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Low-temperature properties of the heavy fermion system $YbIr_2Si_2$

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Abstract

We report here the magnetic susceptibility, specific heat and electrical resistivity on high-quality single crystals of $YbIr_2Si_2$. It crystallizes either in the I-type body-centered $ThCr_2Si_2$ or P-type $CaBe_2Ge_2$ structure. P-type sample orders magnetically below 0.7 K whereas the I-type system remains paramagnetic down to 40 mK and shows heavy fermion behavior. Low-temperature resistivity and specific heat of this compound has strong similarity with $YbRh_2Si_2$ down to 400 mK. However, below 200 mK $YbIr_2Si_2$ attains Fermi-liquid ground state in contrast to $YbRh_2Si_2$ which shows non-Fermi-liquid behavior.

Keywords: Heavy fermions; Quantum-phase transition; Yb-compounds

Heavy fermion (HF) compounds continue to be at the forefront of condensed matter research for three decades. Yb-based HF systems situated close to a quantum critical point (QCP) are rather rare in literature. Further, we do not have yet any Yb-based heavy fermion superconductor. These facts motivated us to look for new Yb-based heavy fermion systems. In recent years $YbRh_2Si_2$ has been intensively investigated due to its proximity to a QCP. It exhibits pronounced non-Fermi-liquid (NFL) behavior above a low-lying magnetic transition at ($T_N = 70$ mK) [1]. The fact that $YbRh_2Si_2$ displays entirely different kind of quantum criticality, namely a local quantum critical point in contrast to its Ce-counterparts with similar crystal structure such as $CeNi_2Ge_2$ or $CeCu_2Si_2$, poses fundamental questions like (i) whether inspite of the electron hole symmetry between Ce and Yb there is an inherent difference between them, (ii) whether this local QCP would hold for all Yb-based HF systems, and more importantly (iii) whether this local QCP would hinder the appearance of HF superconductivity [2] in Yb-based HF in the vicinity of a QCP. In order to bring $YbRh_2Si_2$ to the QCP one needs either a magnetic field or substitution of Si by larger Ge [3]. However, both magnetic field and substitution affect the intrinsic behavior of the material near the quantum critical regime, in particular the appearance of possible HF superconductivity in $YbRh_2Si_2$. Therefore, we looked for a more cleaner way to reach the QCP. We have now been able to synthesize $YbIr_2Si_2$, and found that it provides a unique opportunity for the investigation of QCP: it is located close to the QCP, but, in contrast to the Rh-homolog, on the non-magnetic side. Thus $YbIr_2Si_2$ and $YbRh_2Si_2$ provide two homologs systems on each side of the QCP. The change from the antiferromagnetic state of $YbRh_2Si_2$ to the non-magnetic heavy fermion state of $YbIr_2Si_2$ can be attributed to the increase of the unit cell volume by $\sim$1%. Thus, a pressure of a few GPa is expected to induce a magnetic state in $YbIr_2Si_2$, providing a model system to invetsigate the behavior near QCP in a clean and ordered Yb–based HF system.

Single crystals were grown from In-flux. By careful tuning we were able to grow two types of crystals: primitive tetragonal ($CaBe_2Ge_2$-P-type) and body centred tetragonal (ThCr2Si2-I-type). Measurements reported here were performed using standard techniques.

The magnetic susceptibility plotted as $1/\chi$ versus T in Fig. 1 shows the very different character of the two compounds. (i) The magnetic susceptibility of the P-type sample is almost an order of magnitude larger than that of the I-type sample. (ii) The magnetic susceptibility of the

