Magnetic properties of UBe_{13} in its superconducting state

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The magnetization has been measured as a function of the magnetic field, $M(H)$, for a UBe_{13} single crystal at $T < T_c$. The results are used to determine the thermodynamic field H_c (0.1 K) = 920 Oe, the Ginzburg-Landau parameter $\kappa = 60$, and the penetration depth $\lambda = 3.6 \times 10^{-5}$ cm. Estimates show that several properties of UBe_{13} can be described quite satisfactorily in terms of an ordinary superconductivity if UBe_{13} is assumed to have two groups of current carriers that interact with each other: "heavy" and "light" carriers.

The compound UBe_{13} is known to exhibit an exceedingly high electron specific heat, C_p (1 K) $\sim \gamma T \approx 1$ J/(mole · K), and a jump of comparable magnitude in the specific heat, ΔC, when this compound goes superconducting.[1] Furthermore, below T_c the dependence $C_p(T)$ is not the exponential dependence predicted by the Bardeen-Cooper-Schrieffer theory. The anomalously high electron specific heat is consistent with the extremely large values[2,3] $|\partial H_{c2}/\partial T|_{T_c} > 200$ kOe/K.

In this letter we report a study of the magnetization of UBe_{13} at $T < T_c$ and a comparison of the results with existing data on other "heavy-fermion" superconductors, such as $CeCu_2Si_2$ (Ref. 4) and UPt_3 (Ref. 5).

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For the measurements of $M(H)$ we use a UBe_{13} single crystal consisting of a parallelepiped with dimensions of $2\times2\times15$ mm, cut along the C_4 axis. An x-ray diffraction analysis of the sample reveals no secondary phases of any sort. We use two methods to measure $M(H)$. In the first method, the magnetic induction of the sample is measured as a function of the magnetic field, and the magnetization is found from the resulting $B(H)$ curves. To measure $B(H)$, we use two miniature bismuth magnetic-field pickups, positioned on mutually perpendicular faces of the sample. A temperature below 1 K is reached by adiabatic demagnetization of erbium-yttrium-aluminum garnet. The apparatus is similar to that described in Ref. 6, used previously to determine the dependence $H_{c2}(T)$ in UBe_{13} (Ref. 2).

Figure 1 shows the measurements of the difference (ΔH) between the values of the magnetic field at the pickups as a function of the applied external field for two temperatures, 0.1 and 0.3 K. Since ΔH is proportional to the magnetization M, we can estimate[1)] the thermodynamic field H_c and the Ginzburg-Landau parameter κ from the results. As T is raised from 0.1 to 0.3 K, $H_c(T)$ decreases from 920 ± 50 to 680 ± 50 Oe, while the parameter $\kappa = 60 \pm 5$ remains constant within the measurement errors. The same method was used for control measurements of $M(H)$ with a niobium parallelepiped of identical dimensions. In this case we found $H_c(4.2\ \text{K}) = 2.8$ kOe and $\kappa = 3$, in fair agreement with published data.

In the second method, we determined $M(H)$ from the signal representing the difference between two compensated coils, in one of which we placed a cell holding the sample, cooled to a low temperature. The coils themselves were placed in a Dewar filled with liquid helium and connected to a microwebermeter. The difference signal was fed to a chart recorder as the external magnetic field, parallel to the axis of the sample, was varied (a similar method was used in Ref. 7).

Figure 2 shows a family of $M(H)$ curves found by the second method.

To calibrate the difference signal from the coils, we use tin and lead samples of similar dimensions. At weak fields the slope of the $M(H)$ curves for UBe_{13} is found from a comparison with the corresponding data for niobium (in the first method) and for tin and lead (in the second) to be about half that which would be expected in the case of an ideal diamagnet. We may thus conclude that the UBe_{13} sample contains a

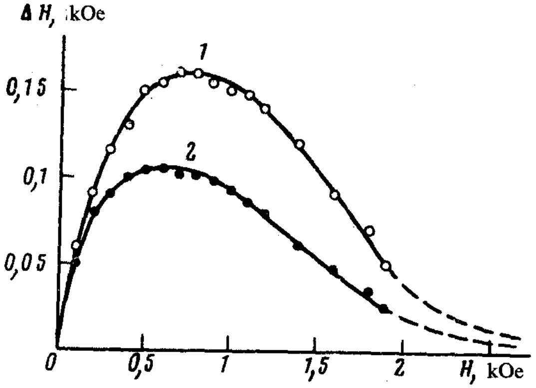

FIG. 1. The difference (ΔH) between the magnetic fields at two mutually perpendicular faces of a UBe_{13} single crystal versus the applied magnetic field at two temperatures. ○—0.1 K; ●—0.3 K.

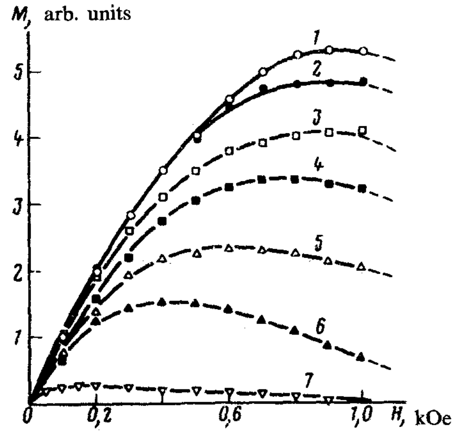

FIG. 2. Family of curves $M(H)$ of the magnetization versus the applied magnetic field H for a UBe_{13} single crystal at several temperatures. ○—0.31 K; ●—0.36; □—0.39; ■—0.57; △—0.70; ▲—0.80; ▽—0.94.

superconducting phase amounting to at least 50% of the sample by volume. Approximately the same content of a superconducting phase was found in studies of $M(H)$ of $CeCu_2Si_2$ (Ref. 4) and UPt_3 (Ref. 5) samples.

When we use the values given above for H_c and κ to estimate the magnetic-field penetration depth λ for UBe_{13} from the expression $\lambda = (\Phi_0\kappa/2\sqrt{2}\pi H_c)^{1/2}$, we find, at $T = 0.1$ K, $\lambda = 3.6\times 10^{-5}$ cm. This value is 2–2.5 times as high as that for[4] $CeCu_2Si_2$ and essentially the same as λ for[5] UPt_3. It should be noted that the values of λ for "heavy-fermion" superconductors with $m^* > 100m_e$ differ only slightly from the typical values of λ for ordinary superconductors. For example, for WBe_{13}, for which we have values $\gamma = 10^{-3}$ J/(mole · K^2), nearly 1000 times lower than for UBe_{13}, and a derivative $|\partial H_{c2}/\partial T|_{T_c} = 570$ Oe/K^2, the penetration depth $\lambda = 2.1\times 10^{-5}$ cm determined from H_c and κ differs by a factor of less than two. The relatively small values found for λ for these three heavy-fermion superconductors may indicate that the screening of the field is caused to a significant extent by "light" carriers with $m^* \approx m_e$. On the other hand, several unusual properties of heavy-fermion superconductors, which cannot be explained in terms of light carriers alone, may be caused by an interaction of heavy and light carriers, e.g., s-f hybridization.

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[1)] In the determination of the magnetic field configuration near the sample we used equipotentials found in an electrolytic bath.

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