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Suppression of the Kondo state in $YbRh_2Si_2$ by large magnetic fields

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Abstract

We present DC-magnetization, $M(B)$, magnetostriction, $\Delta L(B)/L$, and magnetoresistance $\rho(T,B)$ measurements on high-quality single crystals of $YbRh_2Si_2$ in magnetic fields up to 18 T and at temperatures down to 15 mK. At $B^\star \approx 9.5$ T, both $M(B)$ and $\Delta L(B)/L$ show pronounced changes of their slopes, indicative for a broadened phase transition. For fields above $B^\star$, the coefficient A of the Fermi liquid behavior $\Delta\rho = \rho_0 + A(B)T^2$ is reduced to very small values, indicating the suppression of the Heavy Fermion state.

High-field studies in Ce- and U-based compounds have revealed interesting phenomena such as metamagnetic transitions in $CeRu_2Si_2$ and UPt_3 [1,2]. In the case of Yb-based valence-fluctuating compounds with characteristic temperatures $T_0 \gtrsim 70$ K like $YbCu_{5-x}Ag_x$, the application of large magnetic fields induces a metamagnetic-like cross-over to a stable Yb^{3+} state with localized magnetic moments [3]. Here we report on the high-field behavior of $YbRh_2Si_2$ which is the only stoichiometric Yb-based HF system with a characteristic Kondo temperature of the order of 25 K [4]. It is located very close to a quantum critical point (QCP), related to very weak antiferromagnetic order at $T_N = 70$ mK. A very small critical magnetic field $B_c = 0.06$ T, applied perpendicular to the tetragonal c-axis, i.e. in the magnetic easy-plane, is sufficient to drive the system through the field-induced QCP [5]. For $B > B_c$ a Landau Fermi liquid (LFL) state is induced with a strongly field-dependent heavy quasiparticle mass [5].

In order to study the high-field properties in $YbRh_2Si_2$, we performed DC-magnetization $M(B)$, magnetostriction $\Delta L(B)/L$, and magnetoresistance $\rho(T,B)$ measurements on high-quality single crystals ($\rho_0 = 1\ \mu\Omega$ cm) of $YbRh_2Si_2$, prepared as described earlier [4]. For the magnetization and magnetostriction measurements a high-resolution Faraday magnetometer and a CuBe dilatometer have been adapted to dilution refrigerators, respectively. The resistivity was measured with the standard four-terminal AC technique.

The low-T magnetization $M(B)$ shows two anomalies (Fig. 1). The low-field anomaly near at 0.09 T is related to the QCP and indicates the polarization of a small moment of $0.1\mu_B$. The remaining moment is still fluctuating and contributes to the strongly enhanced Pauli-paramagnetic susceptibility [5]. Here, we concentrate on the high-field anomaly. The susceptibility $\chi = dM/dB$ and magnetostriction coefficient $\lambda = d(\Delta L(B)/L)/dB$ show step-like anomalies at $B^\star \approx 9.5$ T, indicative for a broadened second-order phase transition. The polarization at $B^\star$ amounts to $1\mu_B$. With increasing temperature, the kink in $M(B)$ becomes broader but $B^\star$ is not shifted up to 2 K. For $B^\star$ the magnetostriction coefficient λ is negative, indicating a shrinking of the Yb-ions. Since the ionic radius of magnetic Yb^{3+} configuration is smaller than that of the non-magnetic

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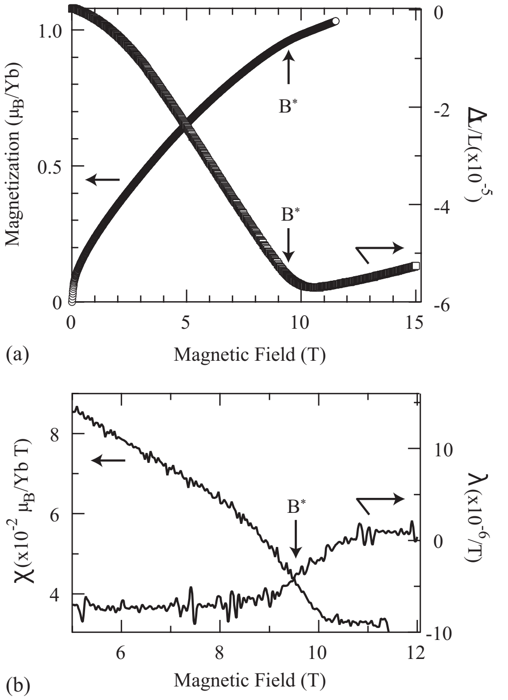

Fig. 1. Magnetization (at 80 mK, left axis) and magnetostriction (at 15 mK, right axis) vs magnetic field ($B \perp c$) (a). Susceptibility $\chi = \mathrm{d}M/\mathrm{d}B$ and magnetostriction coefficient $\lambda = \mathrm{d}(\Delta L(B)/L)/\mathrm{d}B$ vs B (b). Arrows indicate critical field $B^{\star}$.

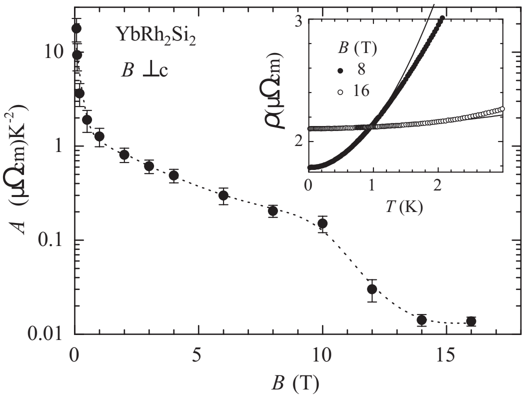

Fig. 2. Magnetic-field dependence of coefficient A (on a logarithmic scale) from Fermi liquid behavior $\rho(T) = \rho_0 + AT^2$ in the electrical resistivity, observed for $B > 0.06\,\mathrm{T}$ ($B \perp c$) [5]. Dotted line is intended as guide to the eyes. Inset shows ρ vs. T for 8 and 16 T. Solid lines represent T^2 behavior.

Yb^{2+} one, the effective valency increases with increasing field and reaches 3+ at $B^{\star}$. The localization of the f-electrons leads to a reduction of the Pauli-paramagnetic contribution to the susceptibility and therefore results in a kink of the magnetization curve.

To get more information on the properties of the heavy quasiparticles around $B^{\star}$, we analyze the field dependence of the coefficient A, derived from the LFL behavior of the electrical resistivity [5]. As shown in Fig. 2, $A(B)$ is drastically reduced upon increasing B from below to above $B^{\star}$. Since it has been shown that the scaling relation $A \propto \gamma^2$ holds at least up to 4 T [5], this indicates a step-like decrease of the quasiparticle mass. Using the value for A/γ^2 determined in [5], a γ-coefficient of about $70\,\mathrm{mJ\,mol^{-1}}\,K^{-2}$, only, is estimated at 16 T.

To conclude, a broadened phase transition at $B^{\star} = (9.5 \pm 0.5)\,\mathrm{T}$ is observed in $YbRh_2Si_2$ for fields applied in the easy magnetic plane, which indicates the complete localization of the 4f-electrons and the suppression of the HF state.

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