Experimental report

07/09/2022

Proposal: **7-01-543** **Council:** 10/2020

Title: Fractional Excitation-induced Phonon Renormalization in alpha-RuCl3

Research area: Physics

This proposal is a new proposal

Main proposer: **Adrian MERRITT**

Experimental team: Alexandre IVANOV

Local contacts: Alexandre IVANOV

Samples: alpha-RuCl3

Instrument	Requested days	Allocated days	From	To
IN8	8	7	15/03/2021	23/03/2021
IN3	1	1	13/03/2021	14/03/2021

Abstract:

alpha-RuCl3 is a promising Kitaev quantum spin liquid candidate, and above the critical magnetic field Bc~7T and below T~6K there is evidence for the half-integer quantized plateau. Recent theoretical work has shown that phonon renormalization in the QSL state should provide a clear indicator of Majorana fermion-phonon coupling. One paper examines the Majorana fermion-phonon interaction and shows that longitudinal/transverse acoustic phonons near the zone boundary soften/harden, respectively, through coupling to the fractionalized spins. Here we propose to measure the phonon dispersion under a magnetic field using INS to observe the phonon renormalization connect to the fractionalized excitations.

Fractional Excitation-induced Phonon Renormalization in α-RuCl$_3$: Experimental Report

A. M. Merritt, A. Ivanov, R. Heid, Y. Su

Eight days of INS beamtime on the IN8 instrument at ILL were used to investigate phonon dispersions in the putative quantum spin liquid $RuCl_3$. These measurements were made with a magnetic field, in the [110]-[001] (H, H, L) scattering plane. The $RuCL_3$ phase diagram is shown in Fig. 1. The main region of interest is the half-integer quantized plateau, where the magnetic order is broken under a high magnetic field and, it is claimed, the fractional excitations are revealed. Scans were made at points of interest for parametric studies of both temperature and magnetic field. Two experimental configurations were used, an earlier coarse resolution with open collimators and a later fine resolution with tighter collimations (40'-40'-60'-60'), no horizontal focusing and a Si-PG setup, which significantly reduced counting time (approximately a factor of x10).

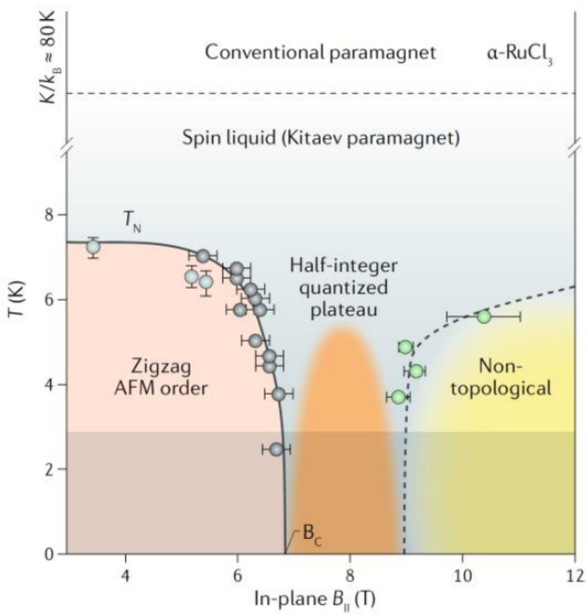

FIG. 1. $RuCl_3$ temperature and magnetic field phase diagram. From Kasahara *et al.*, Nature **559**, 227–231 (2018).

Scans focused on a few experimentally accessible q-points. Along [110], going from the Γ (2,2,0) point to K (2.33, 2.33, 0) to M (2.5,2.5,0) points, we observed the phonon dispersion. As well, we observed the dispersion from (0,0,12) along [001], and from (0.225, 0.225, 12) along [110] to (0.5, 0.5, 12).

The in-plane phonon dispersion is shown in Fig. 2. The significant loss of intensity of the low-energy acoustic phonons makes it difficult to track the dispersion as they cross the K point at (2.33, 2.33, 0). Here, multiple crossing phonon branches necessitated a switch to a configuration with finer resolution.

