

FIG. 2.  $K$  versus  $T$  for Si showing the experimental points and the extrapolated lattice component  $K_g$ . The Debye and melting temperatures are  $\theta$  and MP, respectively.

net carrier concentration was  $2 \times 10^{12}/\text{cm}^3$ . The crystal was so lightly doped that it could not be well characterized as either  $n$ - or  $p$ -type. After the  $K$  had been measured to near the melting point, the electrical resistivity dropped to  $4.6 \Omega\text{-cm}$  and the crystal was now doped with  $8 \times 10^{15}$  acceptors/ $\text{cm}^3$ . These acceptors were identified as copper. The copper was probably introduced during the machining of the germanium sample prior to the measurements.

The room-temperature resistivity of the high-temperature silicon sample was  $440 \Omega\text{-cm}$  with a carrier concentration of  $1.27 \times 10^{13}/\text{cm}^3$  and it was  $n$  type. After the  $K$  had been measured to near the melting point of silicon, the room-temperature resistivity dropped to  $177 \Omega\text{-cm}$ , the carrier concentration rose to  $2.46 \times 10^{13}$ , and it was still  $n$  type. The specific impurities could not be identified. The important conclusion from these measurements is that neither the germanium nor silicon contained enough electrically active impurities to affect the intrinsic polar or bipolar thermal conductivity in any way.

#### APPARATUS

The low-temperature measurements were made with a steady-state, longitudinal heat flow apparatus designed by Slack.<sup>1</sup> The final form of the high-temperature, cylindrical-flow thermal conductivity apparatus was obtained after several modifications. Figure 1 shows the details of the sample in the final version of the high-temperature apparatus. A more detailed description of the entire method and apparatus will be published elsewhere later. The central section of the apparatus is shown in Fig. 1. The vacuum plumbing was designed

so that the sample chamber could be evacuated to  $10^{-6}$  Torr and then filled with ultra-pure helium. The outer ceramic tube serves as the wall of the vacuum chamber for the sample. The external, 3-section electric heater is wound on this tube, and serves to control the average temperature of the sample. The split inner tube holds the sample and all of the removable parts, i.e., thermocouples, heaters, shields, etc., in place.

The cylindrical geometry for measuring the high-temperature thermal conductivity was chosen for reasons previously stated.<sup>6</sup> In the present, more thorough measurements, certain experimental problems arose which will now be given a cursory examination. Ultra-pure helium gas was used for the atmosphere, because it contained a low oxygen content,<sup>7</sup> and thus there were no oxidation problems at high temperatures. The gas served to provide good thermal contact between the sample and the heater and thermocouple wires. The gas also partially helped to suppress the vapor transport of Si and Ge, which would be appreciable at high temperatures in a vacuum. The molybdenum jacket which encased the germanium and silicon reduced the exposed surface area of the samples and hence further reduced the evaporation. This case also held the halves together. Molybdenum was employed for the jacket, axial heater wire, voltage leads, and heater leads because of its previously mentioned chemical stability. The temperature gradients were measured with platinum versus platinum-10% rhodium because these thermocouples are very stable with time and possess well-

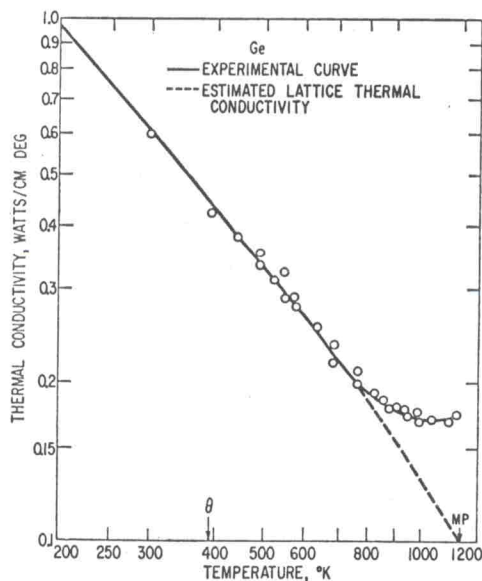


FIG. 3.  $K$  versus  $T$  for Ge showing the experimental points and the extrapolated lattice component  $K_g$ . The Debye and melting temperatures are  $\theta$  and MP, respectively.

<sup>6</sup> G. A. Slack and C. J. Glassbrenner, Phys. Rev. 120, 782 (1960).

<sup>7</sup> J. R. Young and N. R. Whetten, Rev. Sci. Instr. 32 453 (1961).