Low-temperature magnetic susceptibility of Yb(Rh1-xMx)2Si2 (M = Ir, Co) single crystals

T. Westerkamp, Philipp Gegenwart, C. Krellner, C. Geibel, F. Steglich

Angaben zur Veröffentlichung / Publication details:

Westerkamp, T., Philipp Gegenwart, C. Krellner, C. Geibel, and F. Steglich. 2008. "Low-temperature magnetic susceptibility of Yb(Rh1-xMx)2Si2 (M = Ir, Co) single crystals." *Physica B: Condensed Matter* 403 (5-9): 1236–38. https://doi.org/10.1016/j.physb.2007.10.114.

Low-temperature magnetic susceptibility of $Yb(Rh_{1-x}M_x)_2Si_2(M = Ir, Co)$ single crystals

T. Westerkamp[a,*], P. Gegenwart[b], C. Krellner[a], C. Geibel[a], F. Steglich[a]

[a] *Max-Planck-Institute for Chemical Physics of Solids, D-01187 Dresden, Germany*
[b] *First Physics Institute, University of Göttingen, D-37077 Göttingen*

Abstract

We report low-temperature measurements of the magnetic susceptibility of $Yb(Rh_{1-x}M_x)_2Si_2(M = Ir, Co)$ single crystals for $0 \leqslant x_{Ir} \leqslant 0.17$ and $0 \leqslant x_{Co} \leqslant 0.12$. Whereas Ir-doping increases the unit-cell volume and weakens the antiferromagnetic ordering, Co-doping induces chemical pressure and stabilizes antiferromagnetism. Our results prove that Ir-substitution tunes the ground state from the magnetically ordered into the paramagnetic regime. For Co-substitution with $x_{Co} \geqslant 0.07$ two subsequent antiferromagnetic transitions are observed.

Keywords: $YbRh_2Si_2$; Quantum critical point; Non-Fermi liquid

The tetragonal $YbRh_2Si_2$ is a prototype for a clean and stoichiometric heavy fermion system close to a magnetic quantum critical point (QCP) [1]. It displays very weak antiferromagnetic (AF) ordering at $T_N = 0.07\,K$ which is suppressed by small critical magnetic fields of about 0.7 and 0.06 T parallel and perpendicular to the c-axis, respectively [2]. Pronounced non-Fermi liquid effects have been observed in the approach of the field-tuned QCP. The heavy quasiparticle mass diverges stronger than logarithmic [3] and for the Grüneisen ratio a $T^{-0.7}$ divergence has been found [4]. Both observations exclude the conventional itinerant description [5,6] for the QCP in this system. Hall resistivity [7] and thermodynamic measurements [8] have found evidence for an additional low-energy scale $T^\star(H)$ which vanishes at the field-tuned QCP. When crossing $T^\star(H)$ at finite temperatures, all these properties show crossovers that for $T \to 0$ extrapolate to discontinuities that are unexpected within the conventional description of quantum criticality. The jump of the zero-temperature Hall coefficient indicates a drastic change of the Fermi surface volume at the QCP [7]. The energy scale $T^\star(H)$ may then be associated with the suppression of Kondo screening. Future studies should identify the nature of $T^\star(H)$ and reveal the conditions under which it vanishes at the magnetic QCP. For this purpose, a systematic investigation of the volume dependence of the $T - H$ phase diagram of $YbRh_2Si_2$ is needed. The isoelectronic substitution of Rh with either larger Ir or smaller Co may be interesting in this respect.

Here we report the first results on recently synthesized $Yb(Rh_{1-x}M_x)_2Si_2(M = Ir, Co)$ single crystals [9]. The magnetic susceptibility has been determined down to 20 mK using a low-frequency alternating field technique with modulation fields of the order of 0.1 mT, similar as previously used for the study of undoped $YbRh_2Si_2$ [1,2]. Neither temperature dependent out-of-phase signals nor frequency dependence has been observed. Thus, ac-susceptibility represents the differential susceptibility $\chi = dM/dH$ in the limit $H \to 0$.

Fig. 1 displays low-temperature data for $Yb(Rh_{1-x}Ir_x)_2Si_2(x \leqslant 0.17)$ single crystals. A clear AF phase transition is observed for $x = 0.025$ at $T_N = 0.04\,K$. For larger Ir

*Corresponding author. Tel: +49 351 4646 2323; fax: +49 351 4646 2360.
E-mail address: Westerkamp@cpfs.mpg.de (T. Westerkamp).

