Anomalous Resistivity of $CeCoIn_5$ Single Crystals

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Abstract. In-plane angular θ dependent resistivity ρ_{ab} (ADR) was measured on single crystals of $CeCoIn_5$ heavy fermion superconductor at temperatures 3 K $\leq T \leq$ 20 K and in magnetic fields H up to 14 T. We find two different symmetries in ADR in the H-T phase diagram, one in the low field region, while the other in high field region. Both symmetries are in the non-Fermi liquid region. The boundary between the two symmetries of the ADR is the same as the crossover from $d\rho_{ab}(\theta=0)/dH > 0$ to $d\rho_{ab}(\theta=0)/dH < 0$, where $\rho_{ab}(\theta=0)$ is the resistivity when H is perpendicular to the ab-planes.

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The heavy fermion material $CeCoIn_5$ [1] is an unconventional superconductor with the highest superconducting transition temperature T_c of 2.3 K among heavy fermion compounds. Some measurements revealed d-wave parity pairing in this material [2, 3]. The superconductivity is near an antiferromagnetic quantum critical point, while the normal state exhibits pronounced non-Fermi liquid behavior [4]. Understanding the non-Fermi liquid behavior in the normal state of $CeCoIn_5$ can shed light on the nature of unconventional superconductivity of this exotic compound.

In this paper, we present angular θ dependent in-plane resistivity ρ_{ab} and torque τ measurements of $CeCoIn_5$, performed at different temperatures T and applied magnetic fields H. Two distinct symmetries were found in $\rho_{ab}(\theta,H,T)$ in the non-Fermi liquid region. Also, $\tau(\theta,H)$ shows paramagnetism with no evidence of a metamagnetic transition.

Single crystals of $CeCoIn_5$ (T_c = 2.3 K) were grown using the flux method. Typical size of crystals is $0.5\times0.5\times0.1 mm^3$. Both the out-of-plane ρ_c and in-plane ρ_{ab} resistivities were determined by using the electrical contact configuration of the flux transformer geometry [5]. The angular dependent resistivity $\rho_{ab}(\theta)$ and torque $\tau(\theta)$ were measured by rotating the single crystal from $H||c$-axis to $H||a$-axis, with θ the angle between H and the c-axis [see a sketch of the experimental configuration in the Inset to Fig. 1(b)].

Typical angular dependent resistivity curves of $CeCoIn_5$ are shown in Figs. 1(a) and 1(b), measured in low and high applied magnetic fields, respectively (the definition for high and low field regions is given in Fig. 2). Figure 1(a) shows that $\rho_{ab}(\theta)$ measured at 6 K and 3 T displays a four-fold-like symmetry while Fig. 1(b) shows that $\rho_{ab}(\theta)$ measured at 6 K and 8 T displays a six-fold-like symmetry. Note that the two distinct ADR behaviors shown in Figs. 1(a) and 1(b) have nodes at the same angle $\theta \approx 60^0$.

Figure 2 is the H-T phase diagram of $CeCoIn_5$, on which the $\rho_{ab}(H,T)$ data with four-fold-like and six-fold-like symmetry are represented as solid diamonds and solid stars, respectively. The solid squares represent the position of the maximum value of the resistivity, while the hatched line separates the $d\rho_{ab}(\theta=0)/dH < 0$ and $d\rho_{ab}(\theta=0)/dH > 0$ regions. Note that all $\rho_{ab}(H,T)$ with four-fold-like symmetry lies in the $d\rho_{ab}(\theta=0)/dH > 0$ region and the $\rho_{ab}(H,T)$ data with six-fold-like symmetry lies in the $d\rho_{ab}(\theta=0)/dH < 0$ region. Therefore, the change in the symmetry in $\rho_{ab}(\theta)$ correlates with the change in the field dependence of the resistivity measured with $H\perp a$-axis.

Figure 3 displays the angular dependence of the torque measured at 6 K and 3 T. These data are fitted well with $A\sin 2\theta$, with A a fitting parameter which depends on H and T.

