Magnetic and transport properties of a new ferromagnetic orthorhombic compound CePtAl$_2$

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Abstract. We have synthesized polycrystalline samples of CePtAl$_2$ by arc melting method and examined their magnetic, transport and thermal properties by measuring the magnetization, the electrical resistivity, and the specific heat down to 0.4 K. As a result of these measurements, we found that CePtAl$_2$ is a ferromagnetic Ce-based compound with the Curie-temperature $T_C = 2.7$ K.

1. Introduction

It has been reported that ferromagnetism and superconductivity, which are generally contradictory properties, coexist in some U-based compounds [1]. In order to elucidate the coexistence mechanism, it is necessary to investigate similar phenomena in a larger number of compounds. However, no coexistence phenomena have been found except in a few U-based compounds thus far. Ce-based compounds are the promising candidate showing coexistence since they have the same strong correlation between $f$-electrons and conduction electrons as U-based compounds. We have focused on new compounds RPtAl$_2$ (R = Sc, Y, La-Nd, Sm, Gd-Tm, Lu) [2]. As shown in the figure 1, RPtAl$_2$ crystallizes in the orthorhombic MgCuAl$_2$-type structure (space group $Cmcm$, $D_{2h}^{17}$, No. 63) [2]. The magnetization measurements of CePtAl$_2$ down to 2.5 K have revealed that CePtAl$_2$ did not show any phase transition and the effective magnetic moment $\mu_{\text{eff}}$ and the paramagnetic Curie temperature $\theta_P$ were estimated to be 2.52 $\mu_B$/Ce and -20.6 K, respectively. In this study, we have grown polycrystalline samples of CePtAl$_2$ and examined their magnetic and transport properties by measuring the magnetization, the electrical resistivity, and the specific heat down to 0.4 K.

Figure 1. Crystal structure of RPtAl$_2$. Dotted lines represent edges of the chemical unit cell.
2. Experimental Methods

Polycrystalline samples of CePtAl$_2$ are synthesized as the following procedure. First, Ce (99.9%), Pt (99.99%), and Al (99.999%) were weighed in the ideal 1:1:2 atomic ratio and melted using an arc furnace under an Ar gas atmosphere. Next, the samples wrapped in Ta foils were sealed in an evacuated quartz tube to prevent oxidation and annealed in a muffle furnace at 1320 K for one week. The annealed samples were characterized by a powder X-ray diffraction experiment. Almost all of the Bragg peaks in the diffraction pattern can be indexed on the basis of the MgCuAl$_2$-type structure, although small unidentified impurity peaks are discernible. The lattice parameters were estimated to be $a = 4.218$ Å, $b = 11.062$ Å, and $c = 7.032$ Å, which agree with the reported values within the experimental precision.

The magnetization was measured in the temperature and magnetic-field ranges of $1.8 \leq T \leq 300$ K and $0 \leq \mu_0 H \leq 5$ T, respectively, using a superconducting quantum interference device magnetometer (Quantum Design, MPMS). The electrical resistivity was measured with a dc four-probe method in a temperature range of $0.4 \leq T \leq 300$ K using a $^3$He cryostat. The specific heat was measured with a thermal relaxation method in the temperature range of $0.4 \leq T \leq 10$ K using a $^3$He cryostat.

3. Results and Discussion

Figure 2 shows the temperature dependence of the inverse magnetic susceptibility $H/M$ of CePtAl$_2$. The $H/M$ follows the Curie-Weiss law above 100 K (see the solid line in the figure 2). From the Curie-Weiss fitting of the $H/M$, we obtained the paramagnetic Curie temperature $\theta_p = -5.23$ K and the effective magnetic moment $\mu_{\text{eff}} = 2.42$ $\mu_B$/Ce. The smaller $|\theta_p|$ compared with that reported previously may be ascribable to the magnetic anisotropy: if the polycrystalline samples of the present and the previous studies have a crystallographic preferred orientation, $\theta_p$ value depends on the angle between the orientation direction and the applied field direction. The $\mu_{\text{eff}}$ value is comparable to that reported previously and we can suggest that the Ce ions in CePtAl$_2$ are in the trivalent state because this value is in excellent agreement with the theoretical value $\mu_{\text{calc}} = 2.54$ $\mu_B$/Ce for a free Ce$^{3+}$ ion. The inset of the figure 2 shows the temperature dependence of the magnetic susceptibility $M/H$ at low temperatures. $M/H$ increases steeply below 3 K. This behavior is reminiscent of the ferromagnetic transition.

