HIGH FIELD MAGNETIZATION MEASUREMENTS ON HOLMIUM NICOTINATE DIHYDRATE

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Abstract

The holmium nicotinate dihydrate compound has the formula unit [Ho(C₅H₄NCO₂)₃(H₂O)₂]₂, the holmium ions occur in pairs (a dimeric molecular crystal structure).

Magnetization measurements on crystals of HoND compound infields up to 12 Tesla have been conducted in the temperature range from 2 K up to 25 K. The HoND single crystal behavior was observed to be paramagnetic, where the initial magnetic susceptibility decreases linearly with increasing temperature. The holmium magnetic moment is highly anisotropic and highly field dependent at temperatures less than 20 K. The holmium magnetic moment is a linear function of the applied magnetic field at temperatures higher than 20 K.

Introduction

The lanthanide nicotinate dihydrate series has been investigated using optical, electron paramagnetic resonance, magnetic susceptibility¹,² (Baker et al., 1986), and by nuclear magnetic resonance in holmium nicotinate³ (Bleany, 1990). This paper reports measurements on the magnetization of the holmium nicotinate dihydrate compounds which have the formula unit [Ln(C₅H₄CO₂)₃(H₂O)₂]₂ where Ln is the lanthanide element Ho. Low temperature measurements in the range from 2 K up to 25 K have been done with a magnetic field up to 12 Tesla applied along the principal crystallographic direction. The crystals are monoclinic, space group symmetry P2₁/c with dimensions 0.9567(6) nm, 1.1596(2) nm and 1.7811(4) nm for lattice constants a,b,c, and the angle b=91.4 degrees⁴ (Prout et al., 1985).

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The crystals contain two dimeric molecules with the formula unit presented above, for brevity we denote it LnND. The unit cell contains two dimeric molecules, related by a reflection in the ac plane. The Ln ions occur in relatively isolated centro symmetric pairs, the separation between the two ions is approximately 43 nm, and there is no point symmetry at the Ln ion site. The structure of the LnND crystals with different Ln elements have been determined by X-ray diffraction. They are isostructural, the variations in the parameters being very small\(^5\) (Moore at al., 1972). For more details about the crystal structure see as an example\(^1\) (Baker, 1986).

**Crystal Growth**

Crystals were grown by evaporation from aqueous solutions of lanthanide nitrates and nicotinate acid \(^6\) (Hutcheson & Mckay, 1977). The external morphology of HoND crystals grown using the above method provides an easy way for visual identification of crystallographic directions. So it was easy to mount the crystals in the sample holders in order to execute the magnetization measurements. For more details about crystal growth and crystal structure, see reference \(^1\) (Baker et al., 1986).

**Experiment**

The magnetic measurements on holmium nicotinate dihydrate single crystals have been made at liquid helium temperature and above using a closed cycle cryostat, this was possible by changing the flow rate of liquid helium. Measurements were made at 5, 10 and 25K. The magnetic field was set up by a superconducting coil and its maximum value was 12 Tesla. The magnetic field was applied along the a-axis (the long axis of the crystal), and in a plane perpendicular to the a-axis. The system used to do the measurements was the vibrating sample magnetometer (VSM) at the Schuster Laboratory, Manchester University.
Results and Discussion

Magnetization measurements of the holmium nicotinate dihydrate single crystals along the two different directions allow us to calculate the holmium magnetic moment per ion as a function of the applied magnetic field and as a function of temperature.

In figure (1), the field dependent of the holmium ion magnetic moment is presented at three different temperatures 5 K, 10K, and 25 K. It seems that the holmium moment decreases with increasing temperature, because thermal agitation opposes alignment. In dilute magnetic systems such as HoND, the holmium ions will be far separated from each other and so any interaction between them will be negligible, except those Ho$^{3+}$ ions within a dimer have a relatively strong magnetic dipole - dipole interaction. This assumption was already confirmed by magnetic susceptibility measurements on thulium nicotinate dihydrate compound TmND(7) (Baker et al., 1983), where it was found that long range magnetic order is absent even down to 0.55 K. So the Curie law will be closely obeyed for this system. The initial magnetic susceptibility decreases linearly with increasing temperature, see figure (2). At temperatures higher than 25 K the holmium moment varies linearly with the applied magnetic field.

When the magnetic field was applied in a plane perpendicular to the a-axis, the magnetic moment per holmium ion have a similar dependence on applied magnetic field and temperature as for the a-axis case. The holmium magnetic moment is anisotropic (direction dependent), because of the crystalline electric field at the holmium ion site, and the holmium moment will be hardly quenched since the 4f electrons are shielded by the outer electrons. Experimentally it is anisotropic, since the exact numerical values for the field dependence of the holmium ion moment are different for the two different directions, see figure 1 and 2. From optical measurements on TmND, an absorption signal was found at a field strength that varied with field direction with respect to the crystal axes(1) (Baker et al., 1986).
This confirms the anisotropic properties of the magnetic moment of Ho\(^{3+}\) ion. At temperatures higher than 20 K, the field dependence of the holmium magnetic moment is isotropic.

We can make a comparison between the magnitude of the holmium moment deduced from nuclear magnetic resonance\(^{(8)}\) (Lataifeh, 1994) and the value we get from magnetization measurements at liquid helium temperatures (T=4.2 K or 5.0 K). The agreement is quite satisfactory when the field was applied along the a-axis, and it is also good at higher applied fields when the field is applied in a plane perpendicular to the a-axis, see table [1]. The difference between the two values of the magnetic moment for Ho\(^{3+}\) ion in HoND observed from NMR and magnetization measurements will be due to all the holmium ions within the sample and we calculate the average value for Ho\(^{3+}\) ion, while in NMR only one Ho\(^{3+}\) ion was taken into consideration and the effect of all kinds of interactions will produce the holmium magnetic moment.

**Acknowledgements**

We would like to thank Dr. Robin Graham for technical help, Dr. David Bunbury and Dr. Henry Hall for their invitation to do the above work in the Schuster Laboratory, Manchester University, U.K.

**Figure Captions**

**Figure 1:** Field dependence of the holmium magnetic moment in HoND compound for three different values of temperature. The applied magnetic field is parallel to the a-axis.

**Figure 2:** Field dependence of the holmium magnetic moment in HoND compound for three different values of temperature. The magnetic field applied perpendicular to the a-axis.
Table (1)

The holmium magnetic moment $\mu$ deduced from NMR and magnetisation measurements at 4.2 K and 5 K. (Units are in Bohr magnetons).

* Applied field along the $z$-axis.

<table>
<thead>
<tr>
<th>$B_0$ (Tesla)</th>
<th>$\mu$ from NMR</th>
<th>$\mu$ from magnetization</th>
</tr>
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<tr>
<td>6.0</td>
<td>8.4</td>
<td>7.85</td>
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<td>8.03</td>
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</table>

* Applied field in a plane perpendicular to the $a$-axis

<table>
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<th>$B_0$ (Tesla)</th>
<th>$\mu$ from NMR</th>
<th>$\mu$ from magnetization</th>
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<tr>
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</tr>
</tbody>
</table>
Figure Captions

Figure 1: Field dependence of the holmium magnetic moment in HoND compound for three different values of temperature. The applied magnetic field is parallel to the a-axis.
Figure 2: Field dependence of the holmium magnetic moment in HoND compound for three different values of temperature. The magnetic field applied perpendicular to the a-axis.
Notes


References


