Experimental report

03/02/2017

Proposal: **5-41-825** **Council:** 4/2015

Title: Evolution of the Field Induced Magnetic Structure in Neodymium Tetraboride

Research area: Physics

This proposal is a continuation of 5-41-762

Main proposer: **Oleg PETRENKO**

Experimental team: Daniel BRUNT
Oleg PETRENKO

Local contacts: Andrew WILDES

Samples: HoB4
NdB4

Instrument	Requested days	Allocated days	From	To
D7	5	5	03/12/2015	10/12/2015

Abstract:

We are proposing to investigate the field induced magnetic structure and diffuse scattering of NdB4. NdB4 is a rare experimental realisation of the Shastry-Sutherland lattice, a frustrated lattice with an exact ground state solution. NdB4 shows a range of novel and unusual properties believed to arise due to the competition between the magnetic and quadrupolar interactions. We have grown single crystals of NdB4 and characterised them using magnetisation measurements. We have also performed a neutron experiment on D10 in order to determine the magnetic structure in zero field. Our refinements have suggested the low temperature magnetic structure is helical. This experiment will give us a fuller understanding of the magnetisation process in NdB4.

The rare earth borides have garnered a great deal of attention for the diverse range interesting and unusual properties, ranging from various magnetic phase transitions, heavy fermion behaviour, mixed valence phenomena to superconductivity [1]. In recent years the rare earth tetraborides $R\mathrm{B}_4$ have been investigated extensively. $R\mathrm{B}_4$ is a rare experimental realisation of the Shastry-Sutherland lattice (SSL) [2]. $R\mathrm{B}_4$ crystallises into a tetragonal structure, where the R ions form a network of squares and equilateral triangles in the basal plane which topologically maps to the SSL [2]. It been suggested the competition between the magnetic and quadrupolar interactions is crucial to establishing a ground state, giving rise to a variety of properties observed in this family [3]. These properties include fractional magnetisation features [4], diverse phase diagrams in relatively low fields [5] and a plethora of magnetic structures [6, 7]. NdB_4 shows successive phase transitions at T_{N1} = 7 K and T_{N2} = 4.6 K for $H \parallel [001]$, with an additional transition at T_Q = 17.2 K for $H \perp [001]$ seen in the magnetic susceptibility [8]. Our previous single crystal measurements have shown $T_{\mathrm{N2}} < T < T_{\mathrm{N1}}$ is an incommensurate antiferromagnetic state with a propagation vector of (δ, δ, δ'), where δ = 0.15 and δ' = 0.4. While for $T < T_{\mathrm{N2}}$ we observed commensurate reflections corresponding to a $\mathbf{q}$ = 0 structure appearing along side incommensurate peaks of type $\mathbf{q}$ = (0, δ'', δ'), where δ'' = 0.2.

Although the original proposal was to investigate the evolution of magnetic ordering in NdB_4 in an applied magnetic field, upon obtaining further results from a previous experiment it was decided to start with zero-field measurements. Large single crystals of NdB_4 were grown with isotoppically enrich ^{11}B to reduce neutron absorption. We investigate the evolution of the magnetic structure with temperature using the D7 diffractometer. Two channels were measured, the non-spin flip (NSF) which is sensitive to the nuclear component as well as the component of the magnetic moment parallel to the polarisation. The second channel is the spin-flip (SF), which is sensitive to the magnetic moment perpendicular to the polarisation.

We have investigated the temperature evolution of the magnetic structure of NdB_4 in the $(h0l)$ scattering plane at temperatures T = 30, 12, 6.5 and 1.5 K. The high temperature phase (12 K) is shown in Fig. 1(a). The spin-flip channel shows the appearance of the (100) reflection suggesting this phase is antiferromagnetic, while there is diffuse scattering appearing around the expected positions of the incommensurate reflections in the intermediate temperature phase. This is most likely arising due to short range correlations forming before the on-set of magnetic order.

In the intermediate temperature phase (6.5 K), we expected an incommensurate phase with a propagation vector of $\mathbf{q}$ = (δ, δ, δ'), the reciprocal space intensity map for 6.5 K is shown in Fig. 1(b). The detectors on D7 have a degree of out of plane coverages so we are able to see (δ, δ, δ')-type reflections. As can be seen these are peaks are appearing at (0.15 0 0.4), and the values of δ and δ' are consistent with those measured on D10.

Cooling to the low temperature phase (1.5 K), the reciprocal space intensity map is shown in Fig. 1(c). First of all the intermediate temperature phase incommensurate reflections shift positions to (1.8 0 0.4), (2.2 0 0.4), (1.8 0 0.6) and (2.2 0 0.6). While there is the appearance of additional reflections appearing at (0.4 0 0.2), (0.4 0 $\bar{0.2}$), (0.6 0 0.2) and (0.6 0 $\bar{0.2}$) as well as equivalent positions in the reciprocal space map. The appearance of this second set of peaks was unexpected and it would be interesting to perform further measurements on a single crystal diffractometer, like D10, in order to determine the nature of these reflections.

