Unusual properties of UBe_{13}

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The temperature dependence of the resistance of UBe_{13} samples has been studied. Neutron bombardment and doping with iron suppress the superconductivity and have a slight effect on $\rho(T)$ at $T > 30$ K. A study of H_{c2} in UBe_{13} single crystals shows that near T_c there is no anisotropy of H_{c2}; this anisotropy arises only when the temperature is lowered. The absence of an anisotropy of H_{c2} near T_c can be attributed to an anisotropic distribution of impurities and defects.

The unusual properties of the compound UBe_{13} have been reported elsewhere.[1,2] It has exceedingly high values of the electronic specific heat, $\gamma \approx 1$ J/(mole · K^2), and of the derivative of the second critical field with respect to the temperature, $\partial H_{c2}/\partial T \approx 250$ kOe/K; the Hall voltage behaves anomalously in strong magnetic fields; and there are several other distinctive features. All these facts indicate that the nature of the superconductivity in the compound UBe_{13} is not trivial; for example, it may result from a pairing of electrons in a p state.[1] It is quite possible, however, that other hypotheses could be advanced to explain these unusual properties.[2]

In this letter we report a study of the anisotropy of $H_{c2}(T)$ and of the magnetoresistance $\rho(H)$ of UBe_{13} single crystals. We also report data on the changes in the temperature dependence of the resistivity, $\rho(T)$, of polycrystalline UBe_{13} samples after bombardment with thermal neutrons, hydrogenation (annealing in hydrogen), and doping with small amounts of iron.

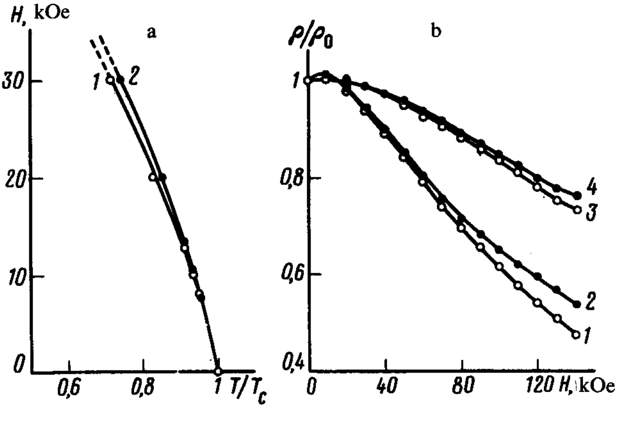

FIG. 1. a: Second critical field versus the temperature for a UBe_{13} single crystal for two orientations of the magnetic-field vector with respect to the crystallographic axes. 1—$H\|C_2$; 2—$H\|C_4$. b: Anisotropy of the magnetoresistance, $\rho(H)/\rho_0$, of a UBe_{13} single crystal at two temperatures. 1, 2—1.9 K; 3, 4—4.2 K. (Even curve labels) $H\|C_4$; (odd labels) $H\|C_2$.

Figure 1a shows the temperature dependence $H_{c2}(T)$ for two orientations of the magnetic-field vector with respect to the axes of the single crystal: $H\|C_2$ (curve 1) and $H\|C_4$ (curve 2). In each case, the current is directed perpendicular to the magnetic field, along the C_2 axis of the sample. The dimensions of the sample are $1\times1\times5$ mm. The values of $H_{c2}(T)$ are found from the central points of the superconducting transition in $\rho(T)$. We see from Fig. 1a that near T_c there is no anisotropy in H_{c2} for a given sample; the anisotropy becomes significant only at $T<0.9T_c$, reaching $\sim 7\%$ at $T=0.75T_c$. This behavior of the anisotropy $H_{c2}(T)$ is also typical of the "heavy-fermion" superconductor $CeCu_2Si_2$, which has been studied previously.[1] We have studied $H_{c2}(T)$ for six samples cut along both the C_2 axis and the C_4 axis. We find that the critical temperature (at $H=0$) of all the samples cut along the C_4 axis averages 0.05 K lower, while the derivative $\partial H_{c2}/\partial T$ is 1.4 times higher. This difference in the values of T_c and $\partial H_{c2}/\partial T$ may be due to an anisotropic distribution of impurities and defects, for which the probability to localize along planes perpendicular to C_2 is comparatively high, as can be seen from photographs of sections of the single crystals studied.

We do not rule out the possibility that an anisotropic distribution of impurities may also be responsible[3] for the absence of a significant anisotropy of H_{c2} near T_c. According to Ref. 4, there should be such an anisotropy for systems with a nontrivial pairing.

A study of the single crystals above T_c in strong magnetic fields has shown that the anisotropy of the magnetoresistance $\rho(H)$ is relatively slight in these crystals. Figure 1b shows the results on $\rho(H)/\rho_0$ for the orientations $H\|C_2$ and $H\|C_4$ for two temperatures: 1.9 K (curves 1 and 2) and 4.2 K (curves 3 and 4). The curves with even labels correspond to the orientation $H\|C_4$, and those with odd labels correspond to $H\|C_2$. We see from Fig. 1 that in a 75-kOe field the anisotropy of $\rho(H)$ does not exceed 2%; this figure is an order of magnitude lower than that in the case of a heavy-fermion system such as $CeCu_6$ (Ref. 5).

