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Crossover from Landau Fermi liquid to non-Fermi liquid behavior: Indications from Hall measurements on $CeCoIn_5$

C. Capan [a,b], S. Singh [a,1], S. Nair [a], M. Nicklas [a], H. Lee [c], J.F. DiTusa [b], Z. Fisk [c], S. Wirth [a,*], F. Steglich [a]

[a] *Max Planck Institute for Chemical Physics of Solids, Nöthnitzer Straße 40, 01187 Dresden, Germany*
[b] *Department of Physics and Astronomy, Louisiana State University, Baton Rouge, LA 70803, USA*
[c] *Department of Physics, University of California, Irvine, CA 95616, USA*

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Abstract

We conducted Hall effect measurements on the heavy-fermion superconductor $CeCoIn_5$ for temperatures 0.05–5 K and for pressures up to 1.2 GPa. A scaling of the magnetic field H is introduced for the differential Hall coefficient, $R_H^d = \partial\rho_{xy}(T,H)/\partial H$ resulting in a single generic curve for $R_H^d(H)$ curves obtained at different T. We argue that the peak feature apparent in this generic curve corresponds to the crossover from non-Fermi liquid to Landau Fermi liquid behavior.

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Keywords: Superconductivity; Heavy-fermion metal; Landau Fermi liquid

The compound $CeCoIn_5$ is particularly suited to investigate the interplay of quantum criticality and unconventional superconductivity (SC) in which the pairing might be mediated by magnetic fluctuations. It exhibits the highest superconducting critical temperature, T_c, among the Ce-based ambient pressure superconductors [1], a magnetic field tuned quantum critical point (QCP) may exist [2] close to the upper critical field of SC, H_{c2}, and SC may hide an antiferromagnetic (AFM) order.

Hall effect measurements are a well established tool to shed light on the electronic properties of materials close to a QCP. Accordingly, such measurements have early been conducted for $T \geqslant 1$ K [3], even for applied pressures p [4]. In our case, we want to concentrate on the low-T region 0.05 K $\leqslant T \leqslant$ 5 K and $p \leqslant 1.2$ GPa. At these T well below the coherence temperature $T^* \approx 40$ K no anomalous Hall contribution is found. However, interpretation of Hall effect in $CeCoIn_5$ is complicated since SC inhibits a determination of the initial Hall coefficient and multiple bands at the Fermi level contribute to the Hall signal with a field dependent cyclotron mass [5].

For Hall measurements, isothermal field sweeps were conducted on single crystalline $CeCoIn_5$ samples with $H \| c$. Measurements under pressure were carried out in a piston cylinder type pressure cell. The evolution of the Hall resistivity ρ_{xy} (left) and its differential $R_H^d = \partial\rho_{xy}/\partial H$ (right) for increasing p at $T = 120$ mK is shown in Fig. 1. A changing slope of $\rho_{xy}(H)$, as obvious from the $T = 120$ mK data, is observed for $0.1 \leqslant T \leqslant 0.3$ K at $p = 0$ and 0.3 GPa resulting in a minimum of $|R_H^d|$ (arrow). This feature is suppressed with increasing p and can no longer be resolved at 1.2 GPa.

For further analysis, the H-values of the ambient pressure isothermal $R_H^d(T,H)$ vs. H curves were scaled by H_{min}^d. Here, H_{min}^d denotes the field value at which $|R_H^d|$ assumes its minimum for $70 \leqslant T \leqslant 200$ mK. As seen in

* Corresponding author. Tel.: +49 351 4646 3229; fax: +49 351 4646 3232.
E-mail address: wirth@cpfs.mpg.de (S. Wirth).
[1] Present address: Laboratoire de Physico-Chimie de l'Etat Solide, Université Paris-Sud, 91405 Orsay, France.

