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## Thermal Conductivities of No. 430 Stainless Steel and 2S Aluminum Specimens

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NBS

**U. S. DEPARTMENT OF COMMERCE**
**NATIONAL BUREAU OF STANDARDS**

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## I. INTRODUCTION

Two specimens, designated as Stainless Steel (No. 430) and Aluminum (2S), were submitted for calibration measurements of thermal conductivity by the Atomic Energy Commission, Richland, Washington, in connection with a project undertaken by the General Electric Company.

Both specimens had a diameter of 2.54 cm.

## II. PREPARATION OF THE SPECIMENS

The general arrangement of the test apparatus is shown in Figure 1.

The upper end of each specimen was drilled to provide a well for circulation of the coolant and the lower end was drilled to accommodate the heater. The internal heating element was made by passing nichrome wire through multiple-hole porcelain tubing. Chromel-alumel thermocouples were attached at intervals of about 4 cm. along the length of the bar. One thermocouple was attached to the lower end of the specimen. The completed specimen was supported on a thin nichrome pin located in the bottom of a thick-walled stainless steel guard cylinder. The guard cylinder was also equipped with thermocouples and a heater element, and at the top with a copper coil through which the coolant was circulated. The specimen-guard assembly was suspended in a large sheet-metal container and the entire system insulated with a fine granular insulation.

## III. TEST METHOD

Electrical energy was supplied to the heater elements and adjusted so that a minimum temperature difference between bar and guard existed at the thermocouples just above the heaters. Cooling water at constant temperature was pumped through the well in the specimen and through the coil on the guard cylinder. When steady temperature conditions had been attained, the emfs of the thermocouples (reference junctions at 0C) and the current through and voltage drop across the bar heater were measured by means of standard resistors and a precision potentiometer. Temperature conditions were considered satisfactorily steady when no thermocouple on the bar changed temperature at a rate greater than 0.3 degree C per hour; several readings taken over a period of three or more hours were averaged for each test. Thermocouple readings were subsequently converted to degrees Centigrade, using data determined by a calibration of the thermocouple wire.

To calculate the thermal conductivity, observed temperatures of the bar and guard were plotted versus position along the bar as abscissae and smooth curves were drawn through the points along the bar and along the guard. Corrections to the measured heat input to the bar to account for heat interchange between the bar and guard were made on the basis of the temperature differences between them determined from the curves and using the conductivity of the granular insulation at the appropriate mean temperature. The corrections were made for the heat interchange (a) between the lower end of the bar and the guard cylinder, (b) between the bar and guard at the heater region, and (c) between bar and guard for each thermocouple span. The average rate of heat flow between any two thermocouples on the bar was thus computed and used, together with the measured distance and temperature difference between them, and the cross-sectional area of the specimen, to calculate the average thermal conductivity for that span. In the case of the aluminum specimen, the calculated heat exchange between bar and guard below the first span was less than 0.8 percent (heat gained by bar) and for all six spans was less than 0.3 percent of the electrical heat input to the bar. For the stainless steel specimen, these exchanges were, respectively, less than 5 percent and 4 percent of the heat input. It is believed that corrections to account for these exchanges were evaluated with an uncertainty of not more than

## III. TEST METHOD

Electrical energy was supplied to the heater elements and adjusted to give a suitable temperature difference between bar and guard measured at the thermocouple just above the heaters. Cooling water at constant temperature was pumped through the well in the specimen and through the well in the guard cylinder. When steady temperature conditions had been attained, the emf of the thermocouples (reference junctions at 0°C) and the current through and voltage drop across the bar heater were measured by means of standard resistors and a precision potentiometer. Temperature conditions were considered sufficiently steady when no thermocouple on the bar changed temperature at a rate greater than 0.1 degree F per hour; several readings taken over a period of three or more hours were averaged for each test. Thermocouple readings were subsequently converted to degrees Fahrenheit, using data determined by a calibration of the thermocouple wire.