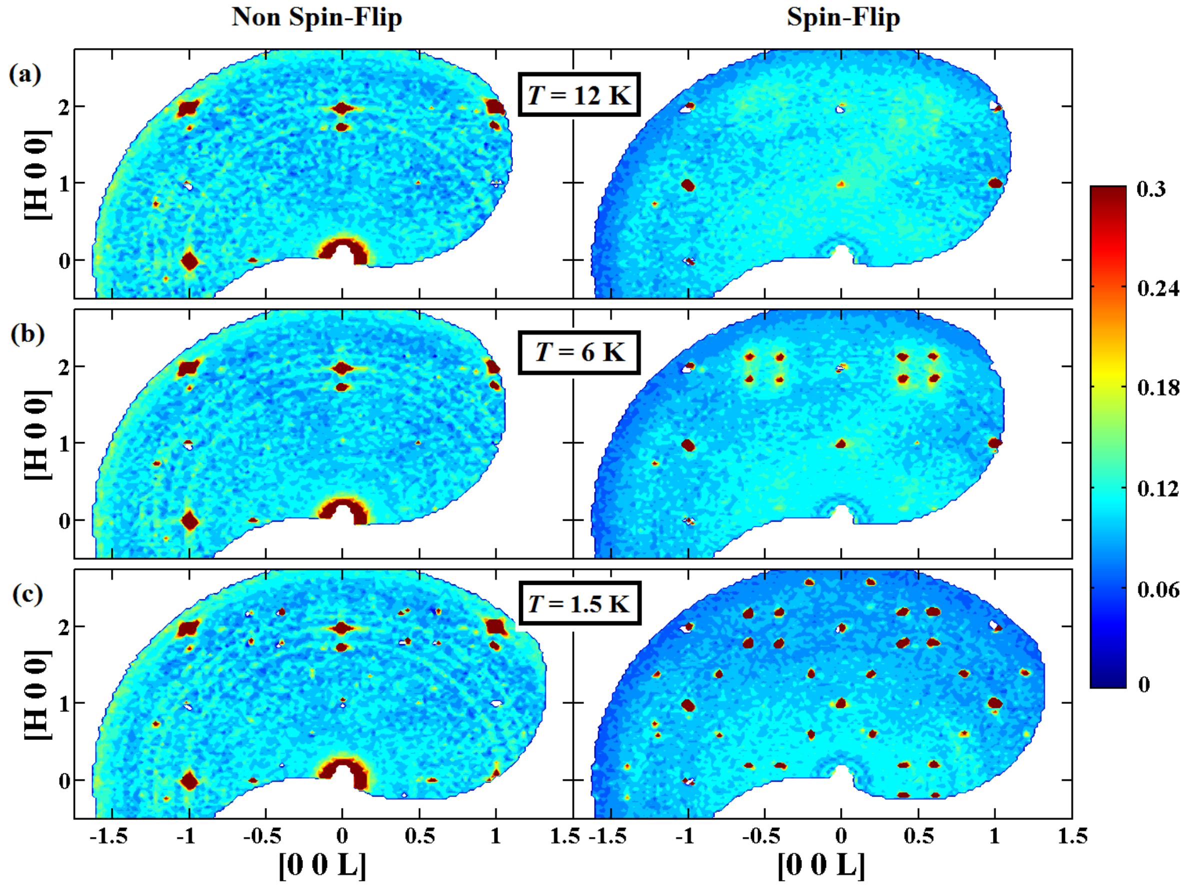

Figure 1: Single crystal neutron diffraction maps of $(h0l)$ plane for NdB_4 using the D7 diffractometer. The non spin-flip (left column) and spin-flip (right column) channels at different temperatures (a) 12 K, (b) 6 K and (c) 1.5 K are shown.

[1] J. A. Blanco *et al.*, Phys. Rev. B **73** (2006) 212411
[2] S. Shastry, and B. Sutherland, Physica **108** B (1981) 1069
[3] D. Okuyama *et al.*, J. Phys. Soc. Japan **77** (2008) 044709
[4] S. Matas *et al.*, J. Phys.: Conf. Series **200** (2010) 032041
[5] R. Watanuki *et al.* Physica B **378-380** (2006) 594
[6] K. Semensmeyer *et al.* Phys. Rev. Lett. **101** (2008) 177201
[7] S. Michimura *et al.* Physica B **378-380** (2006) 596
[8] R. Watanuki *et al.* J. Phys. Conference Series **150** (2009) 042229