Experimental report

16/01/2024

Proposal: **5-51-598**

Council: 4/2023

Title: Dyzaloshinski-Moriya interaction and spin canting in SrRuO3

Research area: Physics

This proposal is a new proposal

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Samples: SrRuO3

Instrument	Requested days	Allocated days	From	To
D3	6	7	06/06/2023	14/06/2023
ORIENTEXPRESS	0	1	07/06/2023	08/06/2023

Abstract:

Polarized neutron diffraction under an external magnetic field can determine even weak antiferromagnetic canting of a ferromagnetic material. We therefore propose to study the G- and C-type canting components that are symmetry allowed in ferromagnetic SrRuO3. Since the Heisenberg magnetic interaction is known for this material, we can determine the strength of the Dzyaloshinski-Moriya interaction from these canting values.

Instrument	D3
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The purpose of this experiment was to study the Dyzaloshinski-Moriya interaction in the single crystal of $SrRuO_3$. $SrRuO_3$ is the infinite layered ruthenate with ferromagnetic order at ambient pressure and zero field with the order moment of $1.6\mu_B$ and T_c=165K [1, 2]. The relation between the anomalous Hall effect and Berry phase due to the Weyl point has been evidenced for $SrRuO_3$ and by now this compound is known as a FM Weyl semimetal [3]. $SrRuO_3$ crystal deviates from cubic perovskite structure due to the rotation and tilting of the octahedral and crystalizes from cubic in Pnma structure (a=5.53Å, b=7.85Å and c=5.57Å) [see 5] with considering the two transitions that happen at 975K and 800K. The crystal distorts heavily with rotated RuO_6 octahedra (9̊) at low temperatures. As a result, $SrRuO_3$ illustrates structural twinning with six different domain orientations [4]. Detwinning the crystal requires applying uniaxial pressure or magnetic field [1, 5]. $SrRuO_3$ shows strong spin-orbit coupling that can be concluded from the noticeable anisotropy in its magnetization measurement and for the anisotropy magnon gap of 1 mev [1, 6].

The finite Dzyaloshinski-Moriya (DM) interactions cant the magnetic moments out of the ferromagnetic state. Symmetry analysis in Pnma space group shows that the ferromagnetic *z* component is coupled with G-type *y* and C-type *x* components. This can also be deduced from the crystal structure. The G-type tilting of the octahedrons around orthorhombic *a* yields the G-type *y* component, and the C-type rotation around *b* yields the C-type *x* component. However, the size of the DM interaction that drives the canting microscopically cannot be reliably estimated from DFT calculations [5]. Although many general phenomena such as skyrmions originate from the DM interaction, due to the difficulties of determining only a few quantitative studies are reported [7]. Despite the comprehensive study of magnetic excitations in $SrRuO_3$, the DM interaction in this crystal cannot be easily obtained by magnon dispersion fitting [8, 9]. One can calculate the DM interaction from the canting angle of the magnetic moments. The canting size in $SrRuO_3$ is small (only some percentage of the main component), therefore we need polarized neutrons for a precise determination. The polarized neutron experiment provides the opportunity to study the nuclear magnetic interfaces by measuring flipping ratios, that prevent the squaring of the tiny canted components. Therefore, one can measure even small magnetic moments.

In this experiment we explored the nuclear magnetic interference terms by measuring flipping ratios. We studied a cube-shaped single crystal of $SrRuO_3$. The sample was cooled down to 2K in a field of 9T. The applied magnetic field helps us in two ways, it aligns the sample spins and guides the spin of neutron beam [5]. By applying magnetic field of 9T along the cubic [110] direction, the structural domains with the orthorhombic c parallel to the field grow on the cost of the other domains. Therefore, we detwinned the sample and achieved a monodomain state. The absence of twining is important for the precision of the spin-density analysis. In this experiment, a set of data collection with independent flipping ratios, i.e., ratios of the Bragg reflection intensities for neutron spin parallel and antiparallel to the external magnetic field of 0.7T and 3.5T were measured at 2K. Due to the time limitation smaller data sets with selected Bragg reflections were measured at different temperatures (60 K, 120 K, 170 K, 210K) under the magnetic field of 0.7T and 9T. The Fig. 1 shows the comparison of the experimental and calculated flipping ratio of the 2K 3.5T data set. Fig. 2 depicts the magnetic model that describes the experimental flipping ratios with canted moments at the Ru position and sizeable moment at the oxygen sites.

