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MAGNETIC PROPERTIES OF HoNi₃ SINGLE CRYSTAL

Yuzo Hashimoto

Department of Physics, Fukuoka University of Education, Munakata, Fukuoka 811-41, Japan

Abstract. Magnetization and susceptibility measurements have been done on single crystal HoNi₃ compound. It showed a ferromagnet with a Curie temperature of 56 K. Isothermal magnetization curves indicated that magnetic moments are partially quenched by crystal field effects. Fourth order crystal field parameters are necessary to understand the magnetism of HoNi₃ compound.

HoNi₃ takes a rhombohedral PuNi₃ type structure, in which rare earth atoms take two crystallographic sites I (3a) and II (6c). Magnetic studies on RNi₃ have been done [1-3]. These reported that the magnetic moment of Ni atoms are null and rare earth moments in each different sites were partially quenched by the effect of crystal field. Powder neutron diffraction measurement on HoNi₃ [1] indicated that the compound is a ferromagnet in which moments are directed along the b-axis at 4.2 K, while the magnitude of moments in each site was partially quenched as 9.3 \( \mu_B \) and 7.9 \( \mu_B \) for site I and II, respectively. In this work, magnetization and susceptibility measurements have been done on a single crystal and resistivity measurement on a polycrystalline sample.

Inverse susceptibility vs. temperature curves along the principal axes indicated Curie-Weiss behavior, where effective moment is 10.7 \( \mu_B \) which is close to that of Ho³⁺ free ion. Anisotropy of asymptotic Curie point was observed. Easy direction of magnetization in paramagnetic region is in the c-plane. Temperature dependence of resistivity indicated a typical bend at Curie temperature and a small change of slope at 25 K which is similar but very smaller than that of TbNi₃. Magnetization measurements have been done by using vibrating sample magnetometer under a static field up to 20 kOe and pulse field method up to 90 kOe. Figure 1 indicates temperature dependence of magnetization along the b-axis under low applied field. The curve (b) in figure 1 measured under 50 Oe shows a sharp reduction of magnetization at about 55 K. A same behavior was seen in a curve along c-axis. Curie temperature was determined at 56 K. When applied field is increased, (a) indicates a two step reduction of magnetization at 25 K. This anomaly corresponds to that mentioned by the small bend of resistivity curve, and then vanishes when field is increased. Figure 2 shows isothermal curves along each principal axis at 4.2 K. Dotted lines are magnetization processes in descending pulsed field.

Fig. 1. – Temperature dependence of magnetization along b-axis under applied fields 50 Oe (b) and 1.0 kOe (a).

Fig. 2. – Isothermal magnetization curves along each principal axis at 4.2 K. Dotted lines are magnetization processes in descending pulsed field.

Fig. 3. – Isothermal magnetization curves along b-axis.
along the b and c-axis, respectively. Magnitude of spontaneous moment at 4.2 K is estimated to be 8.2 $\mu_B$ by extrapolating high field magnetization to $H = 0$ in the b axis. This value is close to those obtained by neutron diffraction measurement [1]. The reduction of moment from $gJ$ value expected for Ho$^{3+}$ free ion is considered partial quenching by crystal field effect. As seen in figure 4 magnetization stands up rapidly along the hard magnetization axis. Magnetization curve at 4.2 K shows three steps increasing process. These processes may be due to the existence of the two sites with different anisotropy. When temperature increases, third step disappear at 10 K and second one at 20 K. Spontaneous moments does not appear in the direction up to Curie temperature. Summary of magnetic measurements are listed in table I. From the anisotropy of asymptotic Curie points $\theta_p$ we can estimate an averaged second order crystal field parameter $B^0_p$ by the equation $k (\theta_p - \theta_p \perp) = -3 (2J - 1)(2J + 3) B^0_p/10$, where $k$ is a Boltzman's constant and $J$ total angular momentum.

Table I. - Results of magnetic measurements.

| $T_c$ (K) | $\theta_{p \perp}$ (K) | $\theta_{p ||}$ (K) | $N_{\text{eff}}$ | $B^0_p$ (cm$^{-1}$) |
|-----------|-----------------|-----------------|-----------|-----------------|
| 56.0      | 35.0            | 6.0             | 10.7      | 0.236           |

The crystal field Hamiltonian for each Ho site are written in terms $O^0_2$, $O^0_4$, $O^0_6$, $O^0_8$, and $O^0_6$ as mentioned in [2]. The crystal field parameters $B^m_p$ were estimated by point charge model. Calculated parameters up to fourth order, where the b-axis was taken to be z direction and considering ions within the 40 Å radius sphere, are listed in table II. Second order parameters indicate that easy direction is in basal plane (site I) and along c axis (site II) as for TbNi$_3$ [3]. Fourth order parameters are changed in sign compared with TbNi$_3$, which is caused by change of sign of Stevens factor. Magnetization curves were examined by use of mean field theory as mentioned in previous paper [3] using $B^0_p$ value for second order parameter. Simulated value could not get fine agreement with these curves in detail, but it succeeds in explaining it qualitatively. Although magnetic moments tend to array in parallel direction by weak crystal field and relatively strong exchange interaction, a collinear structure cannot be obtained by considering only second order terms of crystal field. Negative sign of fourth order term stabilizes moment array in the b direction. And these are necessary to explain a relatively large anisotropy between the a and b axes. The crystal field effects have an important role in the compound, especially fourth order term is necessary to interpret characteristics of magnetism of HoNi$_3$ compound.

Table II. - Crystal field parameters $B^m_p$ (cm$^{-1}$) for each site calculated by point charge model.

<table>
<thead>
<tr>
<th></th>
<th>$B^2_p$</th>
<th>$B^4_p \times 10^3$</th>
<th>$B^6_p \times 10^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>3.70</td>
<td>-7.13</td>
<td>-0.130</td>
</tr>
<tr>
<td>II</td>
<td>-1.02</td>
<td>-2.16</td>
<td>1.18</td>
</tr>
</tbody>
</table>