</thead>
<tbody>
<tr>
<td>276.257 279.005 281.786 284.571 287.361 290.156 292.966 295.797</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HEATER POWER REFERENCE TEMPERATURE SPECIMEN RESISTANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.6886-002 275.523 1.7569-003</td>
</tr>
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Table 5. Basic semi-processed isothermal electrical resistivity data for Armco iron, specimen 2a.

<table>
<thead>
<tr>
<th>Isothermal Resistivity Data for Armco Iron (2A)</th>
<th>19 Mar 69 230 PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference Temperature</td>
<td>Specimen Resistance</td>
</tr>
<tr>
<td>4.071</td>
<td>1.2915-004</td>
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<table>
<thead>
<tr>
<th>Isothermal Resistivity Data for Armco Iron (2A)</th>
<th>12 Mar 69 445 PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference Temperature</td>
<td>Specimen Resistance</td>
</tr>
<tr>
<td>19.813</td>
<td>1.3050-004</td>
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<table>
<thead>
<tr>
<th>Isothermal Resistivity Data for Armco Iron (2A)</th>
<th>7 Mar 69 125 PM</th>
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</thead>
<tbody>
<tr>
<td>Reference Temperature</td>
<td>Specimen Resistance</td>
</tr>
<tr>
<td>75.931</td>
<td>2.3580-004</td>
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<table>
<thead>
<tr>
<th>Isothermal Resistivity Data for Armco Iron (2A)</th>
<th>8 Mar 69 1020 AM</th>
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<tbody>
<tr>
<td>Reference Temperature</td>
<td>Specimen Resistance</td>
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<tr>
<td>76.485</td>
<td>2.7220-004</td>
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<table>
<thead>
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<th>11 Mar 69 1055 AM</th>
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<tbody>
<tr>
<td>Reference Temperature</td>
<td>Specimen Resistance</td>
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<tr>
<td>77.907</td>
<td>5.4940-004</td>
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<table>
<thead>
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<th>Isothermal Resistivity Data for Armco Iron (2A)</th>
<th>25 Mar 69 730 PM</th>
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<tbody>
<tr>
<td>Reference Temperature</td>
<td>Specimen Resistance</td>
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<tr>
<td>192.734</td>
<td>9.8005-004</td>
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<table>
<thead>
<tr>
<th>Isothermal Resistivity Data for Armco Iron (2A)</th>
<th>2 April 69 415 PM</th>
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<tbody>
<tr>
<td>Reference Temperature</td>
<td>Specimen Resistance</td>
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<tr>
<td>275.206</td>
<td>1.6250-003</td>
</tr>
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</table>
Table 6. Basic semi-processed temperature gradient data for Armco iron, specimen 4.

