Anisotropic Transport and Magnetic Properties of Frustrated CeRhSn

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Abstract

The resistivity ρ, magnetic susceptibility χ, and specific heat C were measured for a single crystal of the valence-fluctuating hexagonal system CeRhSn. Strong anisotropy in both the resistivity ($\rho_a > \rho_c$) and magnetic susceptibility ($\chi_c > \chi_a$) was found. A hump appears in $\rho_c(T)$ below 7 K, where both C/T and χ exhibit strong upturns. Power-law behaviors $\chi_c \propto T^{-1.1}$ and $\chi_a \propto T^{-0.35}$ were found below 4 K and 16 K, respectively, down to 0.4 K. These results suggest the presence of unquenched moments in the quasi-Kagome lattice.

Key words: valence fluctuation; non-Fermi liquid; geometrical frustration

Recently, cerium-based equiatomic compounds CeTX, where T is a transition metal and X is an *sp* element, have received much attention. These compounds exhibit anomalous physical properties such as heavy-fermion behavior, valence fluctuation, and hybridization gap behavior. Most of CeRhX (X=Al, P, As, In, Sb, and Bi) belong to the valence fluctuation system, except for X=Bi (heavy-fermion) [1]. Both CeRhAs and CeRhSb possess high thermopower due to the narrow hybridization gap [2]. CeRhSn was classified into the valence fluctuating system [3,4], because the magnetic susceptibility strongly deviates from the Curie-Weiss law. In view of the hexagonal ZrNiAl-type structure, anisotropic physical properties are expected as was reported for CePdAl [5]. The quasi-Kagome lattice of Ce ions in CePdAl allows the existence of frustrated Ce^{3+} paramagnetic moments between antiferromagnetically ordered chains of Ce^{3+} ions below $T_N = 2.7$ K [6]. Here, we report transport and magnetic properties of a single crystal of CeRhSn.

A single crystal of CeRhSn was prepared by the Czochralski method in an induction furnace. Single-crystal X-ray diffraction analysis confirmed the ZrNiAl-type structure, where layers composed of Ce and Rh atoms alternate along the c-axis with layers composed of Rh and Sn atoms. Neither impurity phase nor off-stoichiometry was detected by the electron-probe microanalysis. A part of the asgrown crystal was annealed at 900 °C for three weeks. The electrical resistivity was measured by a conventional four-probe method. The specific-heat measurement was performed by an adiabatic calorimeter using a heat-pulse technique. The magnetic susceptibility for $2 < T < 300$ K was measured using a commercial SQUID magnetometer. The measurement down to 0.4 K was performed by a Faraday force magnetometer at ISSP, University of Tokyo [7].

Fig. 1 shows the resistivity data, ρ_a and ρ_c along the a- and c-axis, respectively. At all temperatures, ρ_a is about three times larger than ρ_c. With decreasing temperature, ρ_a increases and passes through a large and broad peak at 70 K, being typical of valence fluctuating system. By contrast, ρ_c monotonically decreases and exhibits a shoulder at 50 K, then shows a hump at 7 K, as is shown in the inset. At the lowest temperature of 0.4 K, ρ_a and ρ_c are 135 $\mu\Omega$cm and 45 $\mu\Omega$cm, respectively. The ρ_a and ρ_c for the annealed sample are same to those for the asgrown crystal (see inset of Fig. 1). This suggests that the large residual resistivity does not originate from microcracks and stresses

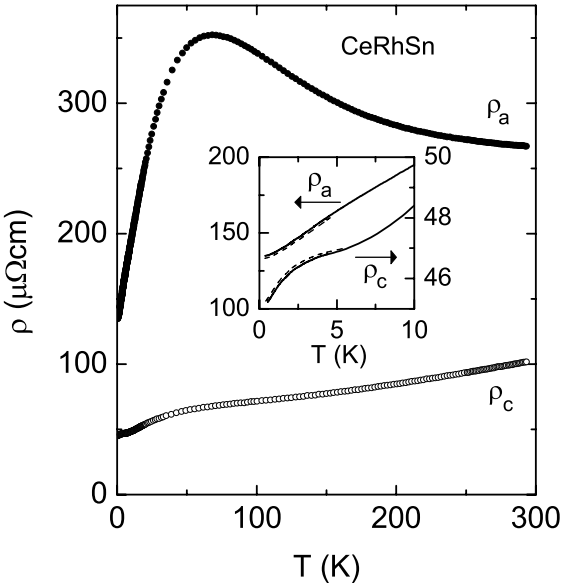

Fig. 1. Temperature dependence of resistivity of CeRhSn along the a- and c-axis. Inset shows the data below 10 K. Solid lines are the data for the asgrown crystal and dashed lines for the annealed crystal.

but from possible atomic disorder and/or geometrical frustration.

