Low-temperature thermal expansion and magnetostriction of $YbRh_2(Si_{1-x}Ge_x)_2$ ($x = 0$ and 0.05)

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Abstract

We report a comparative study of the low-temperature thermal expansion and magnetostriction of the non-Fermi liquid (NFL) system $YbRh_2(Si_{1-x}Ge_x)_2$ ($x = 0$ and nominally 0.05). The undoped compound ($x = 0$) shows a sharp phase transition anomaly, related to antiferromagnetic ordering at $T_N = 70$ mK, that is suppressed by a small critical field $B_c = 0.06$ T ($B \perp c$). By contrast, very tiny anomalies at $T_N = (20 \pm 5)$ mK and $B_c = (0.027 \pm 0.005)$ T are observed in the $x = 0.05$ system. The NFL behavior above T_N is not affected by the Ge substitution.

The tetragonal heavy fermion system $YbRh_2Si_2$ is located very close to an antiferromagnetic (AF) quantum critical point (QCP). At $B = 0$ it shows pronounced non-Fermi liquid (NFL) behavior, i.e. $C/T \propto -\log(T)$ from 10 K down to 0.3 K, below which it diverges stronger than logarithmic [1]. Well below the AF phase transition at $T_N = 70$ mK it enters a Landau Fermi liquid state with a very heavy quasiparticle mass [2]. From both, the magnetic entropy at T_N [2] and μSR experiments [3] a very small value of about $10^{-2}\ \mu_B/\mathrm{Yb}$ for the ordered moment in the AF state is deduced. The application of pressure to $YbRh_2Si_2$ increases T_N [5] as expected, because the ionic volume of the magnetic $4f^{13}$ Yb^{3+} configuration is smaller than that of the non-magnetic $4f^{14}$ Yb^{2+} one. Expanding the crystal lattice by randomly substituting Ge for the smaller isoelectric Si atoms allows one to reach the zero-field QCP. Below, we report a comparative study of low-temperature thermal expansion and magnetostriction measurements on pure ($x = 0$) and Ge-doped (nominal concentration: $x = 0.05$) $YbRh_2(Si_{1-x}Ge_x)_2$.

Single crystalline platelets with residual resistivities of 1 μΩ cm ($x = 0$) [2] and 5 μΩ cm ($x = 0.05$) [4] were grown from In flux. The T_N vs. pressure diagram of the Ge-doped system matches perfectly with that found for pure $YbRh_2Si_2$ if the pressure axis is shifted by -0.2 GPa [5]. This reveals an effective Ge-content of 0.02 ± 0.004 in agreement with the microprobe analysis [6]. The large difference between nominal and effective Ge-content is due to the fact, that Ge dissolves better than Si in the In-flux. The thermal expansion coefficient α is defined as $L^{-1}\mathrm{d}L/\mathrm{d}T$, where L denotes the sample length. For temperatures between 50 mK and 6 K, a high-resolution capacitive dilatometer of pure silver was used. The low-temperature measurements including the magnetostriction were performed in a CuBe dilatometer.

Above 100 mK, we observe for both systems a negative $\alpha(T)$ with a moderate anisotropy $\alpha_\perp \approx 1.5\alpha_\parallel$ (Fig. 1). No significant difference between the two systems is found. The pronounced NFL effects visible in α/T vs. T are discussed in Ref. [7]. At lower temperatures, the pure compound shows a sharp phase transition at $T_N = 70$ mK that has disappeared for the $x = 0.05$ system (inset Fig. 1). For the latter the onset of the very weak phase transition observed recently in specific-heat measurements at $T_N = (20 \pm 5)$ mK [6], becomes visible only below about 25 mK.

It has been shown recently, that the AF order in $YbRh_2Si_2$ is suppressed by critical magnetic fields B_c of

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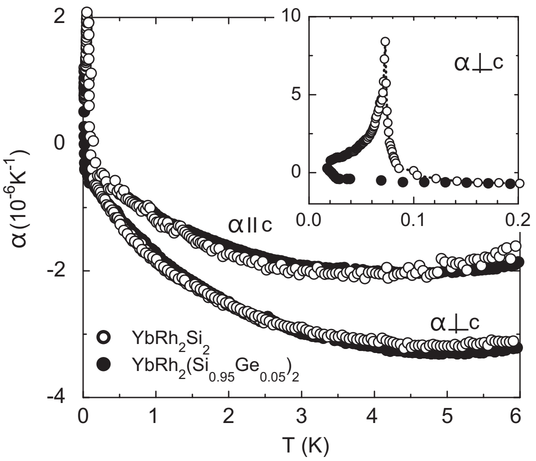

Fig. 1. Linear thermal expansions of $YbRh_2(Si_{1-x}Ge_x)_2$ for $x = 0$ (open circles) and $x = 0.05$ (solid circles) along and perpendicular to the tetragonal c-axis. The inset displays the low-temperature data for $\alpha \perp c$.

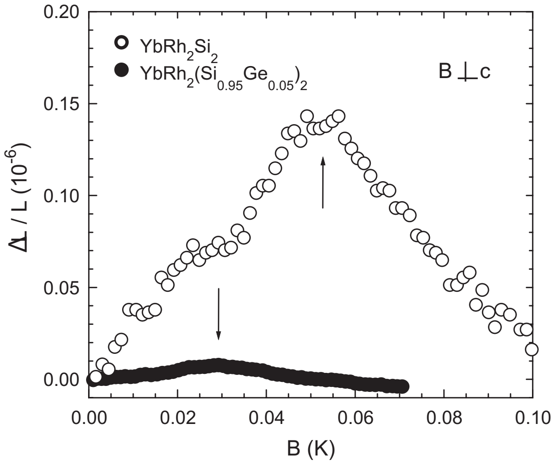

Fig. 2. Isothermal length change $\Delta L/L$ (along the magnetic field) vs. B, applied perpendicular to the c-axis. Data for $YbRh_2Si_2$ (open circles) and $YbRh_2(Si_{0.95}Ge_{0.05})_2$ (solid circles) are taken at $T = 15$ mK and $T \approx 10$ mK, respectively. Arrows indicate critical fields B_c.

0.06 T (0.66 T) applied perpendicular (parallel) to the c-axis [2]. The isothermal magnetostriction $\Delta L/L$ for the pure compound shows a clear kink at B_c, indicative of a second-order phase transition (Fig. 2). The negative slope of the magnetostriction for $B > B_c$ results from the magnetic polarization of the Yb^{3+} moments [8]. For the $x = 0.05$ system we observe much smaller changes in $\Delta L/L$ (in order to reduce the noise, several independent measurements have been averaged). This might be related to different in-plane orientations of the two samples, and/or to the effect of the Ge-substitution. A kink, indicative for B_c, is visible at (0.027 ± 0.005) T. A similar value for the critical field in the Ge-doped system has been deduced from specific heat measurements [6].

In summary, the volume expansion produced by a tiny substitution of Si by Ge in $YbRh_2(Si_{1-x}Ge_x)_2$ reduces T_N and B_c to about 20 mK and 25 mT for (nominal) $x = 0.05$. Thus in this system, NFL behavior can be studied extremely close to a zero-field QCP [6,7].

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