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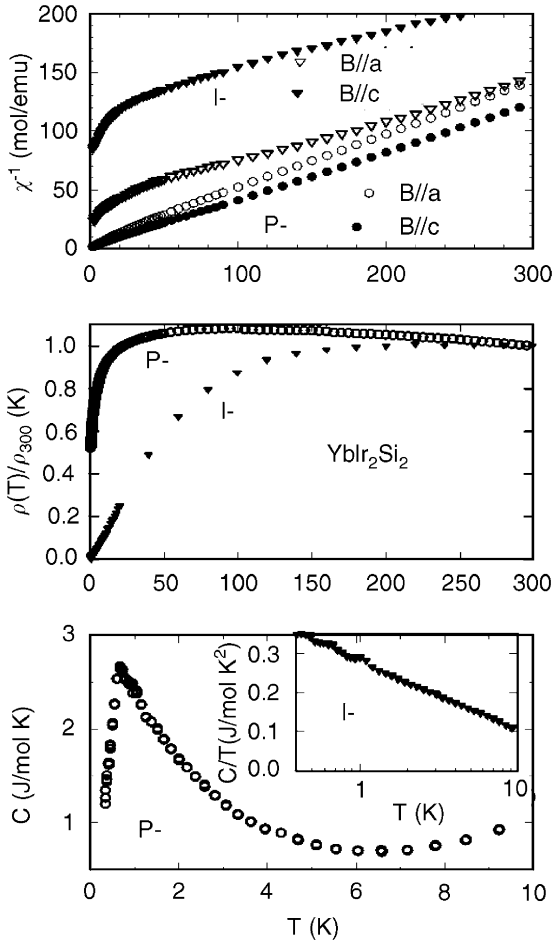

Fig. 1. Comparison of the magnetic susceptibility (χ), the resistivity (ρ) and the specific heat, C, of P-type and I-type $YbIr_2Si_2$.

P-type sample is essentially isotropic whereas the I-type sample shows considerable anisotropy. At high temperatures one observed in both compounds and along both directions a Curie–Weiss behavior with a similar slope, i.e. a similar effective moment close to that of Yb^{3+}. However, the paramagnetic Curie–Weiss temperature, θ_P of the P-type sample is much smaller (−10 K) compared to that of the I-type sample (−82 K along the easy plane). The smaller θ_P for P-type sample indicates a rather weak Kondo scale, while the large θ_P value in I-type sample results from crystal field effect and large Kondo scale.

The resistivity (ρ) shows in both samples a T-dependence which is typical for Kondo lattice systems. Also here the temperature of the maximum in ρ (T) which is related the Kondo scale, is much lower for P-type than for I-type. While the residual resistivity ratio (RRR) of P-type compound is 2, the I-type samples has a very high RRR of more than 200. Very high value of RRR for the I-type crystals confirms very high quality and ordered nature of the sample while the P-type sample probably has significant amount of disorder, likely Ir–Si site exchange. Below 200 mK I-type shows quadratic temperature-dependence characteristic of Fermi liquid behavior while in the temperature range 0.5–10 K the resistivity behavior is similar to the non-Fermi-liquid behavior in $YbRh_2Si_2$.

Specific heat of P-type sample exhibits a prominent anomaly presumably due to a magnetic transition at 0.7 K. On the other hand, the specific heat data of I-type sample do not show any evidence of magnetic order down to 50 mK. The C/T of I-type sample increases much more smoothly below 10 K as in the case of $YbRh_2Si_2$, and over a narrow temperature range (0.5–2 K) it shows NFL-like behavior ($\Delta C/T = \gamma_0 \ln(T_0/T)$) similar to that of $YbRh_2Si_2$. Below 400 mK, $\Delta C/T$ shows a tendency to saturation as expected for a Fermi-liquid ground state. The value of C/T at the lowest temperature is 0.37 J/mol K^2 thus classifying $YbIr_2Si_2$ as a new Yb-based heavy fermion compound. At high temperatures, the magnetic part of the specific heat exhibits broad Schottky type peak with a maximum around 85 K which corresponds to a crystal field splitting of 200 K (~17 meV) which is consistent with neutron scattering results [4].

In this paper we contrast the behavior of P-type and I-type $YbIr_2Si_2$. Magnetic susceptibility, resistivity and specific heat indicate a rather low Kondo temperature in P type, while that of I-type is much larger, even larger than in $YbRh_2Si_2$. P-type sample orders magnetically at 0.7 K whereas no phase transition is observed in I-type sample down to 20 mK. It exhibits Fermi-liquid behavior below 0.4 K. These results point that I-type $YbIr_2Si_2$ is placed on the non-magnetic side in contrast to $YbRh_2Si_2$ which is on the magnetic side of the QCP. The NFL-like behavior above 0.5 K signals the nearness to QCP. Since the volume of $YbIr_2Si_2$ is only 1% larger than $YbRh_2Si_2$ we suspect a moderate pressure of few GPa would be enough to cross the QCP from nonmagnetic side. As $YbIr_2Si_2$ is stoichiometric with lowest amount of disorder one might even hope to discover pressure induced superconductivity near QCP.

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