<table>
<thead>
<tr>
<th>Time</th>
<th>THERMAL CONDUCTIVITY DATA FOR ARMCO IRON</th>
<th>TEMPERATURES</th>
<th>HEATER POWER</th>
<th>REFERENCE TEMPERATURE</th>
<th>SPECIMEN RESISTANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1140AM</td>
<td>1922030 19 9400 4653 41 644.0 22.0 1.0 3.0</td>
<td>78.525 79.454 80.357 81.276 82.202 83.120 84.052 84.986</td>
<td>3.8325-002</td>
<td>76.037</td>
<td>2.6360-004</td>
</tr>
<tr>
<td>540PM</td>
<td>3369920 34.950 0 4657.94 656.0 23.0 1.0 3.0</td>
<td>85.882 88.762 91.707 94.665 97.655 100.657 103.692 106.759</td>
<td>1.1778-001</td>
<td>76.078</td>
<td>3.5730-004</td>
</tr>
<tr>
<td>1130AM</td>
<td>5301325 54.950 0 4652.75 636.0 21.0 1.0 3.0</td>
<td>101.934 109.460 117.232 125.095 133.085 141.150 149.336 157.630</td>
<td>2.9131-001</td>
<td>76.395</td>
<td>5.4095-004</td>
</tr>
<tr>
<td>915AM</td>
<td>7259100 75.000 0 4792.45 653.0 23.0 1.0 3.0</td>
<td>152.379 167.752 183.675 199.786 216.138 232.694 249.537 266.661</td>
<td>5.4293-001</td>
<td>77.302</td>
<td>1.1159-003</td>
</tr>
<tr>
<td>THERMAL CONDUCTIVITY DATA FOR ARMCO IRON(4)</td>
<td>13 DEC 68</td>
<td>835PM</td>
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<tr>
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<tr>
<td>7294.00</td>
<td>75.100</td>
<td>4807.35</td>
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<tr>
<td>2475.63</td>
<td>2824.80</td>
<td>3191.90</td>
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<tr>
<td>1597.60</td>
<td>200.00</td>
<td>305.46</td>
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<table>
<thead>
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<tr>
<td>200.283</td>
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<td>250.132</td>
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<td>520.650</td>
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<table>
<thead>
<tr>
<th>THERMAL CONDUCTIVITY DATA FOR ARMCO IRON(4)</th>
<th>19 DEC 68</th>
<th>500PM</th>
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<tr>
<td>4114.970</td>
<td>42.6300</td>
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<td>227.50</td>
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<td>534.88</td>
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<td>241.62</td>
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<table>
<thead>
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</thead>
<tbody>
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<td>203.059</td>
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<td>218.768</td>
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<tr>
<td>234.810</td>
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<td>1.2081-003</td>
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<table>
<thead>
<tr>
<th>THERMAL CONDUCTIVITY DATA FOR ARMCO IRON(4)</th>
<th>20 DEC 68</th>
<th>1025AM</th>
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<tbody>
<tr>
<td>6274.050</td>
<td>65.0000</td>
<td>1729.90</td>
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<td>105.08</td>
<td>1279.67</td>
<td>1565.42</td>
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<td>1.7451-003</td>
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<table>
<thead>
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<th>THERMOCOUPLE TEMPERATURES</th>
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</thead>
<tbody>
<tr>
<td>239.225</td>
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<tr>
<td>278.073</td>
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<tr>
<td>318.060</td>
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<td>1.7441-003</td>
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<thead>
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<th>THERMAL CONDUCTIVITY DATA FOR ARMCO IRON(4)</th>
<th>20 DEC 68</th>
<th>340PM</th>
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</thead>
<tbody>
<tr>
<td>5075.600</td>
<td>52.5800</td>
<td>1729.00</td>
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<td>630.10</td>
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<th>THERMOCOUPLE TEMPERATURES</th>
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<tr>
<td>222.654</td>
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<tr>
<td>247.070</td>
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<tr>
<td>272.191</td>
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<td>1.4515-003</td>
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Table 6 (Cont.)

<table>
<thead>
<tr>
<th>THERMAL CONDUCTIVITY DATA FOR ARMCO IRON(4) 16 DEC 68 1135 AM</th>
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<tbody>
<tr>
<td>404476  4.2000  -0.00  653.0  23.0  -0.0  1.0</td>
</tr>
<tr>
<td>17.57  20.46  23.52  26.60  29.29  32.21  35.13  37.71</td>
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<tr>
<td>60.03  200.00  26.06</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>THERMOCOUPLE TEMPERATURES</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.313  5.541  5.760  5.972  6.179  6.379  6.572  6.766</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HEATER POWER  REFERENCE TEMPERATURE  SPECIMEN RESISTANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.6988-003  4.053  1.3030-004</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>THERMAL CONDUCTIVITY DATA FOR ARMCO IRON(4) 16 DEC 68 1225PM</th>
</tr>
</thead>
<tbody>
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<td>5.2713-003  4.054  1.3045-004</td>
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<td>200.92  230.19  257.34  282.63  306.01  328.25  349.51  369.68</td>
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<td>201.11  230.50  257.74  283.13  306.70  328.90  350.22  370.46</td>
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<td>146.98  164.66  181.48  197.47  212.33  226.66  240.45  253.44</td>
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<td>HEATER POWER REFERENCE TEMPERATURE SPECIMEN RESISTANCE</td>
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<td>Thermal Conductivity Data for Armco Iron(4) 17Dec68 455PM</td>
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<td>Thermal Conductivity Data for Armco Iron(4) 18Dec68 1150AM</td>
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<td>282.46    200.00 48.55</td>
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<td>Thermocouple Temperatures</td>
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Table 7. Basic semi-processed isothermal electrical resistivity data for Armco iron, specimen 4.

