Experimental report

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Title: Magnetic and nuclear structures ofelectric-field-induced ferromagnetic metal Ca2RuO4

Research area: Physics

This proposal is a continuation of 5-51-504

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Samples: Ca2RuO4

Instrument	Requested days	Allocated days	From	To
D9	6	4	19/09/2016	23/09/2016

Abstract:

In the 4d-electron layered calcium ruthenate Ca2RuO4, a complex interplay between equivalent spin-orbit coupling and electron correlation energies foster exotic physics, an area of significant interest in recent years. Importantly, the comparable energy scales of strong electron correlations and SOC in this ground state mean that Ca2RuO4 is highly susceptible to outside perturbation, where applied pressure or chemical substitution results in a transition from an AFM insulator to a FM metal. Recently it has been reported that under applied electric fields, Ca2RuO4 undergoes a metal-insulator transition (MIT) with concomitant structural modifications [8,9]. This MIT provides a unique opportunity to investigate the role of SOC and the interplay of structural and electron degrees of freedom. In 2015 we used the hot neutron diffractometer D9 with in-situ applied electric fields to reveal significant structural and magnetic modifications in the metallic state in Ca2RuO4. Here we propose to use D9 to complete our investigation of the nuclear and magnetic structures under applied electric fields.

Experiment Report

Magnetic and nuclear structures of electric-field-induced ferromagnetic metal Ca_2RuO_4

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Proposal ID: 5-41-888
Instrument: D9
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Introduction

In the 4d-electron layered calcium ruthenate series Ca_2RuO_4, a complex interplay between equivalent spin-orbit coupling (SOC) and electron correlation energies foster exotic physics, and a ground state that is highly sensitivity to external perturbation where applied pressure [1] or chemical substitution [2] results in a transition from an AFM insulator to a FM metal. Recently it has been reported that under applied electric fields, Ca_2RuO_4 undergoes a metal-insulator transition (MIT) with concomitant structural modifications [3]. Here we used single crystal neutron diffractometer D9 to investigate the link between the MIT and changes to the nuclear and magnetic structures of Ca_2RuO_4.

Setup

D9 was setup with a wavelength λ = 0.8416 Å, and a orange cryostat sample environment. In a prior experiment (5-51-504), the standard 4-circle goniometer stage was used. However the cooling power of this system was not enough to overcome the small amount of Joule heating arising from the current flow, limiting the lowest temperature to 45K. In addition, a copper sample holder was designed to further improve thermal conductivity. A small single detwinned Ca_2RuO_4 crystal was mounted in the (HK0) plane in order to access the primary (100) A-type AFM and potential B-type AFM (101) reflections. Contacts were made directly to the sample such that in-situ electric fields could be applied along the c-axis, with a constant current applied with Keithley 2400 Source Measure Unit, which was controlled and monitored via in-house designed software.

Results

Since a full refinement of the nuclear structure had been conducted in the prior experiment, the focus for these measurements was the study of the magnetic structure at temperatures below 45K. Previously it was identified that AFM order was fully suppressed at T=45K. At room temperature a 440mA current was applied, which initiated the metal insulator transition. The crystal remained in the metallic state down to a lowest stable temperature of T=10K. Within the limits of the (HK0) plane, primary nuclear and magnetic reflections were measured for extended count times to study potential AFM and FM magnetic phases at lowest temperatures. The main result is shown in Figure 1. These measurements were measured at 30K, above the expected transition to ferromagnetism ~20K. A weak AFM feature is present at I=440 mA, which shows a steady increase with decreasing current. When the sample switched back to the insulating state the AFM fully recovered.

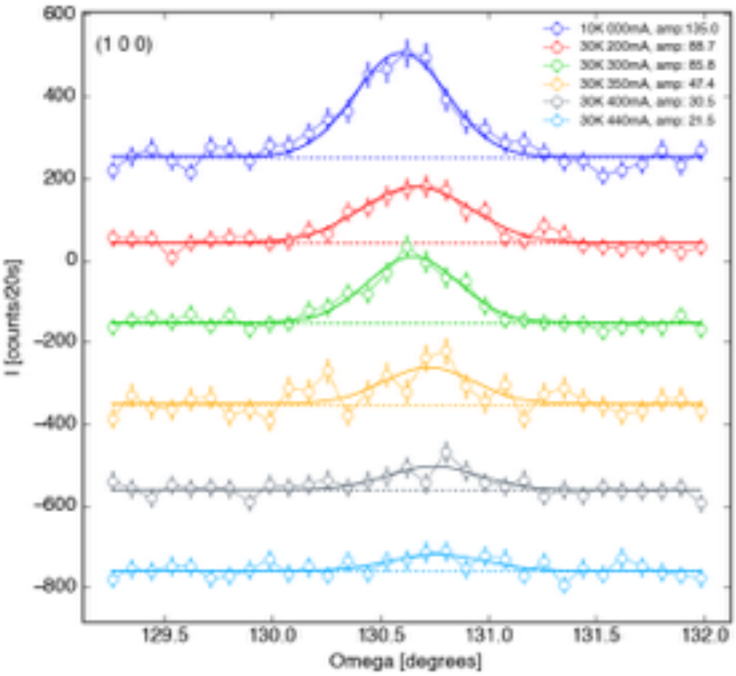

Figure 1. Tracking the primary antiferromagnetic reflection (100) from the initial metallic state with I=440mA, back down to the normal insulating state.

Outlook

Analysis of the structural peaks to identify any additional ferromagnetic component at lowest temperature is currently ongoing. With the results from this experiment and 5-51-504, we are currently developing a comprehensive understanding of the underlying nuclear structure, with a particular focus on the RuO6 octahedral distortion, tilt and rotation and on the suppression of the antiferromagnetic state, and how these changes compare with other approaches to the metal insulator transition - temperature, Sr-ion substitution and hydrostatic pressure.

References

[1] F. Nakamura et al,. PRB 65, 220402(R) (2002).
[2] S. Nakatsuji & Y. Maeno, PRL 84, 2666 (2000).
[3] F. Nakamura et al., Sci. Reports 3, 2536 (2013).