Metamagnetism of $PrCu_2X_2$ (X=Si and Ge)

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Abstract

Magnetic behavior in low temperatures has been investigated on $PrCu_2X_2$ (X=Si and Ge) single crystal compounds with anomalously high Neel temperatures. The compound $PrCu_2Si_2$ shows a very sharp one-step metamagnetic transition in the c-axis magnetization process at low temperature, while $PrCu_2Ge_2$ shows a four-step metamagnetic process in the virgin ascending process e-step one in the descending one where magnetization decreases rapidly and crosses over one of the ascending process; a peculiar irreversible process appears, which has been never seen yet.

Key words: Metamagnetism; Antiferromagnetism; $PrCu_2X_2$ (X=Si and Ge);

1. Introduction

The ternary compounds $PrCu_2X_2$ (X=Si, Ge) are of special interest, belonging to a large family crystallizing in the tetragonal $ThCr_2Si_2$-type structure. They order antiferromagnetically below anomalously high Neel temperatures comparing to those of the corresponding Gd compounds [1,2]. The specific heat coefficient is much enhanced; for PrCu2Si2, γ=225 mJ/mol [1], indicating unusually strong s-f hybridization. Some origins have been suggested for these anomalous characters: a quadrupolar Kondo scattering [3], a preferential hybridization of the f-electrons [4], a anisotropic exchange interaction due to the radial extension of 4f-electrons [2] and so on. Moreover, the existence of another magnetic transition below TN was suggested [2,5]. Then, magnetic study on $PrCu_2X_2$ (X=Si and Ge) single crystal compounds have been performed to know more details of the magnetic behavior. The measurements of magnetic susceptibility and magnetization have been carried out using a sample extracting magnetometer at the Institute of Solid State Physics, University of Tokyo.

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2. Result and Discussion

The magnetic susceptibility is anisotropic between the c-axis and the direction in the basal plane for both compounds. Here, the easy direction is the c-axis. Within the basal plane, it is isotropic for the Ge-compound while it along the [110] direction is slightly easier than one along the [100] direction for the Si-compound. In the temperature dependence of the c-axis susceptibility, it shows a cusp at 19.5 K and 14.4 K for the Si-compounds and the Ge-compounds, respectively, which is associated with Neel temperature. No anomaly can be observed below T_N for the Si-compound n contrast to the previous suggestion [5]. For the Ge-compound, an anomalous behavior appears around 3.5 K indicating a magnetic transition (The details will be given soon [6].) In the basal plane, there is no detectable anomaly.

Magnetization curves along the main symmetry axes of the tetragonal cell at 2 K are shown for a $PrCu_2Si_2$ single crystal compound in Fig. 1. Magnetization in the basal plane is isotropic; one along the [100] direction is identical to one along the [110] direction, and it is almost linear. The c-axis magnetization, the easy axis magnetization shows a very sharp one-step metamagnetic transition. It keeps a very small

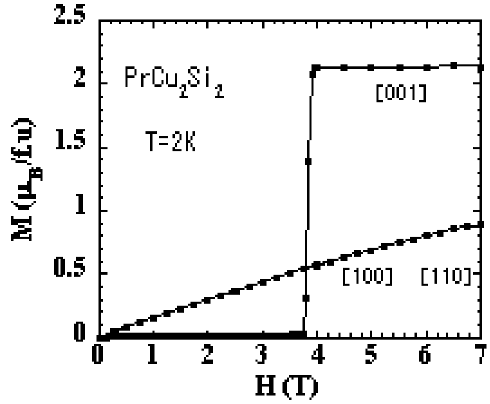

Fig. 1. Magnetization curves along the main symmetry axes of the tetragonal cell at 2 K on a $PrCu_2Si_2$ single crystal.

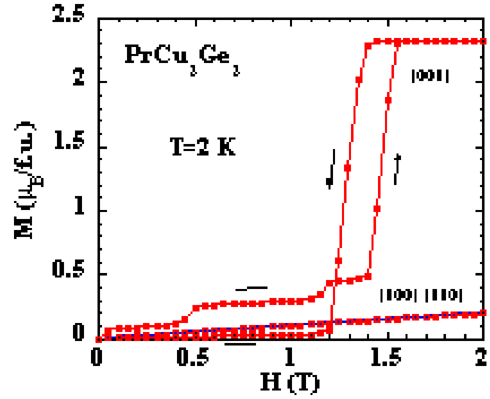

Fig. 2. Magnetization curves along the main symmetry axes at 2 K on a $PrCu_2Ge_2$ single crystal.

value below the critical transition field H_c= 3.8 T, increases rapidly at H_c and reaches the saturation value of 2.17 μ_B/f.u. This value is smaller than the theoretical Pr^3+ moment but is in good agreement with the result from neutron studies [5,7]. This metamagnetic process persists up to T_N although it smooths with increasing temperature.

For $PrCu_2Ge_2$, very peculiar behavior can be seen in the c-axis process while behavior in the basal plane is usual and similar to one of $PrCu_2Si_2$ as shown in Fig.2. Along the c-axis, *an irreversible magnetization process* appears in the virgin magnetization process; in the ascending process, it is a four-step metamagnetic one where magnetization increases rapidly around 0.2 T, 0.45 T, 1.15 T and 1.45 T followed by saturation. Then in the descending process after saturation, it decreases rapidly around 1.3 T, crosses over one of the ascending process and reaches a very small value below 1.2 T. Here is a large hysteresis. This irreversible process appears only in the virgin state (which means the first magnetization measurements after cooling down). The process in the second run becomes a one-step one similar to the virgin descending process; it is a reversible process similar to one of $PrCu_2Si_2$. Regarding to the four-step process, magnetization of each plateau is 0.09 μ_B, 0.27 μ_B, 0.45 μ_B and 2.34 μ_B (=saturation value M_s), corresponding to 1/26 M_s, 3/26 M_s, 5/26 M_s and M_s, respectively. It is difficult to explain this process on the basis of a simple antiferromagnetic structure with the propagation vector (0, 0, 1) reported [5,7]. Instead of it, this large common denominator suggests a long period antiferromagnetic structure. Metamagnetic transitions can be responsible for a spin-flip. With respect to the one-step metamagnetic process in $PrCu_2Si_2$ and the second run of $PrCu_2Ge_2$, the transition field H_c is 3.8 T and 1.3 T, respectively. The H_c of the Si-compound is about three times larger than one of the Ge-compound while the ordering temperature is not so different. To explain the high ordering temperature for the Si-compound, additional effects should be added to the origin for the Ge-compound. Magnetization below H_c is unusually small for both compounds which should not be responsible for a magnetic anisotropy. Because the anisotropy is not so large comparing to those of family Pr-compounds which have a huge uni-axial magnetic anisotropy [8,9].

Anomalous magnetic behaviors above mentioned are unknown yet although some effects such as strong crystal field effects, quadrupolar effects and strong s-f electron hybridization have been proposed. Further study is now in progress.

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