NEUTRON DEPOLARIZATION IN MnF_2

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We observed depolarization of a beam of polarized neutrons passing through a sample in the region of T_N as well as at $T << T_N$. Estimates explain the depolarization at $T \sim T_N$ as being due to the existence of magnetic fluctuations (long-wave spin waves), and at $T << T_N$ as being due to the presence of inhomogeneous magnetization regions such as domains.

The depolarization of a beam of polarized neutrons passing through a magnetically-ordered crystal yields information on the magnetic fluctuations in a system (long-wave fluctuations near phase transitions, spin waves, etc.) [1]. The condition for the existence of weakly-damped spin waves in an antiferromagnet at $T \leq T_N$ [2] is smallness of their wave vector k in comparison with the reciprocal correlation radius $\kappa \sim \tau^{2/3}/a$, where $\tau = |(T - T_N)/T_N|$, and a is a quantity on the order of the lattice constant. In [3] there was introduced a cutoff parameter with respect to k, corresponding to the fact that the only neutrons that enter the detector are those scattered by spin waves with $k < p = p\theta$, where p is the neutron momentum and θ is the angle subtended by the detector. Under the experimental conditions, when $\theta \sim 0.5°$ and $\lambda \sim 2$ Å, this limitation means that $\tau >> 10^{-4}$, i.e., the depolarization can be due to spin waves at least within several tenths of a degree of T_N. Its value is then

$$\frac{\Delta P}{P} \approx \frac{0.02}{R(T)} \frac{T}{T_N}, \tag{1}$$

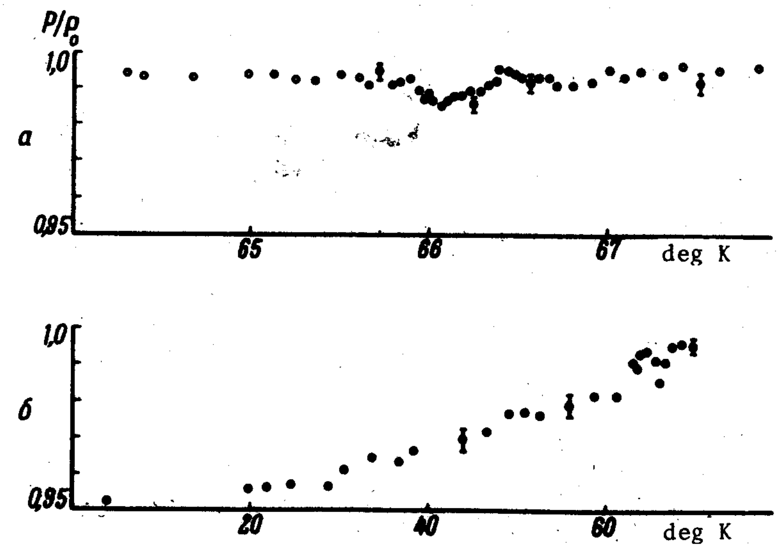
where R(T) is the renormalized dimensionless spin-wave velocity [3]. At low temperatures we have $R >> 1$. However, as shown in [2], the renormalization of the velocity at $T \sim T_N$ can lead in the hydrodynamic region to $R(T) \sim 1$. Then $\Delta P/P$ is actually on the order of several tenths of one per cent.

We have investigated MnF_2 (single crystals as well as large-grain polycrystals) in a large temperature interval using a crystal polarized-neutron spectrometer with wavelength $\lambda = 2$ Å. The samples were placed in a variable-temperature cryostat. The temperature was stabilized within 0.01°K. The magnetic field at the sample location was $\sim$ 0.6 Oe. The C axis of the single crystal was oriented accurate to ± 15° relative to the neutron polarization vector for $C \parallel \vec{P}$ and accurate to ± 5° at $C \perp \vec{P}$.

Near the Neel temperature we observed a weak depolarization, both in the single crystal and in the polycrystals (regardless of their orientation). The figure shows the experimental results of a polycrystal 18 mm thick. The depolarization near $T_N \approx 66.4$°K (Fig. a) amounts, in accord with (1), to 0.8 - 1%.

What we did not expect was neutron depolarization at $T << T_N$ and arbitrary crystal orientation. The value of the depolarization depends on the sample thickness. The maximum depolarization for the polycrystalline sample of 18 mm thickness at T = 4.2°K is $\sim$ 5% (Fig. b). The fact that the depolarization is indeepndent of the crystal orientation suggests the existence of regions of inhomogeneous magnetization. Then, according to [4], the polarization of the beam passing through the sample is determined by the expression

$$P = P_0 \exp\left[- \frac{g^2}{3v^2} < B^2 > d\delta\right], \tag{2}$$



Temperature dependence of the polarization: a) near T_N, b) $T << T_N$.

where P_0 and P are the polarizations of the indicent and transmitted beams, δ is the linear dimension of the regions, <B> is the average induction in them, d is the sample thickness, v is the neutron velocity, and g is the gyromagnetic ratio for the neutron.

Assuming (2) an experimentally observed depolarization ∿ 5%, we obtain $4\pi\langle M\rangle = \langle B\rangle = \sqrt{17/\delta}$ (Gauss).

If it is assumed that the depolarization is due to domain walls whose dimension for MnF_2 is ∿ 10^2 Å [5, 6], then we obtain that M in the wall is equal to the sublattice magnetization, a value which in all probability is not realistic [7]. On the other hand, assuming the existence of regions of the ferromagnetic-domain type, which have large dimensions (e.g., the domains for NiF_2 are approximately 10^2 times larger than for iron [9]), then we obtain for δ ∿ 10 mm a value of M ∿ 0.1 G in such a domain. This agrees in order of magnitude with the value ∿ V^2M_0/c^2 (V is the electron velocity and M_0 is the sublattice magnetization) of the spontaneous moment due to the relativistic interactions in transition-metal fluorides [10]. This value of M leads to non-collinearity of the sublattices [10].

There is still no experimental proof of the existence of such a moment in MnF_2, although the presence of a "parasitic" ferromagnetic moment in the measurements is indicated in [11]. Its value is smaller by an approximate factor of 100 than the value obtained from depolarization. This difference is probably due to the specifics of the experiments. In neutron experiments, the obtained value of the magnetization, 0.1 G, has the meaning of a local value rather than a value averaged over the entire sample.

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