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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 ($T \geq 40$ mK) magnetization measurements on YbRh_2Si_2 and YbIr_2Si_2 at magnetic fields up to 11.5 T and under hydrostatic pressure $P \leq 1.35$ 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 $4f^{13}\text{Yb}^{3+}$ configuration is smaller than that of the nonmagnetic $4f^{14}\text{Yb}^{2+}$ 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 $B^* \approx 10$ 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 ($\text{RRR} = 225$) 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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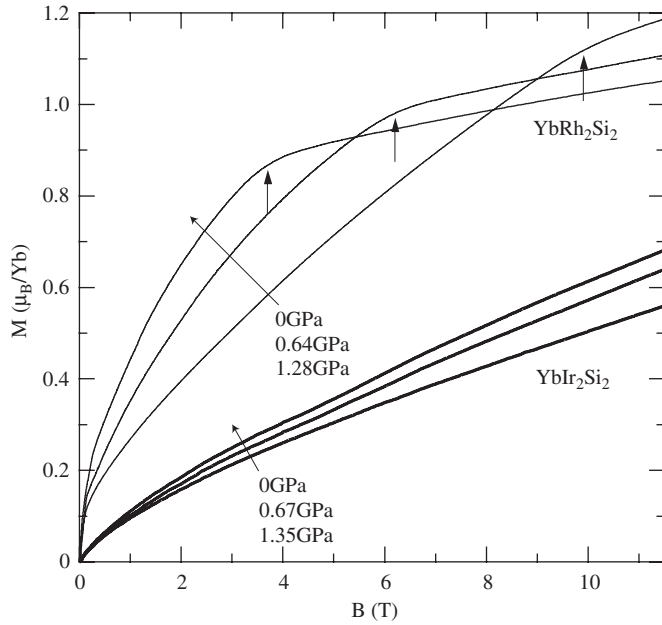


Fig. 1. Magnetization of YbRh₂Si₂ (thin solid lines, measured at 40, 40 and 60 mK, for $P = 0, 0.64$ and 1.28 GPa, respectively) and YbIr₂Si₂ (thick solid lines, measured always at 50 mK) under ambient and hydrostatic pressure for $B \perp c$. Vertical arrows indicate characteristic field B^* for YbRh₂Si₂ [5].

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 YbRh₂Si₂ and YbIr₂Si₂ under ambient pressure as well as under hydrostatic pressure for $B \perp c$. The shape of $M(B)$ in YbRh₂Si₂ changes drastically under pressure and it shows a kink at $B^* = 9.9, 6.2$ 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^* [7]. More details are discussed in Ref. [5].

On the other hand, the effect of pressure on YbIr₂Si₂ is much smaller compared to that on YbRh₂Si₂ indicating a substantially smaller Grüneisen constant. The slope of $M(B)$ in YbIr₂Si₂ 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 YbIr₂Si₂ 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.

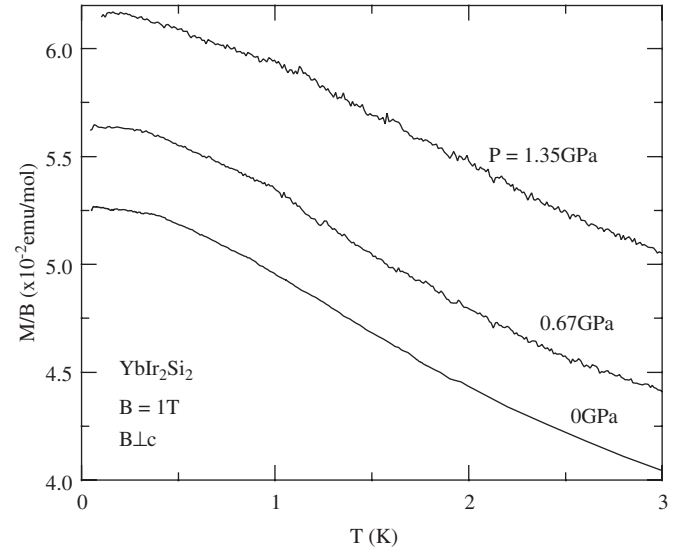


Fig. 2. Temperature dependence of the magnetization of YbIr₂Si₂ under ambient and hydrostatic pressure for $B \perp c$.

The temperature dependence of M/B of YbIr₂Si₂ 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 YbIr₂Si₂ is expected to have a similar value as in YbRh₂Si₂ ($\kappa_T = 5.3 \times 10^{-12} \text{ Pa}^{-1}$ [8]), we can roughly estimate the Grüneisen constant $\Gamma = -\partial \ln T_K / \partial \ln V = 1/\kappa_T \times \partial \ln(1/\chi_{\text{Pauli}}) / \partial P$ of YbIr₂Si₂ from the pressure dependence of χ_{Pauli} using the compressibility of YbRh₂Si₂. The pressure dependence gives $\Gamma = -22$, which is much smaller than -130 observed in YbRh₂Si₂ [5].

To summarize, we have reported low-temperature magnetization measurements of YbRh₂Si₂ and YbIr₂Si₂ under hydrostatic pressure. The smaller pressure dependence of the magnetization of YbIr₂Si₂ results in a smaller Grüneisen constant compared to that of YbRh₂Si₂. Up to 1.35 GPa no signature of magnetic order has been found in YbIr₂Si₂ and the system still shows a LFL ground state. Therefore, larger pressure is needed to induce magnetic order in YbIr₂Si₂.

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