Measurements of $\tau(\theta)$ at the same temperature and different values of the applied magnetic field (1 T $\leq H \leq$ 14 T) show that the parameter A displays an H^2 dependence (see Inset to Fig. 3). Hence the torque data follow:

$$\tau = -\frac{H^2}{2}(\chi_c - \chi_a)\sin 2\theta \qquad (1)$$

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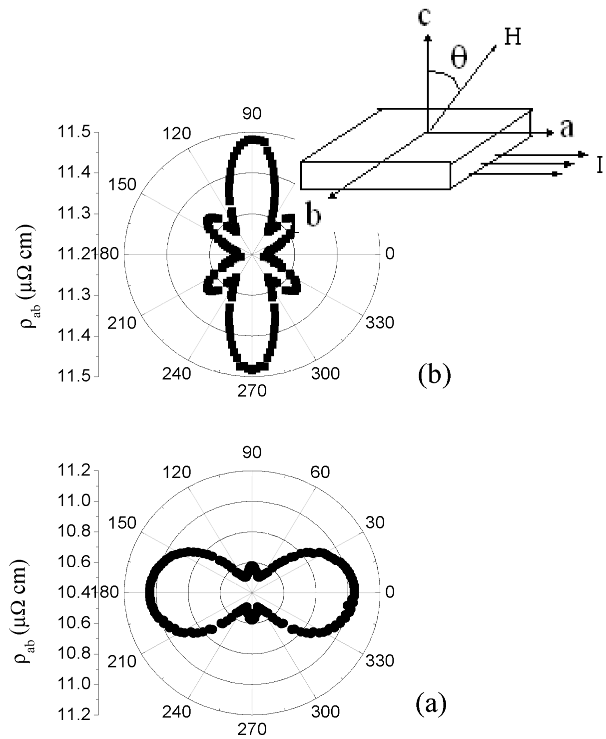

FIGURE 1. Polar plot of angular dependent resistvity of $CeCoIn_5$ measured at (a) 6 K and 3 T and (b) 6 K and 8 T. Plot (a) shows four–fold-like symmetry while plot (b) shows six-fold-like symmetry.

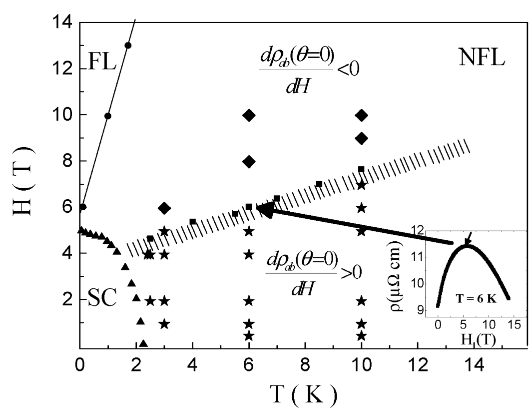

FIGURE 2. Field-temperature *H-T* phase diagram of CeCoIn5. The angular dependent resistivity data with four-fold-like (diamond) and six-fold-like (solid star) symmetries are shown. The solid squares represent the position at which $\rho_{ab}(\theta=0)$ is maximum.

This indicates anisotropic paramagnetism in the non-Fermi liquid region, which reflects the anisotropy between the *a*- axis and *c*- axis. Hence, there is no metamagnetic transition between 1 T and 14 T. This means that the change in the ADR behavior is not due to the spin ordering.

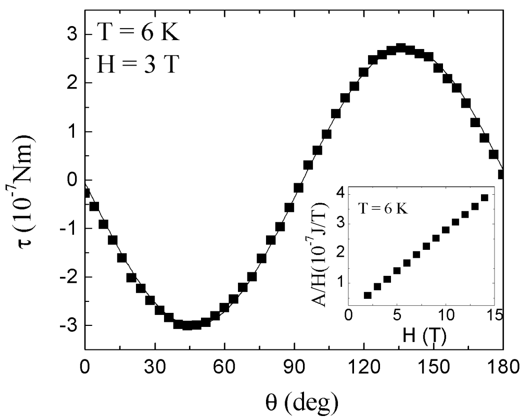

FIGURE 3. Plot of the angular θ dependent torque τ measured at 6 K in a magnetic field of 3 T. The solid line is a fit of the data with $sin2\theta$. Inset: Plot of A/H vs H.

In summary, we measured the angular dependent resistivity (ADR) and torque of $CeCoIn_5$. Two distinct ADR behaviors appear in the non-Fermi region, i.e., a four-fold-like symmetry and a six-fold-like symmetry, separated by the boundary between $d\rho_{ab}(\theta=0)/dH < 0$ and $d\rho_{ab}(\theta=0)/dH > 0$, where $\rho_{ab}(\theta=0)$ is the resistivity when H is perpendicular to the *ab*-planes. The normal state in the non-Fermi liquid region is paramagnetic, with no evidence for any metamagnetic transition. Therefore, the change in the behavior of the ADR is not due to spin ordering.

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