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Polarized SANS: critical scattering in invars

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Abstract

Small-angle polarized neutron scattering experiments on ordered invar $Fe_{75}Pt_{25}$ alloy were performed using a special "inclined" magnetic field geometry. Two contributions to the critical magnetic scattering were studied in the temperature range around $T_C \approx 400$ K. One of them comes from the pair-spin correlation function. Another contribution is made by the three-spin chiral fluctuations. It is separated from other contributions as the asymmetric part of the polarization-dependent scattering.

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Keywords: Three-spin chiral fluctuations; Critical scattering of polarized neutrons

1. Introduction

The spin chirality in the spiral magnetic structures may be successfully studied by polarized neutrons [1,2]. Moreover, it was understood that not only static but also dynamic chirality may be investigated by small-angle polarized neutron scattering (SAPNS) using a special "inclined" geometry of the applied magnetic field (**H** is inclined with respect to the wave vector **k**). The presence of non-collinear spin fluctuations, particularly three-spin chiral ones, is generally strongly enhanced in the critical region near a magnetic phase transition. It was shown in Refs. [3–5] that for ferromagnets (in "inclined" geometry) the neutron scattering from the three-spin fluctuations results in the appearance of an asymmetric contribution to the polarization-dependent cross-section. Later this method was extended to study the spin-wave dynamics in ferromagnets [6]. Here we report on the results of an SAPNS experiment with the "inclined" geometry for an ordered invar $Fe_{75}Pt_{25}$ alloy. The results are compared with those experiments performed previously on the disordered alloy $Fe_{65}Ni_{35}$ [7].

2. Experimental and theoretical background

The polycrystalline sample of invar alloy $Fe_{75}Pt_{25}$ has a tablet-shape with a diameter of

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12 mm and a thickness of 1 mm. The alloy was prepared from pure components and homogenized 100 h at 1100°C. After fast cooling, the sample was annealed 100 h at 600°C to retain the ordered state. The SAPNS experiment was performed at the SANS-2 scattering facility of the FRG-1 research reactor in Geesthacht (Germany). A polarized beam of neutrons with an initial polarization of $P_0 = 0.93$, a wavelength of $\lambda = 0.58$ nm ($\Delta\lambda/\lambda = 0.1$) and a divergence of 1.0 mrad was used. The scattered neutrons were detected with a position-sensitive detector with 128×128 elements. The scattering was measured in the temperature range from $T = 370$ to 470 K, i.e. from below to far above $T_C \approx 400$ K. The external magnetic field $\mathbf{H}$, changing from 1 to 230 mT, was applied at an angle of $\phi = 45°$ with respect to the incident beam $\mathbf{k}$ ("inclined" geometry).

According to Refs. [2–5], the magnetic scattering cross-section of a magnetized sample has the form $\sigma(q,\omega) = \sigma_0(q,\omega) + (\mathbf{q}\cdot\mathbf{P}_0)(\mathbf{q}\cdot\mathbf{m})\sigma_{ch}(q,\omega)/q^2$, where the second term is determined by chiral dynamical spin fluctuations, and $\mathbf{P}_0$ and $\mathbf{m}$ are neutron polarization and direction of the sample magnetization, respectively.

In the case of small-angle scattering, the ω integrated chiral contribution to the cross-section changes sign with θ and may be easily extracted from the total scattering intensity. Following Refs. [3–5], we investigate experimentally the quantity

$$P_A(\theta) = \Delta I_A(\theta)/I_m(\theta). \quad (1)$$

We separated the magnetic critical scattering from the non-magnetic contributions by subtracting from the total scattered intensity the paramagnetic and nuclear scattering at $T \gg T_C$, i.e. $I_m(\theta, T) = I_t(\theta, T) - I_t(\theta, 850)$, where the total scattering intensity I_t is defined as:

$$I_t(\theta) = \tfrac{1}{4}[I_+(\theta) + I_+(-\theta) + I_-(\theta) + I_-(-\theta)]. \quad (2)$$

$I_+(\theta)$ and $I_-(\theta)$ are ω integrated intensities with the polarization directed along and opposite to the field. The asymmetric contribution to the scattering is obtained as:

$$\Delta I_A(\theta) = \tfrac{1}{4}[I_+(\theta) + I_-(-\theta) - I_+(-\theta) - I_-(\theta)] \quad (3)$$

3. Results

The measured SAPNS intensity is well described by the Ornstein–Zernike expression:

$$I(q) = A(q^2 + \kappa^2)^{-1}, \quad (4)$$

where A and κ are the scattering amplitude and the inverse correlation length, respectively. As shown in Fig. 1, the correlation radius $R_C = \kappa^{-1}$ increases for decreasing temperature when temperature approaches $T_C \approx 400$ K and tends to saturate below T_C. The value of A in Eq. (4) demonstrates a similar behaviour (not shown).

