Magnetic Specific Heat of RPd$_2$Si$_2$ Compounds (R=Nd, Dy and Ho)

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ABSTRACT

The magnetic specific heat of some RPd$_2$Si$_2$ compounds (where R = Nd, Dy and Ho) has been studied. All the compounds order antiferromagnetically at low temperature. The results show that, NdPd$_2$Si$_2$, DyPd$_2$Si$_2$ and HoPd$_2$Si$_2$ show a $\lambda$-type anomaly around 2.1K, 8.8K, and 5.3K, respectively, which corresponds to the antiferromagnetic ordering temperature $T_N$. In NdPd$_2$Si$_2$ and DyPd$_2$Si$_2$, a Schottky anomaly is observed around 15K and 44K, respectively.

INTRODUCTION

Most of the ternary RM$_2$X$_2$ compounds (R = rare earth, M = transition metal, X = Si, Ge etc.), so called 1-2-2 type, crystallize in the tetragonal ThCr$_2$Si$_2$-type structure$^1$. The structure is characterized by a simple layer structure; the rare earth atoms, which bear magnetic moments, occupy an equicrystallographic site. The same atoms lie on the alternative layers stacked perpendicular to the c-axis. From expecting to find out new and interesting phenomena reflected by this layer structure, considerable studies on these compounds have been accumulated$^{2,3}$. The magnetic properties of several of this type of compounds have been reported in the literature. Such as, CePd$_2$Si$_2$$^4$ and EuPd$_2$Si$_2$$^5$ show anomalous properties as strongly correlated electron systems. Most other compounds, which have been previously studied, show antiferromagnetism and other interesting magnetic properties. Such as TbPd$_2$Si$_2$$^6$ and DyPd$_2$Si$_2$$^7$ show multistep metamagnetic behaviors in the magnetization processes. In this paper, magnetic behaviors on some RPd$_2$Si$_2$ compounds have been studied by specific measurements.

EXPERIMENTAL

The polycrystalline samples were prepared by arc-melting a stoichiometric mixture of the pure elements (R: purity of 3N, Pd: 3N, and Si: 5N) in an argon atmosphere. The tetragonal ThCr$_2$Si$_2$-type structure was confirmed by X-ray powder diffraction. The specific heat has been performed by a relaxation method under zero field at various temperatures between 1.8 and 300 K using a PPMS (Quantum Design).

RESULTS AND DISCUSSION

The crystallinity and phase purity of the products were examined by XRD. As shown in figure 1, all compounds crystallize in the naturally layered ThCr$_2$Si$_2$-type structure with the space group I4/mmm. The values of lattice parameters calculated by a least squares program

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and the results are consistent with the literature values. The relationship between rare earth atoms and lattice parameter is plotted in figure 2. The lattice parameter $a$ decreases almost linearly as atomic number of rare earth elements increases. This change in lattice parameter could be due to the lanthanide contraction.

![Figure 1. Powder XRD data of RPd$_2$Si$_2$ compounds.](image1.png)

![Figure 2. Lattice parameters of RPd$_2$Si$_2$ compounds at room temperature (The data of R=Gd, Tb are from literature).](image2.png)

The thermal variations of the magnetic specific heat $C_{\text{mag}}$ and entropy $S_{\text{mag}}$ of RPd$_2$Si$_2$ are shown in figure 3-6. The magnetic contribution of specific heat is deduced from subtracting the specific heat of nonmagnetic compound YPd$_2$Si$_2$ from total specific heat of RPd$_2$Si$_2$ compounds, respectively. As shown in figure 3, a $\lambda$-type anomaly, indicating the second-order transition, is observed around 2.1K in NdPd$_2$Si$_2$, which corresponds to the antiferromagnetic ordering temperature $T_N$, and a broad peak around 15K, which is a Schottky contribution attributed to the crystalline electric field (CEF) splitting. The
magnetic entropy is obtained from the numerical integration of $C_{\text{mag}}/T$ vs $T$. The $S_{\text{mag}}$ is released about Rln2.2 below $T_N$, which is considered an exited doublet in the ground state. In DyPd$_2$Si$_2$ compound (figure 4), A cusp which indicates an antiferromagnetic transition is seen at 8.8 K and another anomaly is observed at the lower temperature around 2.2K, it should be expected for a first order transition, indicating a quite small latent heat associated with this transition. A Schottky anomaly is observed around 44K which is also corresponds to the CEF splitting. The $S_{\text{mag}}$ is released about Rln5.9 below $T_N$, doublet ground state is considered in DyPd$_2$Si$_2$. In HoPd$_2$Si$_2$ compound (figure 5), a $\lambda$-type anomaly is observed around $T_N$ = 5.3 K, the $S_{\text{mag}}$ is released about Rln3.6 below $T_N$, which is considered an exited triplet at the ground state.

Figure 3. Temperature dependences of magnetic specific heat $C_{\text{mag}}$ and magnetic entropy $S_{\text{mag}}$ of NdPd$_2$Si$_2$.

Figure 4. Temperature dependences of magnetic specific heat $C_{\text{mag}}$ and magnetic entropy $S_{\text{mag}}$ of DyPd$_2$Si$_2$.
Figure 5. Temperature dependences of magnetic specific heat $C_{\text{mag}}$ and magnetic entropy $S_{\text{mag}}$ of HoPd$_2$Si$_2$.

Figure 6. The magnetic transition temperature $T_N$ versus de-Gennes factor of RPd$_2$Si$_2$.

The magnetic transition temperature $T_N$ in an isostructural series of rare-earth compounds is proportional to de Gennes factor. Figure 6 represents the Neel temperature versus de Gennes factor. The de Gennes factor is expressed as $dG=(g-1)^2J(J+1)$, where $g$ is the lande factor and $J$ is the total angular momentum of the $R^{3+}$ Hunds rule ground state. In a series of rare-earth compounds, structure and type of magnetic ordering according to the RKKY theory, a direct relationship is expected between the magnetic transition temperature and the de Gennes factor. In Figure 6, we observe a very good agreement between the experimental values and the expected values from the de Gennes rule.
CONCLUSION

The magnetic properties of the RPd$_2$Si$_2$ compounds have been studied by measurements of specific heat. The present results on these compounds show an antiferromagnetic behavior and a $\lambda$-type anomaly around $T_N$, respectively. Schottky anomaly is observed in NdPd$_2$Si$_2$ and DyPd$_2$Si$_2$ compound above magnetic transition temperature, respectively. Magnetic transition temperatures of RPd$_2$Si$_2$ compounds are correspond to de Gennes rule.

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