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Journal

Journal of Magnetism and Magnetic Materials, 76-77(C)

ISSN

0304-8853

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Publication Date

1988-12-02

DOI

10.1016/0304-8853(88)90463-5

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Peer reviewed

INVITED PAPER

HIGH FIELD SPECIFIC HEAT OF SINGLE CRYSTAL UPt_3 G.R. STEWART ^a, Z. FISK ^b, J.L. SMITH ^b, J.J.M. FRANSE ^c, A. MENOVSKY ^c
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Low temperature specific heat data of aligned single crystals of UPt_3 , $\text{RRR} = 140$, with high magnetic field applied either along the c -axis or perpendicular to the c -axis are reported. No evidence for a metamagnetic transition as observed previously in susceptibility and resistivity measurements is seen, with no change for H in the c -direction and large ($\approx 20\%$), temperature-dependent changes observed for H perpendicular to c . Magnetoresistivity measurements on one of the single crystals indicate that the transition in resistivity occurs at a lower field in our sample than observed in the sample reported on previously (18 vs. 20 T).

1. Introduction

Magnetization vs. field measurements at 4 K by Frings et al. [1] on a single crystal of UPt_3 have shown a departure from linearity of M vs. H for H in the a or b direction starting at 15 T and returning again to linear behavior above perhaps 30 T. Concomitantly, there is [2] a peak in the magnetoresistance of UPt_3 , with H in the a – b plane, centered at 20 T. For a field in the c -axis direction, the magnetic susceptibility of UPt_3 is only half of that observed for the field in the a – b plane. Also, there is no transition in the M vs. H data for H parallel to the c -axis up to 34 T, the upper limit of the measurement. The question remains, what is the nature of this high field transition? Is it a transition from a spin fluctuation ground state into a magnetically ordered state, i.e. a “metamagnetic” transition?

From a broader perspective, UPt_3 is one [3] of three known [4] heavy fermion superconductors, with strong electron corrections, high effective masses and magnetic correlations which nevertheless do not suppress superconductivity. Amongst the heavy fermion superconductors, UPt_3 has the strongest evidence of such magnetic behavior, i.e. UPt_3 has a $T^3 \ln T$ term in the low temperature specific heat [3] which is now interpreted as evidence for antiferromagnetic spin fluctuations. Also, recent neutron diffraction experiments [5] indicate that pure UPt_3 is an antiferromagnet at 5

K with an order moment of $(0.02 \pm 0.01)\mu_B$, even though no sign of any such magnetic transition is seen in the specific heat. (A transition into an ordered state with a local moment of $0.02\mu_B$ at 5 K would, if 1 K broad, create a specific heat anomaly equal in magnitude to 25% of the observed size of the specific heat. Therefore, the transition observed by neutron diffraction must be itinerant.)

In order to investigate this metamagnetic transition and the recent neutron diffraction results more fully, we have performed high field specific heat measurements on flux-grown, needle-like single crystals with a resistivity ratio, $R(300 \text{ K})/R(T_c^+)$, of 140. Approximately 10 crystals with a total mass of 15 mg were aligned so that the specific heat, C , could be measured both with H parallel to the c -axis and also with H in the a – b plane. The high field calorimeter used has been described elsewhere [6].

2. Results and discussion

Previous specific heat results on single crystals of UPt_3 , but randomly aligned, up to 11 T have already been reported [7]. These data indicate an increase of C with H below 7 K and a decrease of C with H above 7 K. Data for zero and 17 T along the c -axis are shown in fig. 1; data for zero field and $H = 19$ T aligned in the a – b plane are shown in fig. 2.

Fig. 1. Low temperature specific heat, C , divided by temperature vs. temperature squared for needle-like single crystals with their c -axis aligned along the field direction in 0 (dots) and 17 T (triangles). The reason for reaching 17 instead of 19 T for these measurements were technical difficulties with the magnet. The lowest temperature for which data were measured was 2.5 K.

Considering the data of fig. 1 first, it is clear that, within the error of our measurement, the specific heat of UPt_3 is unchanged by 17 T applied parallel to the c -axis. This total lack of change of C with such a high field is unique in the heavy fermion systems for which high field (up to 24 T) specific heat data exist [4,8] (CeCu_2Si_2 , superconducting and non-superconducting, UPe_{13} , CeAl_3 , CeCu_6 , UPt_4Au). (Lower – 5.5 T – field data for an aligned single crystal of CeCu_6 also show [9] no change in C below 2 K for field in 2 of the 3 orthorhombic crystal symmetry directions.) Based on the lack of any structure in the M vs. H data for H parallel to the c -axis in UPt_3 , however, this lack of change of C with H is not unexpected. It should be stressed, however, that $\partial C/\partial H$ is not as simply determined from $M(H)$ as sometimes supposed – $\partial C/\partial H$ is calculable from an integral over field of $\partial^2 M/\partial T^2$, not just simply $\partial C/\partial H \propto \partial M/\partial H$.

The field used to obtain the data of fig. 2 is 19 T. Is this field sufficiently high to investigate the transition observed in the resistivity and susceptibility? This is an important question, since the sample measured in ref. [1] is different from that under investigation here and variation among samples of UPt_3 for at least some properties has been observed [4]. In order to investigate this, we have measured the magnetoresistance to 19 T of one of the crystals used in our specific heat experiment. The peak in the magnetoresistance occurs at

approximately 18 T, so that – at least from the point of view of resistivity – the field used for the specific heat measurements is already high enough to see the transition. However, as observed in fig. 2, no transition is visible in the specific heat. In comparison with the 11 T data of ref. [7], the only changes are that the increase (decrease) at lower (higher) temperature is more pronounced, and the crossover point, where no change in C with H is observed, is shifted downward to ≈ 4 K, vs. 7 K for the 11 T data. Thus, in UPt_3 19 T in the a - b plane increases the specific heat by $\approx 20\%$ at 2.5 K and decreases the specific heat by $\approx 20\%$ at 9 K. Rather than suppressing the spin-fluctuation caused upturn in the C/T data, the field perpendicular to the c -axis accentuates this feature.

In conclusion, the specific heat results for the field along the c -axis, i.e. no change to 17 T, seem consistent with the magnetization data. Future high field work on a single crystal of CeCu_6 needs to be carried out to determine if this result in UPt_3 is unique. For H perpendicular to the c -axis, the suppression of the crossover point where $\Delta C(H) = 0$ from 7 K, at 11 T, to 4 K at 19 T, the much steeper upturn in the field data for C/T , and the lack of any anomaly in the smoothly varying data remain puzzling. Clearly, field measurements of the specific heat of UPt_3 to 24 or even 30 T are needed.

The work performed at the University of Florida was performed under DOE grant DE-FG05-86ER45268. Work at Francis Bitter Na-

Fig. 2. C/T vs. T^2 data as in fig. 1, on the same set of aligned single crystals, only with the field applied perpendicular to the c -axis in 0 (dots) and 19 T (triangles).

tional Magnet Laboratory supported by NSF under DMR 8511 789. Work at Los Alamos National Laboratory supported by the US DOE.

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