Experimental report

07/09/2018

Proposal: **4-01-1563** **Council:** 4/2017

Title: Left-handed magnons in the metallic ferromagnet SrRuO3

Research area: Physics

This proposal is a new proposal

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Experimental team: Kevin JENNI

Local contacts: Paul STEFFENS

Samples: SrRuO3

Instrument	Requested days	Allocated days	From	To
THALES	6	0		
IN12	0	6	28/06/2018	04/07/2018

Abstract:

Recently Onoda, Michenko and Nagaosa propose SrRuO3 as a candidate material for the realization of the left-handed magnon. SrRuO3 fulfills all four necessary conditions which are needed: (i) basically quenched orbital moment, (ii) strong SOI, (iii) finite contribution of the majority and minority spins to the density of states at EF, and (iv) band degeneracy near the Fermi level. We succeeded in growing large single crystals of SrRuO3 at Cologne University and already started to investigate the magnon dispersion. The main characteristics of the magnon dispersion were determined as Δ=0.88meV and D=108 meVÅ^2. In order to get deeper inside into the character of the magnon modes we want to continue the investigation with polarized neutron scattering. This is particularly interesting with regard to a recent discussed theory concerning the magnetic excitations in SrRuO3, like the proposed relation of the anisotropy gap to the Weyl fermions and to the anomalous Hall effect, or like the left-handed magnon.

Experimental Report

Instrument	IN12
Proposal Number	4-01-1563
Proposal	Left-handed magnons in metallic ferromagnet $SrRuO_3$
Experimentalist	Kevin Jenni, Paul Steffens, Markus Braden
Local Contact	Wolfgang Schmidt

In their recent study, Onoda, Michenko and Nagaosa (OMN) investigated the handedness of magnons in a ferromagnet taking into account the relativistic spin-orbit interaction [1]. They find that under certain conditions the spin excitations can become left-handed whereas they are always right-handed in a normal ferromagnet. OMN define four necessary conditions for a material which can exhibits these left-handed magnons and propose $SrRuO_3$ as a candidate which fulfills all these rules.

Following this suggestion, we wanted to study the handedness of the spin excitations in $SrRuO_3$ with polarized neutron scattering. Large single crystals were successfully grown with the floating zone method in our institute in Cologne. Previous neutron experiments and dilatometer measurements showed that the crystals are strongly twinned but can be untwinned by applying a magnetic field and cooling down into the ferromagnetic phase (T_C = 160 K) [2]. The crystal even stays untwinned when the magnetic field is switched off and the twinning can be recovered by heating the material above T_C (magnetic shape-memory effect). For the polarization analysis planned in this experiment untwinned crystals were needed to ensure a proper evaluation of the results. Therefore, we decided to use the following experimental setup. One crystal was oriented in the $[011]/[0\bar{1}1]_{cubic}$ scattering plane and the horizontal magnetic field was aligned in the $[0\bar{1}1]_{cubic}$ direction. After cooling down the crystal in 3 T magnetic field to 10 K all structural twins are oriented with their orthorhombic c-axis ($[0\bar{1}1]_{cubic}$ and easy axis) along the magnetic field. The scattering plane becomes $[100]/[001]_{orthorhombic}$ and it is possible to measure the magnon at $(100)_{orthorhombic}$ and $(011)_{cubic}$ respectively. In the following we use the cubic setup of the cell. The analysis of the flipping ratios with one flipper before and one flipper after the sample revealed that the strong internal magnetic field of the crystal depolarizes the neutrons when the guide field, provided by the horizontal magnet, is too weak. Therefore, we used the strongest possible field of 3.8 T. Even with this strong magnetic field the full polarization analysis with both flippers was feasible (Flipping ratios around 7). Because of the experimental setup the

