CHIRAL FLUCTUATIONS IN MnSi ABOVE THE CURIE TEMPERATURE MEASURED WITH POLARIZED INELASTIC NEUTRON SCATTERING*

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Using polarized inelastic neutron scattering the antisymmetric part of the dynamical susceptibility in non-centrosymmetric MnSi is determined. The paramagnetic fluctuations are found to be incommensurate with the chemical lattice and to have a chiral character. We show that antisymmetric interactions must be taken into account to properly describe the critical dynamics in MnSi above the Curie temperature. The inelastic neutron data is interpreted within the framework of the SCR-theory, taking into account the Dzyaloshinskii–Moriya interaction.

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1. Introduction

Ordered states with helical arrangement of the magnetic moments are described by a chiral order parameter $\vec{C} = \vec{S}_1 \times \vec{S}_2$, which yields the left- or right-handed rotation of neighboring spins along the pitch of the helix. The detection of chiral fluctuations is, however, a difficult task and it is only

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recently that chiral fluctuations could be observed in triangular antiferromagnets with polarized-neutron scattering when an external magnetic field is applied [1, 2].

The metallic compound MnSi crystallizes in the cubic space group $P2_13$ that lacks a center of symmetry. The Curie temperature is $T_C = 29.5$ K. Below T_C the magnetic moments build a ferromagnetic spiral along the [1 1 1] direction with a period of approximately 180 Å. The spontaneous magnetic moment of Mn is $\mu \simeq 0.4\mu_B$ that is strongly reduced from the free ion value of $2.5\mu_B$. The four Mn atoms are placed at the positions (u, u, u), $(\frac{1}{2}+u, \frac{1}{2}-u, -u)$, $(\frac{1}{2}-u, \frac{1}{2}+u, -u)$, $(\frac{1}{2}+u, -u, \frac{1}{2}-u)$. Being a prototype of a weak itinerant ferromagnet, the magnetic fluctuations in MnSi have been investigated in detail by means of polarized [3] and unpolarized neutron scattering [4].

2. Experimental

We investigated the paramagnetic fluctuations in a single crystal of MnSi on the triple-axis spectrometer TASP at the neutron spallation source SINQ. The spectrometer was operated in the constant final energy mode with a neutron wave vector $\vec{k}_f$=1.97 Å^{-1}. In order to suppress contamination by higher order neutrons a pyrolytic-graphite filter was installed in the scattered beam. To polarize the incident neutron beam a remanent FeCoV/TiN-type bender was inserted after the monochromator. The advantage of such a device is that to reverse the spin of the neutron no spin flipper is necessary thanks to the remanent magnetization of the super-mirror coatings of the benders [5]. The polarization of the neutron beam was maintained along the neutron path by a guide field B_g=10G that defines the polarization of the neutrons $\vec{P}_0$ with respect to the scattering vector $\vec{Q}$. We did not analyze the polarization of the scattered neutrons during the course of these experiments. The sample was mounted in a standard ^{4}He orange-cryostat of ILL-type with the [1 0 0] and [0 1 1] crystallographic in the scattering plane. The measurements were performed around the (0 1 1) Bragg reflection in the paramagnetic phase.

3. Results

A typical constant-energy scan at $\hbar\omega$=0.5 meV and T = 35 K using a polarized beam as described above is shown in Fig. 1. In a first step we chose the polarization of the neutron beam along the scattering vector $\vec{Q}$, repeated the measurements with the polarization aligned along $-\vec{Q}$ and then calculated the difference between the two sets of measurements. It is obvious from Fig. 1 that the inelastic scattering is polarization dependent.

Of particular importance, we find that the neutron peaks appear at positions incommensurate with respect to the chemical lattice, namely at $\vec{Q} = \vec{\tau} \pm \vec{\delta}$ ($\vec{\tau}$ is a reciprocal lattice vector).

In order to discuss our results we start with the general expression for the cross-section of magnetic scattering with polarized neutrons

$$\frac{d^2\sigma}{d\Omega d\omega} \sim \sum_{\alpha,\beta}(\delta_{\alpha,\beta}\hat{Q}_\alpha\hat{Q}_\beta)A^{\alpha\beta}(\vec{Q},\omega)+\sum_{\alpha,\beta}(\hat{\vec{Q}}\cdot\vec{P}_i)\sum_{\gamma}\varepsilon_{\alpha,\beta,\gamma}\hat{Q}^\gamma B^{\alpha\beta}(\vec{Q},\omega)\,, \quad (1)$$

