

Experimental report

19/08/2024

Proposal: 4-05-873

Council: 4/2023

Title: Excitations in the plaquette phase of the Shastry-Sutherland compound, $\text{SrCu}_2(\text{BO}_3)_2$

Research area: Physics

This proposal is a continuation of 4-01-1655

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Samples: $\text{SrCu}_2(\text{BO}_3)_2$

Instrument	Requested days	Allocated days	From	To
ORIENTEXPRESS	0	2	03/07/2023	04/07/2023
			11/09/2023	12/09/2023
THALES	7	7	11/09/2023	18/09/2023

Abstract:

We propose a 7 day inelastic neutron scattering experiment on ThALES to determine the excitation spectrum in the plaquette phase of the Shastry-Sutherland compound, $\text{SrCu}_2(\text{BO}_3)_2$. The Shastry-Sutherland lattice consists of spin pairs (dimers) embedded in a square lattice with inter-dimer coupling, J , and intra-dimer coupling, J' . It has an exact dimer product ground state for low J'/J . Upon increasing the ratio, J'/J , the system enters a plaquette singlet phase and finally the Néel state. $\text{SrCu}_2(\text{BO}_3)_2$ is unique since it is topologically equivalent to the Shastry-Sutherland lattice and with the possibility to tune J'/J by applying pressure. Therefore, SCBO presents an amazing experimental playground for theoretical predictions. One such prediction is the existence of what is known as the square or void plaquette phase. Previous experimental evidence contradicts this prediction but the conclusions are far from rock solid with only limited data. With the proposed experiment we aim to determine the excitation spectrum in the plaquette phase and thereby understand the nature of this phase.

Excitations in the plaquette phase of the Shastry-Sutherland compound, $\text{SrCu}_2(\text{BO}_3)_2$

Proposal no: 4-05-873

Beamtime: ThALES (Sep 11-17 2023)

Experiment team: Mohamed Zayed (Carnegie Mellon University Qatar), Ellen Fogh and Federico Pisani (École Polytechnique Fédérale de Lausanne)

Local contacts: Arno Hiess, Paul Steffens

The Shastry-Sutherland (SS) lattice consists of spin pairs (dimers) embedded in a square lattice (see Fig. 1a) and with inter-dimer coupling, J , and intra-dimer coupling J' . It has an exact dimer product ground state for $J'/J \leq 0.675$ [1]. Upon increasing the ratio of J'/J , the system goes through a quantum phase transition to a plaquette singlet state followed by a transition to a Néel phase [2]. $\text{SrCu}_2(\text{BO}_3)_2$ (SCBO) is a unique material since it is topologically equivalent to the SS lattice [3]. With $J'/J \sim 0.6$ close to the critical point, SCBO presents remarkable experimental testing grounds for the SS model. The ratio J'/J may be tuned by applying pressure and the resulting phase diagram resembles that theoretically predicted for the SS model [4] (see Fig 1b).

