Experimental report

05/10/2019

Proposal: **5-42-492** **Council:** 10/2018

Title: Nucleation and Stabilisation of low temperature skyrmions in Cu2OSeO3

Research area: Physics

This proposal is a new proposal

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Samples: Cu2OSeO3

Instrument	Requested days	Allocated days	From	To
D33	6	3	19/07/2019	22/07/2019

Abstract:

Studies of cubic chiral magnets reveal a universal magnetic phase diagram, composed of helical spiral, conical spiral as well as a skyrmion lattice phase (SkL), confined in a small pocket of the magnetic field-temperature phase diagram, just below Tc.
By combining neutron diffraction with magnetisation measurements we have found a remarkable deviation from this universal behavior. We have observed a new "tilted spiral" conical state in Cu2OSeO3, where the spiral wave vector is tilted away from the magnetic field direction and gives rise to strong diffuse scattering.
By investigating the stability region of this novel phase and its co-existence with the metastable conical phase by fast cooling the sample under magnetic field, we saw that we stabilised long-lived SkL correlations over a large fraction of the phase diagram and for all directions of the magnetic field with respect the the main crystallographic axis (<001>, <110> and <111>). We wish to investigate these new phases and their topology, as there are theoretical predictions for the co-existence of tilted skyrmions with the tilted conical phase.

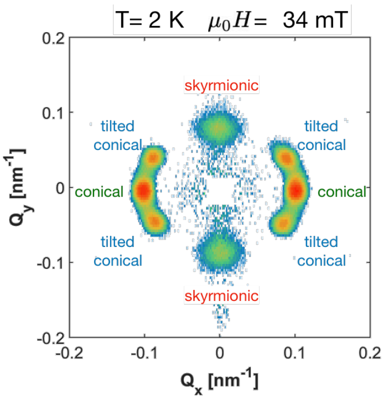
The experiment was performed on D33 using neutrons with a wavelength of 8 Å and a sample detector distance of 12 m. The sample was placed in the horizontal magnetic field cryomagnet and the magnetic field, $\mu_0\vec{H}$ was applied both parallel and perpendicular to the incoming neutron beam propagation vector $\vec{k}_i$. In this experiment we focused on the configuration $\mu_0\vec{H} \parallel [001]$, for which, depending on the strength of the magnetic field, the helical, conical, tilted conical and low temperature skyrmionic phase are stabilized [1-3].

In order to investigate the stability limits of each of the phases and the respective scattering intensities, we performed rocking scans ±7 deg around the optimum position of the [001] helical Bragg peaks, as a function of temperature and magnetic field. Fig. 1 shows the pattern obtained by adding the data of the rocking scan at T=2 K and μ_0H= 0.034 mT and whick illustrates the co-existence of three phases: the conical, tilted conical and skyrmionic phase.

As seen in Figure 2 the values of the magnetic field that stabilise the helical/conical and tilted conical phases respectively do not depend on the way the specific magnetic field value was reached (either by decreasing or by increasing the absolute value of the magnetic field). These phases thus appear at specific regions of the phase diagram independently from the magnetic history. In contrast the skyrmionic scattering appears at different regions of the phase diagram depending on the magnetic history, in agreement with [2,3]. Thus, this low temperature skyrmionic scattering should be time-dependent and evolve towards the thermodynamically stable limit. In the search for such a time dependence we followed the change of the SANS intensity when changing the magnetic field by performing a series of stroboscopic measurements at 2 and 10 K and for different target magnetic fields. However, we could not see any significant time dependence. We thus concluded that the short-time response of the sample to a change of the magnetic field is much faster than the time resolution of these stroboscopic measurements, which due to the combined response of the instrument and the cryomagnet was 1-2 seconds.

In the search for a time dependence of the scattered skyrmionics intensity we finally looked on the behavior of the skyrmionics scattering above the μ_0H_{C2} line. In fact, according to theory, skyrmions cannot persist above μ_0H_{C2} because in the field polarized state the inter-skyrmion interactions becomes repulsive [3,4]. Thus at μ_0H_{C2} the skyrmion lattice should dissolve releasing individual skyrmions, or skyrmion droplets [4], in a way that resembles the sublimation of a solid.

