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Longitudinal Spin Fluctuations in Nickel

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The longitudinal and transverse spin fluctuations in Ni have been measured below T_C by means of polarized neutron scattering in the momentum range $0.06 < q < 0.18 \text{ \AA}^{-1}$. In transverse scans spin wave peaks at $E_q = Dq^2$ appear as expected from early measurements performed with unpolarized neutrons. The longitudinal magnetic scattering $\chi_L(q, E)$, on the other hand, is quasielastic without any signature of inelastic peaks near E_q . The q and T dependences of $\chi_L(q, E)$ resemble the paramagnetic scattering above T_C , i. e. the linewidth is roughly proportional to $q^{2.5}$ and the integrated intensity $I(q)$ is proportional to $(q^2 + \kappa_z^2)^{-1}$.

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1. INTRODUCTION

During the past 20 years a great deal of theoretical work has been done in order to understand the properties of the longitudinal fluctuations in isotropic ferromagnets below T_C .¹⁻⁴ Mean-field theory predicts that the wave vector dependent susceptibility $\chi_L(q)$ diverges like $1/q$ in zero field and diverges like $1/\sqrt{H}$ at $q = 0$. The theoretical works on the dynamics of the longitudinal fluctuations are still controversial. The predicted spectra range from quasielastic peaks to spin wave like excitations or even a mixture of both.

In order to identify the longitudinal fluctuations Mitchell et al.⁵ have used polarized neutron scattering and identified a quasielastic cross section for $\chi_L(q, E)$ in Pd 10%Fe. The linewidth Γ is comparable with the spin wave energy (peak position of the transverse fluctuations). These results explain why the longitudinal scattering was not observed in previous experiments with unpolarized neutrons (in zero field). The results, however, are not sufficiently precise to test the theoretical predictions.

In order to shed more light on the dynamics of the longitudinal fluctuations in isotropic ferromagnets we decided to study the spin dynamics in ^{60}Ni because: 1) ^{60}Ni is a single element ferromagnet. 2) The magnetic scattering of Ni near T_C is similar to the scattering from a localized ferromagnet and has been characterised in detail.⁶ 3) The dipolar interactions are expected to be very weak, i. e. $q_D \simeq 0.013 \text{ \AA}^{-1}$ (Ref. 7), so that it should be possible to observe the $1/q$ dependence without interference from dipolar interactions. 4) T_C is reasonably low (631 K) so that a simple and small furnace can be used.

II. EXPERIMENTAL

The neutron scattering experiments were conducted on the polarized triple axis spectrometer IN20 at the High Flux Reactor at the Institut Laue Langevin. Bussler crystals set for the (111) reflection were used for the monochromator and the analyzer. The final neutron energy E_f was kept fixed at 14.7 meV and the collimations were all 40° . Higher order neutrons were removed by means of a pyrolytic graphite filter which was mounted after the sample.

The large (25 g) isotopically enriched single crystal ^{60}Ni was mounted with the $[-1\ 1\ 1]$ axis vertical inside a specially designed evacuated furnace which fitted between the pole pieces of an electromagnet. Because of the depolarization of the neutron beam by the orientational averaging of the magnetic domains we performed all measurements in a vertical field of 1.1 kOe near the $(1\ 1\ 1)$ Bragg reflection in the $[1\ 1\ 1]$ direction. This value was large enough to ensure a reasonable polarization of the beam and it was still sufficiently small so that the longitudinal fluctuations were not quenched. The temperature control was stable to within ± 0.3 K over the period of our measurements. The lattice constant of Ni is $3.53\ \text{\AA}$ and the nearest inverse plane distance is $3.07\ \text{\AA}^{-1}$.

