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

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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 $0.05\text{ K} \leqslant T \leqslant 5$ 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

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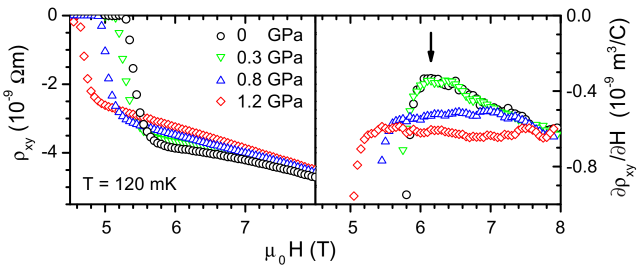

Fig. 1. Evolution of the isothermally measured Hall resistivity ρ_{xy} (left) and differential Hall coefficient $\partial\rho_{xy}/\partial H$ (right) of $CeCoIn_5$ with pressure at 120 mK. The arrow indicates the "peak feature" referred to in the text.

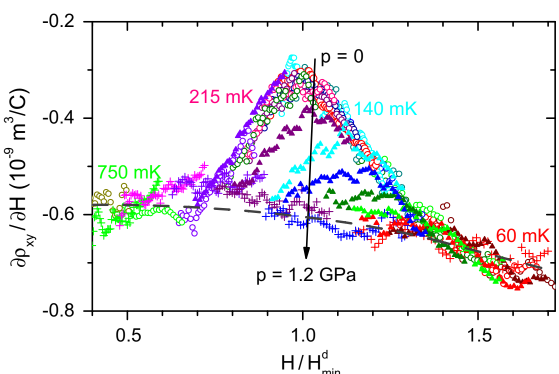

Fig. 2. Summarized differential Hall coefficient for $p = 0$ (○), 0.8 GPa (▲) and 1.2 GPa (+) illustrating the increasing suppression of the Hall "peak feature" (arrow in Fig. 1). Magnetic fields are scaled with respect to H^{d}_{min} and different temperatures are presented by different colors.

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 $-R^{d}_{H} \approx 6 \times 10^{-10}$ m^3/C with a slight H dependence (7×10^{-10} m^3/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} m^3/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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References

[1] C. Petrovic et al., J. Phys.: Condens. Matter 13 (2001) L337.
[2] J. Paglione et al., Phys. Rev. Lett. 91 (2003) 246405; A. Bianchi et al., Phys. Rev. Lett. 91 (2003) 257001.
[3] Y. Nakajima et al., J. Phys. Soc. Jpn. 73 (2004) 5; M.F. Hundley et al., Phys. Rev. B 70 (2004) 035113.
[4] Y. Nakajima et al., J. Phys. Soc. Jpn. 75 (2006) 023705.
[5] H. Shishido et al., J. Phys. Soc. Jpn. 71 (2002) 162; T. Maehira et al., J. Phys. Soc. Jpn. 72 (2003) 854; D. Hall et al., Phys. Rev. B 64 (2001) 212508.
[6] M. Nicklas et al., J. Phys.: Condens. Matter 13 (2001) L905; V.A. Sidorov et al., Phys. Rev. Lett. 89 (2002) 157004.
[7] M. Yashima et al., J. Phys. Soc. Jpn. 73 (2004) 2073.
[8] J. Fenton, A.J. Schofield, Phys. Rev. Lett. 95 (2005) 247201.