Figure 3 shows the magnetic-field dependences of the magnetization $M$ of CePtAl$_2$ measured at 1.8 and 5 K. In contrast to the paramagnetic behavior of $M$ measured at 5 K, $M$ measured at 1.8 K shows ferromagnetic behavior, i.e., $M$ increases steeply by applying magnetic field and saturates above 2 T.

![Figure 2](image2.png)

**Figure 2.** Temperature dependence of the inverse magnetic susceptibility $H/M$ of CePtAl$_2$ measured at 0.1 T. The inset shows the low-temperature part of the magnetic susceptibility $M/H$.

![Figure 3](image3.png)

**Figure 3.** Magnetic-field dependences of the magnetization $M$ of CePtAl$_2$ measured at 1.8 K and 5 K.
Figure 4 shows the temperature dependence of the electrical resistivity $\rho$ of CePtAl$_2$. The low-temperature part of $\rho$ is shown in the inset. The $\rho$ decreases almost linearly with decreasing temperature in the high temperature region. However, $\rho$ decreases rapidly below 2.7 K as indicated by an arrow in the inset. The decrease temperature corresponds to the temperature at which the magnetic susceptibility $M/H$ increases steeply.

Figure 5 shows the temperature dependence of the specific heat $C$. The $C$ has a clear $\lambda$-type jump at $T_C = 2.7$ K. This means that the increase in $M/H$ and the decrease in $\rho$ are due to the second-order ferromagnetic transition at $T_C$. The negative $\theta$ (antiferromagnetic) obtained in this study may be explained by the magnetic anisotropy described above; if we measure the $M/H$ with the different sample angle to the magnetic field, positive $\theta$ (ferromagnetic) may be obtained. The temperature dependence of the total entropy $S$ deduced by integrating $C/T$ in temperature is also shown in the figure 5. Since the $S$ value at $T_C$ is 3.9 J/mol K, which corresponds to 68% of $R\ln2$ ($R$ : gas constant), we consider that the ground doublet of Ce$^{3+}$ is responsible for the ferromagnetic transition. Here, the 32% reduction of $S$ is not explained by the Kondo effect since the $\rho$ does not show any signature of the Kondo effect and the localized nature of $4f$ electrons are kept down to low temperatures. By considering the fact that the $C$ increases with decreasing temperature below 9 K, the reduced $S$ value at $T_C$ can be ascribable to the development of short-range ferromagnetic correlation above $T_C$. In fact, the $S$ value reaches 98% at 9 K.

Note that ferromagnetic Ce compounds are rather rare compared with antiferromagnetic ones. Therefore, further studies of CePtAl$_2$ such as pressure effect measurements are worth performing to search for the coexistence of ferromagnetism and superconductivity.

![Figure 4](image1.png)

**Figure 4.** Temperature dependence of the electrical resistivity $\rho$ of CePtAl$_2$. The inset shows the low-temperature part of $\rho$.

![Figure 5](image2.png)

**Figure 5.** Temperature dependences of the specific heat $C$ and the total entropy $S$ of CePtAl$_2$.

4. **Conclusion**

In this study, we have grown polycrystalline samples of CePtAl$_2$ and measured their magnetic, transport, and thermal properties. We have found that CePtAl$_2$ is a ferromagnetic Ce-based compound with the Curie temperature $T_C = 2.7$ K. Since the electrical resistivity does not show any signature of the Kondo effect, we consider that the localized nature of $4f$ electrons is kept down to the low temperatures. The development of the ferromagnetic short-range correlation is responsible for the reduced entropy at $T_C$.

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