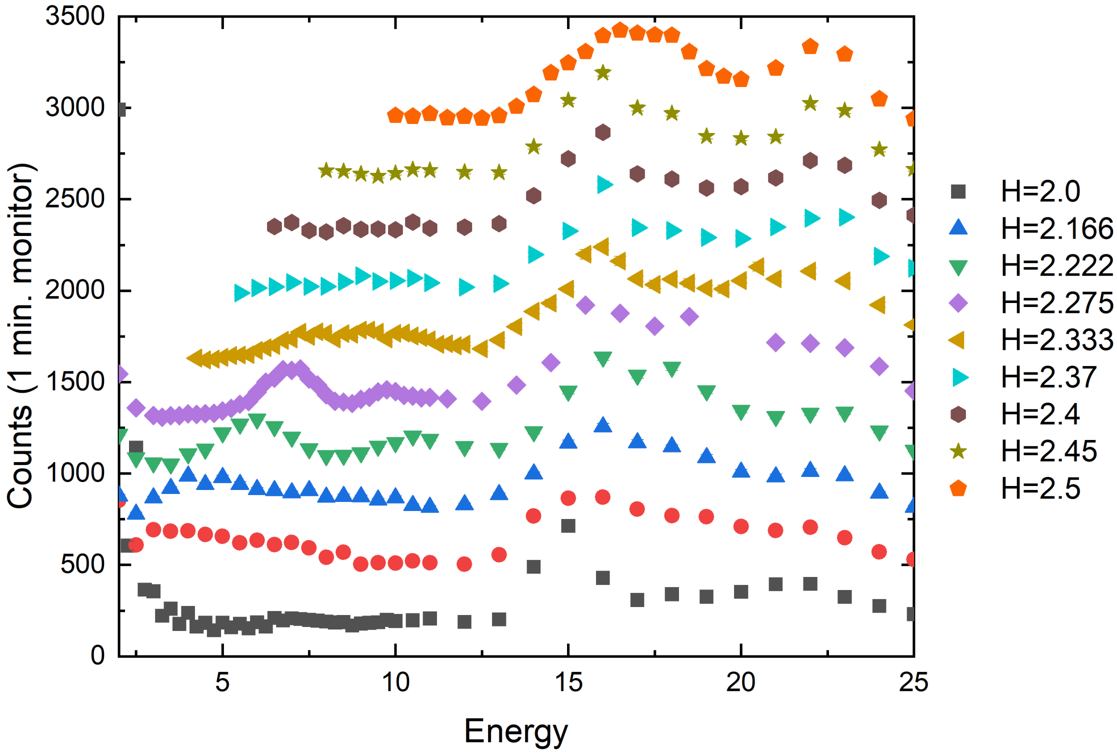

FIG. 2. Dispersion along [110] from (220), **Q**=(H,H,0). Offset of 300 counts applied.

The out-of-plane phonons near the (0,0,12) Bragg peak were strong and well-separated, making it straight forward to fit the peaks. Of particular note is a hardening effect upon cooling from 120K to 10K, as shown in Fig. 3. Here, an energy change of approximately 0.11meV is observed; this is much smaller than the expected phonon renormalization effect, but still significant. However, the phonon renormalization effect is predicted to be mainly an in-plane effect, making it unclear how the out-of-plane phonons could be related.

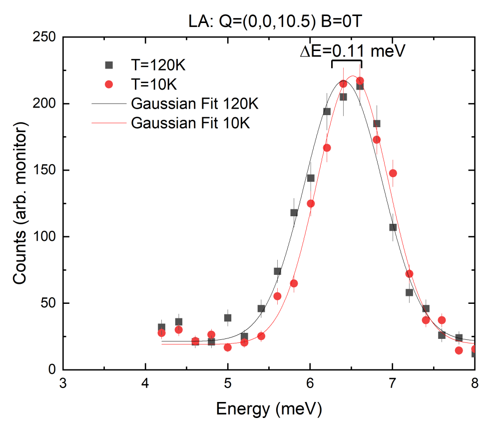

FIG. 3. Energy scans at (0,0,10.5). The phonon hardening effect is clear. The peaks have been fit with Gaussian profiles using a free peak width parameter.

With the fine resolution, we focused on a few points of interest to make parametric scans. In particular we focused on temperature- and magnetic field-dependency. Our results on the magnetic field dependency are summarized in Fig. 4. It is clear that there is no obvious phonon renormalization effect, as any changes in the phonon energies are within the error bars of the fits.

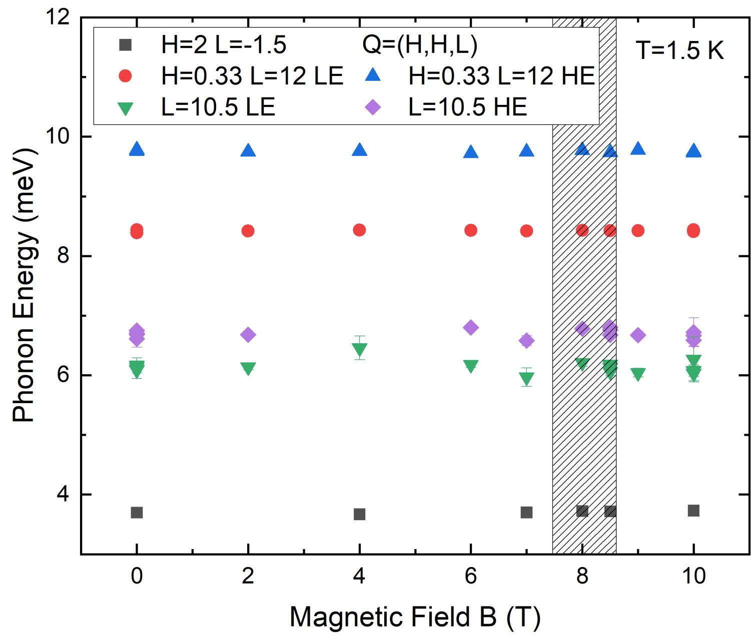

FIG. 4. Fit phonon peaks at various Q points as a function of magnetic field. All scans were conducted at T=1.5K. The shaded region marks the half-integer quantized plateau phase. LE and HE denote low-energy and high-energy phonons, respectively, to clarify the branches found in the same momentum transfers.

Due to the change in experimental configuration, we were unable to make a thorough study of the in-plane phonons at the required energy resolution. However, the out-of-plane phonons have yielded interesting and curious results, which we will explore more in the future.