

# Low-temperature thermal expansion and magnetostriction of $\text{YbRh}_2(\text{Si}_{1-x}\text{Ge}_x)_2$ ( $x = 0$ 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  $\text{YbRh}_2(\text{Si}_{1-x}\text{Ge}_x)_2$  ( $x = 0$  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.

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**Keywords:** Non-Fermi liquid; Quantum critical point;  $\text{YbRh}_2\text{Si}_2$

The tetragonal heavy fermion system  $\text{YbRh}_2\text{Si}_2$  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  $\mu\text{SR}$  experiments [3] a very small value of about  $10^{-2} \mu_B/\text{Yb}$  for the ordered moment in the AF state is deduced. The application of pressure to  $\text{YbRh}_2\text{Si}_2$  increases  $T_N$  [5] as expected, because the ionic volume of the magnetic  $4f^{13} \text{Yb}^{3+}$  configuration is smaller than that of the non-magnetic  $4f^{14} \text{Yb}^{2+}$  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:  $x = 0.05$ )  $\text{YbRh}_2(\text{Si}_{1-x}\text{Ge}_x)_2$ .

Single crystalline platelets with residual resistivities of  $1 \mu\Omega \text{ cm}$  ( $x = 0$ ) [2] and  $5 \mu\Omega \text{ cm}$  ( $x = 0.05$ ) [4] were

grown from In flux. The  $T_N$  vs. pressure diagram of the Ge-doped system matches perfectly with that found for pure  $\text{YbRh}_2\text{Si}_2$  if the pressure axis is shifted by  $-0.2$  GPa [5]. This reveals an effective Ge-content of  $0.02 \pm 0.004$  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  $\alpha$  is defined as  $L^{-1}dL/dT$ , 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  $\alpha/T$  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  $\text{YbRh}_2\text{Si}_2$  is suppressed by critical magnetic fields  $B_c$  of

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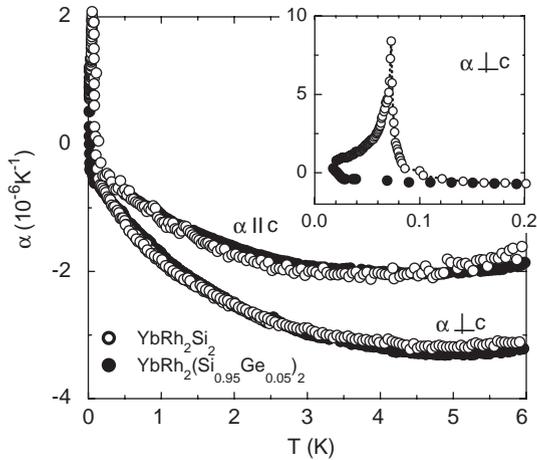


Fig. 1. Linear thermal expansions of  $\text{YbRh}_2(\text{Si}_{1-x}\text{Ge}_x)_2$  for  $x = 0$  (open circles) and  $x = 0.05$  (solid circles) along and perpendicular to the tetragonal  $c$ -axis. The inset displays the low-temperature data for  $\alpha \perp c$ .

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  $\text{Yb}^{3+}$  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  $(0.027 \pm 0.005)$  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  $\text{YbRh}_2(\text{Si}_{1-x}\text{Ge}_x)_2$

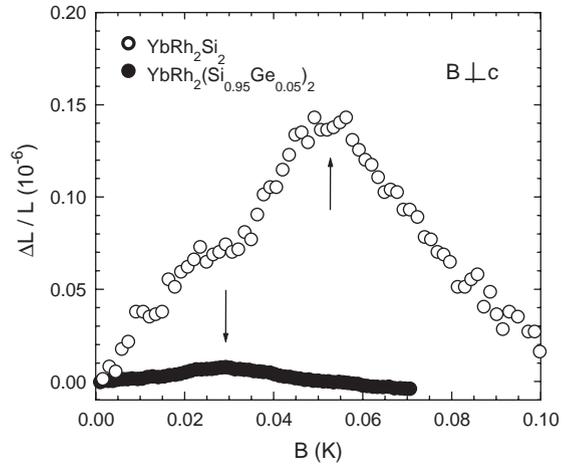


Fig. 2. Isothermal length change  $\Delta L/L$  (along the magnetic field) vs.  $B$ , applied perpendicular to the  $c$ -axis. Data for  $\text{YbRh}_2\text{Si}_2$  (open circles) and  $\text{YbRh}_2(\text{Si}_{0.95}\text{Ge}_{0.05})_2$  (solid circles) are taken at  $T = 15$  mK and  $T \approx 10$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

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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