Physica B 186–188 (1993) 355–357
North-Holland

PHYSICA B

Physics of YbBiPt

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YbBiPt has a low temperature linear specific heat coefficient of 8 J/mol Yb K^2 and a small specific heat anomaly at 0.4 K. We discuss new experiments on the specific heat of diluted YbBiPt, magnetic field dependent effects and electrical resistivity in pure YbBiPt. We argue that in this material the Kondo and crystal field energy scales are small and of comparable magnitude, placing YbBiPt in the same class as many uranium heavy electron compounds.

YbBiPt crystallizes in the noncentrosymmetric cubic half-Heusler structure. Its lattice parameter, as well as the effective moment extracted from the Curie–Weiss type temperature dependence of the magnetic susceptibility measured up to 340 K, indicate that Yb in this compound is essentially trivalent. The temperature dependent electrical resisitivity is monotonically increasing with increasing temperature and negatively curved, with some weak features, indicating crystal field effects. A typical resistance ratio between 300 K and 1 K is 10 for crystals grown from Bi-flux, indicating reasonably stoichiometric and well ordered material. A complete structural refinement for site occupancies has not as yet been completed, but X-ray powder data are consistent with Bi occupying the special (0, 0, 0) site in the structure.

Interest in this material derives from the very large C_p/T = ratio of 8 J/mol Yb K^2 at low temperature. At 0.4 K there is a specific heat anomaly containing very little entropy [1], whose nature is still being investigated. The magnetic susceptibility $\chi(T)$ indicates that this is a magnetic transition of some kind, and recent μSR experiments [2] are compatible with small ordered moments statistically distributed and the presence of a paramagnetic component. The smallness of the observed ordered moment is consistent with the absence of a distinct nuclear specific heat contribution which is to be expected from Yb nuclei in the presence of an ordered moment of order of magnitude $1\mu_B$. However, there is an upturn in the specific heat near 50 mK (fig. 1) with an associated feature in the AC magnetic susceptibility. This does not appear to be a nuclear Schottky anomaly, but rather a second low temperature phase transition. The important question to address here is whether this compound is to be classified as a Kondo lattice material, or whether other physics is dominating the properties.

Neglecting the possible phase transition below 0.1 K, the integrated entropy to 1 K is very nearly $R \ln 2$ J/mol Yb K. The value to 20 K is approximately $R \ln 5$ J/mol Yb K. Thinking in crystal field terms, the $J = 7/2$ f^{13} configuration will be split in the cubic environment into two doublets, Γ_6 and Γ_7, and a Γ_8 quartet. These entropy considerations then suggest that a doublet plus quartet lie below 20 K [3]. Inelastic neutron data being reported at this conference on a polycrystalline sample have been analyzed as having Γ_7 lowest with the Γ_8 almost degenerate with it, the splitting being of order of 1 K, and the Γ_6 at much higher energy, 60 K. Magnetic susceptibility measurements in the vicinity of 1 K indicate an effective moment in low fields larger than that expected for either the Γ_7 or Γ_8 state. Further, the magnetization as a function of field (fig. 2) is strongly curved at low temperature, but the shape is not well fit with a Brillouin function. The entropy of the doublet plus quartet is removed on cooling to low temperatures, but the qualitative conclusion from the μSR is that the moments present are very much reduced from those

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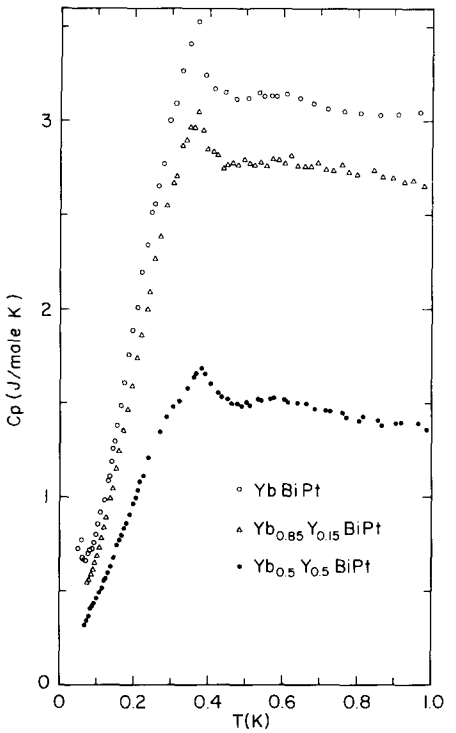

Fig. 1. Low temperature specific heat of YbBiPt, $Yb_{0.85}Y_{0.15}BiPt$ and $Yb_{0.5}Y_{0.5}BiPt$.

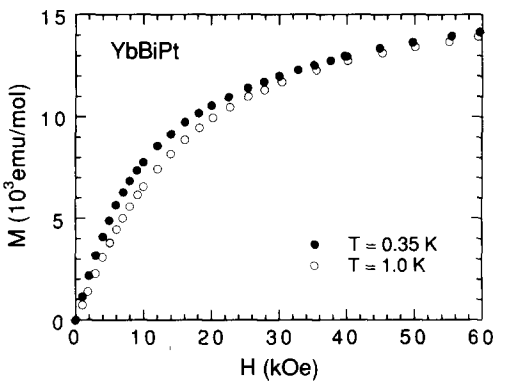

Fig. 2. Magnetization as a function of field for YbBiPt at $T = 0.35$ K and 1.00 K.

expected for either the Γ_7, the Γ_8 or a combination thereof. While part of the large linear term in the specific heat might in principle be ascribed to a Schottky anomaly from the quartet, the fact that the ground state doublet entropy also disappears in the manner that it does, and the observed moment reduction, suggest that a Kondo-type mechanism is involved. The Kondo energy scale must be similar to the small crystal field energy scale, indicating that both effects ought to be treated together and that the usual crystal field analysis will not be an accurate way in which to discuss the physics.