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<th>Temperature 2</th>
<th>Temperature 3</th>
<th>Temperature 4</th>
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### Table 7 (Cont.)

**Isothermal Resistivity Data for ARMCO Iron**

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**Isothermal Resistivity Data for ARMCO Iron**

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<th>Specimen Temperature</th>
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**Isothermal Resistivity Data for ARMCO Iron**

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**Isothermal Resistivity Data for ARMCO Iron**

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**Isothermal Resistivity Data for ARMCO Iron**

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**Isothermal Resistivity Data for ARMCO Iron**

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**Isothermal Resistivity Data for ARMCO Iron**

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**Isothermal Resistivity Data for ARMCO Iron**

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Table 8. Parameters in eqs. 1, 2, and 3 for Armco iron, specimen 2.

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<th>THERMOPOWER</th>
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Table 9. Parameters in eqs. 1, 2, and 3 for Armco iron, specimen 2a.

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<th>ELECTRICAL RESISTIVITY</th>
<th>THERMOPOWER</th>
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<td>1.30552541×10^4</td>
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<td>-7.35622503×10^-10</td>
<td>-1.63749922×10^1</td>
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<tr>
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<td></td>
<td>2.47951058×10^-11</td>
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Table 10. Parameters in eqs. 1, 2, and 3 for Armco iron, specimen 4.

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<tr>
<th>COEFFICIENTS FOR</th>
<th>THERMAL CONDUCTIVITY</th>
<th>ELECTRICAL RESISTIVITY</th>
<th>THERMOPOWER</th>
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<td>-6.42942844×10^2</td>
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<tr>
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<td>1.69059561×10^-6</td>
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<tr>
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<td>-2.42733181×10^-6</td>
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<tr>
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<td>-6.21776147×10^-9</td>
<td>1.98402296×10^-6</td>
<td>1.54381788×10^4</td>
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<td>-1.01722378×10^-6</td>
<td>-1.2733650×10^4</td>
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<tr>
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<td>6.34295244×10^3</td>
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<tr>
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<td>7.10720281×10^-9</td>
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<tr>
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These parameters are listed in E format. This format is illustrated by the following example: 1.788-004 = 1.788 × 10^-4
Table 11  Thermal conductivity deviations for Armco iron, specimen 2.

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<th>MEAN TEMPERATURE</th>
<th>TEMPERATURE DIFFERENCE</th>
<th>OBSERVED CONDUCTIVITY</th>
<th>CALCULATED CONDUCTIVITY</th>
<th>THERMAL CONDUCTIVITY DEVIATION</th>
</tr>
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<td>94.026</td>
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<td>9.55E+001</td>
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<th>MEAN TEMPERATURE</th>
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<th>CALCULATED CONDUCTIVITY</th>
<th>THERMAL CONDUCTIVITY DEVIATION</th>
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<td>8.64E+001</td>
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<tr>
<td>161.479</td>
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<td>8.49E+001</td>
<td>8.46E+001</td>
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<tr>
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<td>13.572</td>
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<table>
<thead>
<tr>
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<th>CALCULATED CONDUCTIVITY</th>
<th>THERMAL CONDUCTIVITY DEVIATION</th>
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<tr>
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<td>Temperature Difference</td>
<td>Observed Conductivity</td>
<td>Calculated Conductivity</td>
<td>Percent Deviation</td>
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<th>Percent Deviation</th>
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<table>
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<th>Observed Conductivity</th>
<th>Calculated Conductivity</th>
<th>Percent Deviation</th>
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</thead>
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Table 11 (Cont.)

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<td>CALCULATED CONDUCTIVITY</td>
<td>PERCENT DEVIATION</td>
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<th>PERCENT DEVIATION</th>
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Table 12  Electrical resistivity deviations for Armco iron, specimen 2.

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Table 14  Thermal conductivity deviations for Armco iron, specimen 2a.

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Table 14 (Cont.)

