Experimental report

08/08/2023

Proposal:	**7-01-575**	**Council:**	10/2022
Title:	Continued Investigation of Phonon Renormalization in RuCl3		
Research area:	Physics		

This proposal is a continuation of 7-01-543

Main proposer: **Adrian MERRITT**

Experimental team:
Zisheng YAO
YU HAO WU
Ryan O'CONNOR
Natan GARRIVIER
Yung Hsiang TUNG
Po Chun CHANG
Yixi SU
Hang LI
Adrian MERRITT
Johannes DORA
PIKESH PAL
Laura Susanne JUNKERS
Enmanuel DUARTE ANAYA
Nicoletta RUSTA
Andrea ALESSIO

Local contacts: Alexandre IVANOV

Samples: RuCl3

Instrument	Requested days	Allocated days	From	To
IN8	6	6	30/05/2023	05/06/2023

Abstract:

In putative Kitaev quantum spin liquid (QSL) candidate RuCl3 is of significant interest. It displays a zigzag antiferromagnetic ground state at low temperatures without a magnetic field, but under a strong magnetic field the magnetic order is broken and a half-integer quantized plateau appears, which is believed to be a signature of the QSL. It is theorized that a strong acoustic phonon renormalization effect will appear in this state due to Majorana fermion-phonon coupling, with opposite signs for longitudinal and transverse acoustic phonons. We have previously taken measurements on this system at IN8 and other instruments and shown several phonon anomalies in the acoustic phonons in the regions of interest under magnetic fields. We believe, however, that the phonon anomalies are not definitively due to the Majorana fermion-phonon coupling, and that additional measurements are needed to establish their true nature and examine other phonons of interest.

Continued Investigation of Phonon Renormalization in α-$RuCl_3$: 7-01-575 Experimental Report

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

Six days of INS beamtime on the IN8 instrument at ILL were used to investigate phonon dispersions in the putative quantum spin liquid (QSL) $RuCl_3$. These measurements were made with a magnetic field, in the [100]-[001] [H, 0, L] scattering plane and the magnetic field along [-1,2,0]. 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 through a phonon renormalization effect (See Ye *et al.*, Physical Review Research **2.3** (2020): 033180. Scans were made at points of interest for parametric studies of both temperature and magnetic field. The main experimental configuration was (40'-40'-60'-60') collimations, no horizontal focusing and a Si-PG setup, which resulted in an energy resolution at the elastic line of approximately 0.25 meV.

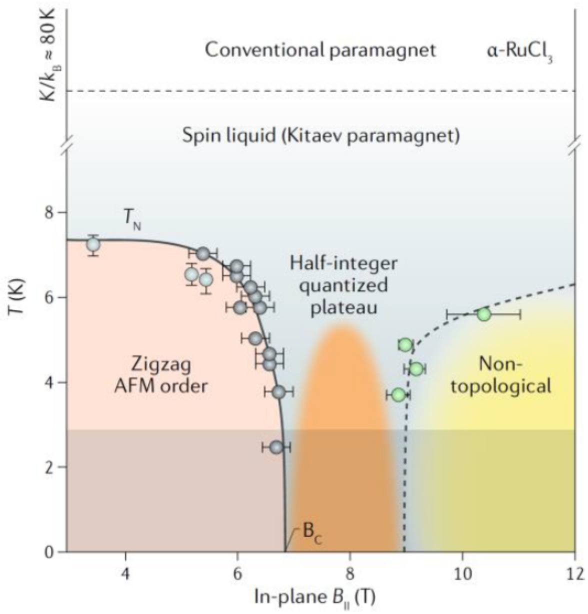

FIG. 1. $RuCl_3$ temperature and magnetic field phase diagram. From Kasahara *et al.*, Nature **559**, 227–231 (2018).

Scans were conducted near the (4,0,0) and (0,0,12) Bragg peaks, focusing on the longitudinal and transverse acoustic phonons. Temperature and magnetic field were varied from 120K-1.5K and 0T-10T, respectively. Example scans are shown below in Figs. 2 and 3; the former shows longitudinal acoustic phonons from (12,0,0) at (10.5, 0, 0), while the latter shows longitudinal acoustic phonons from (3,0,0) at (3.4,0,0). The first subfigures in each show parametric scans by magnetic field at base temperature, while the second subfigures show phonon changes with temperature from 1.5K to 120K. At both (0,0,10.5) and (3.4, 0, 0), the phonon hardens upon cooling by approximately 0.12meV from 120K to 10K; these are differences of approximately 1.8% and 1% for the out-of-plane and in-plane phonons, respectively. More work must be done to conclude if these changes in phonon energy are due to the lattice or have another mundane mechanism, or if they are due to the predicted phonon renormalization effect. However, the field-dependent study is still of interest. The phonon energies within the putative QSL phase are shown in the cyan curves within both figures, at 8T, but the phase is expected to extend at least ±0.5T. From bracketing the data at 8T compared to 0T and 10T,