To calculate the thermal conductivity, observed temperatures of the bar and guard were plotted versus position along the bar and smooth curves were drawn through the points along the bar and along the guard. Corrections to the measured heat input to the bar to account for heat interchange between the bar and guard were made on the basis of the temperature difference between them obtained from the curves and using the conductivity of the granular insulation at the appropriate mean temperature. The corrections were made for the heat interchange (a) between the lower end of the bar and the guard cylinder, (b) between the bar and guard at the heater region, and (c) between bar and guard for each thermocouple zone. The average rate of heat flow between any two thermocouples on the bar was thus computed, which, together with the measured distance and temperature difference between them, and the cross-sectional area of the specimen, was used to calculate the average thermal conductivity for that zone. In the case of the aluminum specimen, the calculated heat interchange between bar and guard below the first zone was less than 0.8 percent ([illegible]) and for all the zones was less than 0.3 percent of the electrical heat input to the bar. For the stainless steel specimen, these percentages were, respectively, less than 3 percent and 4 percent of the total input. It is believed that corrections to account for these exchanges were evaluated with an uncertainty of not more than

20 percent, consequently, the uncertainty in the rates of heat flow used in computing the thermal conductivities was of the order of not more than 0.2 percent for the aluminum and 2 percent for the stainless steel.

For each of the separate tests, the thermal conductivity was computed for each of the six 4-cm. thermocouple spans on the bar, corresponding to the mean temperature existing in each span.

## IV. TEST RESULTS

The values of thermal conductivity obtained for each test span were plotted against their corresponding mean temperatures for each of the two specimens.

The results of the measurements on the stainless steel specimen are shown in Figure 2, and are represented by a smooth curve faired through the plotted values.

In the case of the aluminum specimen (Fig. 3), the data appeared to be best represented by two straight lines of different slope, intersecting at a mean temperature of about 220° C. The lines were determined by the method of least squares, using all of the points falling within their respective mean temperature ranges. Because of faulty readings of the thermocouple between the third and fourth spans in the tests of the aluminum specimen, these two spans were treated as one span 8 cm. in length, and only five conductivity values were obtained in each test.

Table 1 lists thermal conductivity values for each specimen for various mean temperatures, as taken from the curves.

## V. DISCUSSION OF RESULTS

The plotted points show some scatter from the curves faired through them. Such scatter is an inverse measure of the precision of the measurements, as affected by such factors as small random inaccuracies in determining the thermocouple locations on the bar, slight heat conduction along the thermocouple wires near the hot junctions, and possible slight inhomogenieties in the thermocouple wires. The latter two possible factors would be of chief importance

20 percent, consequently, the uncertainty in the amount of heat flow used in computing the thermal conductivity was of the order of not more than 1.2 percent for the alumina and 2 percent for the stainless steel.

For each of the specimens tested, the thermal conductivity was computed for each of the six local thermocouple spans on the bar, corresponding to the mean temperature existing in each span.

## IV. TEST RESULTS

The values of thermal conductivity obtained for each test span were plotted against their corresponding mean temperature for each of the two specimens.

The results of the measurements on the stainless steel specimen are shown in Figure 2, and are represented by a smooth curve faired through the plotted values.

In the case of the alumina specimen (Fig. 3), the data appeared to be best represented by two straight lines of different slope, intersecting at a mean temperature of about 300° C. The lines were determined by the method of least squares, using all of the points falling within their respective mean temperature ranges. Because of faulty readings of the thermocouple between the third and fourth spans in the case of the alumina specimen, these two spans were treated as one span 4 cm. in length, and only five conductivity values were obtained in each test.

Table I lists thermal conductivity values for both specimens for various mean temperatures as taken from the curves.

## V. DISCUSSION OF RESULTS

The plotted points show some scatter from the curves (about 1 percent). Some scatter is to be expected because of the limitations of the measurements, as affected by such factors as small random uncertainties in determining the thermocouple locations on the bar, slight heat conduction along the thermocouple wires near the hot junctions, and possible slight inhomogeneities in the thermocouple wire. The latter two possible factors would be of minor importance in the case of the aluminum specimen, in which temperature differences between adjacent thermocouples were relatively small because of its high thermal conductivity. To minimize heat conduction effects, small thermocouple wires (No. 26 A.W.G.) were used and were led away from the hot junction for a few centimeters in the plane of its cross section, in which the temperature should be fairly uniform. However, since the temperature gradients along the bar ranged from 4 to 24 degrees C per centimeter in the several tests, some conduction effect on individual thermocouple readings probably could not be avoided.

Since the factors involved in inaccuracies in measurements of thermocouple positions and temperatures were random in nature, their effect was probably to decrease the precision of the values obtained for each span rather than to affect the overall results in any one direction.

in the case of the [illegible], in which frequency differences between adjacent [illegible] were relatively small compared to [illegible]. To summarize [illegible], small [illegible] (D, 2D [illegible]) were [illegible] than the [illegible] in the [illegible] of the [illegible], in which the [illegible]. However, [illegible] the [illegible] from [illegible] in the [illegible] [illegible].