Fig. 2 shows the magnetic susceptibility $\chi \equiv M/B$ of CeRhSn at $B = 0.05$, 0.1, and 0.2 T. There is no broad maximum which is observed in conventional valence fluctuation systems. With decreasing temperature, χ_a and χ_c increase and exhibit an upturn below 10 K and 20 K, respectively. At the lowest temperature of 0.4 K, χ_c is ten times larger than χ_a. This strong anisotropy resembles that found in the isostructure antiferromagnet CePdAl [5]. Magnetic-field dependence in $\chi_c(T)$ appears for $T < 2$ K, while χ_a is independent of B. It is noteworthy that χ_a and χ_c for the annealed sample showed identical results above 2 K. The dashed lines show power-law behaviors below 4 K and 16 K, respectively; $\chi_a = 0.0051T^{-0.35}$ and $\chi_c = 0.059T^{-1.1}$. This divergent behavior as $T \to 0$ is different from the asymptotic dependence predicted for the AF spin fluctuations near to the quantum critical point [8]. Instead, the power-law behavior was reported in a disordered system containing unquenched spins [9]. In CeRhSn, unquenched spins may exist due to possible atomic disorder and/or geometrical frustration. Assuming the presence of a small fraction of free Ce^{3+} ions, the fraction is estimated as $\frac{0.059}{C} \times 100 = 7.3$ %, where C is the paramagnetic Curie constant for 1 mole Ce^{3+}. The inset of Fig. 2 shows temperature dependence of the specific heat divided by temperature, C/T. With decreasing T, C/T exhibits the $logT$ dependence for $1 < T < 5$ K. The fitting the data for $8 < T < 15$ K to $C/T = \gamma + \beta T^2$ gives $\gamma = 0.061$ J/molK^2 and $\beta = 5.83 \times 10^{-4}$ J/molK^4 (dashed line in inset of Fig. 2). The relation $\gamma = 0.18\pi^2 k_B/T_K$ leads to $T_K = 240$ K [10]. The entropy of the upturn part above the dashed line in the inset is estimated as 0.45 J/molK. It is 7.9 % of Rln2, in good agreement with the fraction of 7.3 % of Ce^{3+} ions estimated from the analysis of $\chi_c(T)$.

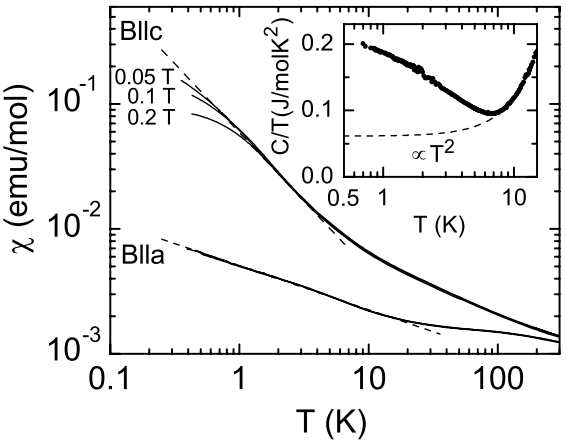

Fig. 2. Temperature dependence of the magnetic susceptibility under various magnetic fields. Dashed lines are the fitted results (see text). Inset shows the specific heat divided by temperature C/T vs. T.

In summary, we have revealed highly anisotropic behavior in transport and magnetic properties of single crystal CeRhSn. High-temperature properties are consistent with the characteristic temperature of $T_K = 240$ K. Below 7 K, however, we observed a hump in $\rho_c(T)$ and strong enhancement of both C/T and $\chi(T)$. Such enhancement may be attributed to the presence of unquenched moments in the quasi-Kagome lattice of the Ce-Rh plane. In order to explore the type of disorder, NMR studies are on going.

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