**Thermal Conductivity Data for Armco Iron(2A) 19 Mar 69 810 PM**

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**Thermal Conductivity Data for Armco Iron(2A) 20 Mar 69 1045 AM**

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**Thermal Conductivity Data for Armco Iron(2A) 20 Mar 69 1200 Noon**

<table>
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<th>Temperature</th>
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<th>Observed Thermal Conductivity</th>
<th>Calculated Thermal Conductivity</th>
<th>Percent Deviation</th>
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<td>16.353</td>
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<td>0.0</td>
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<tr>
<td>17.080</td>
<td>0.715</td>
<td>5.58+001</td>
<td>5.64+001</td>
<td>-1.1</td>
</tr>
<tr>
<td>17.789</td>
<td>0.701</td>
<td>5.70+001</td>
<td>5.87+001</td>
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<td>18.468</td>
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<td>6.09+001</td>
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<td>19.117</td>
<td>0.641</td>
<td>6.24+001</td>
<td>6.29+001</td>
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<td>6.48+001</td>
<td>1.9</td>
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45
## Table 14 (Cont.)

### Thermal Conductivity Data for Armco Iron (12A) 26 Mar 69 1200 Noon

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<th>Calculated Thermal Conductivity</th>
<th>Percent Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>212.561</td>
<td>6.947</td>
<td>8.060+001</td>
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</tr>
<tr>
<td>219.559</td>
<td>7.049</td>
<td>7.920+001</td>
<td>7.990+001</td>
<td>-0.8</td>
</tr>
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<td>226.623</td>
<td>7.078</td>
<td>7.900+001</td>
<td>7.930+001</td>
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<td>233.717</td>
<td>7.111</td>
<td>7.850+0.1</td>
<td>7.870+001</td>
<td>-0.3</td>
</tr>
<tr>
<td>240.846</td>
<td>7.146</td>
<td>7.830+001</td>
<td>7.810+001</td>
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<tr>
<td>248.015</td>
<td>7.192</td>
<td>7.780+001</td>
<td>7.760+001</td>
<td>0.3</td>
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<tr>
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### Thermal Conductivity Data for Armco Iron (12A) 26 Mar 69 715 PM

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<th>Observed Thermal Conductivity</th>
<th>Calculated Thermal Conductivity</th>
<th>Percent Deviation</th>
</tr>
</thead>
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<tr>
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<tr>
<td>231.706</td>
<td>13.240</td>
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<td>7.890+001</td>
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<tr>
<td>245.013</td>
<td>13.375</td>
<td>7.760+001</td>
<td>7.780+001</td>
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</tr>
<tr>
<td>258.456</td>
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<td>7.670+001</td>
<td>7.670+001</td>
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</tr>
<tr>
<td>272.039</td>
<td>13.653</td>
<td>7.610+001</td>
<td>7.580+001</td>
<td>0.4</td>
</tr>
<tr>
<td>285.779</td>
<td>13.829</td>
<td>7.510+001</td>
<td>7.500+001</td>
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</tr>
<tr>
<td>299.737</td>
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### Thermal Conductivity Data for Armco Iron (12A) 27 Mar 69 445 PM

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<th>Observed Thermal Conductivity</th>
<th>Calculated Thermal Conductivity</th>
<th>Percent Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>235.266</td>
<td>2.658</td>
<td>7.950+001</td>
<td>7.860+001</td>
<td>1.2</td>
</tr>
<tr>
<td>237.935</td>
<td>2.700</td>
<td>7.750+001</td>
<td>7.840+001</td>
<td>-1.1</td>
</tr>
<tr>
<td>240.629</td>
<td>2.688</td>
<td>7.800+001</td>
<td>7.820+001</td>
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<tr>
<td>243.307</td>
<td>2.668</td>
<td>7.840+001</td>
<td>7.790+001</td>
<td>0.6</td>
</tr>
<tr>
<td>245.976</td>
<td>2.671</td>
<td>7.850+001</td>
<td>7.770+001</td>
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</tr>
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<td>248.654</td>
<td>2.683</td>
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<td>7.750+001</td>
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<tr>
<td>251.360</td>
<td>2.729</td>
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<td>7.730+001</td>
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Table 14 (Cont.)

