Experimental report

15/09/2016

Proposal: **5-41-871** **Council:** 4/2016

Title: Investigation into new incommensurate reflections found in the frustrated magnet, NdB4

Research area: Physics

This proposal is a continuation of 5-41-762

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Samples: NdB4

Instrument	Requested days	Allocated days	From	To
D10	5	5	09/06/2016	16/06/2016

Abstract:

We are proposing to investigate newly discovered incommensurate reflections in NdB4. NdB4 is a rare experimental realisation of the Shastry-Sutherland lattice, a frutrated lattice with an exact ground state solution. NdB4 shows a range of novel and unusal properties believed to arise due to the competition between the magnetic and quadrupolar interactions. Previously we have performed neutron experiments on D7, which has given us a good insight into the magnetic structure of NdB4 as well as discovering the new incommensurate reflections. This experiment will compliment our previous D10 measurements and allow us to get a complete picture of the magnetic structure 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 small 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 [9]. 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. Later polarised neutron experiments also revealed the presence of additional incommensurate reflections in the low temperature phase corresponding to $\mathbf{q}$ = (0, δ', δ'').

We have carried out single crystal neutron diffraction on D10. Our aim was to collect a full set of the intensities of the newly observed incommensurate phase as well as the high temperature phase ($T_{\mathrm{N1}} < T < T_Q$) to determine the magnetic structure of both. The temperature dependence of the intensity of two types of incommensurate reflection is shown in Fig. 1. There is in increase in intensity at T_{N2} = 4.6 K for both reflections.

The temperature dependence of the (001) and (003) reflections are shown in Fig. 2(a). As can be seen there is a large increase in the intensity at T_{N2}. This increase is quite surprising as we would only expect an increase in the intensity of this reflection if we had a ferromagnetic component in the ab-plane. However, magnetisation and polarised neutron experiments have shown no indication of ferromagnetism in NdB_4. This implies there is a structural phase transition at T_{N2}. The temperature dependence of the (100) reflection is shown in Fig. 2(b). As can be seen there is a slight increase at T_Q = 17 K with the onset of antiferromagnetic order, while there is a dramatic increase in the intensity at T_{N2}, which suggests a change in the commensurate magnetic phase between the intermediate temperature phase ($T_{\mathrm{N2}} < T < T_{\mathrm{N1}}$) and the low temperature phase ($T < T_{\mathrm{N2}}$).

We have also performed psi-scans for reflections of $(0k0)$-type to check for the presence of multiple scattering. These are shown in Fig. 3(a) and (b). As can be seen there is a huge variation in the intensity as a function of psi, which appears to be random. To determine whether this is arising due to the magnetic ordering we performed a small psi scan at two different temperatures. These are shown in Fig. 3(c) and (d). There is no significant temperature dependence between the two suggesting it is due to the sample. We currently believe these fluctuations is arising due to many similar aligned crystallites, however due to the large change in intensity at different psi values, magnetic refinements have become a significant challenge with the present data and further investigation may be needed.

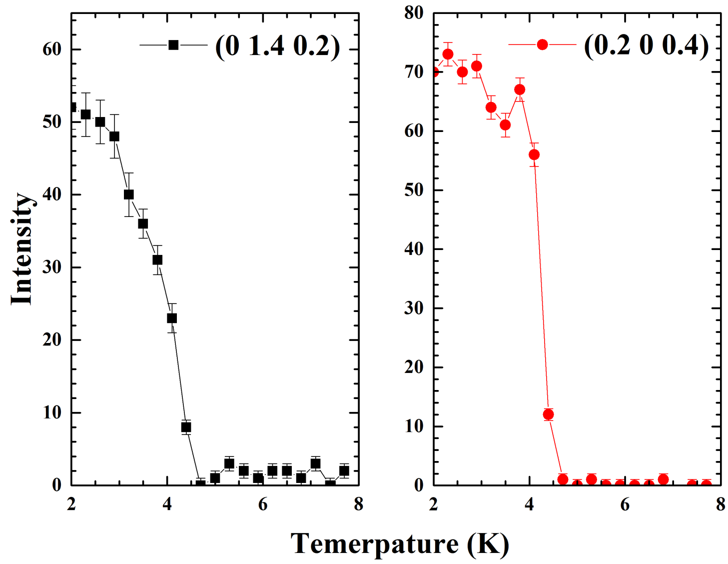

Figure 1: Temperature dependence of the intensity of the two low temperature phase incommensurate reflections.

