Experimental report

09/04/2026

Proposal: **5-31-2981** **Council:** 4/2023

Title: Verifying possible pressure-induced Kitaev quantum spin liquid state in honeycomb magnet Na2Co2TeO6

Research area: Physics

This proposal is a new proposal

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Samples: Na2Co2TeO6

Instrument	Requested days	Allocated days	From	To
D20	4	4	26/10/2023	30/10/2023

Abstract:

Spin-orbit coupled honeycomb magnets with Kitaev interaction have received much attention, due to their potential of hosting exotic quantum states including the quantum spin liquids (QSL). Na2Co2TeO6 (NCTO) has recently been intensively studied as a putative Kitaev material. Hydrostatic pressure is expected provide a clean and reproducible way to continuously modify the exchange interactions in honeycomb Kitaev materials to realize the pure Kitaev QSL state, by compressing the lattice and altering the electronic structure as well as the Kitaev-to-Heisenberg coupling ratio accordingly. Very recently, it¿s theoretically predicted that the strength of the Heisenberg interaction will be negligible if the shrinkage of the in-plane Co-Co bond length exceed about 6 %, leaving a dominant Kitaev interaction quite promising for the realization of a true QSL state in NCTO. Therefore, we propose to conduct high-pressure neutron powder diffraction experiments on NCTO to clarify the evolution of its magnetic structure with hydrostatic pressure, to map out the pressure-temperature phase diagram, and to verify the theoretically proposed pressure-induced QSL state.

Possible pressure-induced Kitaev quantum spin liquid state in honeycomb magnet $Na_2Co_2TeO_6$

Abstract

We investigated the effect of hydrostatic pressure on the Kitaev quantum spin liquid candidate $Na_2Co_2TeO_6$ using high-pressure neutron powder diffraction. A pronounced suppression of the antiferromagnetic transition temperature T_N with increasing pressure is observed. Pressures up to 8 GPa were applied, and no structural phase transition was detected within this range.

Experimental Results

Approximately 10 mg of NCTO powder was used. Neutron diffraction measurements were performed with a wavelength of $\lambda = 2.41$Å. A Paris–Edinburgh press cell equipped with BN anvils and a TiZr gasket was employed to generate pressures up to ~8 GPa. Pressure values were calibrated using known structural transitions of Pb. Five pressure points were investigated: 1.0, 3.8, 5.5, 6.6, and 8.1 GPa. At each pressure, diffraction patterns were collected over a temperature range from 32 K to 5 K.

We first applied a small pressure of 1.1 GPa, and collected a set of diffraction patterns of different temperatures, which helps identify the transition temperature. Each pattern was collected by 2 hours for great statistics. Long scan at 5 K (base temperature) were performed for better analyses. Several magnetic peaks arise upon cooling, which can be indexed by propagation vector k = (1/2, 0, 0). The temperature dependence of the intensity of magnetic peaks shows typical behavior of order parameters. The same measurement protocol was repeated for all pressure points, with approximately one day required per pressure.

Fig. 1(a) shows the temperature dependence of the integrated intensities of magnetic peaks under different pressures. The corresponding transition temperatures T_N are extracted and summarized in Fig. 1(b). A clear suppression of T_N with increasing pressure is observed, indicating that long-range magnetic order is progressively weakened.

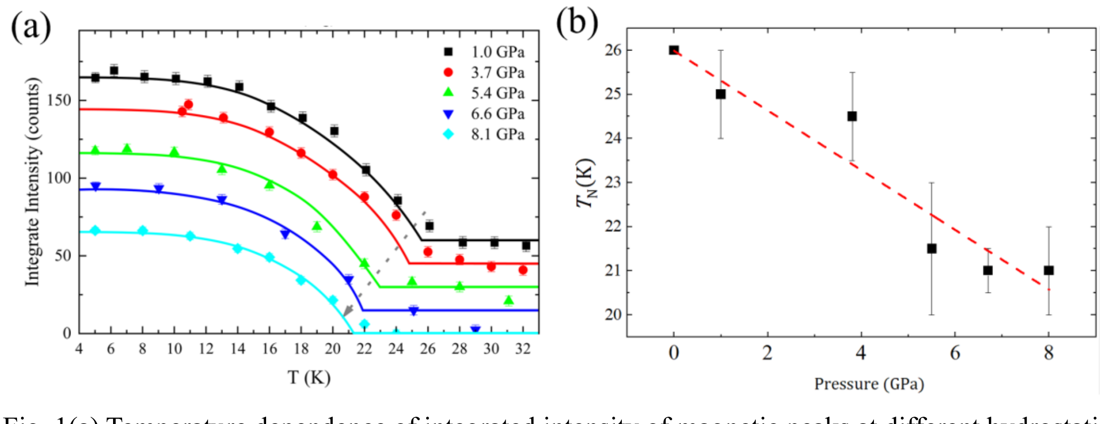

Fig. 1(a) Temperature dependence of integrated intensity of magnetic peaks at different hydrostatic pressure. The solid lines are the guide to the eyes. (b) The change of T_N with pressure, the red dash line is the linear fit of the experimental data.

Below 8 GPa, T_N decreases monotonically with pressure, with an overall reduction of approximately 21%. Comparing with other Kitaev candidates, distinct behavior is observed. For example, $BaCo_2(AsO_4)_2$ shows dT_N/dP ≈ 0.07 K/GPa while α-$RuCl_3$ and α-Li_2IrO_3 exhibit positive slopes of ~ 1 K/GPa and ~ 1.5 K/GPa.

In contrast, NCTO exhibits a negative pressure coefficient, $dT_N/dP \approx -0.75$ K/GPa, indicating a fundamentally different response. This behavior is characteristic of systems without a spin gap approaching a quantum critical point.

Such suppression of T_N may originate from pressure-induced enhancement of magnetic frustration or modification of competing exchange interactions, which destabilize long-range order. Meanwhile, the absence of structural transitions suggests that the effect is primarily electronic rather than crystallographic. These results imply that higher pressures may further suppress magnetic order and potentially stabilize a quantum disordered phase.