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THE UPPER CRITICAL FIELD OF SUPERCONDUCTING UPt_3 ALLOYED WITH BORON.

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Measurements of $H_{c2}(T)$, on two very pure samples of hexagonal $UPt_3B_{0.11}$, are presented for H//a, H//b and H//c. A "kink" in $H_{c2}(T)$ is observed for both basal plane directions. The values of dH_{c2}/dT are comparable with those of pure UPt_3.

1. INTRODUCTION

Heavy fermion superconductors attract a lot of interest because the superconducting order parameter in these compounds might be non-scalar, leading to the possible existence of more than one superconducting phase. In particular for UPt_3 there is growing evidence for a multi-component phase diagram. Specific heat measurements in zero field of UPt_3 (1) reveal two anomalies separated by 60 mK, suggesting that there are two nearly degenerate superconducting states. The upper critical field of UPt_3 shows large anisotropy when the field direction is rotated from the basal plane to the hexagonal axis (c-axis), and a change of slope is seen for a field direction in the basal plane (2-6) This change in slope is reported to be a sharp kink by some authors (3-5), and a positive curvature by others (2,6). Recently a theoretical approach is made (7-9), explaining the double peak in the specific heat with a coupling between the superconducting order parameter and the observed small antiferromagnetic moment M_s. In this model M_s is fixed to one basal plane direction and acts as a symmetry breaking field. Calculations predict a kink in $H_{c2}(T)$ for one direction in the basal plane, and anisotropy for field directions within the basal plane. No basal plane anisotropy has been observed by the authors of ref. (4), whereas in ref. (10) a small anisotropy has been reported. Previously it has been shown that alloying UPt_3 with small amounts of boron leads to an increase of T_c (11). Moreover it has been shown that the double peak in the zero field specific heat is not altered or depressed by the addition of small amounts of boron (12). In this paper we report on $H_{c2}(T)$ measurements of $UPt_3B_{0.11}$ (nominal concentration of boron) for field directions parallel to the a,b and c-axis. A comparison is made with the data for UPt_3. In our investigation special attention has been given to the question whether there is basal plane anisotropy, whether both H//a and H//b show a change in slope, and whether the change in slope is a sharp kink or a positive curvature.

2. EXPERIMENTAL

The two samples investigated are both cut from the same Czochralski-grown single crystalline rod. Both samples are annealed in the same way. Growing and annealing procedures were described previously (12). The homogeneity of the boron content was confirmed by microprobe analysis. The absolute value of the boron content, however, can not be checked in this way. Therefore we will refer to the 11% boron content as a nominal value. The samples are of high purity as is indicated by the low ρ_0-value of 0.29 $\mu\Omega$cm (for I//c-axis). The RRR-value as defined by R(294K)/R(0K) is 536, and the transition temperature in zero field is 559 mK. Sample 1 exhibits a small mosaik of 3°, and sample 2 of 5°, as was shown by Laue-pictures. Resistance was measured in a ^{3}He-cryostat with a four point AC-method, using a transformer coupled bridge and a current density of 0.2 A/cm^2 (sample 1) and 0.1 A/cm^2 (sample 2). The temperature was measured with a RuO_2 thermometer which was calibrated in field against a capacitance thermometer. The samples were cut into the shape of a rectangular bar and the demagnetization correction is estimated to be always less than 0.8 %.

3. RESULTS AND DISCUSSION

The results are presented in figs 1 and 2 for sample 1 (I//c) and sample 2 (I//b), respectively. The transition temperatures have been determined from the 50% value of the resistance in the normal state. The latter being defined as the point where the resistance deviates from the normal state T^2 behaviour. The width of the transition as determined from the 10% and 90% values of the normal state resistance is (16±2) mK and does not broaden with magnetic field up to 1.4 Tesla. Refering to the data in figs. 1 and 2, we stress 4 important facts.