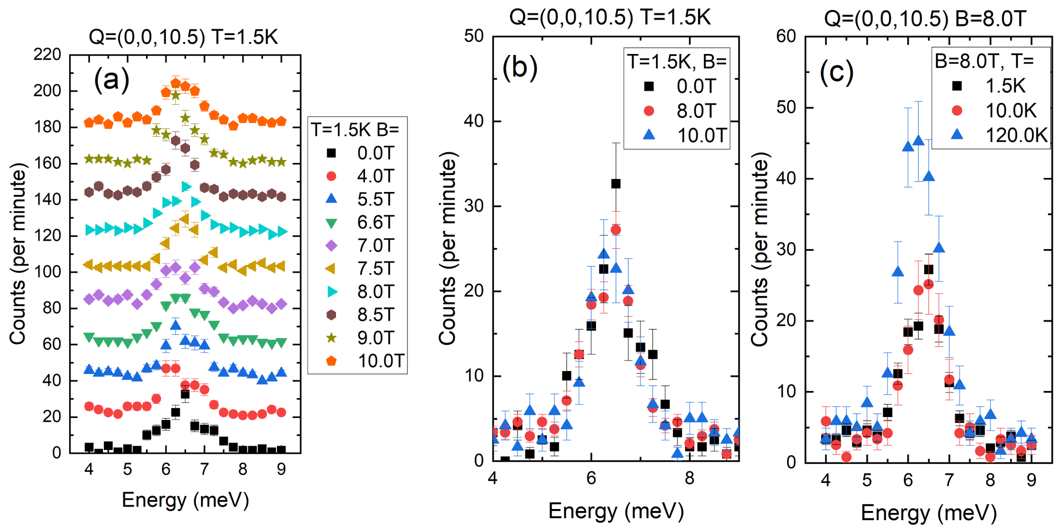

FIG. 2. Scans of interest at Q=(0,0,10.5). (a) Constant-Q=(0,0,10.5) scans at T=1.5K while varying magnetic field B. Plots are incremented by 20 counts for clarity. (b) Constant-Q=(0,0,10.5) scans at T=1.5K while varying magnetic field. (c) Constant-Q=(0,0,10.5) scans at B=8.0T while varying temperature.

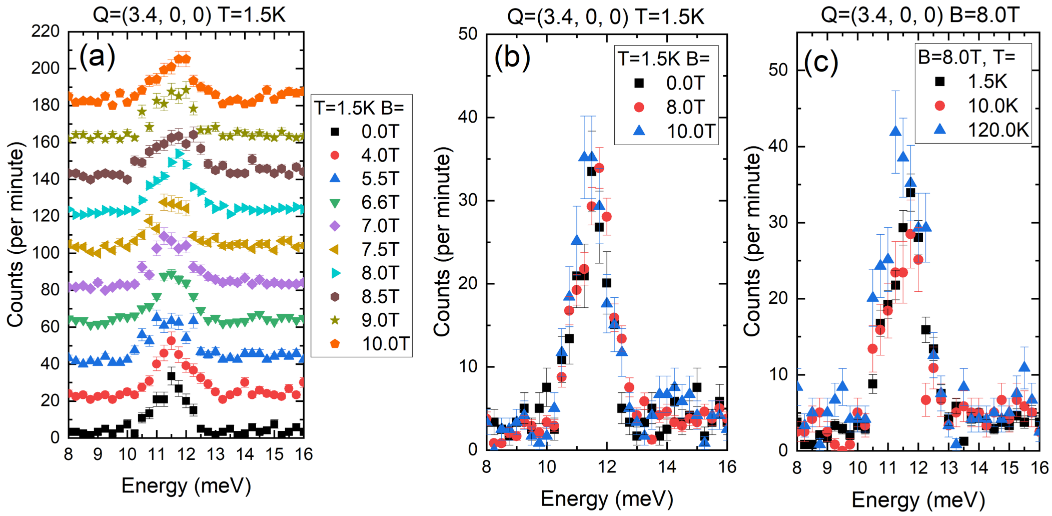

FIG. 3. Scans of interest at Q=(3.4, 0, 0). (a) Constant-Q=(3.4, 0, 0) scans at T=1.5K while varying magnetic field B. Plots are incremented by 20 counts for clarity. (b) Constant-Q=(3.4, 0, 0) scans at T=1.5K while varying magnetic field. (c) Constant-Q=(3.4, 0, 0) scans at B=8.0T while varying temperature.