The effect of the magnetic field on the inverse correlation length R_C at $T = 402$ K is shown as the inset of Fig. 1. The value of R_C is observed to decrease for increasing fields. It is interesting to note that the amplitude A does not depend on H. This behaviour of R_C is a result of a crossover to the strong field regime, which is determined by the condition $T(R_C^{-1}a_0)^z = g\mu H$, where $z \simeq \frac{5}{2}$ and a_0 is a constant of the order of 1 A (see, e.g., Ref. [8]). The points, except one at a weak field $H = 1$ mT, lay on a line in a log–log scale. The fit gives value of the parameter $1/z = 0.30 \pm 0.02$, which differ slightly from the theoretical value of $1/z = \frac{2}{5}$.

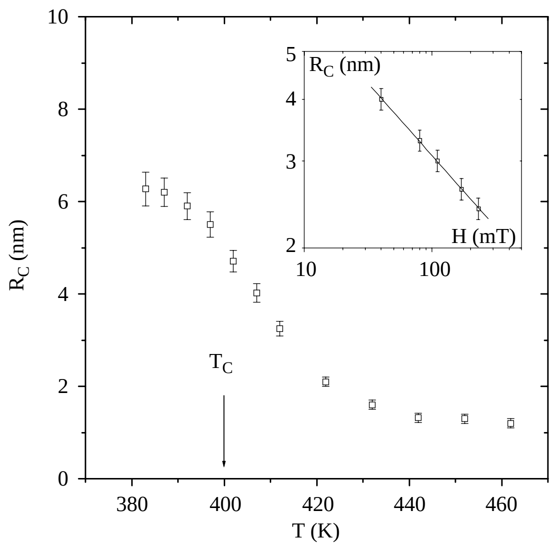

Fig. 1. The temperature dependence of R_C obtained from a fit at $H = 1$ mT for $Fe_{75}Pt_{25}$. An inset shows the correlation length R_C as a function of the magnetic field at $T = 402$ K.

Fig. 2 provides typical examples of the polarization $P_A(k\theta)$ as a function of the magnetic field at $T = 402$ K. P_A is q-independent within the error bars for $k\theta > \kappa$. We have averaged the value of P_A over all these points and studied $\bar{P}_A$, as a function of the temperature and the magnetic field. It appears that $\bar{P}_A$ is temperature independent in a broad temperature range near T_C (Fig. 3) what may indicate that the applied magnetic field is relatively large. Inside this temperature range, $\bar{P}_A$ changes linearly with the magnetic field (see the inset of Fig. 3) in agreement with the theoretical prediction [3]: $P_A = ((g\mu H)/E)(k/\kappa)$.

A similar experiment has been performed on the invar alloy $Fe_{65}Ni_{35}$ [7]. It was shown [9] that two different length scales for the magnetic correlations coexist in invar FeNi alloys around the mean critical temperature $\langle T_C \rangle$. It is assumed that a long-range disorder leads to local variations in T_C and therefore to a coexistence of long-range magnetic inhomogeneities along with short-range critical fluctuations. The set of the data for FeNi, shows a different behaviour compared to FePt. For FeNi, P_A has been fitted in the form $P_A = P_A^0 + \alpha k\theta$ (Fig. 4). Further, it was found that the parameter α saturates quickly with field. The saturated value α_s decreases as the temperature increases (see Fig. 5). P_A^0 does not depend on the

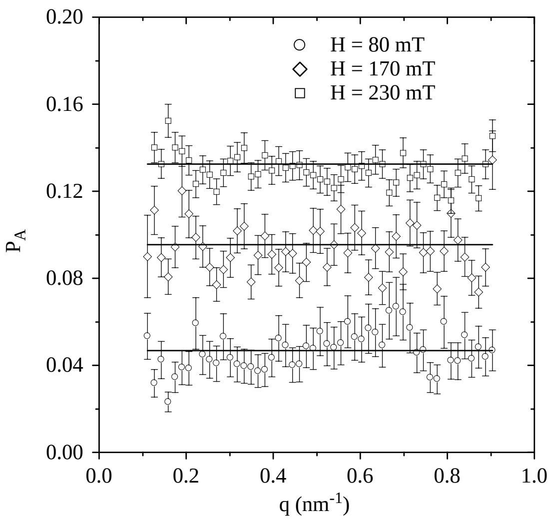

Fig. 2. The polarization $P_A(k\theta)$ as a function of q at a magnetic field of $H = 80, 170$, and 230 mT at $T = 402$ K for $Fe_{75}Pt_{25}$.

