Experimental report

07/09/2022

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Title: Skyrmion manipulation using radialcurrents

Research area: Physics

This proposal is a new proposal

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Samples: MnSi

Instrument	Requested days	Allocated days	From	To
D33	4	4	05/07/2021	09/07/2021

Abstract:

Magnetic skyrmions show promise for future data storage applications due to their topological protection, the existence of skyrmion lattices (SkL) at a wide range of temperatures and magnetic fields, and the remarkably low current densities required to drive their motion. Here we propose an experiment which uses geometry to directly exert a Magnus torque on the SkL of MnSi, allowing for direct observation of skyrmion motion, SkL-crystal lattice coupling, and potentially new skyrmion dynamics.

Skyrmion manipulation using radial currents

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Background

Magnetic skyrmions show promise for future data storage applications due to their topological protection and the existence of skyrmion lattices (SkL) at a wide range of temperatures and magnetic fields. As demonstrated by Jonietz *et al.* [1] and Okuyama *et al.* [2], the SkL in the cubic helimagnet MnSi can be rotated using electrical currents of order $j \sim 10^6$ A/m^2. This is substantially smaller than the roughly 10^9 A/m^2 required to drive magnetic domain walls through racetrack memory devices. Here, the observed SkL was attributed to the combination of the electrical current and a thermal gradient in the sample.

We performed an experiment attempting to use geometry to directly cause a SkL rotation without relying on a thermal gradient.

Fig. 1 Corbino sample used in the SANS experiment. The MnSi crystal is resting on a sapphire disk. A HTS is soldered to the center and eight silver wires are attached to the perimeter to produce a radial electric current.

Corbino sample

For the SANS experiment we used a sample in a Corbino geometry with current contacts at the center and periphery of an ideally circular crystal. The device is shown in Fig. 1. Here the elliptical MnSi has major and minor axes of approximately 7×6 mm^2 and a thickness of 220 μm. The current is applied to the central contact a high-temperature superconducting (HTS) tape and at the perimeter via eight silver wires. The MnSi crystal rests on a sapphire disk and is held in place only by the electrical connections. Strain relief is provided by a loop on each of the silver wires. Voltage contacts on the MnSi crystal itself are used to monitor the sample temperature.

SkL tilting due to self-field effects

The electrical current in the sample will cause an additional self-field. Since the skyrmions are only weakly coupled to the crystalline lattice this will cause a tilting of the SkL around the current direction. When the current is parallel to the scattering vector this is directly observable in the SkL diffraction pattern, as shown in Fig. 2.

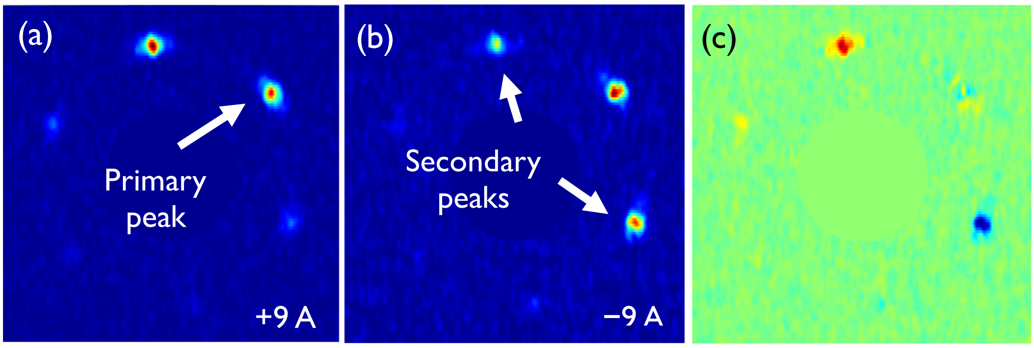

Fig. 2 SkL tilting due to the self-field when the current is parallel to the scattering vector. (a) Diffraction pattern that nominally satisfy the "primary peak" for a positive current. (b) The same for a negative current. (c) Subtraction of panels (a) and (b).

For both the diffraction patterns in Figs. 2(a) and 2(b) the SkL is nominally rocked onto the "primary peak" on the upper right diagonal. The SkL tilting is manifested by the intensity of the "secondary" peaks that change depending on the current direction. Figure 2(c) shows a subtraction of the two diffraction pattern. From this it is clear that the secondary peaks change intensity while the primary one remains unchanged.

The above effect is only observed when the SkL scattering vector is parallel or antiparallel to the current direction. When these are perpendicular both the primary and secondary peaks move towards or away from the Ewald sphere in the same manner and no change of intensities are observed. This is confirmed by the order parameter shown in Fig. 3, obtained from spatially resolved measurement in all four quadrants of the sample.

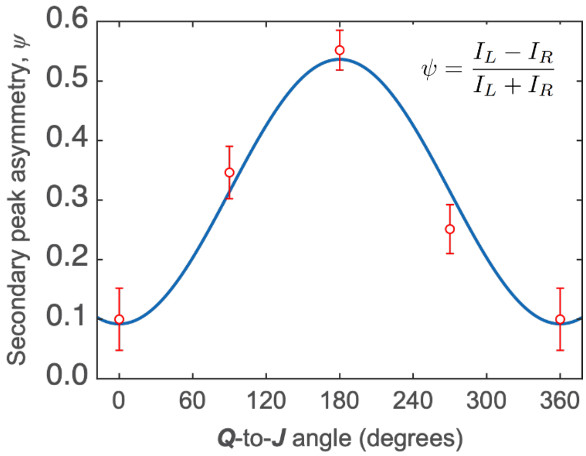

Fig. 3 Order parameter defined as the difference between the intensity of the secondary peaks divided by their sum.

SkL rotation

No rotation of the SkL as observed for current up to ±9 A. However, subsequent SANS measurements performed on a different sample at the Paul Scherrer Institute did show a clear rotation. Furthermore, the rotation is non-monotonic as the electric current is increased. This indicate a competition between the effects electrical and thermal currents.

Outlook

We hypothesize that a thermal gradient is required to cause a SkL rotation, even in a Corbino geometry, which will explain the discrepancy between the ILL and PSI results. Further SANS experiment should be carried out to confirm or refute this. In addition, the nonmonotonic SkL rotation observed at PSI will allow a separation of the two competing effects. We are currently performing both a finite element analysis of the sample and molecular dynamics simulations to address this.

References

1. F. Jonietz *et al*., Science **330**, 1648–1651 (2010).
2. D. Okuyama *et al.,* Commun. Phys. **2**, 79 (2019).