Experimental report

05/11/2018

Proposal: **4-04-487**

Council: 10/2016

Title: Investigating the motion skyrmionsby neutron spin echo spectroscopy

Research area: Physics

This proposal is a new proposal

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Samples: MnSi

Instrument	Requested days	Allocated days	From	To
IN15 Ferromagnetic echo	10	10	23/05/2018	02/06/2018

Abstract:

The movement of skyrmions under an electric current and their velocity is an important issue that has been addressed theoretically [1] and experimentally through the Hall resistivity [2] (Fig. 1a). Theoretical results are summarized in Fig. 1b, where the current-driven motion of a skyrmion lattice (SkX) is compared to that of the corresponding helical phase (HL) revealing noticeable differences in the thresholds required to set the motion of SkX and HL. Furthermore, impurities (i.e. defects) as high as 10% do affect the HL motion but not the SkX one, which explains the robustness of this phase.
The goal of the experiment was the direct experimental investigation of the skyrmion movement in the bulk MnSi, using high-resolution neutron spin-echo (NSE) spectroscopy on IN15, in a way similar to the seminal experiment by E. Forgan et al., who about 16 years ago investigated the vortex motion in type-II superconductors [4]. Fig. 2 shows a photo of the sample arrangement with a slab of MnSi, with dimensions 1.8*0.8*0.6 mm^3 cut along ⟨111⟩, with its ends soldered to copper wires, which were ultimately connected to the electric current source. The resistivity of the sample was measured using the 4-point method and was used to determine its (average) temperature, which at relatively high currents (up to 3 Å, leading to a maximum current density of ~ 2 10^6 A/m^2) is different from that of the thermometer on the sample stick. This local determination of the sample temperature provides reliable results as shown in Fig. 3 that display the temperature dependence of the derivative of the measured resistance with respect to temperature (dR/dT), measured at zero magnetic field and for 0, 1 and 2 A flowing through the sample. The maximum marks the transition to the helimagnetic state at T_C as expected from literature [5].
The measurements on IN15 were performed at a wavelength of 8 Å. A horizontal magnetic field was applied parallel to the incoming neutron beam using the ORTF magnet. In this configuration the chiral magnetic scattering is depolarized and for this reason the measurements were performed in the Intensity Modulated NSE configuration, with two compact re-polarisers, one in front and another one after the sample. However, the limited beam dimensions of these re-polarisers also limited the angular coverage of the setup which amounted to some detector pixels corresponding to one specific SKL peak.
For the measurements we used the same protocol as in [4], and the phase shift was determined by taking measurements with both directions of the electric current, which should give opposite phase changes. In this way the accuracy was enhanced, and long-term drifts in the echo phase were removed. Fig. 4 shows the effect of the electric current on the echo phase, as measured for B=0.2 T and T=27.8 K, i.e. at the center of the skyrmion lattice phase. At low currents the effect is zero and a phase shift starts to appear only when the current density exceeds $10^6 A/m^2$, a threshold that is about a factor of 2 higher than in Fig. 1(a). However, the effect was very weak and most surprisingly not monotonic, as the phase shift first increases, goes through a maximum at a current density of ~ 1 A/m^2 but then drops rapidly and even changes sign when the current density exceeds $2\cdot 10^6 A/m^2$. Furthermore, at this relatively high current density the skyrmion lattice peak intensity decreased substantially. However, due to the limited angular coverage of the IN15 setup it was not possible to follow the effect of the current on the SkX scattering. Thus, it is not clear whether this change of sing in the velocity and the decrease in intensity are correlated and whether at these current densities the SkX scattering broadens or the skyrmion lattice "melts". The recent work of [6] indicates that current densities of ~ 1 A/m^2 may deform the skyrmion lattice in the bulk MnSi and induce a rotation that remains even after switching off the current. These effects might explain the IN15 results and possibly the change of sign shown in Fig. 4.