[illegible]

Table 1.

| Mean temperature °C | Thermal conductivity, watt/cm (deg C) No. 430 Stainless steel | No. 2S Aluminum |
|---|---|---|
| 75 | 0.249 | 2.18 |
| 100 | .251 | 2.19 |
| 150 | .255 | 2.22 |
| 200 | .259 | 2.24 |
| 250 | .261 | 2.24 |
| 300 | .264 | 2.21 |
| 350 | .266 | 2.19 |
| 400 | .267 | 2.17 |
| 450 | .268 | --- |
| 500 | .269 | --- |
| 550 | .270 | --- |
| 600 | .271 | --- |
| 650 | .272 | --- |

# APPARATUS FOR MEASURING THE THERMAL CONDUCTIVITY OF METALS

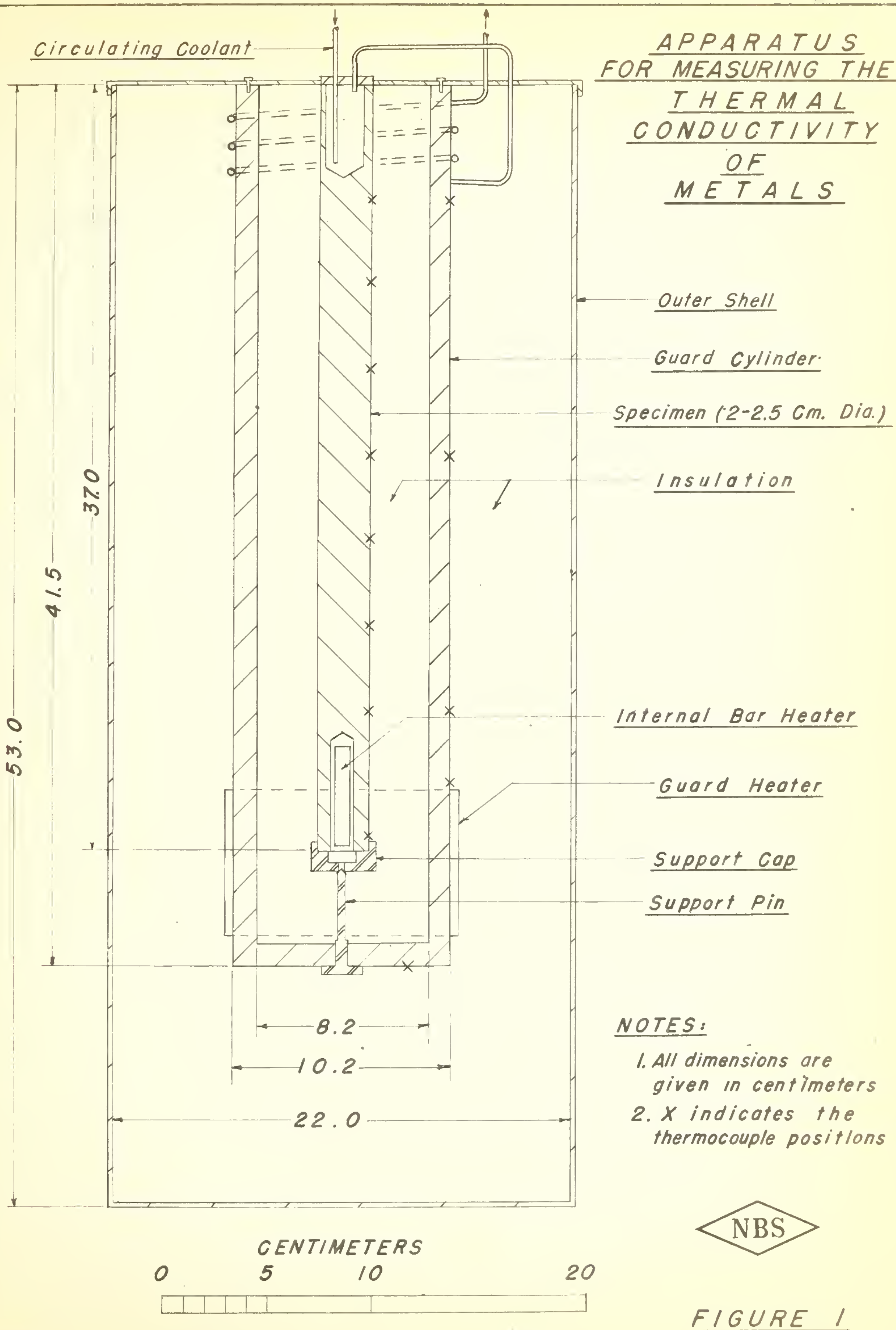
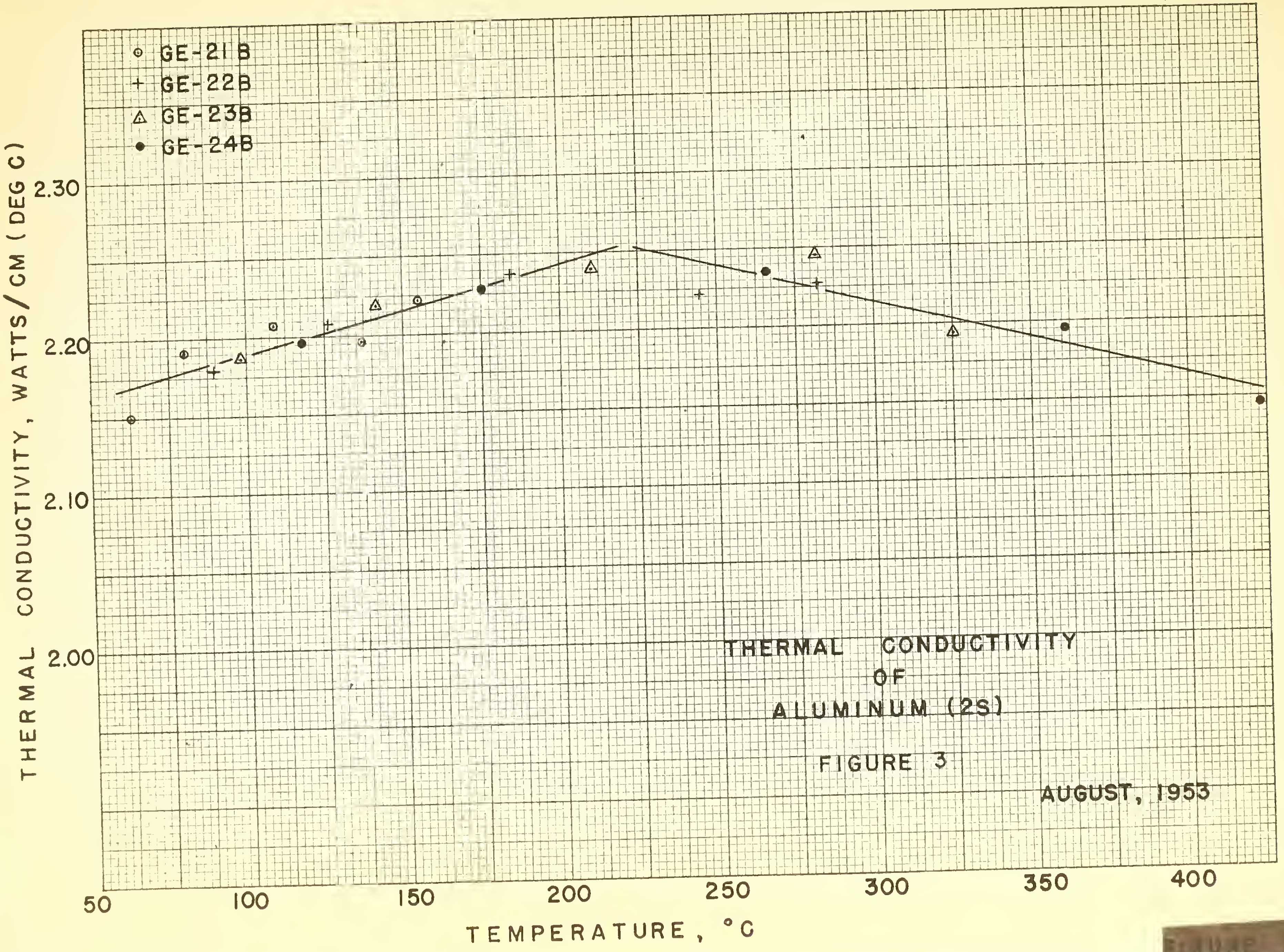



FIGURE 1

February 27, 1953


GE-21 B
GE-22 B
GE-23 B
GE-24 B
2.30
2.20
2.10
2.00
THERMAL CONDUCTIVITY, WATTS/CM (DEG C)
50
100
150
200
250
300
350
400
TEMPERATURE, °C
THERMAL CONDUCTIVITY
OF
ALUMINUM (2S)
FIGURE 3
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