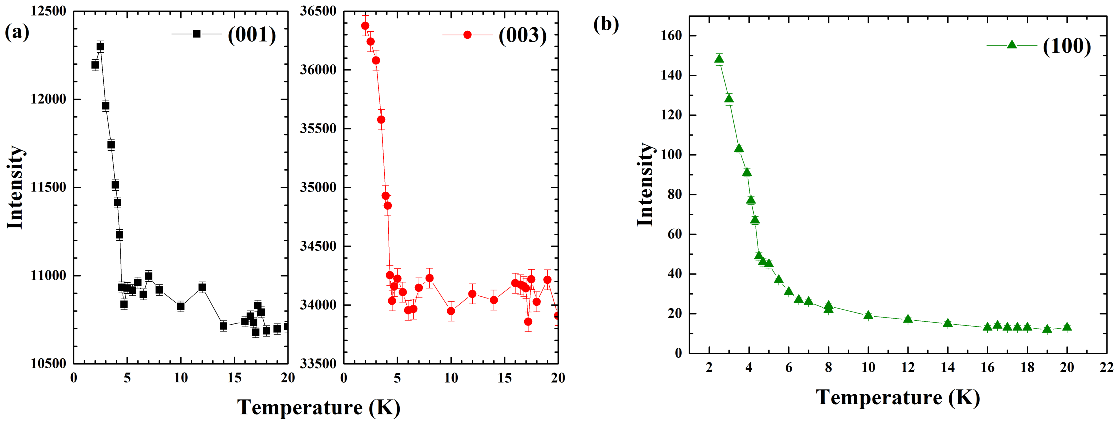

Figure 2: Temperature dependence of the intensity of (a) $(00l)$-type reflections and (b) (100) reflection.

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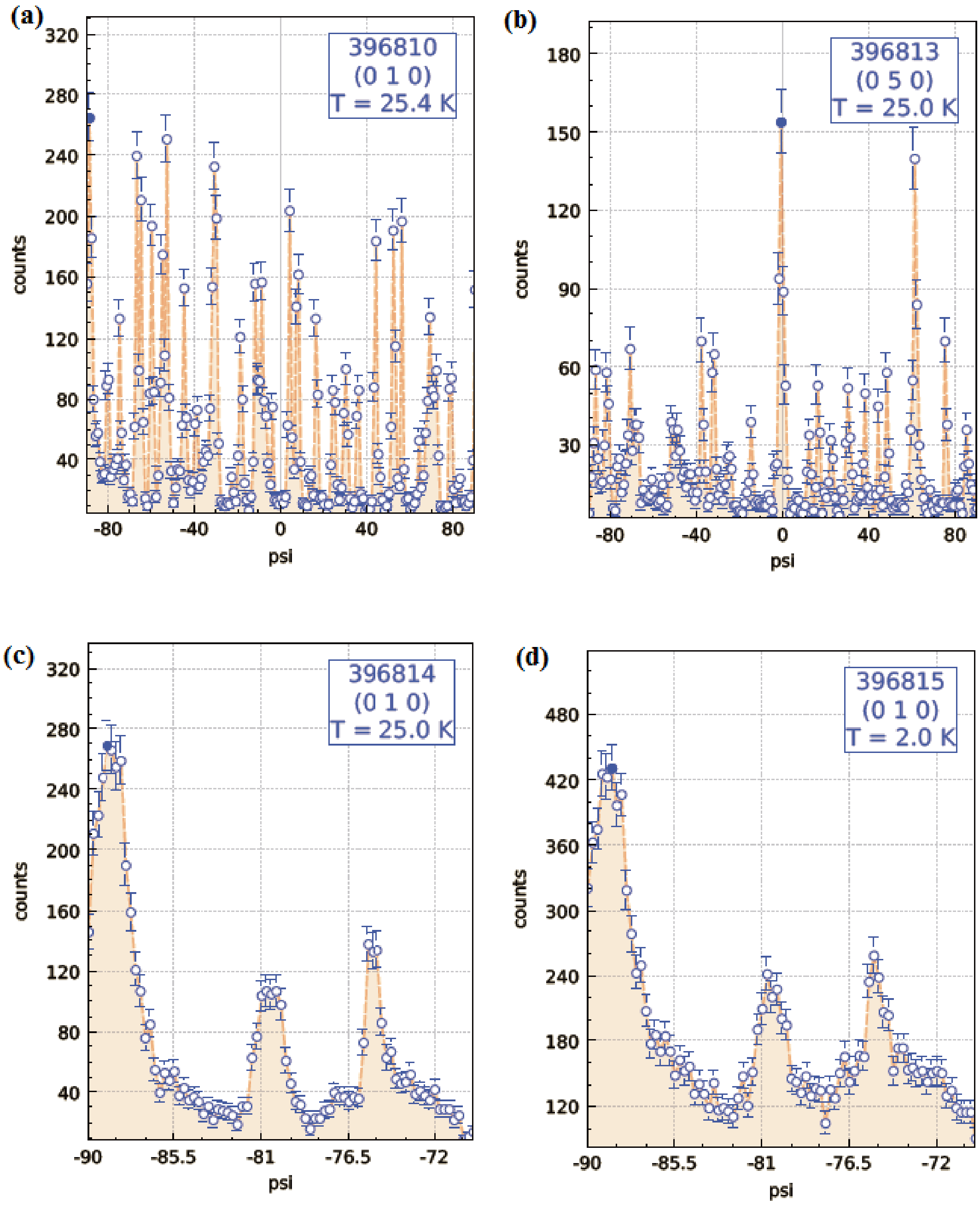

Figure 3: psi scans of the intensity of (a) the (010) reflection, (b) the (050) reflection. (c) and (d) show a smaller psi scan to demonstrate the temperature dependence between $T = 25$ and 2 K respectively.