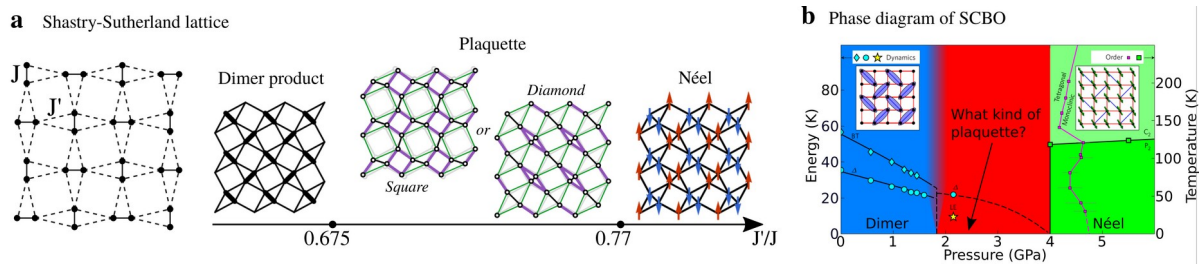
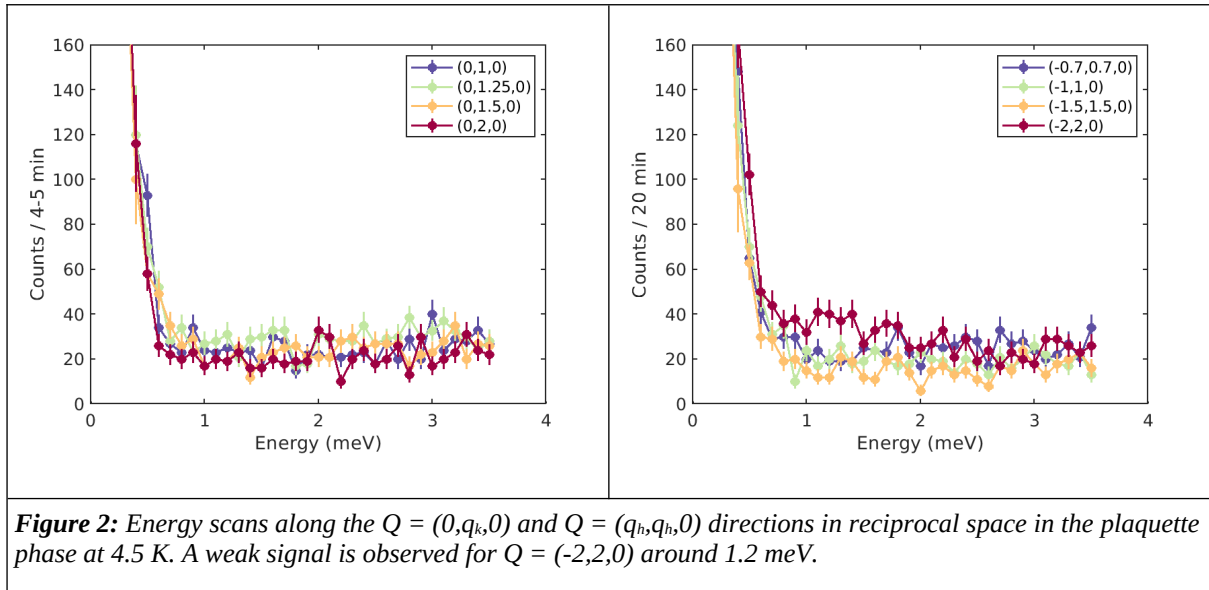


Figure 1: (a) Illustration of the SS lattice with inter-dimer and intra-dimer coupling, J and J' , respectively, as well as the theoretically predicted phase diagram [5]. (b) Experimental phase diagram of SCBO under pressure [4].

In this experiment we focused on magnetic excitations in the plaquette phase above 1.8 GPa. It was performed with a 60mg single crystal of SCBO in a Paris-Edinburgh pressure cell. The crystal was oriented with (HK0) in the horizontal scattering plane.

In the plaquette phase there is evidence in the specific heat of a transition around 2K [6] but in a previous experiment on IN8 (proposal nr. 4-01-1655) we saw no difference between 1.5 and 4.5 K so we decided for this experiment to stay at 4.5 K. We performed a number of energy scans at fixed Q and observe a weak signal for $Q = (-2,2,0)$ around 1.2 meV, Fig. 2.



In summary, the inelastic signal was too weak to draw any conclusions on the nature of the plaquette phase.

- [1] B. S. Shastry and B. Sutherland, *Physica* **108B**, 1069-1070 (1981)
- [2] A. Koga and N. Kawakami, *Phys. Rev. Lett.* **84**, 4461–4464 (2000)
- [3] S. Miyahara and K. Ueda, *Phys. Rev. Lett.* **82**, 3701 (1999)
- [4] M. E. Zayed et al. *Nature Physics* **13**, 962 EP (2017)
- [5] J. Y. Lee et al., *Phys. Rev. B* **9**, 041037 (2019)
- [6] J. Guo et al., *Phys. Rev. Lett.* **124**, 206602 (2020)