Low-temperature high-field magnetization of $YbRh_2Si_2$ and $YbIr_2Si_2$ under hydrostatic pressure

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Abstract

We report low-temperature ($T \geqslant 40\,mK$) magnetization measurements on $YbRh_2Si_2$ and $YbIr_2Si_2$ at magnetic fields up to 11.5 T and under hydrostatic pressure $P \leqslant 1.35\,GPa$. The magnetization slope in $YbRh_2Si_2$ changes drastically under pressure, while that of $YbIr_2Si_2$ is less sensitive to pressure. Isofield $M(T)$ curves of $YbIr_2Si_2$ under pressure up to 1.35 GPa saturate at low temperatures without signature of a magnetic transition. Thus, $YbIr_2Si_2$ has Landau Fermi liquid ground state up to 1.35 GPa and larger pressure is needed to reach the quantum critical point and to induce magnetic order.

Keywords: $YbRh_2Si_2$; $YbIr_2Si_2$; Quantum critical point; Magnetization; Hydrostatic pressure

The physical properties of Kondo lattice systems in the Landau Fermi liquid (LFL) state are governed by the Kondo temperature T_K, which for heavy fermion (HF) systems is very sensitive to the application of pressure. This is due to the generally large Grüneisen constant $\Gamma = -\partial \ln T_K / \partial \ln V$ in HF systems, reaching values up to a few hundreds [1]. Therefore, the application of pressure is very effective to change the physical properties of such systems. Here, we report magnetization measurements on the Yb-based HF systems $YbRh_2Si_2$ and $YbIr_2Si_2$ at temperatures down to 40 mK, fields up to 11.5 T, and under hydrostatic pressure up to ~1.4 GPa.

Both $YbRh_2Si_2$ and $YbIr_2Si_2$, crystallizing in the tetragonal $ThCr_2Si_2$ structure, are located close to a quantum critical point (QCP). $YbRh_2Si_2$ with a single ion Kondo scale T_K of about 25 K is located on the antiferromagnetic (AF) side in the Doniach phase diagram ($T_N = 70\,mK$), whereas $YbIr_2Si_2$ with a T_K of 40 K shows a paramagnetic heavy LFL ground state [2,3]. Contrary to the Ce case in Yb-based compounds T_K decreases and the system becomes more magnetic under pressure, because the ionic volume of the magnetic $4f^{13}Yb^{3+}$ configuration is smaller than that of the nonmagnetic $4f^{14}Yb^{2+}$ one.

The AF order in $YbRh_2Si_2$ is suppressed by a small magnetic field of $B_c = 0.06\,T$, applied in the easy magnetic plane perpendicular to the tetragonal c-axis. Above B_c the system shows LFL behavior with a strongly field-dependent quasiparticle mass. The application of a high magnetic field $B^\star \approx 10\,T$, corresponding to T_K leads to the suppression of the heavy fermion state [4,5].

Since $YbIr_2Si_2$ remains paramagnetic at zero field and very clean single crystals (RRR = 225) are available it is most suitable for a pressure study across the QCP [3].

High-quality single crystals were grown from In-flux as described earlier [2,3]. The DC magnetization was measured utilizing a high-resolution capacitive Faraday magnetometer [6]. Hydrostatic pressure was produced by using a miniaturized CuBe piston–cylinder pressure cell of 6 mm outer diameter and 3.2 g total weight. The pressure cell including the single crystalline sample ($YbRh_2Si_2$ 6.0 mg, $YbIr_2Si_2$ 8.1 mg) was mounted on the magnetometer. The sample magnetization is obtained after subtraction of the background magnetization of the empty pressure cell. The pressure is determined by the difference between the

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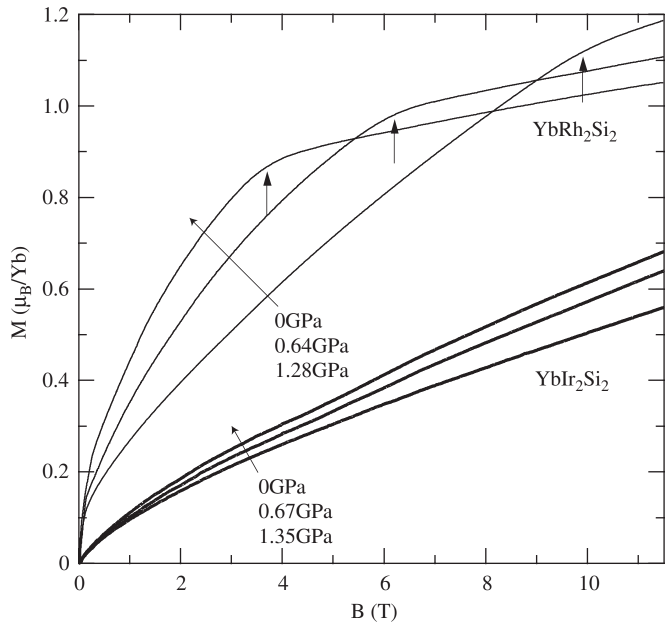

Fig. 1. Magnetization of $YbRh_2Si_2$ (thin solid lines, measured at 40, 40 and 60 mK, for $P = 0$, 0.64 and 1.28 GPa, respectively) and $YbIr_2Si_2$ (thick solid lines, measured always at 50 mK) under ambient and hydrostatic pressure for $B \perp c$. Vertical arrows indicate characteristic field $B^{\star}$ for $YbRh_2Si_2$ [5].