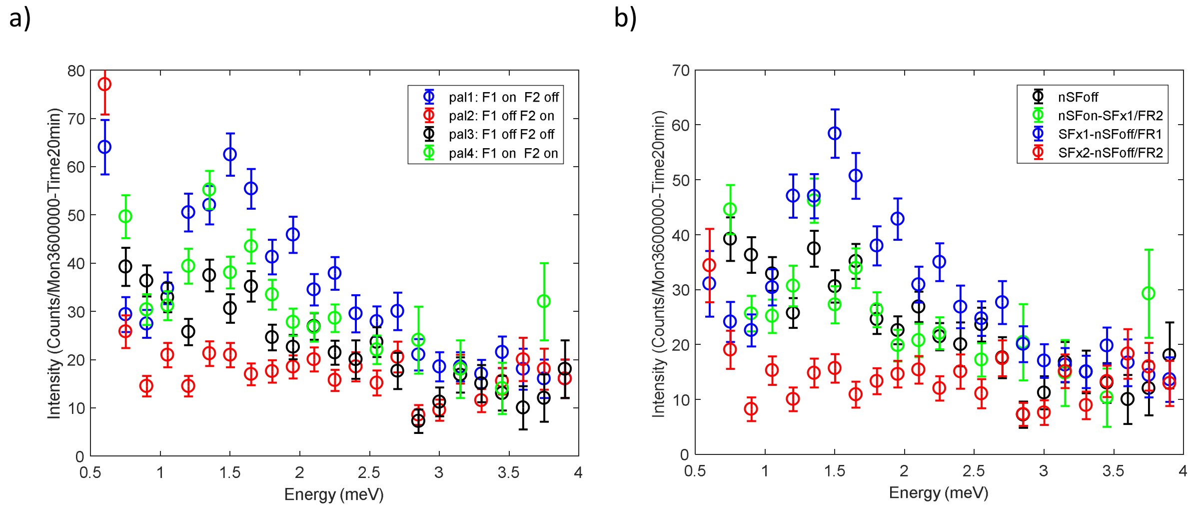

Figure 1: Constant Q scans at Q(011). a) All four flipper configurations are shown. The raw data shows already a clear difference between both SFx channels. b) The nSFon channel is corrected by subtracting the with FR2 weighted SFx1 channel. The SFx channels are corrected for the nuclear part (nSFoff) weighted with the flipping ratios. The difference between the channels becomes even more pronounced.

polarization analysis is restricted to the neutron polarization along Q, defined as x direction. Combined with the two flippers (F1 and F2) four channels can be measured: nSFoff (F1 off F2 off), nSFon (F1 on, F2 on), SFx1 (F1 on, F2 off), SFx2 (F1 off, F2 on). These channels are sufficient for the extraction of the chiral ratio which determines the handedness of the magnon.

The magnon was measured at Q(011) with constant Q scans in all for channels. Due to the small sample volume of circa 0.5 cm^3 and the reduced flux caused by the polarization analysis long counting times around (20 min per point) were necessary for the inelastic scans. Fig. 1 a) displays the recorded data for all four channels. The magnon is evident in the SFx1 channel around 1.5 meV. This value is in agreement with previous measurements of the gap shift in a magnetic field. A clear difference between the both SFx channels is visible. The both nSF channels seem to be different in the way that the nSFon channel is higher in intensity than the nSFoff channel. The correction of the data (Fig. 1b)) solves this discrepancy and the two nSF channels are equal within the error bars, as expected. The difference between the both SFx channels becomes even more pronounced after correcting the data with the flipping ratio weighted nSFoff channel. For the evaluation of the chiral part of the magnetic scattering one needs to build the sum and difference of both SFx channels (Fig. 2 a)) to obtain the chiral ratio (Eq. 3).

$$\text{SFx1: } \bar{x}x = \boldsymbol{M}_\perp \boldsymbol{M}_\perp^* + i(\boldsymbol{M}_\perp \times \boldsymbol{M}_\perp^*)_x \tag{1}$$

$$\text{SFx2: } x\bar{x} = \boldsymbol{M}_\perp \boldsymbol{M}_\perp^* - i(\boldsymbol{M}_\perp \times \boldsymbol{M}_\perp^*)_x \tag{2}$$

$$r_{\text{chiral}} = \frac{I_{x\bar{x}} - I_{\bar{x}x}}{I_{x\bar{x}} + I_{\bar{x}x}} \tag{3}$$

Since the raw data showed already a pronounced difference in the both SFx channels the chiral ratio goes up to 0.65 (Fig. 2 b)). As expected the chiral ratio reaches its maximum at the gap energy of the spin excitation. Over a broad energy range (0.75 – 3.5 meV) the chiral ratio is positive and greater than zero. The scattering due to the magnon consists mainly of chiral magnetic scattering, as expected.

