Electrical and magnetic properties of RCu (R = La, Ce, Pr, and Nd) systems

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Abstract

We have investigated the transport and magnetic properties of the RCu (R = La, Ce, Pr and Nd) systems by means of the ac electrical resistivity ρ and dc magnetization χ measurements. For LaCu, bulk superconductivity is observed with a superconducting transition temperature of 6.15 K as inferred from a sudden drop to zero value in the $\rho(T)$ curve and the diamagnetic behavior in the $\chi(T)$ curve. The occurrence of a peak in the $\chi(T)$ curve and a drop off in the $\rho(T)$ curve indicate that antiferromagnetic transition occurs in CeCu and NdCu with transition temperatures T_N of 3.72 and 10 K, respectively. A magnetization study reveals that an antiferromagnetic transition occurs at $T_N \approx 13$ K for PrCu.

1. Introduction

During the past few decades there have been a lot of research activities on the R–Cu (R = rare earth ions) compounds because of their interesting properties. Among the large variety of R–Cu systems, RCu have been reported to crystallize in orthorhombic FeB-type or cubic CsCl-type structure depending on the R ions [1–3]. For R = La, Ce, Pr, Nd, and Yb, RCu is of the FeB-type structure. Ac susceptibility study of LaCu indicates that a superconducting transition occurs at $T \sim 5.85$ K [4]. An antiferromagnetic transition was observed in CeCu with a Néel temperature T_N ranging from 2.7 to 3.6 K [2,5]. Magnetization measurements of PrCu and NdCu reveal anomalous characteristics in these compounds [3] and it is possible that PrCu and NdCu become magnetically ordered at low temperatures. In this paper, we report ac electrical resistivity and dc magnetization studies of the FeB-type RCu (R = La, Ce, Pr, and Nd) systems. We found that NdCu and PrCu become antiferromagnetic with $T_N \approx 10$ and 13 K, respectively.

2. Experimental details

The polycrystalline samples of RCu (R = La, Ce, Pr, and Nd) were prepared by arc-melting the high-purity elements (R elements: 99.99%, Cu: 99.9999%) together on a water cooled copper hearth in a Zr-gettered argon atmosphere, with no subsequent annealing. Ac electrical resistance $\rho(T)$ measurements on bar-shaped samples were performed in a helium dewar with four-wire technique using a Linear Research Model LR 400 ac resistance bridge operating at a frequency of 16 Hz with silicon diode and germanium thermometers as temperature sensors. Dc magnetization

measurements were performed using Quantum Design MPMS SQUID magnetometer from 2 to 300 K in various applied magnetic fields.

3. Results and discussion

The ac electrical resistivity ρ versus temperature T curves for RCu ($R = \text{La, Ce, Pr and Nd}$) are plotted in Fig. 1(a) for $0 \text{ K} \leq T \leq 300 \text{ K}$ and in Fig. 1(b) for $0 \text{ K} \leq T \leq 30 \text{ K}$. For LaCu, the superconducting transition occurs in the $\rho(T)$ curve below 6.4 K with the midpoint transition temperature T_c (50%) = 6.15 K and a transition width $\Delta T_c = 0.2 \text{ K}$. Dc magnetization measurement at $H = 10 \text{ G}$ reveals a diamagnetic transition occurring at the same temperature and indicating bulk superconductivity in this sample.

Fig. 1. Electrical resistivity as a function of temperature for RCu ($R = \text{La, Ce, Pr and Nd}$) compounds with (a) $0 \text{ K} \leq T \leq 300 \text{ K}$ and (b) $0 \text{ K} \leq T \leq 30 \text{ K}$.

Above T_c , the $\rho(T)$ curve exhibits typical characteristics of common metals and can be expressed as $\rho(T) = \rho_i + \rho_{\text{ph}}(T)$ with a residual resistivity $\rho_i = 1.33 \mu\Omega\text{-cm}$. The phonon contribution to the resistivity $\rho_{\text{ph}}(T)$ can be fitted by the semi-empirical Block-Grüneisen formula using a Debye temperature $\Theta_D = 120 \text{ K}$ and an electron-phonon interaction constant $C \approx 0.25 \mu\Omega\text{-cm/K}$. The large value of the RR ratio ($\rho(300 \text{ K})/\rho(7 \text{ K}) = 57$) reflects the high sample quality. The values of ρ at all temperatures T for RCu ($R = \text{Ce, Pr, and Nd}$) are larger than those of LaCu at the corresponding T and reveal the importance of the magnetic scattering contribution. As shown in Fig. 1(b), a rapid drop in the $\rho(T)$ curves occurs at $T \approx 4 \text{ K}$ for CeCu and $T \approx 12 \text{ K}$ for NdCu. This indicates that magnetic ordering occurs in these compounds below these temperatures. For PrCu, a small change in the slope of the $\rho(T)$ curve is observed at $T \approx 15 \text{ K}$, in consistency with the magnetization data which show an antiferromagnetic transition at the corresponding temperature (see below).