**THERMAL CONDUCTIVITY DATA FOR ARMCO IRON(2A) 3 APRIL 69 430 PM**

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<th>Observed Conductivity</th>
<th>Calculated Conductivity</th>
<th>Percent Deviation</th>
</tr>
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<tbody>
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<td>277.356</td>
<td>2.718</td>
<td>7.63×001</td>
<td>7.55×001</td>
<td>1.1</td>
</tr>
<tr>
<td>280.090</td>
<td>2.749</td>
<td>7.52×001</td>
<td>7.53×001</td>
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</tr>
<tr>
<td>282.841</td>
<td>2.753</td>
<td>7.52×001</td>
<td>7.51×001</td>
<td>0.1</td>
</tr>
<tr>
<td>285.596</td>
<td>2.750</td>
<td>7.50×001</td>
<td>7.50×001</td>
<td>-0.1</td>
</tr>
<tr>
<td>288.356</td>
<td>2.762</td>
<td>7.50×001</td>
<td>7.49×001</td>
<td>0.2</td>
</tr>
<tr>
<td>291.125</td>
<td>2.776</td>
<td>7.46×001</td>
<td>7.48×001</td>
<td>-0.2</td>
</tr>
<tr>
<td>293.911</td>
<td>2.796</td>
<td>7.42×001</td>
<td>7.46×001</td>
<td>-0.6</td>
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**THERMAL CONDUCTIVITY DATA FOR ARMCO IRON(2A) 4 APRIL 69 920 AM**

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<th>Observed Conductivity</th>
<th>Calculated Conductivity</th>
<th>Percent Deviation</th>
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<tbody>
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<td>285.966</td>
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Table 15  Electrical resistivity deviations for Armco iron, specimen 2a.

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<th>MEAN TEMPERATURE</th>
<th>TEMPERATURE RANGE</th>
<th>OBSERVED RESISTANCE</th>
<th>CALCULATED RESISTANCE</th>
<th>PERCENT DEVIATION</th>
<th>INTRINSIC RESISTANCE</th>
</tr>
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<tr>
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<td>1.293-004</td>
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<td>1.557-007</td>
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<tr>
<td>11.158</td>
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<td>1.295-004</td>
<td>1.296-004</td>
<td>-0.05</td>
<td>3.557-007</td>
</tr>
<tr>
<td>17.293</td>
<td>11.624</td>
<td>1.301-004</td>
<td>1.301-004</td>
<td>0.03</td>
<td>1.006-006</td>
</tr>
<tr>
<td>18.412</td>
<td>4.644</td>
<td>1.302-004</td>
<td>1.302-004</td>
<td>0.07</td>
<td>1.106-006</td>
</tr>
<tr>
<td>25.634</td>
<td>4.770</td>
<td>1.314-004</td>
<td>1.315-004</td>
<td>-0.07</td>
<td>2.256-006</td>
</tr>
<tr>
<td>27.699</td>
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<td>3.756-006</td>
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<td>1.719-004</td>
<td>1.716-004</td>
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<td>70.853</td>
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<td>2.682-004</td>
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</tr>
<tr>
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<td>4.793-004</td>
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<td>3.502-004</td>
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<tr>
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<td>1.508-003</td>
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<td>1.379-003</td>
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<td>1.574-003</td>
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Table 16  Thermovoltage deviations for Armco iron, specimen 2a.

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<tr>
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</tr>
<tr>
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<td>1.84</td>
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<td>4.21</td>
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<td>89.65</td>
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Table 17  Thermal conductivity deviations for Armco iron, specimen 4.

<table>
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<th>Observed Thermal Conductivity</th>
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<th>Percent Deviation</th>
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<th>Observed Thermal Conductivity (W/m·K)</th>
<th>Calculated Thermal Conductivity (W/m·K)</th>
<th>Percent Deviation</th>
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<table>
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<tr>
<th>Mean Temperature (°C)</th>
<th>Temperature Difference (°C)</th>
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<th>Calculated Thermal Conductivity (W/m·K)</th>
<th>Percent Deviation</th>
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### Table 17 (Cont.)

**Thermal Conductivity Data for Armco Iron(4)** 16 Dec 68 1135 AM

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<th>Percent Deviation</th>
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**Thermal Conductivity Data for Armco Iron(4)** 16 Dec 68 1225 PM

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**Thermal Conductivity Data for Armco Iron(4)** 16 Dec 68 1500 PM

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### Table 17 (Cont.)