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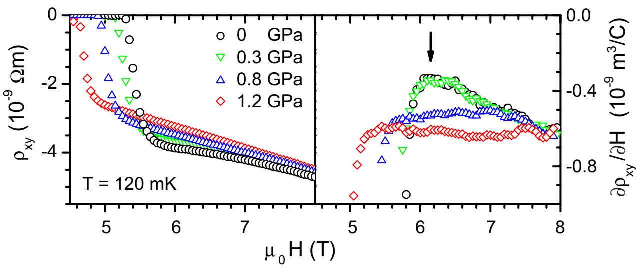

Fig. 1. Evolution of the isothermally measured Hall resistivity ρ_{xy} (left) and differential Hall coefficient $\partial\rho_{xy}/\partial H$ (right) of $CeCoIn_5$ with pressure at 120 mK. The arrow indicates the "peak feature" referred to in the text.

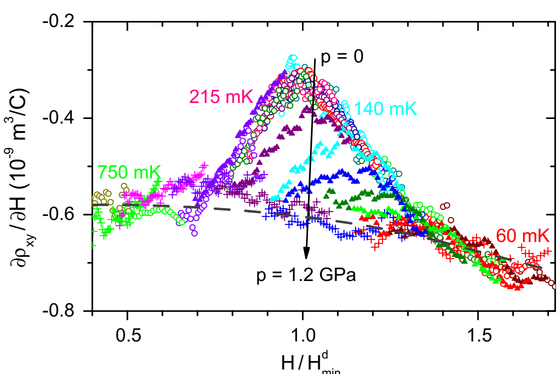

Fig. 2. Summarized differential Hall coefficient for $p = 0$ (○), 0.8 GPa (▲) and 1.2 GPa (+) illustrating the increasing suppression of the Hall "peak feature" (arrow in Fig. 1). Magnetic fields are scaled with respect to H^d_{min} and different temperatures are presented by different colors.

Fig. 2(○), all scaled R^d_H curves collapse onto a single, generic curve. For T below/above the given range, the H-values were scaled such that this generic curve is further completed towards larger/smaller values H/H^d_{min}. Here, $\mu_{eff} \propto 1/H^d_{min}$ can be viewed as effective mobility, averaged over all Fermi surfaces (FS) contributing.

The ambient pressure R^d_H data between $0.7 \leqslant H/H^d_{min} \leqslant 1.3$ mark a distinct "peak feature", whereas smaller and larger scaled fields appear to form an underlying "base line" of weak H-dependence (dashed line, Fig. 2). This "peak feature" is likely related with the AFM spin fluctuations (SF), based on the following observations:

(i) p dependence: Applying pressure to $CeCoIn_5$ drives the system towards a heavy Landau Fermi liquid (LFL) state [6] by gradually suppressing the AFM SF [7]. This is likely related to the *increase* of T_c with p for small p, leading to maximum T_c at $p^* \sim 1.3$ GPa. Our R^d_H data at $p = 1.2$ GPa (+, Fig. 2), i.e. slightly below p^*, approach the base line, with minor deviations at $H/H^d_{min} \sim 0.7$. For intermediate $p = 0.8$ GPa, the R^d_H values appear to be reduced for lower fields only. Note that for H scaling at $p > 0$ the H^d_{min} values obtained at $p = 0$ were used.

(ii) R^d_H values: At low H ($< 0.7H^d_{min}$) we obtain $-R^d_H \approx 6 \times 10^{-10}$ m³/C with a slight H dependence (7×10^{-10} m³/C at $1.5H^d_{min}$). This value agrees remarkably well with the one reported [4] for the non-magnetic analogue $LaCoIn_5$ (-5.5×10^{-10} m³/C). Generally, pressure drives Ce from a $4f^1$ towards a non-magnetic $4f^0$ configuration. Moreover, R^d_H of the Ce- and the La-based compound agree well at $\mu_0 H = 7$ T, i.e. in the LFL regime.

(iii) The T dependence of H^d_{min} as obtained from the scaling (Fig. 2) tracks the crossover [2] from non-Fermi liquid to LFL behavior (not shown).

The "peak feature" might be related to AFM SF or to the opening of an AFM gap at the FS if a spin density wave is formed. The latter may also cause a discontinuity in R^d_H [8]. However, pressure suppresses the "peak feature" while changing the FS only little [5]. Note that Hall measurements (unlike thermodynamic ones) are sensitive to even weak fluctuations. Hence, the anisotropic AFM SF might be considered as a precursor of a gap opening.

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