The pronounced decrease in the resistivity of the UBe_{13} single crystals with increasing field agrees quantitatively with the values found previously for $\rho(H)$ for polycrystalline samples.[2] Preliminary measurements showed that the derivative $\partial\rho/\partial H$

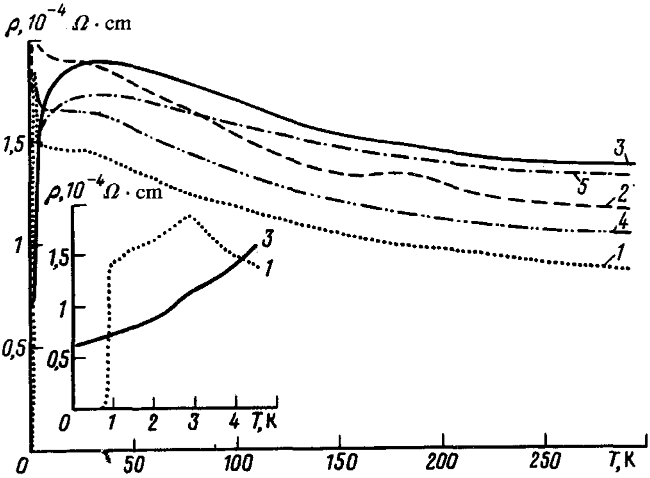

FIG. 2. Temperature dependence of the resistivity of polycrystalline samples. 1—Initial sample; 2—after annealing in hydrogen; 3—after neutron bombardment; 4—$UBe_{13}Fe_{0.02}$; 5—$UBe_{13}Fe_{0.05}$. The inset shows $\rho(T)$ at $T<5$ K for the original sample (curve 1) and for a bombarded sample (curve 3).

remains negative at fields up to 210 kOe, where (at $T = 1.7$ K) the ratio $\rho(H)/\rho_0$ becomes equal to 0.17.

For some more-detailed studies of the effect of defects and impurities on the properties of UBe_{13}, we used some polycrystalline samples.

Figure 2 shows the temperature dependence of the resistivity, $\rho(T)$, for several samples: 1) the original UBe_{13}; 2) a sample which has been annealed for 2 h in hydrogen at 700 °C and a pressure of 1 bar; 3) a sample which has been bombarded by thermal neutrons ($\Phi = 8.6\times10^{17}$ n/cm^2); 4) $UBe_{13}Fe_{0.02}$; 5) $UBe_{13}Fe_{0.05}$. The inset shows $\rho(T)$ in the temperature interval 0.1–4.2 K for the initial sample (curve 1) and for the bombarded sample. A comparison of the curves in Fig. 2 shows that the temperature dependence $\rho(T)$ of the hydrogenated sample (curve 2) and of the weakly doped $UBe_{13}Fe_{0.02}$ (curve 4) is essentially the same as that of the initial sample. All the samples go superconducting, but at different values of T_c.

As the iron content is increased (curve 5) and also after bombardment (curve 3), the superconducting transition is suppressed, and $\rho(T)$ does not vanish at any point down to 0.1 K. At temperatures > 100 K, there is no substantial change in the dependence $\rho(T)$. At low temperatures (i.e., at $T < 50$ K), the curves of $\rho(T)$ for the superconducting samples are different from those for the nonsuperconducting samples. The bombardment reduces the magnetic susceptibility by no more than 20%. It should be noted that curve 3 (for example) is extremely similar to the curve of $\rho(T)$ for the heavy-fermion nonsuperconducting system[1] $CeAl_3$ and can be essentially brought into coincidence with the latter by simply changing the ordinate scale.

It may be that the superconductivity in the compound UBe_{13} is due in large part to an interaction of "light" and "heavy" current carriers. If the bombardment or doping causes a disruption of the interaction between two groups of carriers by virtue of a reduction of their mean free path l and an intensification of localization, superconductivity may disappear as a result.1) It should be noted that the disappearance of superconductivity in $UBe_{12.94}Cu_{0.06}$ is accompanied by no significant change in γ in comparison with that of UBe_{13} (Ref. 6).

Another possibility[3] is that the spacing (d) of the uranium atoms may be important for the onset of superconductivity in UBe_{13}. Meisner *et al.*[7] have studied the correlation between d and the superconducting and magnetic characteristics of compounds with actinides are rare earths. We do not rule out the possibility that by varying d and l (by hydrostatic compression, for example) we could cause a nonsuperconducting heavy-fermion compound with anomalous magnetic properties to go superconducting.

In conclusion we should point out that the results that have been obtained do not rule out the possibility that the superconductivity in the compound UBe_{13} is of a nontrivial nature. It may be that the polarization of light carriers, which results from their interaction with heavy $5f$ electrons, promotes pairing in a triplet state which is extremely sensitive to defects and impurities in the system.

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[1)] A partial decomposition of the compound UBe_{13} may also result in the suppression of superconductivity during bombardment and doping.

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