We report here additional specific heat results. We first note that both YBiPt and LuBiPt, with the same structure as YbBiPt, have very small γs, of approximately 1 mJ/mol RE K^2 [4], suggesting that the underlying band structure of the YbBiPt is that of a semimetal. Isostructural YbSbPt orders magnetically at 0.35 K (fig. 3), with a pronounced specific heat anomaly, very different in shape from that of YbBiPt, and in this case a clearly identified nuclear term is found in the specific heat below 100 mK. Neglecting the Schottky piece, an integrated entropy of $R \ln 2$ is not obtained until close to 1 K, consistent with the idea that we are dealing with a frustrated lattice. A series of alloys of $Yb_{1-x}Y_xBiPt$ have been measured (fig. 1). For $x = 0.15$ and 0.5, the low temperature specific heat scales closely with Yb content. Surprisingly, the low temperature C_p feature remains fixed at 0.4 K for these compositions. For larger x, the specific heat per mole Yb decreases quite strongly, making plausible the idea that f–d interactions renormalize sizeably the underlying semimetallic electronic structure. Such an interpretation awaits considerable further specific heat work, particularly to determine how the entropy per Yb evolves with T, as a function of x, and also how the small changes in lattice parameter with x enter into the picture. Dilutions of YbBiPt with Lu are under way concerning this last aspect.

As mentioned above, a peculiar spin glass picture for the low temperature magnetic transition has been suggested by previous μSR experiments [5]. It is worth keeping in mind that the μ^+ could considerably alter

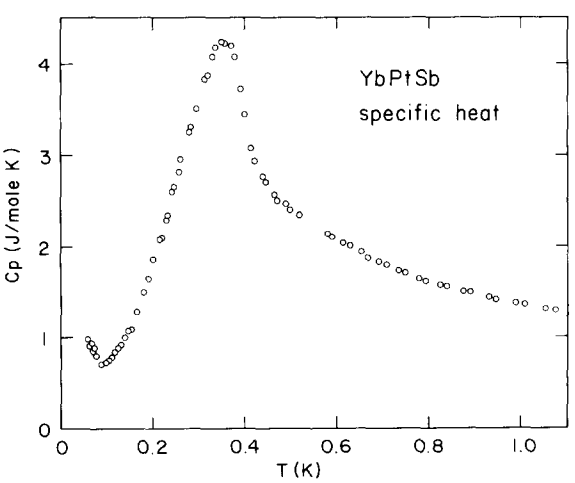

Fig. 3. Low temperature specific heat of YbSbPt.

its local environment in a material such as YbBiPt in which the energy scales of interest are small. The lack of dilution effect on the freezing temperature is not expected in a spin glass. Further, an AC susceptibility investigation of the ordering feature does not show a frequency dependence. Finally, the AC susceptibility feature at 0.4 K (fig. 4) has been tracked in magnetic fields and found to shift to lower temperatures quadratically in applied field H. However, other features, like a maximum close to 0.1 K, are evident in χ_{AC}, and we do not have a detailed understanding of this measurement. We mention also that the electrical resistivity decreases linearly with T below 4 K and has a break in slope at the C_p anomaly, to a constant value at lower temperature. One possibility is that the C_p anomaly signals an order of small moment type, with perhaps considerable disorder present. We note that the FCC Yb sublattice is, for some kinds of exchange coupling, frustrated.

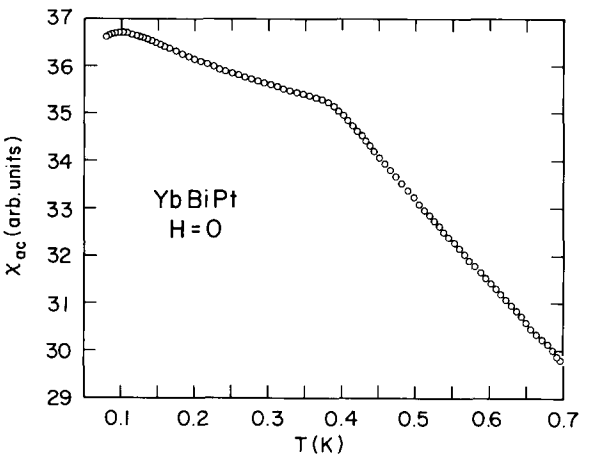

Fig. 4. Low temperature AC susceptibility of YbBiPt, measured at 84 Hz.

The Kondo features in this system are subtle. We infer them from the lack of ordered moment compatible with the possible crystal field ground states, yet the full loss of entropy at low temperature as expected from the energy level determinations by inelastic neutron scattering. This Kondo scale must be small to give a large γ and this does not conflict with the very small Curie–Weiss θ seen in the magnetic susceptibility. The small Kondo scale and comparable crystal field scale found via neutrons suggest that a strong mixing of the two may be present. This would place YbBiPt in the same class of behavior as many of the uranium heavy electron materials, except that in the present case both these energy scales are roughly one to two orders of magnitude smaller than found in most such uranium materials. We also wish to reemphasize that the semimetallic character of the half-Heusler structure with trivalent rare earth may allow substantial renormalization of the underlying electronic structure by f–d correlation effects.

Acknowledgments

Work at Los Alamos was performed under the auspices of the US Department of Energy. Work at ETH Zürich profited from financial support of the Schweizerische Nationalfonds. Research at UCSD supported by the National Science Foundation under Grant No. DMR 91-07698.

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