Suppression of the Kondo state in YbRh$_2$Si$_2$ 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$_2$Si$_2$ in magnetic fields up to 18 T and at temperatures down to 15 mK. At $B^* \approx 9.5$ T, both $M(B)$ and $\Delta L(B)/L$ show pronounced changes of their slopes, indicative for a broadened phase transition. For fields above $B^*$, 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$_2$Si$_2$ and UPt$_3$ [1,2]. In the case of Yb-based valence-fluctuating compounds with characteristic temperatures $T_0 \lesssim 70$ K like YbCu$_5$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$_2$Si$_2$ which is the only stoichiometric Yb-based HF system with a characteristic Kondo temperature of the order of 25 K [4].

In order to study the high-field properties in YbRh$_2$Si$_2$, 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$_2$Si$_2$, 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 $0.1 \mu_B$. With increasing temperature, the kink in $M(B)$ becomes broader but $B^*$ is not shifted up to 2 K. For $B^*$ the magnetostriction coefficient $\lambda$ 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
Yb$^{2+}$ one, the effective valency increases with increasing field and reaches 3$^+$ at $B^\ast$. 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 $B^\ast$, 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 $B^\ast$. 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 $A/g^2$ determined in [5], a $g$-coefficient of about 70 mJ mol$^{-1}$ K$^{-2}$ only, is estimated at 16 T.

To conclude, a broadened phase transition at $B^\ast = (9.5 \pm 0.5)$ T is observed in YbRh$_2$Si$_2$ for fields applied in the easy magnetic plane, which indicates the complete localization of the 4f-electrons and the suppression of the HF state.

References