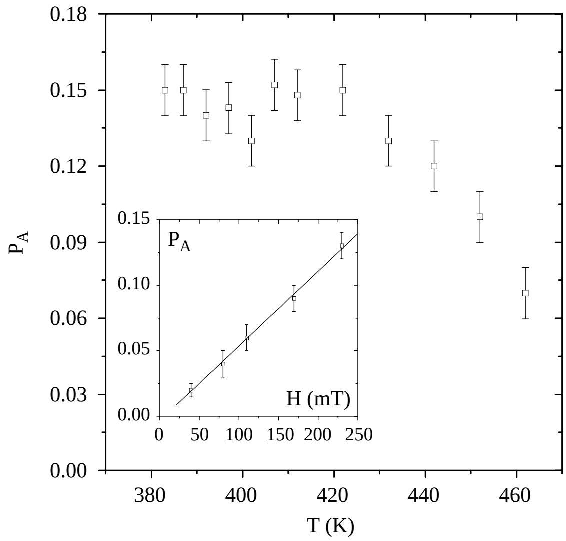

Fig. 3. The temperature dependence of $\bar{P}_A$ at $H = 230$ mT. An inset shows the polarization P_A as a function of the magnetic field at $T = 402$ K for $Fe_{75}Pt_{25}$.

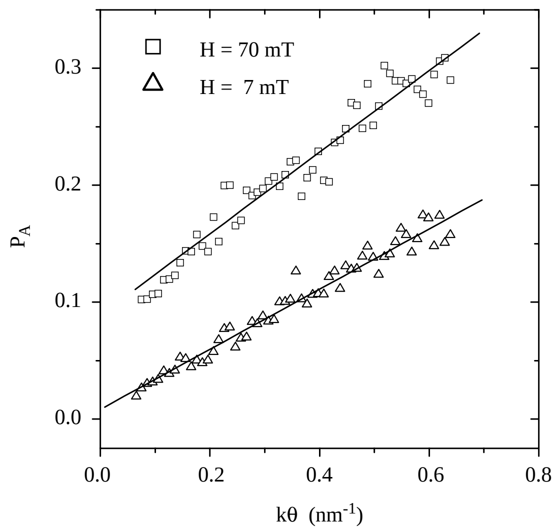

Fig. 4. The polarization $P_A(k\theta)$ for $Fe_{65}Ni_{35}$ in a magnetic field of $H = 7$ and 70 mT at $T = 483$ K.

temperature and is proportional to the magnetic field. These results were interpreted as follows. The measured value of P_A for $Fe_{65}Ni_{35}$ consists of two contributions: scattering from the three-spin critical fluctuations (like in the case of FePt) and scattering on the spin waves that comes from the large magnetic inhomogeneities. It is important to

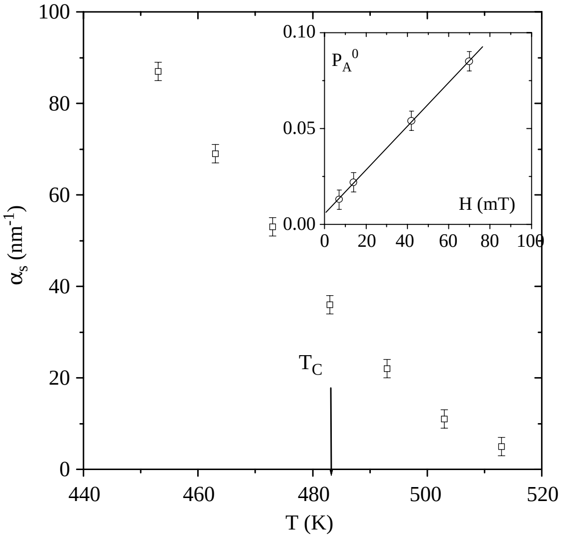

Fig. 5. The temperature dependence of the parameter α_S for $Fe_{65}Ni_{35}$. An inset shows the magnetic field dependence of P_A^0.

stress that the spin waves may exist only in magnetically ordered state, i.e. in the long-range magnetic inhomogeneities, but not in critical fluctuations above T_C. The q-independent part of the scattering P_A^0 is attributed to the three-spin chiral fluctuations. The linearly dependent part of P_A originates from the spin-wave scattering in agreement with Ref. [6]: $P_A(\theta) \sim \langle S \rangle TD^2\theta$, where D is the spin-wave stiffness. It does not contain the magnetic field dependence but is saturated at low magnetic fields in the critical range. As a result, the T dependence of α_s should be the same as for D^2 averaged over a spatial distribution of the long-range inhomogeneities.

4. Conclusion

The asymmetric part of the polarization-dependent scattering was studied in the critical region of the invar ordered alloy $Fe_{75}Pt_{25}$ and the invar disordered alloy $Fe_{65}Ni_{35}$. Data for the ordered $Fe_{75}Pt_{25}$ are interpreted as scattering from the critical three-spin chiral fluctuations only. Data for disordered $Fe_{65}Ni_{35}$ require for their interpretation an additional contribution for the scattering from spin waves. The last fact is related to the long-range disorder that results in local variations in T_C and therefore to the coexistence of two scale lengths of magnetic correlations.

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