#### Thermal Conductivity Data for Armco Iron (4) 16 Dec 68 505PM

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#### Thermal Conductivity Data for Armco Iron (4) 16 Dec 68 540PM

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#### Thermal Conductivity Data for Armco Iron (4) 16 Dec 68 600PM

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<td>5.76 x 10^1</td>
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### Table 17 (Cont.)

**Thermal Conductivity Data for Armco Iron (4) 16 Dec 68 6:35 PM**

<table>
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<th>Observed Conductivity</th>
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<tbody>
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<td>4.63×10^1</td>
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<tr>
<td>15.096</td>
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<td>4.95×10^1</td>
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<tr>
<td>16.051</td>
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<tr>
<td>16.951</td>
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<tr>
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<tr>
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**Thermal Conductivity Data for Armco Iron (4) 17 Dec 68 11:00 AM**

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**Thermal Conductivity Data for Armco Iron (4) 17 Dec 68 11:55 PM**

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<td>------------------</td>
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<td>----------------------</td>
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<th>Thermal Conductivity</th>
<th>Percent Deviation</th>
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### Table 17 (Cont.)

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<th>Percent Deviation</th>
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<th>Observed Thermal Conductivity</th>
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<th>Percent Deviation</th>
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Table 18  Electrical resistivity deviations for Armco iron, specimen 4.

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<th>PERCENT DEVIATION</th>
<th>INTRINSIC RESISTANCE</th>
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Table 19  Thermovoltage deviations for Armco iron, specimen 4.

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Table 20  Transport properties of Armco iron, specimen 2.

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Figure 1. Division of Armco iron rod. Each of the 12 pieces shown was machined into a circular cylinder for measurement.
Figure 2. Thermal conductivity deviations for Armco iron, specimen 2.
Figure 3. Electrical resistivity deviations for Armco iron, specimen 2.
Figure 4. Thermovoltage deviations for Armco iron, specimen 2.
Figure 5. Thermal conductivity deviations for Armco iron, specimen 2a.
Figure 6. Electrical resistivity deviations for Armco iron, specimen 2a.
Figure 7.  Thermovoltage deviations for Armco iron, specimen 2a.
Figure 8. Thermal conductivity deviations for Armco iron, specimen 4.
Figure 9. Electrical resistivity deviations for Armco iron, specimen 4.
Figure 10. Thermovoltage deviations for Armco iron, specimen 4.
Figure 11a. Thermal conductivity of Armco iron, specimen 2.
Figure 11b. Electrical resistivity of Armco iron, specimen 2.
Figure 11c. Lorenz ratio of Armco iron, specimen 2.
Figure 11d. Thermopower of Armco iron, specimen 2.
Figure 12a. Thermal conductivity of Armco iron, specimen 2a.
Figure 12b. Electrical resistivity of Armco iron, specimen 2a.
Figure 12c. Lorenz ratio of Armco iron, specimen 2a.
Figure 12d. Thermopower of Armco iron, specimen 2a.
Figure 13a. Thermal conductivity of Armco iron, specimen 4.
Figure 13b. Electrical resistivity of Armco iron, specimen 4.
Figure 13c. Lorenz ratio of Armco iron, specimen 4.
Figure 13d. Thermopower of Armco iron, specimen 4.
Figure 14. Deviations of the thermal conductivities of each specimen from the mean values.
Figure 15. Deviations of the Lorenz ratios of each specimen from the mean values.
Deviations of the computed intrinsic electrical resistivities from the mean values for the three specimens.

Figure 16.
Figure 17. Deviations of the thermopowers from the mean values for three specimens of Armco iron.
8. Appendix

A complete documentation of experimental and numerical procedures was intended to be given in a previous report (Hust, et al.[1]) so that future manipulations with the experimental data could be performed if necessary. Some useful information, overlooked in the preparation of that report, is included here.

The calibration table for the Chromel vs $\text{Au-Fe (Au-0.07 at.\% Fe)}$ thermocouples is given in table I. The derivation of this table is explained in reference [1].

To compute the reference ring temperature from the experimental data one needs the calibration of the platinum resistance thermometer. Table II is the calibration table for the PRT used in this apparatus and designated LN-1037903.

To reanalyze any of the reported data one must have the actual thermocouple positions (nominally 2.54 cm apart) and the diameter of the specimen. Table II contains these data for the previously reported specimens as well as for Armco iron.

