Experimental report

21/07/2016

Proposal: 4-01-1457 **Council:** 10/2014

Title: Detailed Measurements of the Crystalline Electric Field of Shastry-Sutherland Magnets Rare Earth Tetraborides

Research area: Physics

This proposal is a new proposal

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Samples: HoB4
NdB4
ErB4

Instrument	Requested days	Allocated days	From	To
IN4	7	3	17/07/2015	20/07/2015

Abstract:

We propose to measure the crystalline electric field (CEF) levels of NdB4, ErB4 and HoB4 using IN4. These compounds belong to a family of rare earth tetraborides REB4, where the RE ions form a network that maps to the frustrated Shastry-Sutherland lattice. Magnetisation measurements of REB4 show fractional magnetisation plateaux common to all compounds, but can dramatically change between RE ions. This suggest the CEF could play an important role in the properties displayed by the REB4. This experiment will be carried out in zero applied field on powder samples. If successful further investigations into other members will likely be requested.

The Shastry-Sutherland lattice (SSL) has garnered a great deal of theoretical attention as an example of a frustrated lattice that has an exact ground state solution [1]. There are only a handful of experimental realisations of this lattice, one example is the rare earth tetraborides, $R\mathrm{B}_4$. $R\mathrm{B}_4$ crystallises into a tetragonal structure, where the R ions form a network of squares and triangles in the ab-plane, which map to the SSL. Here the nearest neighbour ions form an orthogonal dimer lattice with in-built geometrical frustration. The $R\mathrm{B}_4$ family display a variety of magnetic and electric behaviour. The main type of ordering is antiferromagnetic, with the exceptions of CeB_4 and YB_4 which do not order and PrB_4 which orders ferromagnetically [2]. Fractional magnetisation plateaux are a common feature in the family [3] arising due to a variety of field induced magnetic structure ranging from a simple ferrimagnetic in ErB_4 [4] to a complex striped structure in TmB_4 [5].

HoB_4 shows successive phase transitions at T_{N1} = 7.1 K and T_{N2} = 5.6 K [7]. The zero field structure has been investigated in detail by neutron and X-ray diffraction [8]. Between $T_{\mathrm{N2}} < T < T_{\mathrm{N1}}$ an incommensurate antiferromagnetic magnetic order is formed with $\mathbf{q}$ = $(\delta, \delta, \delta')$, where δ = 0.022 and δ' = 0.43. In the low temperature phase, below T_{N2}, an ordered commensurate antiferromagnetic phase is formed.

We have carried out neutron scattering experiment using IN4 in order to look for and investigate crystal field excitations in a powdered sample of HoB_4. Powders were made by growing single crystals of HoB_4 using the floating zone technique and were ground with an agate pestle and mortar. Isotopically enriched boron, ^{11}B was used to reduce absorption of neutrons. The quality of the sample was checked using powder X-ray diffraction and no significant impurity was present. A variety of temperatures were investigated to track the evolution of the crystal field excitation with temperature. Two incident neutron energies were used 31.6 meV and 8.7 meV. Fig. 1 shows the integrated intensity as a function of energy transfer for an incident energy of 8.7 meV. In the low temperature phase (1.6 and 4 K), there are three main features, two well defined peaks at 2.2 and 2.8 meV and a small feature at 5.5 meV.

In the intermediate temperature phase, the feature at 5.5 meV is no longer visible, while the low energy peak (at 2.2 meV) shifts to 1.6 meV. We also see the a feature appearing at approximately 4.2 meV, this is most likely due to the lower crystal field energy level becoming populated. There is a further shift to lower energies of the peaks in the paramagnetic regime, this slight change could be due to a magnetically induced lattice distortion between the paramagnetic and incommensurate phases. Powder averaged signal of the observed energy levels were broadly flat with only slight modulation of intensity as a function of scattering vector, which is consistent with crystal field levels. Work is currently under way on HoB_4, NdB_4 and ErB_4 to determine the crystal scheme for the $R\mathrm{B}_4$ family.

[1] S. Shastry, and B. Sutherland, Physica **108** B (1981) 1069
[2] K. H. Buschow *et al.*, J. Chem. Phys. **57** (1972) 3910
[3] S. Matas *et al.*, J. Phys.: Conf. Series **200** (2010) 032041
[4] S. Michimura *et al.* Physica B **378-380** (2006) 596
[5] K. Semensmeyer *et al.* Phys. Rev. Lett. **101** (2008) 177201
[6] R. Watanuki *et al.* J. Phys. Conference Series **150** (2009) 042229
[7] J. Y. Kim, B. K. Cho, and S. H. Han, J. Appl. Phys. **105** (2009) 07E116
[8] D. Okuyama *et al.*, J. Phys. Soc. Japan **77** (2008) 044709

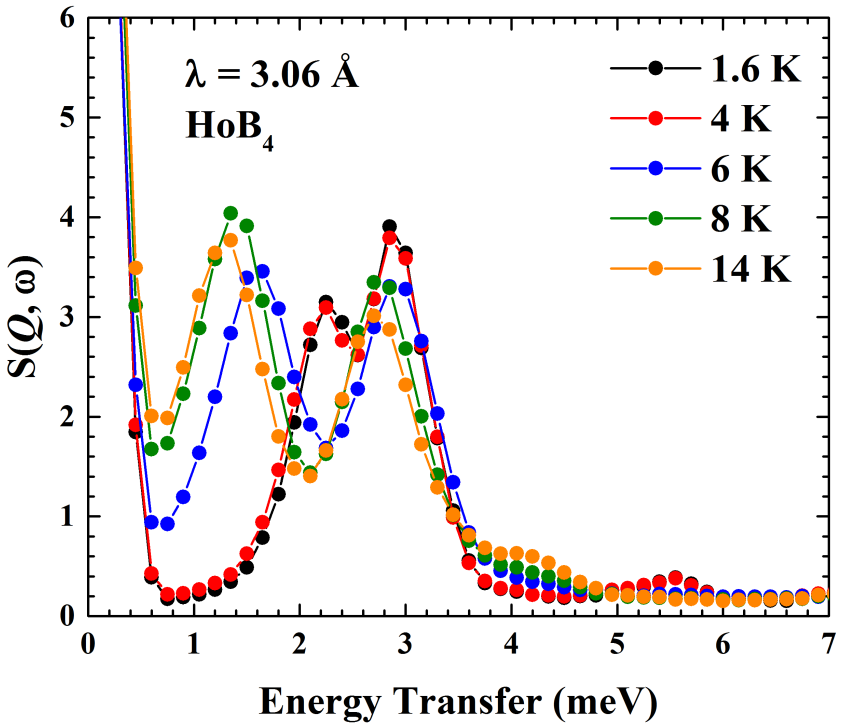

Figure 1: Intensity as a function of energy transfer in different temperatures for HoB_4. An initial energy of 8.7 meV was used which corresponds to a wavelength, λ = 3.06 Å.