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Pressure dependence of the Néel and the superconducting transition temperature of $\text{CeCo}(\text{In}_{0.9}\text{Cd}_{0.1})_5$ studied by thermal expansion

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Abstract

We present low-temperature thermal expansion measurements on the nominally 10% Cd doped CeCoIn_5 . While the superconducting transition temperature is monotonically suppressed, an antiferromagnetic phase evolves in CeCoIn_5 by Cd-doping. For the uniaxial pressure dependence of the Néel temperature along c , we find $(\partial T_N/\partial p)_{\parallel c} = 0.206 \text{ K/GPa}$. The magnetic field dependence (for $B\parallel c$) of T_N is stronger compared to CeRhIn_5 . As no traces of a superconducting transition are resolved in thermal expansion along the c -axis, we estimate a lower limit of the in-plane pressure dependence to $(\partial T_c/\partial p)_{\perp c} = 0.38 \text{ K/GPa}$.

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1. Introduction

The tetragonal CeMIn_5 ($M = \text{Co}, \text{Rh}, \text{Ir}$) family of heavy fermion compounds is ideally suited to study the interplay of magnetic and superconducting (SC) ground states. While CeRhIn_5 orders antiferromagnetically (AFM) below $T_N = 3.8 \text{ K}$ [1], CeIrIn_5 [2], and CeCoIn_5 [3] superconduct below $T_c = 0.4$ and 2.3 K , respectively. The observed non-Fermi liquid behavior in the Co-115 close to the upper critical field of the superconductivity is believed to originate from a magnetic quantum critical point which coincides with the upper critical field for superconductivity [4,5]. By doping Cd on the In-sites, CeCoIn_5 can be driven to an AFM ground state and shows superconductivity below $T_c \approx 1.3 \text{ K}$. In a wide range of concentration and pressure, both, SC and AFM coexist [6].

2. Results

Here, we present thermal expansion measurements on $\text{CeCo}(\text{In}_{0.9}\text{Cd}_{0.1})_5$, which orders AFM commensurate with the crystal lattice at $T_N \approx 3 \text{ K}$ [7]. The magnetic intensity below $T_c \approx 1.3 \text{ K}$, where superconductivity is observed in electrical resistivity and specific heat, changes only marginal which points to a coexistence of AFM and SC [8]. The nominally 10% Cd-doped sample can be considered to be shifted by 1.6 GPa with respect to CeRhIn_5 derived from the temperature pressure phase diagram for the latter [6].

The uniaxial thermal expansion coefficient along the c -direction $\alpha_{\parallel c}$ was obtained by means of a high resolution capacitive dilatometer adapted to a $^3\text{He}/^4\text{He}$ dilution refrigerator. Its relative resolution of up to 10^{-11} allows to study pressure dependences of the Néel temperature and the SC transition temperature most sensitively.

Previous specific heat studies showed that T_c is monotonically suppressed by Cd doping and vanishes at $x \approx 0.15$. Simultaneously, antiferromagnetism appears at $x \approx 0.05$ and the Néel temperature increases as x increases.

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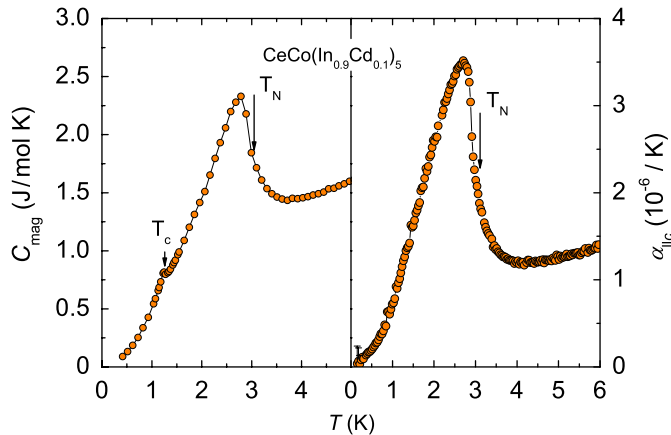


Fig. 1. Temperature dependence of the magnetic contribution to the specific heat C_{mag} (left) and the uniaxial thermal expansion coefficient $\alpha_{\parallel c}$ along the tetragonal c -direction for $\text{CeCo}(\text{In}_{0.9}\text{Cd}_{0.1})_5$.

In Fig. 1, the magnetic contribution to the specific heat is shown, measured in a commercial physical property measurement system (PPMS, quantum design). A lambda-like anomaly, indicative for a second order phase transition is detected at T_N . A second, much smaller anomaly marks the onset of superconductivity. In the right part of Fig. 1, the thermal expansion parallel to the c -direction vs. temperature is plotted. The Néel temperature $T_N \approx 3$ K is in good agreement with the aforementioned results of $C(T)$. An SC phase transition, however, could not be resolved at lower temperatures.