To obtain a better understanding of the magnetic contribution ρ_{mag} in these compounds, a semilogarithmic plot of $\rho_{\text{mag}}(T)$ plot is displayed in Fig. 2. The values of ρ_{mag} are extracted from the measured resistivity $\rho(T)$ of the RCu ($R = \text{Ce, Pr and Nd}$) compounds using $\rho(T) = \rho_{\text{LaCu}}(T) + \rho_{\text{mag}}(T)$, where $\rho_{\text{LaCu}}(T)$ is the resistivity of the isostructural nonmagnetic LaCu sample at the corresponding temperatures. Above the magnetic ordering temperatures, $\rho_{\text{mag}}(T)$ increases monotonically with T for all compounds; in particular, no $\ln T$ decrease is observed in CeCu.

Fig. 3 shows the dc magnetic susceptibilities χ as a function of temperature T for CeCu, PrCu and NdCu measured in an applied field $H = 5 \text{ kG}$ for $0 \text{ K} \leq T \leq 300 \text{ K}$. The magnetic susceptibility for CeCu exhibits a peak at $T = 3.72 \text{ K}$ which indicates the occurrence of antiferromagnetic transition in this compound. While for $T > 100 \text{ K}$, χ follows a Curie-Weiss behavior $\chi = C/(T - \Theta_p)$, with $\Theta_p = -42 \text{ K}$ and the Curie constant $C = N\mu_{\text{eff}}^2/3k_B$ corresponds to an effective moment $\mu_{\text{eff}} = 2.62\mu_B$ per Ce ion. This is shown in Fig. 4, where χ^{-1} versus T data for CeCu, PrCu and NdCu are plotted. The obtained

Fig. 2. Magnetic contribution of the resistivity ρ_{mag} as a function of temperature for RCu ($R = \text{Ce, Pr and Nd}$) compounds.

value of T_N is consistent with the temperature at which a drop off in the $\rho(T)$ curve occurs for CeCu and is higher than the values reported previously [2,5].

For NdCu, $\chi(T)$ also exhibits a peak at $T = 10$ K. The peak position is close to the temperature at which a drop in the $\rho(T)$ curve is observed and

indicates that antiferromagnetic transition occurs in NdCu with $T_N = 10$ K. Above ~ 150 K, the $\chi(T)$ curve also follows a Curie-Weiss behavior with a value of effective moment $\mu_{\text{eff}} = 3.7\mu_B$ and a Curie-Weiss paramagnetic intercept $\Theta_p = -15$ K. The obtained value of μ_{eff} is close to the value of the moment ($\mu_{\text{eff}} = 3.62\mu_B$) for the Nd^{3+} ions.

Fig. 3. Magnetic susceptibility as a function of temperature for RCu ($R = \text{Ce, Pr and Nd}$). The applied magnetic field $H = 5$ kG.

Fig. 4. The inverse susceptibility as a function of temperature for RCu ($R = \text{Ce}, \text{Pr}$ and Nd) compounds.

The magnetic susceptibility curve for PrCu reveals an antiferromagnetic-type transition at $T \approx 13 \text{ K}$, which is close to the temperature that a

change in the $\rho(T)$ slope was observed. The susceptibility curve $\chi(T)$ can be described with the Curie–Weiss law for $T > 160 \text{ K}$ with $\mu_{\text{eff}} = 3.52\mu_B$

Fig. 5. An antiferromagnetic ordering occurs near 13 K as reflected by the minimum in the $d\chi/dT$ versus T curve in an applied field of 5 kG.

and $\Theta_p = -13$ K. The value of Θ_p is close to the observed value of T_N as defined through the inflection point in the $\chi(T)$ curve or the minimum ($T = 13$ K) in the $d\chi/dT$ curve (Fig. 5).

In CeCu, the obtained value of μ_{eff} is close to that of the corresponding Ce^{3+} ions, together with the absence of the $\rho \propto -\ln T$ region in the $\rho_{\text{mag}}(T)$ curve reveals that above the magnetic transition temperature the Kondo interaction plays only a minor role in this system.

In conclusion, we have performed ac electrical resistivity and dc magnetization studies of the RCu ($R = \text{La, Ce, Pr and Nd}$) systems. In addition to reconfirming the existence of a superconducting transition in LaCu and an antiferromagnetic ordering in CeCu, we have found that NdCu and PrCu become antiferromagnetic with $T_N \approx 10$ and 13 K, respectively.

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