Specific Heat of CeMg$_2$Cu$_9$ with a Two-dimensional Ce Arrangement

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Abstract

We have carried out the specific heat measurements under pressures between 0 and 0.91 GPa on CeMg$_2$Cu$_9$, in which the Ce atoms are a two-dimensional arrangement. A large peak is observed at $T_N = 2.5$ K for 0 GPa. $T_N$ increases below 0.89 GPa, and turns to decrease with pressurization. The released magnetic entropy $S_m$ below $T_N$ is about 60% of $R \ln 2$ expected for the twofold spin degeneracy, suggesting Kondo-compensated moments are formed in the low temperature range.

Key words: CeMg$_2$Cu$_9$; specific heat; pressure effect; two dimensionality

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In recent years, pressure effects on the intermetallic compounds with a two-dimensional arrangement of Ce atoms have been studied intensively [1,2], since interesting physical properties such as superconductivity emerge because the pressure controls the correlation between electrons. CeMg$_2$Cu$_9$, which was firstly synthesized by one of the authors (Y. Nakamori), is a good candidate substance with two-dimensional structure, because the nearest neighbor distance along the c-axis between the Ce atoms is almost two-times larger than that in the c-plane [3]. In this paper, we report the results of the specific heat measurements under pressure up to 0.91 GPa on the CeMg$_2$Cu$_9$.

Polycrystalline samples of CeMg$_2$Cu$_9$ and LaMg$_2$Cu$_9$ were prepared by melting stoichiometric amount of consistent metals at 1200°C under about 0.5 MPa Ar atmosphere in a Mo-crucible. Specific heat measurements were carried out by a conventional adiabatic heat-pulse method. A piston-cylinder Cu-Be clamp cell, which contains Apiezon-J oil as pressure-transmitting medium, was used to apply the pressures up to 1 GPa.

Figure 1(a) shows the temperature dependence of the specific heat divided by temperature $C_P/T$ of CeMg$_2$Cu$_9$ at ambient pressure in $0.5 < T < 50$ K. A large peak which indicates an antiferromagnetic transition was observed at $T_N = 2.5$ K. The magnetic specific heat $C_m$ was obtained by subtracting a lattice contribution $C_l$ which is estimated from the $C_P$ of the nonmagnetic LaMg$_2$Cu$_9$, and is shown in Fig. 1(b). The contribution of $C_l$, for example, is about 0.3 and 90% around 2.5 and 30 K of the total, respectively. A Schottky-type anomaly $C_{Sc}$ due to the effects of the excited crystal-field levels is found around 30 K. A Sommerfeld coefficient is roughly estimated to be $\gamma$ $\geq$ 117 mJ/K$^2$mol from the value of $C_m/T$ at $T = 5$ K. The hexagonal symmetry splits the sixfold degenerate state of Ce$^{3+}$ with $J = 5/2$ into three Kramers doublets with the energy gap $\Delta_1$ and $\Delta_2$ from the ground state. The $C_{Sc}(T)$ is described by

$$C_{Sc}(T) = \frac{Nk_B}{T^2} \left[ \frac{\Delta_1^2 e^{-\Delta_1/k_BT} + \Delta_2^2 e^{-\Delta_2/k_BT}}{k_B Z(T)} \right] - \left( \frac{\Delta_1 e^{-\Delta_1/k_BT} + \Delta_2^2 e^{-\Delta_2/k_BT}}{k_B Z(T)} \right)^2,$$

(1)

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Fig. 1. (a) Temperature dependence of specific heat divided by temperature $C_p/T$ for CeMg$_2$Cu$_9$. $C_p/T$ of nonmagnetic LaMg$_2$Cu$_9$ is also plotted. The inset shows that in the low temperature range. (b) Temperature dependence of the magnetic specific heat $C_m$. The solid line is fitting result using eq. (1).

with $Z(T) = 1 + \exp(-\Delta_1/k_B T) + \exp(-\Delta_2/k_B T)$ where $N$ and $k_B$ are Avogadro number and Bornzmann factor, respectively. We estimated the $\Delta_1/k_B = 58$ K and $\Delta_2/k_B = 136$ K from a fit with the equation (1). The fit is shown by the broken line in Fig. 1(b). The released magnetic entropy $S_m$ below $T_N$ obtained by integrating the $C_m/T$ is 60% of the value expected for the twofold spin degeneracy $R\ln 2$, where $R$ is the gas constant, suggesting Kondo-compensated ordered moments are formed in the low temperature range.

Figure. 2(a) shows the $C_p/T$ as a function of $T$ at various pressures up to 0.91 GPa in the range $0.5 < T < 4$ K. The Kondo-compensated ordered moments are still formed in the present pressure range, because the value of released $S_m$ below $T_N$ is not changed by pressure very much. $T_N$ slightly increases up to 0.89 GPa, and turns to decrease with pressurization as shown in Fig. 2(b). The two-dimensional Ce arrangement might be play an important role for that.

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References