Assuming a scattering of $\Delta\alpha \approx 0.2 \times 10^{-6}/\text{K}$ of the data at $T_c \approx 1.3$ K, a lower limit of the uniaxial pressure dependence along c can be estimated with the Ehrenfest relation $(\partial T_c/\partial p) = V_m T_c (\Delta\alpha/\Delta C)$ (V_m : molar volume) to $(\partial T_c/\partial p)_{\parallel c} = 0.040$ K/GPa, whereas the jump anomaly ΔC has been estimated by an equal-area construction in $C(T)/T$. The hydrostatic pressure dependence of the SC transition temperature can be derived from the temperature pressure phase diagram [6,9] and is evaluated to (0.8 ± 0.2) K/GPa. This leads to the conclusion, that the uniaxial in-plane pressure dependence has to be at least $(\partial T_N/\partial p)_{\perp c} = 0.38$ K/GPa and accordingly a jump anomaly in the thermal expansion of $\alpha_{\perp c} = 1.9 \times 10^{-6}/\text{K}$ is expected. Further measurements are needed to confirm this prediction.

The crystal structure of the CeMIn_5 family which consists of an alternating series of CeIn_3 and MIn_2 , stacked along c , gives rise to extended 2D behavior in the physical properties. Thus, an anisotropy of the pressure dependences is expected which indeed has been observed in the isostructural compound CeRhIn_5 [10] and in undoped CeCoIn_5 . For the latter, the uniaxial pressure dependence of the SC transition temperature along c is $(\partial T_c/\partial p)_{\parallel c} = 0.18$ K/GPa while in-plane $(\partial T_c/\partial p)_{\perp c} = 0.3$ K/GPa has been found [11].

We now turn to the analysis of the antiferromagnetic phase transition. In Fig. 2, $\alpha_{\parallel c}$ is shown for various

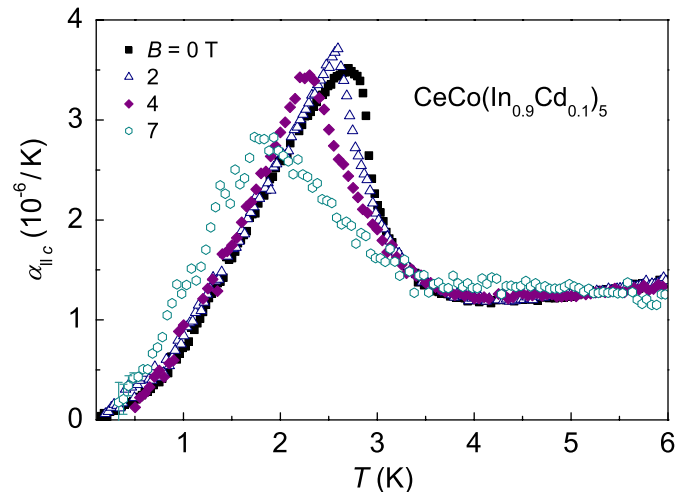


Fig. 2. Uniaxial thermal expansion coefficient $\alpha_{\parallel c}$ along the tetragonal c -direction for various magnetic fields for $\text{CeCo}(\text{In}_{0.9}\text{Cd}_{0.1})_5$.

magnetic fields of $B = 0, 2, 4,$ and 7 T ($B \parallel c$). The anomaly marks the temperature below which the system orders AFM. The uniaxial pressure dependence of the Néel temperature along c for $B = 0$ T yields $(\partial T_N/\partial p)_{\parallel c} = 0.206$ K/GPa. In magnetic fields ($B \parallel c$), T_N is shifted to lower temperatures, similar to CeRhIn_5 , but with an about ten times stronger field dependence compared to the latter [12]. Hence, the antiferromagnetic ground state is much less stable than that of CeRhIn_5 toward external magnetic fields. Since the orientation of the magnetic moments of the Cd-doped CeCoIn_5 is not yet clarified, the origin of this difference remains unclear.

3. Summary

To summarize, we have studied the heavy fermion compound $\text{CeCo}(\text{In}_{0.9}\text{Cd}_{0.1})_5$ by low-temperature thermal expansion measurements. While the results for the Néel temperature are in agreement with specific heat data, no sign of the SC phase transition could be resolved. We assign this to the anisotropy of the uniaxial pressure dependences in this family of compounds. A rough estimation in terms of the Ehrenfest relation leads to an expected jump anomaly of $\Delta\alpha_{\perp c} \approx 1.9 \times 10^{-6}/\text{K}$ which needs to be verified experimentally in future measurements. The pressure dependence of the Néel temperature yields $(\partial T_c/\partial p)_{\parallel c} = 0.206$ K/GPa. The suppression of T_N in external magnetic fields ($B \parallel c$) is significantly stronger than for CeRhIn_5 .

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