where $(\vec{Q},\omega)$ are the momentum and energy-transfers from the neutron to the sample, $\hat{\vec{Q}} = \vec{Q}/|\hat{Q}|$, and α,β,γ indicate Cartesian coordinates. The first term in Eq. (1) is independent of the polarization of the incident neutrons, while the second is polarization dependent through the factor $(\hat{\vec{Q}}\cdot\vec{P}_i)$. $\vec{P}_i$ denotes the direction of the neutron polarization and its scalar is equal to 1 when the beam is fully polarized. It can be shown [6] that $A^{\alpha\beta}$ and $B^{\alpha\beta}$ are the symmetric and antisymmetric part of the scattering function $S^{\alpha\beta}$, that is $A^{\alpha\beta} = \frac{1}{2}(S^{\alpha\beta} + S^{\alpha\beta})$ and $B^{\alpha\beta} = \frac{1}{2}(S^{\alpha\beta} - S^{\beta\alpha})$. $S^{\alpha\beta}$ are the Fourier transforms of the spin correlation function $\langle s_l^\alpha s_{l'}^\beta\rangle$, $S^{\alpha\beta}(\vec{Q},\omega) = \frac{1}{2\pi N}\int_{-\infty}^{\infty} dt\mathrm{e}^{-i\omega t}\sum_{ll'}\mathrm{e}^{i\vec{Q}(\vec{X}_l-\vec{X}_{l'})}\langle s_l^\alpha s_{l'}^\beta(t)\rangle$. The vectors $\vec{X}_l$ designate the positions of the scattering centers in the lattice. Accordingly, a finite contribution to the antisymmetric part of the wave-vector dependent dynamical susceptibility has been measured in MnSi in the paramagnetic phase.

4. Discussion and conclusion

In a similar way as for insulators with localized spin densities, we interpret the antisymmetric interaction observed in MnSi as originating from the spin-orbit coupling in the absence of an inversion center. In that case, the polarization dependent part of the neutron cross-section is given by

$$\left(\frac{d^2\sigma}{d\Omega d\omega}\right)_\Delta \sim (\vec{D}\cdot\hat{\vec{Q}})(\hat{\vec{Q}}\cdot\vec{P}_i)\mathrm{Im}\frac{(\chi^\perp(\vec{q}-\vec{\delta},\omega)-\chi^\perp(\vec{q}+\vec{\delta},\omega))}{2D}\,. \quad (2)$$

The transverse susceptibilities in Eq. (2) for itinerant magnets as given by self-consistent re-normalization theory (SCR) are [8]

$$\chi^\perp(\vec{q}\mp\vec{\delta},\omega) = \frac{\chi^\perp(\vec{q}\mp\vec{\delta})}{1-i\omega/\Gamma_{\vec{q}\mp\vec{\delta}}}\,. \quad (3)$$

$\vec{\delta}$ is the ordering wave vector, $\chi^\perp(\vec{q}\mp\vec{\delta}) = \chi^\perp(\pm\delta)/(1+q^2/\kappa_\delta^2)$ the static susceptibility, and κ_δ the inverse correlation length. For itinerant ferromagnets the damping of the spin fluctuations is given by $\Gamma_{\vec{q}\mp\vec{\delta}} = uq(q^2 + \kappa_\delta^2)$ with $u = u(\vec{\delta})$ reflecting the damping of the spin fluctuations. Here, $\vec{q}$ designates the reduced momentum transfer with respect to the nearest magnetic Bragg peak at $\vec{\tau}\pm\vec{\delta}$. The solid line of Fig. 1 shows calculations of $(d^2\sigma/(d\Omega d\omega))_\Delta$ as defined above which describes the inelastic polarized neutron data well with $\kappa_0 = 0.12$ Å^{-1} and $u = 27$ meVÅ^3 [9]. In conclusion, we have shown that in MnSi the axial interaction leading to the polarized part of the neutron cross-section can been identified as originating from the DM-interaction.

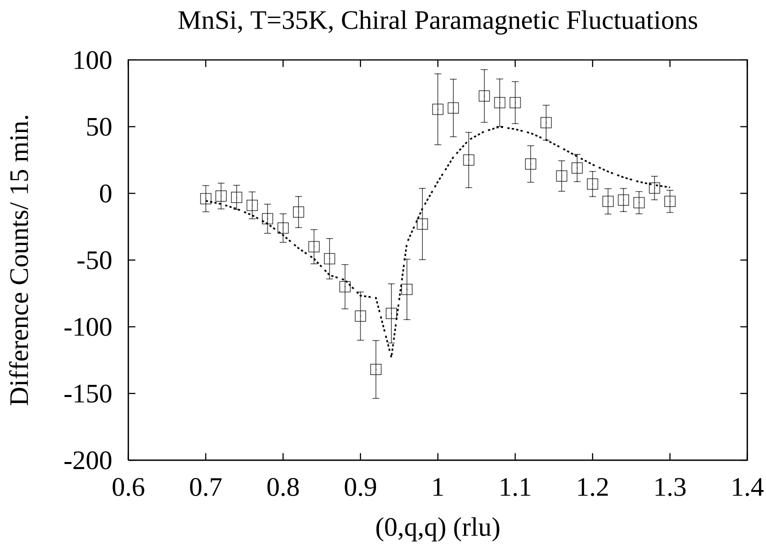

Fig. 1. Polarization dependent part of the dynamical susceptibility measured in MnSi at $T = 35$ K and $\hbar\omega$=0.5 meV. The line is a fit to the data.

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