As reported by Hust, et al.[1] zero emfs were read for each thermocouple to eliminate, as much as possible, the effect of spurious emfs in the potentiometric circuitry. These zero emfs differ for each cryogenic bath and are listed in table IV.
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<td>250</td>
<td>23.11543</td>
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Table III. Thermocouple positions and specimen diameter

**Al-7039**

<table>
<thead>
<tr>
<th>Thermocouple positions (inches from floating sink)</th>
<th>Specimen diameter (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.87540, 1.87550, 2.87560, 3.87540, 4.87570, 5.87560, 6.87560, 7.87580</td>
<td>0.14499</td>
</tr>
</tbody>
</table>

**Be**

<table>
<thead>
<tr>
<th>Thermocouple positions (inches from floating sink)</th>
<th>Specimen diameter (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.86375, 1.86380, 2.86300, 3.86365, 4.86420, 5.86385, 6.86360, 7.86265</td>
<td>0.14421</td>
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</tbody>
</table>

**Hastelloy-X**

<table>
<thead>
<tr>
<th>Thermocouple positions (inches from floating sink)</th>
<th>Specimen diameter (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.87640, 1.87630, 2.87650, 3.87640, 4.87650, 5.87640, 6.87640, 7.87620</td>
<td>0.44432</td>
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</table>

**Ti A-110 AT**

<table>
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<th>Thermocouple positions (inches from floating sink)</th>
<th>Specimen diameter (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.87570, 1.87570, 2.87580, 3.87630, 4.87620, 5.87610, 6.87610, 7.87630</td>
<td>0.44425</td>
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</table>

**Inconel 718**

<table>
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<tr>
<th>Thermocouple positions (inches from floating sink)</th>
<th>Specimen diameter (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.87580, 1.87580, 2.87680, 3.87590, 4.87710, 5.87710, 6.87740, 7.87740</td>
<td>0.44380</td>
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**PO-3 graphite**

<table>
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<th>Thermocouple positions (inches from floating sink)</th>
<th>Specimen diameter (inches)</th>
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<tbody>
<tr>
<td>0.87500, 1.87500, 2.87500, 3.87500, 4.87500, 5.87500, 6.87500, 7.87500</td>
<td>0.42400</td>
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**Armco iron (2c)**

<table>
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<th>Thermocouple positions (inches from floating sink)</th>
<th>Specimen diameters (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.87520, 1.87560, 2.87580, 3.87620, 4.87490, 5.87550, 6.87540, 7.87560</td>
<td>0.14412, 0.14427, 0.14420, 0.14418, 0.14415, 0.14413, 0.14405</td>
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**Armco iron (4c)**

<table>
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<th>Thermocouple positions (inches from floating sink)</th>
<th>Specimen diameters (inches)</th>
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</thead>
<tbody>
<tr>
<td>0.87720, 1.87700, 2.87740, 3.87750, 4.87690, 5.87770, 6.87780, 7.87760</td>
<td>0.14397, 0.14393, 0.14378, 0.14368, 0.14365, 0.14368, 0.14372</td>
</tr>
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</table>

*These diameters are average values between successive thermocouples starting with the end nearest the floating sink.*

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Table IV. Zero emfs of specimen temperature measuring thermocouples
(Thermocouple number 1 is nearest the floating sink)

<table>
<thead>
<tr>
<th>Cryogenic bath</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>liquid helium</td>
<td>1.22</td>
<td>1.01</td>
<td>1.05</td>
<td>1.17</td>
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<td>1.01</td>
<td>1.15</td>
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<td>liquid hydrogen</td>
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<td>0.19</td>
<td>0.25</td>
<td>0.35</td>
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<td>liquid nitrogen</td>
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<td>0.09</td>
<td>0.12</td>
<td>0.11</td>
<td>0.14</td>
<td>0.10</td>
<td>0.13</td>
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<tr>
<td>alcohol and CO₂</td>
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<td>0.12</td>
<td>0.08</td>
<td>0.09</td>
<td>0.12</td>
<td>0.12</td>
<td>0.09</td>
<td>0.14</td>
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<tr>
<td>ice and water</td>
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<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
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</tr>
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</table>
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