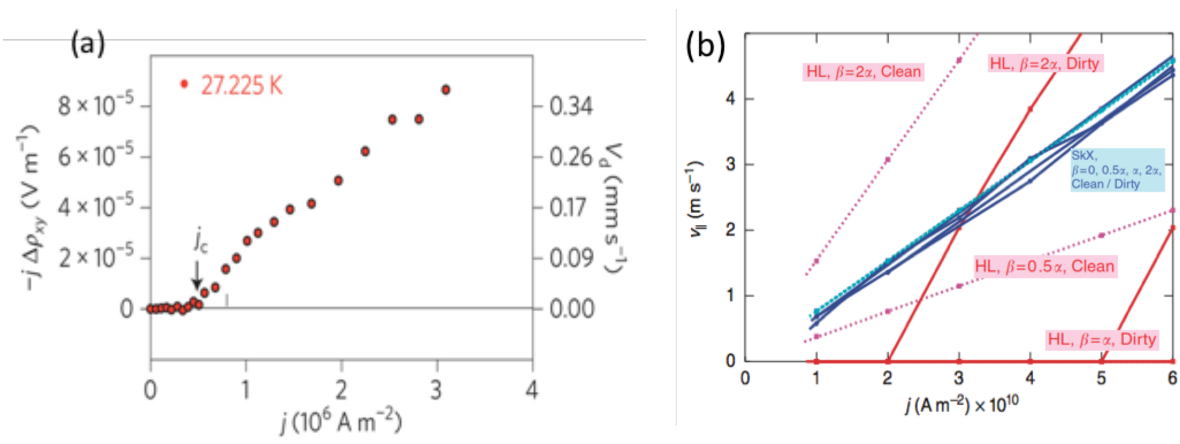

Fig. 1: (a) Typical data of the relation between the current density j in MnSi with the change of the Hall resistivity as a function of current density. The scale on the right-hand side displays the

calculated velocities. The data correspond to a magnetic field of 250 mT (after [2]). (b) calculated longitudinal velocities $v_{||}$ *of the current-induced motions of the helical (HL) and skyrmion crystal (SkX) phases as function of the current density j for several values of a parameter b that describes the coupling between spin-polarized current and local magnetizations (after [3]).*

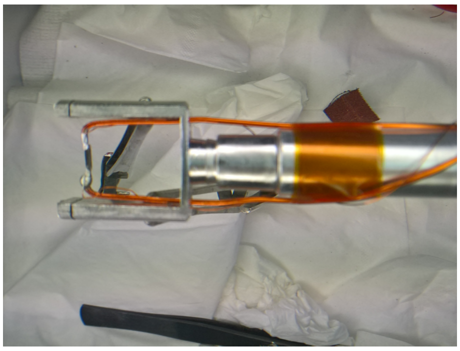

Fig. 2: Photo of the MnSi sample and the arrangement used to investigate the effect of electric current on the Skyrmion motion.

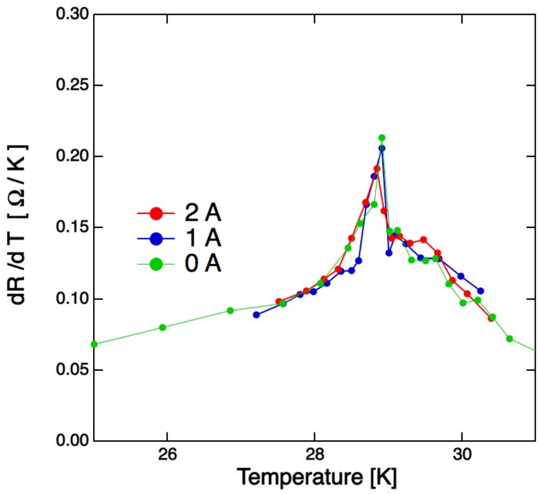

Fig. 3: Temperature dependence of the derivative of the resistance with respect to the temperature of the MnSi sample for different values of the electric current flowing through the sample. The measurements were done at zero magnetic field and the maximum corresponds to the helimagnetic transition at T_C.

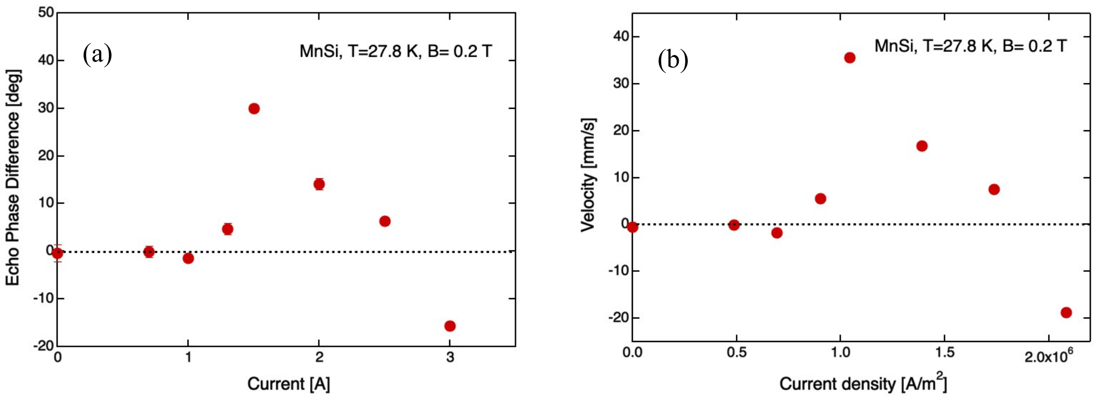

Fig. 4: Experimental results of the phase shift of the NSE group as a function of the electric current through the sample (a). The corresponding velocity versus current density is given in (b). The dta were collected for B=0.2 T and at T=27.8 K, which correspond to the center of the Skyrmion lattice phase of MnSi.

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