Experimental report

21/02/2022

Proposal: **4-01-1645** **Council:** 10/2019

Title: k-space asymmetry of low-energy excitations in the chiral magnet MnSi

Research area: Physics

This proposal is a continuation of 4-01-1584

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Samples: MnSi

Instrument	Requested days	Allocated days	From	To
IN15 Ferromagnetic echo	7	5	25/03/2021	30/03/2021

Abstract:

We have successfully observed by ferromagnetic NSE the effects on neutron energy of the asymmetric dispersion curves predicted for the skyrmion lattice phase of MnSi. This phenomenon - that the excitation energies depend on whether q is parallel or antiparallel to the magnetic field - is predicted to arise due to the Berry phase of the skyrmions. We now propose to carry out an experiment in the same geometry but at a lower magnetic field, so that the magnetic ordering in MnSi is helical, where no asymmetry is predicted; however, this prediction should be checked. For a helical magnet, the scattered intensity depends on the angle between q and the applied magnetic field (which determines the polarisation axis), so it is important to establish whether the energy transfers are independent of this angle.

k-space asymmetry of low-energy excitations in the chiral magnet MnSi

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Introduction

Topological spin textures have attracted great attention both experimentally and theoretically. Among them, the vortex-like spin-swirling texture of the magnetic skyrmion has attracted much attention [1]. Since the magnetic skyrmions in MnSi have a long periodicity (~18 nm), the structure has been examined by using small angle neutron scattering (SANS) in momentum space and Lorentz Transmission Electron Microscope (LTEM) techniques in real space. On the other hand, the dynamics of the magnetic skyrmion have not been clear because an inelastic neutron scattering measurement in which the dynamic structure factor $S(q,\omega)$ can be estimated is not easy with an energy scale of μeV in a small q region.

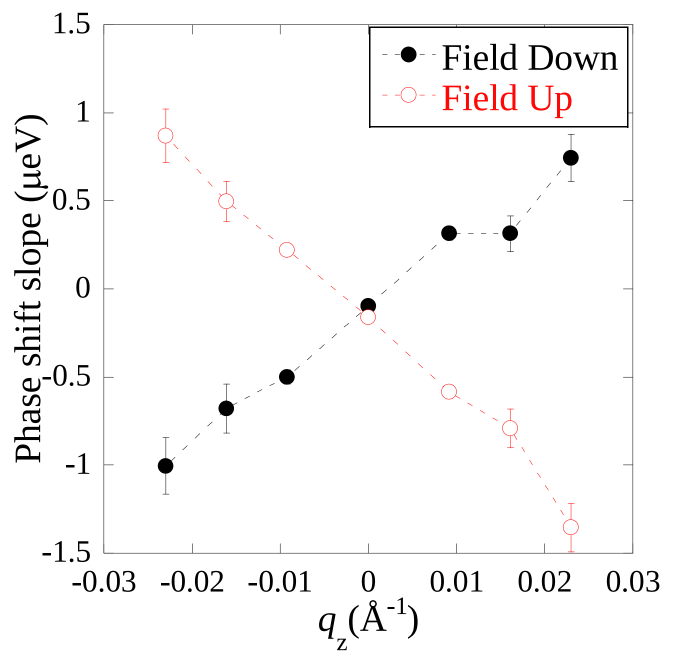

Fig. 1 The slope of the echo phase shift variation with Fourier time *versus* q_z in the skyrmion phase.

Previously we have carried out inelastic measurements on IN15 in MnSi using the spin-echo technique to clarify the dynamics of the skyrmion state. A large phase-shift in spin-echo-signal was observed in this state. The phase varied linearly with Fourier time, indicating an energy shift. Figure 1 shows values of the slope of the phase shift variation with Fourier time, estimated from the echo signal in the skyrmion state. We see that the slope varies with q_z, the momentum along the magnetic field direction. The value of this phase shift also reverses on changing the magnetic field (z) direction. Our results mean that the skyrmion has an asymmetric dispersion, with a different q dependence of the magnetic excitations along $+q_z$ and $-q_z$. This is consistent with a theoretical study calculated by our collaborators [2].The purpose of our follow-up experiment was to confirm the difference between the echo signals in the helical and skyrmion states.