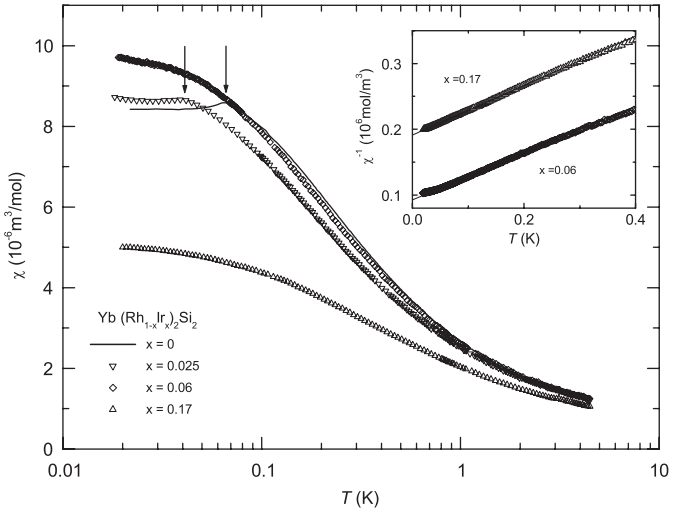

Fig. 1. Temperature dependence of the magnetic susceptibility as χ vs T (on a logarithmic scale) for various $Yb(Rh_{1-x}Ir_x)_2Si_2$ single crystals. The arrows indicate T_N for $x = 0$ and $x = 0.025$. The inset displays the $x = 0.06$ and 0.17 data as χ^{-1} vs T. The solid lines indicate Curie–Weiss behavior (see text).

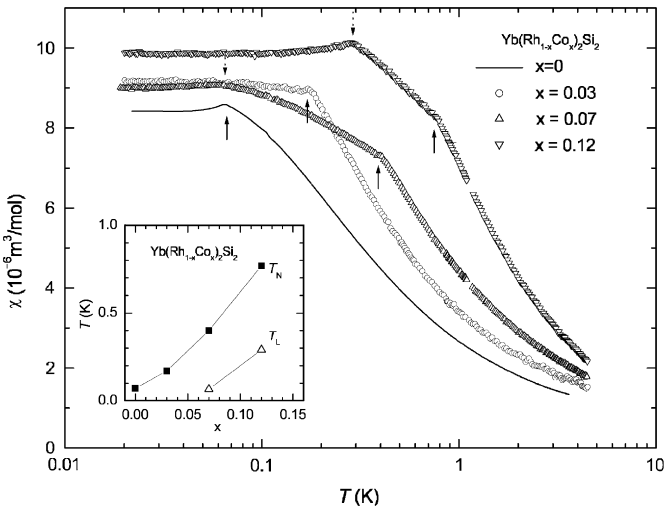

Fig. 2. Temperature dependence of the magnetic susceptibility as χ vs T (on a logarithmic scale) for various $Yb(Rh_{1-x}Co_x)_2Si_2$ single crystals. The solid and dashed arrows indicate the AF ordering temperature T_N as well as a second phase transition T_L, previously found in hydrostatic pressure experiments [10], respectively. The inset displays $T_N(x)$ and $T_L(x)$.

concentrations, the low-temperature susceptibility increases monotonically upon cooling to lowest temperatures. As shown in the inset of Fig. 1, the susceptibility follows a Curie–Weiss-like dependence $\chi(T) = C/(T + \Theta)$ with $\Theta = -0.25\,K$ for $x = 0.06$ and $\Theta = -0.5\,K$ for $x = 0.17$. For both samples a constant C is observed that corresponds to a fluctuating moment of $1.3\mu_B$/Yb. These values are rather similar to those found for pure $YbRh_2Si_2$ and $YbRh_2(Si_{0.95}Ge_{0.05})_2$ [3]. The slight deviation observed at temperatures below 0.05 K for $x = 0.06$ may indicate that this sample is still located at the magnetically ordered side of the QCP with a Néel temperature below 20 mK. From the observed decrease of T_N with increasing amount of Ir it is estimated that the sample with $x = 0.17$ could be on the paramagnetic side of the QCP. In addition, the higher absolute value of Θ in this sample may indicate that this sample is already further away from the QCP.