a) b)

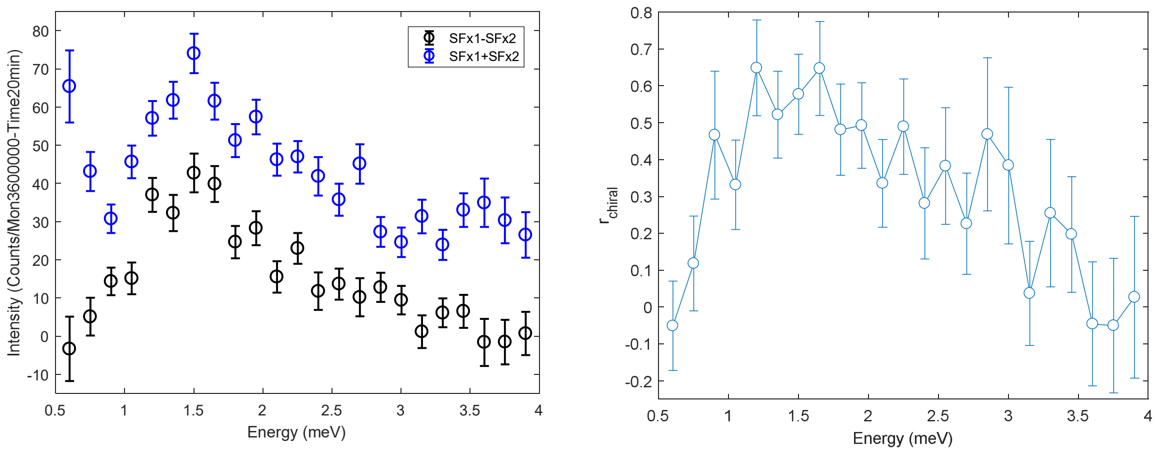

Figure 2: Evaluation of the chiral magnetic scattering: a) Sum and difference of both SFx channels. b) Calculated chiral ratio in dependence of the energy.

We additionally started to follow the dispersion of the magnon with this experimental setup. Due to the low signal there was just enough time for a 4-point scan (Fig. 3). The magnon is again just visible in the SFx1 channel and peaks around 2.5 meV.

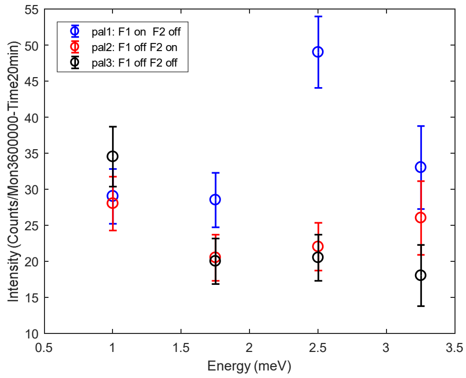

Figure 3: Constant Q scan at Q(0 0.95 0.95) for different flipper configurations

For the analysis of the handedness of the spin excitation, it is necessary to take into account the exact instrumental setup of the experiment. Handedness of the three axes of the spectrometer and the magnetic field direction in relation to the Q-vector have an influence on the sign of the chiral ratio. Our first analysis interprets the chiral scattering of the spin excitation as seen above as the fingerprint of right-handed magnons.

While the results shown above are promising and do not confirm the theoretical proposition of the left-handed magnon, we would like to extend the study of the handedness of the spin excitation in $SrRuO_3$. A variation of the temperature could lead to a change in the chiral ratio since other physical properties of this ferromagnet, e.g. the anisotropy gap and the crystal cell volume, exhibit anomalous temperature behavior. Also the further investigation of the dispersion of the magnon with polarized neutron scattering is worth to consider. To increase the signal intensity and therefore decrease the measuring time, we would use a sample setup of several coaligned crystals.

References

[1] Onoda, A., Mishenko, and N. Nagaosa, J. Phys. Soc. of Japan Letters 77, 013702 (2008).
[2] S. Kunkemöller et al., Magnetic shape-memory effect in $SrRuO_3$, PRB 96, 220406(R) (2017).