Thermal conductivity of UBe_{13} single crystals in the normal and superconducting states

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The temperature dependence of the thermal conductivity K of the compound UBe_{13} has been found experimentally over the temperature interval 0.3–4.2 K. The dependence in the superconducting region is $K = \alpha T^2$. The behavior $K(T)$ in the normal and superconducting states is discussed.

The properties of compounds with "heavy fermions" have recently been the subject of active research and discussion. One well-known example is UBe_{13}, whose properties are rather complex and frequently contradictory (Ref. 1, for example). Further experiments would clearly be useful for identifying the factors which determine the particular behavior of this compound. In this letter we report a study of the thermal conductivity of the UBe_{13} single crystal over the temperature interval from 0.3 to 4.2 K.

The test sample has a cross section of 1.7×1.95 mm^2 and a length of 9 mm. It was cut by an electrical-erosion technique along the [001] direction from a single crystal grown by melting in an rf oven in a beryllium oxide crucible. The thermal conductivity is measured at temperatures above 1 K in a stainless-steel cell 25 mm in diameter and 45 mm long. The cell can be evacuated and, if necessary, filled with helium. One end of the sample is cemented to the lower cap of the cell, and a heater is placed at the other end. The temperature gradient in the sample is determined by a Cu–Cu(0.01% Fe)–Cu differential thermocouple. The junctions of the thermocouple, ~0.1 mm in size, are cemented to the central part of the sample, at a distance of 4.6 mm from each other.

The measurements below 1.24 K are carried out in an adiabatic-demagnetization apparatus. The working medium is 100% erbium-aluminum garnet.[2] The temperature gradient is determined by two thermometers, cemented 4 mm apart[1)] (the dimensions

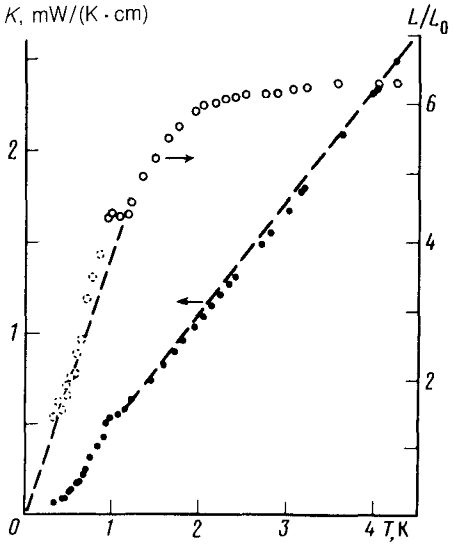

FIG. 1. Temperature dependence of the thermal conductivity K and the reduced Lorentz number L/L_0 (open circles) of a UBe_{13} crystal along the [001] direction. $L_0 = 2.45 \times 10^{-8}$ W · Ω/K². The values of L below T_c were obtained by a linear extrapolation of the resistivity $\rho(T)$ to low temperatures.

of the thermometers are no greater than 1 mm). The duration of the heating of the garnet after the adiabatic demagnetization is about 4 h.

Figure 1 shows the results of the measurements of the thermal conductivity $K(T)$ over the temperature interval from 0.3 to 4.2 K. Also shown here is the temperature dependence of the Lorentz number L, found from the Wiedemann-Franz law $\rho K = LT$. Figure 2 shows the results of the measurements of $K(T)$ at low temperatures in the coordinates $K^{1/2}$, T. It can be seen from this figure that in the superconducting region the values of the thermal conductivity for UBe_{13} can be described well by $K = \alpha T^2$, where $\alpha = 0.53$ mW/(K³ · cm). An inspection of the behavior $K(T)$ at temperatures between 1.4 and 4.2 K quickly reveals that the values found for the

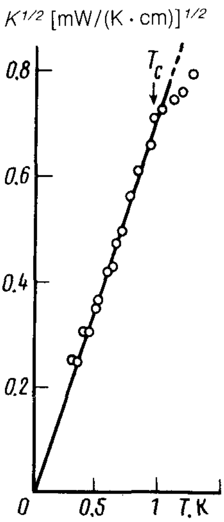

FIG. 2. Thermal conductivity of a UBe_{13} crystal along the [001] direction in the superconducting state. The solid line is an extrapolation of the experimental data in accordance with $K = \alpha T^2$ [$\alpha = 0.53$ mW/(K³ · cm)].

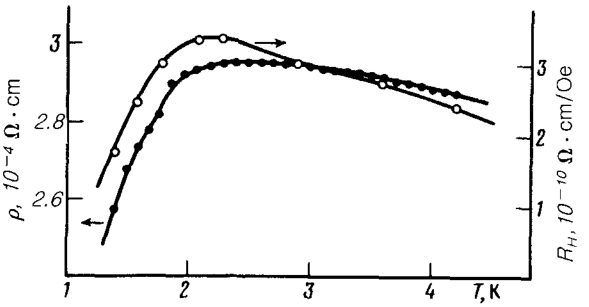

FIG. 3. Temperature dependence of the resistivity ρ and the Hall constant R_H in weak fields ($H \leqslant 10$ kOe) for a UBe_{13} single crystal.

thermal conductivity can be approximated by two straight-line segments which intersect at $T \approx 2.5$ K.

The change in slope of the $K(T)$ dependence at $T \approx 2.5$ K is naturally interpreted as a consequence of the existence of a maximum in the electrical resistance and the Hall constant (Fig. 3). The deviation of the experimental data from the line which would connect the values of K at 1.4 and 4.2 K is $\sim 5\%$ and thus agrees well with the small ($\sim 10\%$) change in the electrical resistance in this temperature interval. On the other hand, the change in the Hall constant in the same temperature interval reaches 50%. It can thus be suggested that carriers other than "light" carriers are contributing to the thermal conductivity. This contribution, probably of electronic origin, is due to a group of "heavy" carriers. We can apparently ignore the participation of phonons in the heat transfer at $T < 4.2$ K, since the contribution of phonons to the heat capacity in this temperature interval should be less than 2%, according to the data of Ref. 3.

Particularly interesting is the quadratic dependence of the thermal conductivity on the temperature at $T < T_c$, which may be interpreted as a manifestation of an "exotic" superconductivity, discussed theoretically in Ref. 4. As follows from Ref. 4, the behavior $K = \alpha T^2$ should prevail if the superconducting gap at the Fermi surface vanishes along lines. It should be noted that for UPt_3, another "heavy-fermion" superconductor,[5] the $K(T)$ dependence in the superconducting region ($T < 0.4$ K) is also approximately quadratic.

We have just learned of measurements of the thermal conductivity of UBe_{13} carried out by a research team from Grenoble using a sample with a cross-sectional area of 0.63 mm^2 and a length of 1.5 mm (Ref. 6). Their results on $K(T)$ in the superconducting region can also be described well by a quadratic curve, but with the slightly smaller coefficient $\alpha = 0.38$ mW/(K$^3 \cdot$ cm).

We wish to thank J. F. Flouquet for furnishing the results of the measurements of the thermal conductivity of UBe_{13} which were published in Ref. 6. We also thank V. I. Nizhankovskiĭ for a discussion.

[1)]The power supplied to the thermometers did not exceed 10^{-12} W, so that the small thermal resistance between the sample and the thermometers had no significant effect on the results of the measurements.

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