Experimental Details

A spin-echo measurement in the helical state was performed on IN15 for comparison with the skyrmion state. The mosaic of MnSi single crystals was set with the [1 1 0] axis vertical in a cryostat with a vertical-field magnet. Incident neutrons with wavelength λ=6 Å were used. The sample was cooled to T=28 K in zero magnetic field; then a magnetic field of either B = +50 or –50 mT was applied. This field value was small enough to avoid realigning the $\boldsymbol{q}$-vector into the conical state with $\boldsymbol{q}$ parallel to the field, and also was outside the region where the skyrmion state is observed. Hence, the sample had the helical magnetic structure. It should be noted that in the zero-field helical structure, the helix $\boldsymbol{q}$-vectors are along {1 1 1} directions. Since the magnetic domains are not aligned by B = ±50 mT, we can measure both the in-horizontal-plane and the out-of-horizontal-plane Bragg reflections The spin-echo measurements for several sample rotation angles close to the elastic peak from the helical phase were performed at T = 28 K under field-up and field-down conditions. The measurements of the background data at 70 K and on the pyrolytic graphite calibration sample were performed under the same conditions as for the experiment in the skyrmion state.

Results

We carried out neutron spin-echo measurements at 28 K and 70 K with the field at the sample either + 50 mT (Field Up) or - 50 mT (Field Down). Note that at 28 K and 50 mT, the sample is in the helical state. The energy shifts, which are estimated from the phase shift slope of the helical state data at $\pm q_z$, are plotted in Fig. 2. This shows that in the helical state, there is no detectable asymmetry in the excitation energies, unlike in the skyrmion case, where there is an asymmetry depending on whether q_z is parallel or antiparallel to the field. This shows that the dispersions in the helical state are clearly different from those in the skyrmion state.

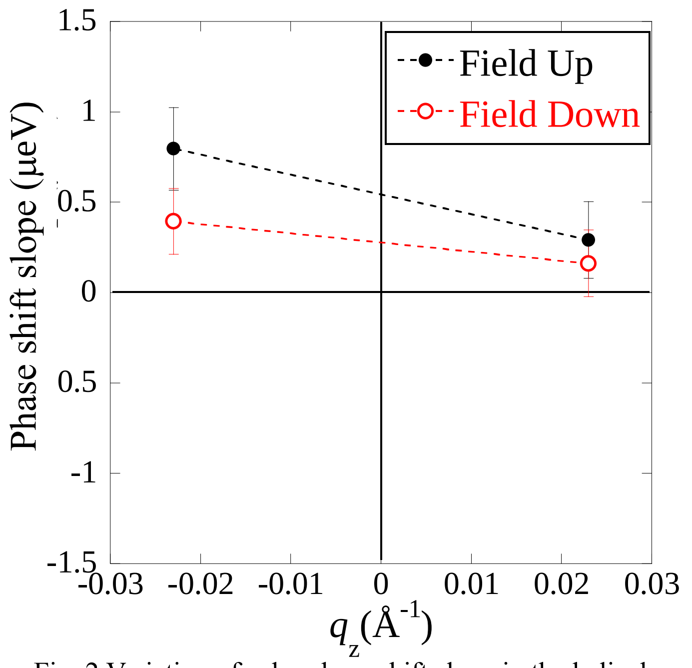

Fig. 2 Variation of echo phase shift slope in the helical state as a function of q_z.

In conclusion, we have examined the dispersion of excitations in the helical state of MnSi by using the neutron spin echo technique. The observed dispersion was symmetric in the helical state while the dispersion in the skyrmion state was different for q-vectors parallel and antiparallel to the magnetic field direction. Our results are consistent with the theoretical prediction, where the asymmetric dispersion should be realized only in the skyrmion state. These results have been submitted for publication.

References:

[1] S. Mühlbauer *et al.*, Science **323** 915 (2009). [2] S. Hoshino and N. Nagaosa, Phys. Rev. B **97**, 024413 (2018) & W. Koshibae and N. Nagaosa, Sci. Rep. **9**, 5111 (2019).