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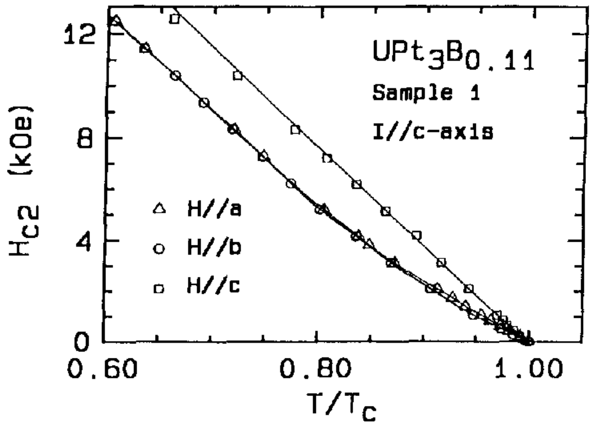

FIGURE 1
$H_{c2}(T)$ for $UPt_3B_{0.11}$ (sample 1, I//c), for H//a and H//b (solid lines are guides to the eye) and for H//c (solid line indicates the initial slope).

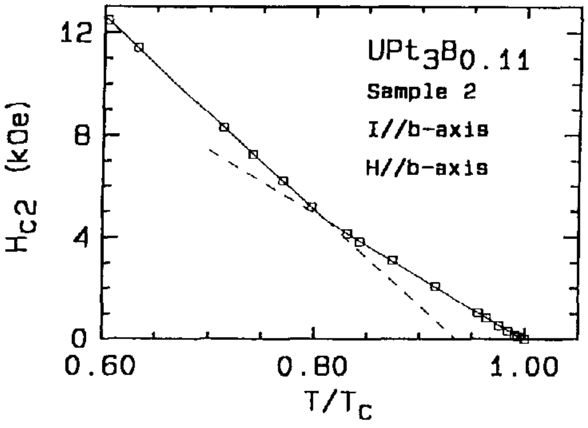

FIGURE 2
$H_{c2}(T)$ for $UPt_3B_{0.11}$ (sample 2, I//b) for H//b (solid lines indicate the two different slopes dH_{c2}/dT).

1) The addition of boron does not appreciably change the characteristics of $H_{c2}(T)$. For the basal plane field direction (sample 2) dH_{c2}/dT is −67 kOe/K below $T_H/T_c = 0.81$ and −45 kOe/K there above (T_H being the temperature where the change in slope occurs). For H//c dH_{c2}/dT is −69 kOe/K. These values are comparible to the values −64, −44 and −71 kOe/K, respectively, for pure UPt_3 (10).

2) For both H//a and H//b $H_{c2}(T)$ shows a change of slope which sets in at $T_H/T_c = 0.81$ (fig. 1). This implies that the overal behaviour of $H_{c2}(T)$ in the basal plane is isotropic, and that the earliest theoretical models, using a large in-plane anisotropy of the antiferromagnetic order, need some refinement.

3) Nevertheless, from the data in fig. 1 a small in-plane anisotropy remains visible. When we denote this as an increase of T_c by going from the H//b phase line to H//a phase line, the upper limit for the anisotropy is 5 mK for $T>T_H$ and 2.5 mK for $T<T_H$ This is in rough agreement with the findings of ref. (10).

4) The experimental results for sample 2 (H//b//I) indeed show a sharp kink at $T_H/T_c = 0.81$, whereas for sample 1 (H//b⊥I) the change of slope sets in above $T_H/T_c = 0.81$ and a small positive curvature is observed. The deviation between the curved phase line of sample 1 and the linear phase line of sample 2 is small, the maximum deviation being 5 mK. The difference between a sharp change of slope or a gradual change of slope (or less sharp kink) might be related to the difference in current densities (10), the current density being a factor two smaller in case of the sharp kink.

In conclusion we have presented data for $H_{c2}(T)$ of single-crystalline $UPt_3B_{0.11}$ and commented on the observed anisotropies.

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