The Thermal Conductivity, Electrical Resistivity, and
Seebeck Coefficient of SRM-735*

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The scarcity of recognized thermal conductivity standards has been a problem in the development of thermal conductivity techniques for many years. This scarcity is an acute problem since many standards are required to cover wide thermal conductivity ranges. The National Bureau of Standards now supplies an austenitic stainless steel to fill one thermal conductivity range, but the standard values are actually based on few data. We have recently tested two apparatus using this standard and the results are supportive of the calibration values stated by the NBS.

One apparatus was developed for measuring the thermal conductivity, λ , electrical resistivity, ρ , and Seebeck coefficient, S , over the temperature range from 300 to 1000 K. The specimen was 78 mm long and had a diameter of 10 mm, and Pt vs Pt + 10 at. % Rh thermocouples were used for all temperature measurements. Total determinate errors were $\pm 0.4\%$, $\pm 2.2\%$, and $\pm 0.3 \mu\text{V/K}$ for ρ , λ and S , respectively. This apparatus, which is designated as the HTL, has been described in detail elsewhere.¹ The apparatus has been used for λ measurements on materials of basic² and applied³⁻⁵ importance.

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The low temperature apparatus (HA) uses Chromel versus Constantan thermocouples for all temperature measurements above 20 K, but the apparatus has a lower temperature limit of 2.6 K using carbon resistance thermometers. The specimen was 69 mm long and had a diameter of 12 mm. The total determinate error for λ measurements was $\pm 6\%$ at 10 K and $\pm 3.5\%$ at 300 K. This apparatus was located in the Kernforschungszentrum, Karlsruhe, West Germany.*

Results

Electrical Resistivity

The electrical resistivity, ρ , values from the HTL and those from the NBS are compared in Fig. 1 which shows the deviations of data about the smooth curve

$$\rho = (154.1 T^{0.0997} - 191.0) \times 10^{-4} \text{ } (\Omega\text{-m}) \quad (1)$$

which was obtained from the NBS calibration data.⁶ The HTL value near room temperature was 0.8% below the line, but this is within the 2% uncertainty claimed by the NBS.⁶ The ρ results are about 1.2% below the above equation and the data from the AGARD-NATO project. The present ρ results join smoothly with the low temperature results from the NBS.

Several measurements of ρ at 295 K were made using a knife-edge apparatus that is accurate to within $\pm 0.1\%$. These measurements indicated that ρ at 295 K is uniform to within $\pm 0.01\%$ of $80.13 \times 10^{-4} \text{ } \Omega\text{-m}$.

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Thermal Conductivity

The percentage differences between the present λ results and the calibration values from the NBS are shown in Fig. 2, and the dashed lines indicate the percentage uncertainty claimed by the NBS⁶ for the standard. The maximum deviation of the HTL results is -3.2% at 470 K, and this is well within the uncertainty of the calibration values. The thermal conductivity results from the helium apparatus are also within the uncertainty band of the standard for $T > 60$ K. The agreement of the HA is not as good below 60 K, however, because of the combination of low thermocouple output and poor sensitivity of the digital voltmeter. This increased error at the low temperatures led to the use of carbon resistance thermometers, CRT, in the HA, but no measurements were made on the standard using the CRTs.

The present results have been plotted in Fig. 3 (see Fig. 4 of reference 1) for comparison with the numerous data used to define the thermal conductivity of the standard. The HA results are in good agreement with the low temperature values from reference 6. The high temperature results possibly indicate that some of the AGARD-NATO results are too high from 300 to 500 K.

Figure 4 shows the thermal conductivity of SRM 735 versus temperature on a log-log scale. The NBS gives the equation

$$\lambda = 1.22 T^{0.432} \text{ (W/mK)} \quad (2)$$

for temperatures above 200 K,⁶ and this equation is represented by a straight line which has been extrapolated below 200 K. The positive deviation of λ from 70 to 200 K is probably due to a peak in the lattice

component of the thermal conductivity. Since the total thermal conductivity can be written as

$$\lambda = \lambda_e + \lambda_l = \frac{L_0 T}{\rho} + \lambda_l$$

where λ_e and λ_l are the electronic and lattice components of the thermal conductivity, respectively, and L_0 is the Sommerfeld value of the Lorenz function ($2.443 \times 10^{-6} \text{ V}^2/\text{K}^2$), both electronic and lattice components of λ can be calculated. The values for λ_e and λ_l shown in Fig. 4 indicate that the high temperature λ is dominated by λ_e and that the positive deviation of λ from the above equation from 70 to 140 K is probably caused by a broad maximum in λ_l .

Seebeck Coefficient

Seebeck coefficient data were obtained from the HTL, but the temperature range does not overlap the S results stated for the standard. The results from the HTL and the low temperature values from the NBS⁶ join smoothly, however, and S can be described from 10 to 973 K to within $\pm 0.05 \text{ } \mu\text{V/K}$ by

$$S = -\frac{358.4}{T^2} + \frac{46.24}{T} - 0.8768 - 4.297 \times 10^{-3} T + 3.057 \times 10^{-6} T^2 \quad (3)$$

where T is in degrees Kelvin and S is in $\mu\text{V/K}$.

Summary

1. Two apparatus have been tested using an austenitic stainless steel thermal conductivity standard (SRM-735) from the National Bureau of Standards.⁶ The ρ test results from the HTL were within $\pm 1.6\%$ of the calibration curve from the NBS and this is within the $\pm 2\%$ accuracy claimed by the NBS.

The ρ results from the HTL are in better agreement with the low temperature ρ values from the NBS. The maximum deviation of any thermal conductivity value from the NBS values was -3.2% at 470 K.

2. Since the HTL has been used successfully on so many materials including an ad hoc thermal conductivity standard,¹ the good agreement of the NBS calibration results and the present HTL results is supportive of the standard values above 300 K. The same statement cannot be made with regard to the HA results, but, at the very least, they do not disagree with the NBS values.

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Figure 1

FIGURE 1: Deviations of electrical resistivity data for SRM 798 from E_4

Figure 3

FIGURE 3: Deviations of Thermal Conductivity Data for SRM 735 from E_{β}^2

Temperature (K)

Figure
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