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Approaching field tuned quantum criticality in $CeIn_{3-x}Sn_x$

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Abstract

We report on the magnetic field evolution of the Neel temperature T_N in the heavy electron system $CeIn_{3-x}Sn_x$ ($x = 0$ and 0.3), as determined by specific heat, magnetocaloric effect, and electrical transport measurements. For the stoichiometric compound, T_N is fully suppressed at $H_c \sim 65\,T$, whereas for $x = 0.3$ the critical field extrapolates to $H_c \sim 30\,T$. An increasing Sommerfeld coefficient γ, obtained above T_N, as field increases is observed and could be related to the a putative quantum critical point at H_c.

Keywords: $CeIn_3$; Heavy fermions; Quantum criticality

$CeIn_3$ is a cubic intermetallic heavy fermion compound with a ground state resulting from the competition of long ranged antiferromagnetism produced by RKKY interactions and the Kondo effect. The former dominates at low temperatures, leading to an antiferromagnetic phase (AFM) for temperatures $T < 10\,K$. However, when submitted to a hydrostatic pressure of $\sim 25\,kbar$, the screening of the 4*f* moments by the conduction electrons compensates the RKKY interaction and a particular situation where neither one of the ground state dominates is proposed to lead to a quantum critical point (QCP) [1]. As observed in other heavy fermion compounds, near the QCP a superconducting phase emerges resulting from the antiferromagnetic spin fluctuations [1].

An alternative way to perturb the interaction between 4*f* moments (and reduce the order temperature T_N) is by tin doping, so to yield $CeIn_{3-x}Sn_x$ [2]. Here, in contrast to pressure effects, at low doping levels a linear increase of the lattice constant is observed as x increases, thus indicating that Sn doping substantially influences the electronic structure of the stoichiometric compound [2]. It has been recently shown that around $x \sim 0.7$, where the ordered phase is fully suppressed, a non-Fermi liquid behavior (subquadratic temperature dependence of the resistivity and logarithmic temperature dependence of the specific heat) characteristic of quantum criticality is also observed [3]. A disadvantage of this binary alloying is its higher degree of disorder, which gives rise to broad transitions and may eventually conspire against the possible emergence of new phases in the vicinity of the QCP.

In this work, we show that a less invasive procedure is to suppress the order parameter by polarizing the 4*f* moments upon applying a magnetic field. Fig. 1 shows the H–T phase boundary of the AFM phase for the stoichiometric compound as determined by transport, specific heat C_p (upper inset), and magnetocaloric effect (MCE) measurements [4]. This phase boundary follows a dependence $T_N = T_{N,0}(1 - (H/H_c)^2)$ with $H_c \sim 65\,T$. The latter is somewhat higher than that recently estimated from magnetization measurements [5]. The absence of irreversibilities in the MCE and the shape of the C_p indicate that the phase transition remains of second order as the field increases. Rather compelling evidence for the existence of a QCP comes from the enhancement of the Sommerfeld coefficient γ for $T > T_N$ as field increases, shown in the lower panel of Fig. 1. It is worth noting that the determination of γ involves an extrapolation of the specific heat data from above T_N down to 0 K, therefore becomes more reliable at higher fields.

The very high field needed to reach the $T_N = 0$ point in pure $CeIn_3$ ($H_c > 60\,T$) makes the experimental study of the

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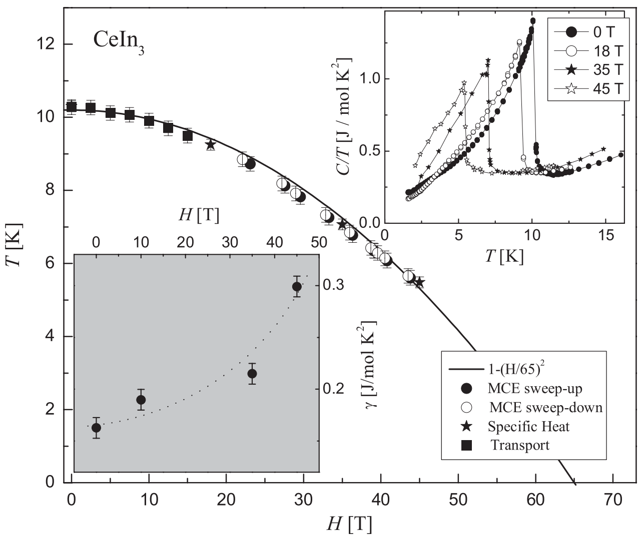

Fig. 1. Main panel: phase boundary determined by transport (square symbols), specific heat (star symbols) and magnetocaloric effect measurements increasing (solid symbols) and decreasing (open symbols) field for $CeIn_3$ together with a solid line fit. Upper inset: specific heat C/T as a function of temperature for $H = 0$, 18, 35, and 45 T. Lower inset: Sommerfeld coefficient γ for $T > T_N$ as a function of field. The dotted line is a guide to the eye.

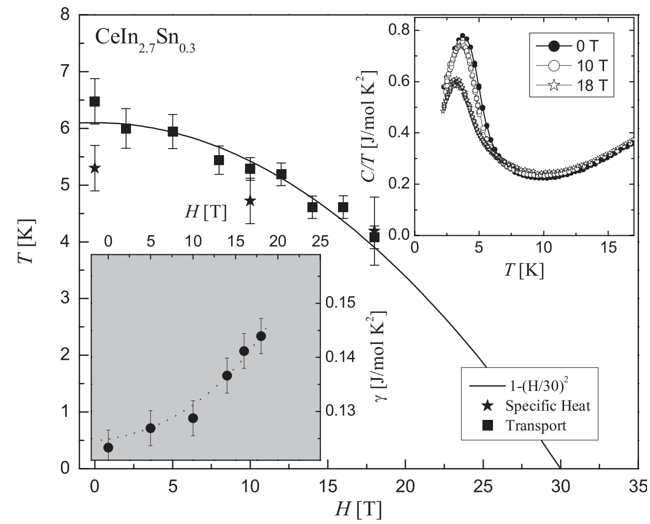

Fig. 2. Main panel: phase boundary determined by electro-transport (squares) and specific heat (stars) for $CeIn_{2.7}Sn_0.3$ together with a solid line fit. Upper inset: specific heat C/T as a function of temperature for $H = 0$, 10, and 18 T. Lower inset: Sommerfeld coefficient γ for $T > T_N$ as a function of field. The dotted line is a guide to the eye.

possible quantum criticality in the stoichiometric compound rather difficult. Slightly alloying $CeIn_3$ with Sn nevertheless ensures a low degree of disorder at the same time as bringing $T_N = 0$ within laboratory accessible magnetic fields (45 T). Fig. 2 shows the phase boundary for the $CeIn_{2.7}Sn_{0.3}$ as determined by a kink in the temperature dependence of the resistivity (square symbols) and the maximum negative derivative of the C/T vs T curves (star symbols). The upper inset of Fig. 2 shows the temperature dependence of the specific heat for $H = 0, 10,$ and 18 T. Clearly, the transition broadens and shifts toward lower temperatures with doping, in agreement with previous reports [3]. The field dependence of γ obtained from the specific heat data for $T > T_N$ is shown in the lower inset of Fig. 2. The trend in γ with increasing H is consistent with the existence of a quantum critical point at H_c. Clearly, further experiments are needed to gain more insight into the field induced quantum criticality in these compounds.

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