In agreement with the theoretical expectations we could observe a long time evolution of the skyrmionic scattering for two magnetic fields close to μ_0H_{C2}. As seen in Fig. 2, the scattered intensity decreases and most importantly the position of the maximum drifts towards lower Q's with time. This result indicates that with increasing time the inter-skyrmion distance increases, which is in qualitative agreement with the "sublimation" description of the transition at μ_0H_{C2}. Further experiments, going to longer times and for magnetic field above and below the μ_0H_{C2} line are required to confirm this hypothesis.



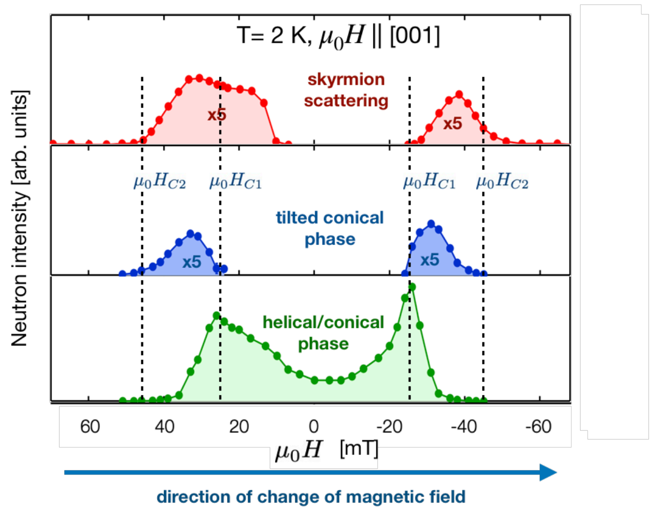


***Figure 1**: SANS pattern obtained by adding the data of the rocking scan at T= 2 K and $\mu_0 H$= 0.034 mT. The peaks reveal the co-existence of three phases: conical , tilted conical and low temperature skyrmionic phase.*

***Figure 2**: magnetic field dependence of the scat-tered intensity for the conical, tilted conical and the low temperature skyrmionic phase at T=2 K. The magnetic field was varied stepwise from 0.1 T to -0.1 T and the values field has been corrected for the demagnetizing effect.*

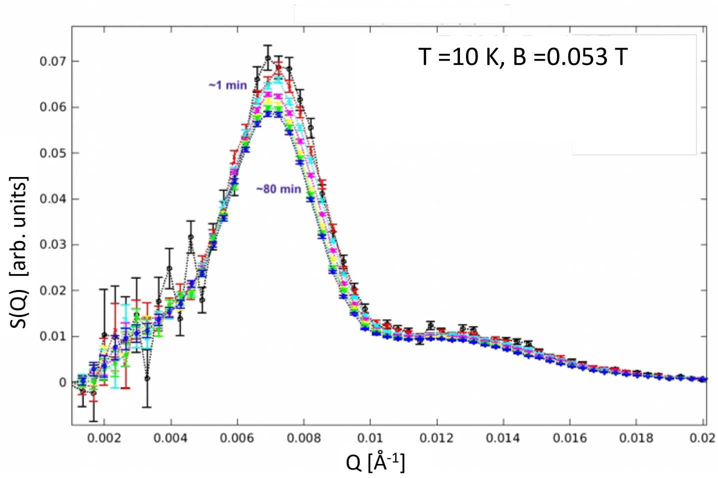


Figure 3: Evolution with time of the skyrmionics scattering at the B_{C2} line, T=10 K and B = 0.053 T. The peak of S(Q) decreases in intensity and moves towards smaller Q's with increasing time. A similar trend is also observed, within the error bars, for the high order peak. The behavior bears similarities with the sublimation of a solid.

References

[1] F. Qian et al, Sci. Adv. **4**, eaat7323 (2018) [2] A. Chacon et al,Nature Physics , 1 (2018)

[3] Bannenberg et el. npj Quant. Mater. 11 (2019) [4] A. Leonov et al., PRB 99 144410 (2019)