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NEUTRON SCATTERING STUDY OF MAGNETIC ORDER IN A Tb$_{0.5}$Dy$_{0.5}$ SINGLE CRYSTAL

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Abstract. - Neutron diffraction measurements have been made on Tb$_{0.5}$Dy$_{0.5}$ and show initial ordering into a spiral antiferromagnetic phase (with decreasing temperature) and then into a ferromagnetic phase. The inter-layer turn angle changed from 35° to 23° as the temperature moved from the Néel to the Curie temperature. In addition, a magnetostriction-related expansion of the c-axis of about 0.4 % was observed over the same temperature range. The periodic moment state persisted somewhat into the nominal ferromagnetic regime and was accompanied by a slight increase in the turn angle (~ 2°).

1. Introduction

The rare earth elements Tb and Dy both order magnetically with decreasing temperature into a (basal plane) spiral antiferromagnetic state, followed at lower temperatures by a transition to a ferromagnetic state. In the ferromagnetic state the b-axis is the easy direction for Tb and the a-axis for Dy. We have used neutron diffraction in order to study the magnetic ordering of a Tb$_{0.5}$Dy$_{0.5}$ alloy single crystal as a function of temperature to examine the effect of the competition of positive and negative basal plane ionic anisotropies on the spin structure and phase transitions.

Magnetostriction results [1] indicate that the easy magnetic axis changes from the b to the a direction below about 100 K.

2. Sample preparation and experimental details

A high quality, oriented, single crystal Tb$_{0.5}$Dy$_{0.5}$ sample was obtained from Ames Laboratory. Rod-shaped samples of dimensions approximately 2 mm × 2 mm × 7 mm were cut for the neutron measurements with the long dimension along the b (1010) axis. A triple-axis neutron spectrometer at the National Bureau of Standards Reactor was used in the diffraction mode to scan the (0002) Bragg peak and the (0, 0, 0, 2 ± δ) magnetic satellites. The neutron energy was 14.7 meV, corresponding to a wavelength of 2.36 Å⁻¹.

3. Results and discussion

Figure 1 shows the integrated intensity of the (0002) peak as a function of temperature. We have subtracted from the data of figure 1 the high temperature value of the (0002) integrated intensity resulting from the nuclear scattering. Note that the intensity has not been corrected for extinction effects and is therefore only approximately representative of the square of the ferromagnetic order parameter. The (0002) intensity begins to rise sharply around 156 K, which we take as the ferromagnetic Curie temperature. This is compared to the differential scanning calorimetry (DSC) value of 152 K [1] and with the value of 150.8 K found by Fujiwara et al. [2] for a polycrystalline sample. The initial rise in intensity below $T_s$ (Fig. 1) is suggestive of critical scattering indicating that the transition is probably not first order as found in pure Dy. The DSC value for $T_C$ corresponds to the temperature where the ferromagnetic transition is complete as given by the knee of the curve in figure 1.

The average of the intensities of the satellite peaks is shown in figure 2. Note that, as $T$ decreases, satellites appear at 206 K (the Néel temperature, $T_N$), increase to a maximum intensity, and then decrease sharply to near zero intensity by 152 K. This compares to $T_N = 205$ K from the DSC data [1] and a value reported by Fujiwara et al. [2] of 204.4 K. However traces of the satellite peaks persist to below 145 K. This same persistence of the magnetic satellite intensity into the
The ferromagnetic region was observed by Dietrich and Als-Nielsen [3] in Tb and indicates a coexistence of the periodic moment and the ferromagnetic states over an appreciable temperature range.

From the average wave vector of the satellite peak positions relative to the (0002) peak we can derive the inter-layer turn angle of the spiral moment. This is shown in figure 3. The angle is initially $35^\circ$ at $T_N$. It decreases to $23^\circ$ at $T_C$, but then increases slightly ($\sim 2^\circ$) as $T$ is lowered below $T_C$. Below $T_C$ the $\delta^\pm$ satellite peaks become asymmetrically placed about the (0002), as was observed also in pure Tb [3]. The spin structure at all temperatures (including below $T_C$) is characteristic of a single component helical modulation. Additional weak harmonics were observed both in the existence region below $T_C$ and above $T_C$, reflecting a bunching of the helical moment components induced by the competing six-fold magnetic anisotropies.

The change in the spiral turn angle in the antiferromagnetic region is accompanied by a expansion of the $c$-axis dimensions as $T$ is lowered from $T_N$ through $T_C$. The magnitude of this magnetostriction-related effect is about $0.4\%$ and is plotted in figure 4. Again this is consistent with the observations of Dietrich et al. [3] for Tb.

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