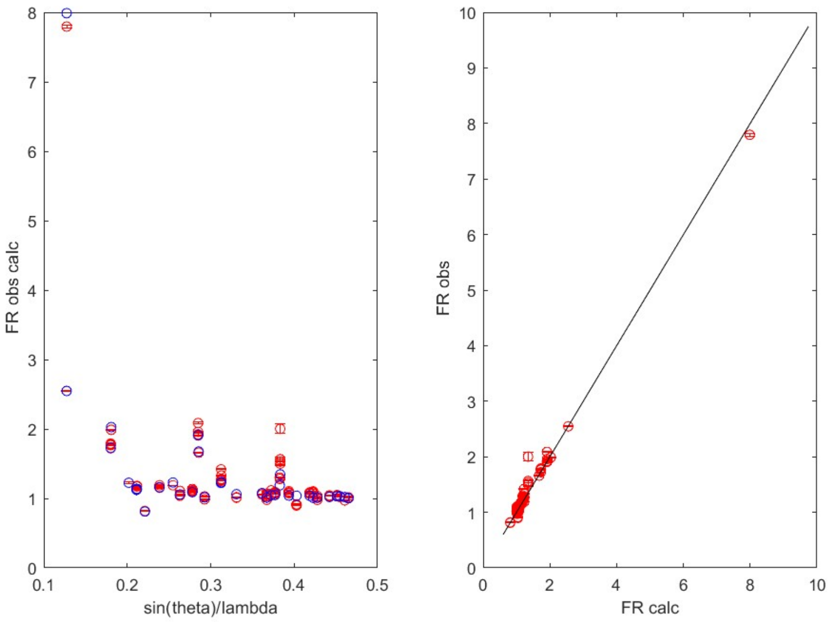

Fig.1: Observed flipping ratios as a function of temperature (red data, blue calculated) and comparison of the experimental and calculated flipping ratios of 2K 3.5T data set.

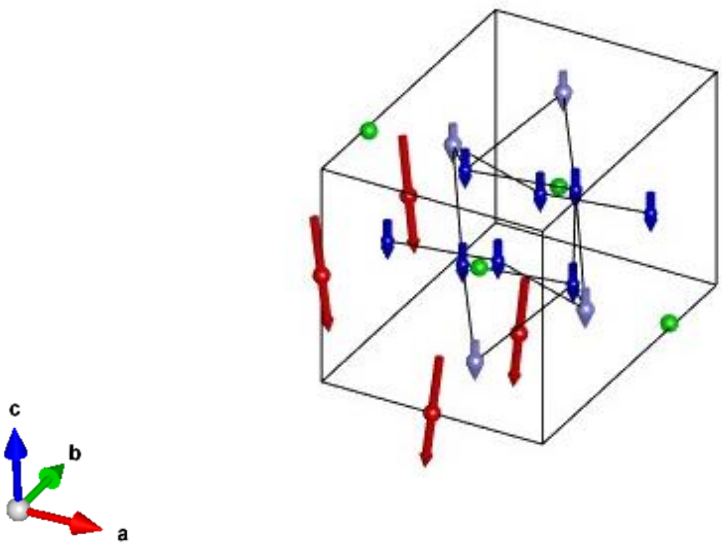

Fig. 2: illustration of the magnetic model describing the experimental flipping ratios at 2K. Red arrows denote Ru moments and blue arrows denote moments of the Oxygen.

In overall, we can state that this experiment was quite successful and productive in collecting data with high statistics in a reasonable time. We were able to detwinn the crystals by applying the 9T magnetic field. Indeed, the canting angle at c magnetic moment in ferromagnetic $SrRuO_3$ can be precisely determined with the flipping ratio method.

References:

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[6] K. Jenni *et al.*, "Interplay of electronic and spin degrees in ferromagnetic $SrRuO_3$: Anomalous softening of the magnon gap and stiffness," *Physical review letters,* vol. 123, no. 1, p. 017202, 2019.

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