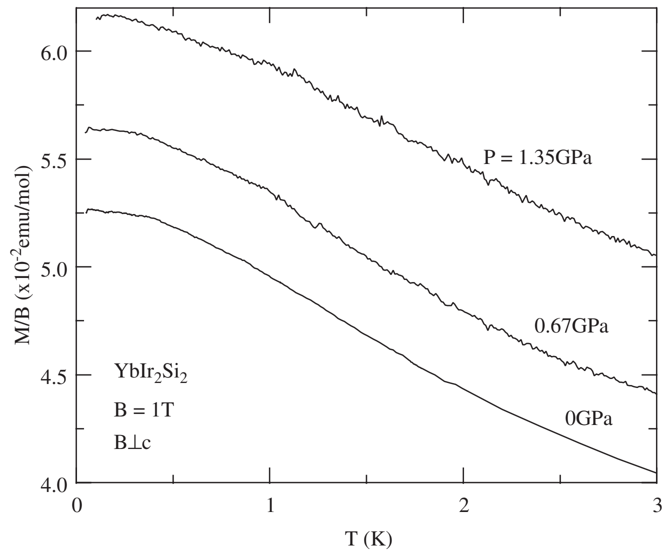

Fig. 2. Temperature dependence of the magnetization of $YbIr_2Si_2$ under ambient and hydrostatic pressure for $B \perp c$.

superconducting transitions of two small Sn samples; one placed inside the pressure-transmitting medium (daphne oil) together with the sample, the other one outside the pressure cell.

Fig. 1 shows the magnetization of $YbRh_2Si_2$ and $YbIr_2Si_2$ under ambient pressure as well as under hydrostatic pressure for $B \perp c$. The shape of $M(B)$ in $YbRh_2Si_2$ changes drastically under pressure and it shows a kink at $B^{\star} = 9.9$, 6.2 and 3.7 T at 0, 0.64 and 1.28 GPa, respectively. This kink is accompanied by a sign change in the magnetostriction [4] and a drastic decrease of the heavy quasiparticle mass and has been ascribed to a field-induced localization of f-electrons [5]. Interestingly, this transition is not accompanied by metamagnetism. This is due to the strong ferromagnetic polarization of the HF state below $B^{\star}$ [7]. More details are discussed in Ref. [5].

On the other hand, the effect of pressure on $YbIr_2Si_2$ is much smaller compared to that on $YbRh_2Si_2$ indicating a substantially smaller Grüneisen constant. The slope of $M(B)$ in $YbIr_2Si_2$ increases slightly with increasing pressure and does not show any signature of field-induced magnetic order. It should be noted that the slight change in the slope of $M(B)$ of $YbIr_2Si_2$ seen at $B{\sim}5$ T and $P = 0.67$ and 1.35 GPa is neither reproducible nor intrinsic. It is due to small temperature drifts which cause changes in the magnetization of the CuBe pressure cell because of the Cu nuclear magnetization changing drastically at lowest temperatures.

The temperature dependence of M/B of $YbIr_2Si_2$ at 0, 0.67 and 1.35 GPa is shown in Fig. 2. For all pressures $M(B)$ saturates at low temperatures, indicating a LFL ground state. Similar behavior is observed at $B = 0.1$ T (not shown). Since the compressibility of $YbIr_2Si_2$ is expected to have a similar value as in $YbRh_2Si_2$ ($\kappa_T = 5.3 \times 10^{-12}\,\mathrm{Pa}^{-1}$ [8]), we can roughly estimate the Grüneisen constant $\Gamma = -\partial \ln T_K / \partial \ln V = 1/\kappa_T \times \partial \ln(1/\chi_{\mathrm{Pauli}})/\partial P$ of $YbIr_2Si_2$ from the pressure dependence of χ_{Pauli} using the compressibility of $YbRh_2Si_2$. The pressure dependence gives $\Gamma = -22$, which is much smaller than -130 observed in $YbRh_2Si_2$ [5].

To summarize, we have reported low-temperature magnetization measurements of $YbRh_2Si_2$ and $YbIr_2Si_2$ under hydrostatic pressure. The smaller pressure dependence of the magnetization of $YbIr_2Si_2$ results in a smaller Grüneisen constant compared to that of $YbRh_2Si_2$. Up to 1.35 GPa no signature of magnetic order has been found in $YbIr_2Si_2$ and the system still shows a LFL ground state. Therefore, larger pressure is needed to induce magnetic order in $YbIr_2Si_2$.

References

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