The scattering geometry described above allows an unambiguous separation of the longitudinal fluctuations (non spin flip scattering) and the transverse fluctuations (spin flip scattering). Unfortunately the non spin flip scattering also contains nuclear scattering contributions such as phonons as well as elastic scattering from the sample and the furnace. In order to determine the background scattering we measured the paramagnetic scattering above T_C for both configurations, non spin flip and spin flip. The difference intensity $I_{n,f} - I_{s,f}$ corresponds to the background intensity that can be subtracted from the non

spin flip scattering below T_C . We also corrected the measurements for finite flipping ratio and for errors in counting time due to higher order neutrons in the incident beam. A more detailed account of the present work will be given elsewhere.⁸

III. RESULTS

The measurements at $\tilde{Q} (1.03\ 1.03\ 1.03)$ in Fig. 1 clearly demonstrate that the spectral shape of the longitudinal scattering (flipper off) is very different from the transverse scattering. The scans were conducted at $T = 0.97T_C$. The transverse fluctuations (flipper on) are clearly inelastic with two spin wave peaks at ± 1 meV. The spectrum closely resembles unpolarsed beam measurements. In contrast the longitudinal scan at $(1.03\ 1.03\ 1.03)$ is dominated by a broad quasielastic peak and a phonon peak near 3.5 meV. Note that the energy scales of both scans are similar.

In Fig. 2 the q -dependence of the longitudinal scattering for $T = 0.98T_C$ is shown. The data have been corrected as described in the previous section. The linewidth of the quasielastic scattering increases rapidly with increasing q , and the intensity decreases. The solid lines through the data represent fits with the double Lorentzian scattering function

$$S(q, E) = 2k_B T \chi''(0) \frac{\kappa_z^2}{\kappa_z^2 + q^2} \times \frac{1}{2\pi} \frac{\Gamma}{E^2 + \Gamma^2} \times \frac{E/k_B T}{1 - e^{-E/k_B T}} \quad (1)$$

convolved with the four dimensional resolution function. The first term is the wavevector dependent susceptibility, the second term the spectral weight function, and the last term contains the temperature factors.

The q -dependence of Γ is shown in Fig. 3. The dynamics of the longitudinal fluctuations is obviously very similar as the paramagnetic scattering above T_C , i. e. $\Gamma \simeq Aq^{2.5}$, where A is of the order of $300\ \text{meV}\text{\AA}^{2.5}$. The thick solid line indicates Γ at T_C .

We have also investigated the q -dependence of the energy-integrated magnetic scattering below T_C . Within the q -range investigated the intensity is proportional to $1/(\kappa_z^2 + q^2)$ as expected for spin diffusion in hydrodynamics.

IV. DISCUSSION

The measurements we have presented above are in qualitative agreement with recent mode-mode coupling calculations by Frey and Schwabl.⁴ They predict that the longitudinal fluctuations are quasiclastic as observed in our experiments. The predicted divergence $1/\kappa_z q$ of the energy-integrated intensity, however, escaped the detection so far, because we did not extend the measurements to small enough q . Our data neither supports nor rules out the predicted strong coupling between longitudinal and transverse fluctuations.^{1,2} Inelastic peaks in the longitudinal scattering should be most pronounced at small q near T_C , where the spin waves are still well defined.

In summary we have succeeded in measuring and parametrizing the longitudinal fluctuations in an isotropic ferromagnet at several temperatures. The qualitative behaviour is similar to that in the paramagnetic phase. With the present data in hand it should be possible to plan detailed measurements at small q in order to answer some fundamental questions in magnetism.

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FIGURE CAPTIONS

1. Longitudinal (flipper off) and transverse scattering (flipper on) at (1.03 1.03 1.03) for $T = 0.97T_C$ and $H = 1.1$ kOe. No corrections have been applied to the data. LA is the longitudinal acoustic phonon.
2. q -dependence of the longitudinal scattering at $0.98 T_C$. The spectrometer resolution is indicated by a horizontal bar.
3. q -dependence of the linewidth of the longitudinal fluctuations. The thick solid line indicates Γ as measured at T_C .

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