We now turn to $Yb(Rh_{1-x}Co_x)_2Si_2$ in which the isoelectronic substitution of Rh with the smaller Co atoms induces chemical pressure. As shown in Fig. 2, with increasing Co-concentration $\chi(T)$ steepens upon cooling from 4 K and T_N (indicated by the solid arrows) shifts towards higher temperatures. For single crystals with $x \geqslant 0.07$ the susceptibility displays two subsequent anomalies upon cooling. The higher ones, indicated by the upwards pointing solid arrows in Fig. 2, correspond to the onset of AF ordering and arise from the continuation of $T_N = 70\,mK$ at $x = 0$, cf. inset of Fig. 2. The lower ones indicated by the downward pointing dotted arrows mark an additional phase transition inside the AF state. Previous measurements of the electrical resistivity of $YbRh_2Si_2$ under hydrostatic pressure have also found this transition, labeled T_L. Isothermal magnetization measurements at 50 mK at a hydrostatic pressure of 1.28 GPa [11] have found two kinks in $M(H)$ at $H_{c,1} = 0.06\,T$ and $H_{c,2} = 0.26\,T$, related to the suppression of T_L and T_N, respectively.

The dependence of the two AF phase transition temperatures T_N and T_L on the Co-concentration in $Yb(Rh_{1-x}Co_x)_2Si_2$ is displayed in the inset of Fig. 2. This plot strongly resembles the temperature vs pressure phase diagram obtained from hydrostatic pressure experiments on $YbRh_2Si_2$ [10] and demonstrates that the main effect of Co-doping is to induce a chemical pressure in the system.

To summarize, the partial substitution of Rh with the larger Ir- or smaller Co-atoms allows to study the effect of small volume changes on the ground state properties of $YbRh_2Si_2$. Chemical pressure induced by Co-substitution stabilizes the AF ordering and gives rise to a second transition T_L, previously observed in pressure experiments. On the other hand, a small volume expansion induced by Ir-doping completely suppresses antiferromagnetism and tunes the system into the Landau Fermi liquid regime. Thermodynamic and transport measurements are under way to study the evolution of the $T^*(H)$ line and field-induced QCP with volume expansion and volume contraction.

References

[1] O. Trovarelli, C. Geibel, S. Mederle, C. Langhammer, F.M. Grosche, P. Gegenwart, M. Lang, G. Sparn, F. Steglich, Phys. Rev. Lett. 85 (2000) 626.

[2] P. Gegenwart, J. Custers, C. Geibel, K. Neumaier, T. Tayama, K. Tenya, O. Trovarelli, F. Steglich, Phys. Rev. Lett. 89 (2002) 056402.

[3] J. Custers, P. Gegenwart, H. Wilhelm, K. Neumaier, Y. Tokiwa, O. Trovarelli, C. Geibel, F. Steglich, C. Pépin, P. Coleman, Nature 424 (2003) 524.

[4] R. Küchler, N. Oeschler, P. Gegenwart, T. Cichorek, K. Neumaier, O. Tegus, C. Geibel, J.A. Mydosh, F. Steglich, L. Zhu, Q. Si, Phys. Rev. Lett. 91 (2003) 066405.
[5] A.J. Millis, Phys. Rev. B 48 (1993) 7183.
[6] T. Moriya, T. Takimoto, J. Phys. Soc. Japan 64 (1995) 960.
[7] S. Paschen, T. Lühmann, S. Wirth, P. Gegenwart, O. Trovarelli, C. Geibel, F. Steglich, P. Coleman, Q. Si, Nature 432 (2004) 881.
[8] P. Gegenwart, T. Westerkamp, C. Krellner, Y. Tokiwa, S. Paschen, C. Geibel, F. Steglich, E. Abrahams, Q. Si, Science 315 (2007) 969.
[9] C. Krellner, et al., unpublished.
[10] S. Mederle, R. Borth, C. Geibel, F.M. Grosche, G. Sparn, O. Trovarelli, F. Steglich, J. Phys. Condens. Matter 14 (2002) 1073.
[11] Y. Tokiwa, P. Gegenwart, T. Radu, J. Ferstl, G. Sparn, C. Geibel, F. Steglich, Phys. Rev. Lett. 94 (2005) 226402.