RESONANT DEPOLARIZATION OF NEUTRONS BY THE DOMAIN STRUCTURE IN FERROMAGNETS

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The passage of polarized slow neutrons through a strongly magnetized iron single crystal was investigated in [1], where it was observed that the beam depolarization in the sample depends in a resonant manner on the applied magnetic field, and has, as a function of the magnetic field intensity, a series of approximately equidistant maxima with depths 1 - 3%.

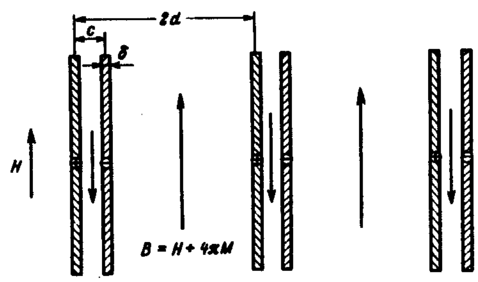
In this paper we attempt to interpret this phenomenon theoretically on the basis of notions concerning the residual domain structure of a ferromagnet in a strong field [2 - 6].

As is well known [7], when neutrons pass through an unmagnetized triaxial ferromagnet they become strongly depolarized as a result of rotations of the polarization vector in the domains. Under the influence of a sufficiently strong magnetic field, the domains oriented at an angle to the field practically vanish, and the magnetization in all the remaining regions become oriented parallel or antiparallel to the external field. This should result in an ordered layered structure (see the figure) with a period 2d, in which the domains magnetized against the field are strongly compressed ($c \ll a$), since the sample is in a state close to total saturation.

Such a residual structure can be formed from the initial domain structure in a continuous manner, for example in a manner similar to that considered in [6].

The domains are separated by narrow transition layers of width δ (shown shaded in the figure), namely Bloch walls, in which the magnetization $\vec{M}$ is smoothly rotated through 180° around the normal to the boundaries, and is on the average perpendicular to the induction $\vec{B} = \vec{H} + 4\pi \vec{M}$ in the domains, the magnetizations of neighboring walls being opposite in direction.

On passing through such a structure, neutrons polarized along the external field $\vec{H}$ become depolarized only as a result of rotation of the polarization vector $\vec{P}$ in the transition layers[1]. Rotation of the beam polarization vector in one Bloch wall was investigated in [8], where it was shown that this rotation is small for thermal neutrons, and occurs non-adiabatically.



The action of the domain walls on the neutron spin can therefore be represented in the form of a sum of δ-like pulses, i.e., their field can be written in the form:

$$B_y(x) = b\delta \sum_{n=0}^{N-1} [\delta(x - 2dn) - \delta(x - 2dn - c)], \qquad (1)$$

where $b \approx 8M$ is the average wall field, N is the total number of periods, the x axis is chosen along the normal to the domain boundaries, and the z axis is parallel to H.

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1) It is shown in [9] that even in the state of total saturation there should exist a depolarization due to magnetization fluctuations, but it is very small when T is lower than the Curie point T_c, and decreases with increasing magnetic field.

Owing to the periodicity of the field $B_y(x)$, the spin of the moving neutron is acted upon by a rotating field perpendicular to $\vec{H}$, with harmonics that are multiples of $\omega = \pi v_{\parallel}/d$, where $v_{\parallel} = v \cos\theta$ is the neutron velocity in the direction normal to the Bloch walls. If the Larmor frequency of the spin precession in the leading field $\vec{B} \parallel \vec{P}_0$ approaches the frequency of one of these harmonics: $\Omega = g_n \bar{B} = k\omega$ (k is an integer), then the spin-flip probability increases strongly - a phenomenon analogous to spin resonance [10]. This explains qualitatively the series of depolarization maxima observed in [1], and also the dependence of their positio positions on the neutron velocity and on the beam orientation relative to the domain structure.

We now perform a more rigorous quantitative calculation of this resonant depolarization, starting from the equation of motion of the polarization vector of a beam of neutrons passing through the sample, in the form [7]

$$dP/dt = g_n [\mathbf{P} \times \mathbf{B}], \qquad g_n = 2\mu_n/\hbar \, , \tag{2}$$

where μ_n is the magnetic moment of the neutron, and $\vec{B}(\vec{r})$ is the induction at the location of the neutron. Recognizing that $B_x = 0$ in the domain structure, we obtain from (2) the following system of equations for P_z and $P_{\pm} = P_x \pm iP_y$:

$$\dot{P}_{\pm} \pm i g_n B_z P_{\pm} = -g_n B_y P_z \, ; \qquad \dot{P}_z = \frac{g_n}{2} B_y (P_+ + P_-) \, . \tag{3}$$

If the total depolarization is small, this system can be solved by the iteration method:

$$P_{\pm}(t) \approx -g_n P_0 \int_0^t d\tau \, B_y(\tau) \, e^{\pm i[\phi(\tau) - \phi(t)]},$$

$$P_z(t) = P_0 + \frac{g_n}{2} \int_0^t d\tau \, B_y(\tau) \, [P_+(\tau) + P_-(\tau)] \, , \tag{4}$$

where $\phi(t) = g_n \int_0^t B_z(\tau) d\tau$, $\tau = v_{\parallel} x$, and P_0 is the initial polarization. After substituting (1) in (4) and performing simple calculations, we obtain the following formula for the resonant depolarization:

$$\frac{\Delta P_z}{P_0} = \frac{2 g_n^2 b^2 \delta^2}{v_{\parallel}^2} \sin^2 \frac{\phi_1}{2} \left[\frac{\sin^2 \frac{\phi_0 N}{2}}{\sin^2 \phi_0/2} + N \right] , \tag{5}$$

$$\phi_0 = 2 g_n \left[H + 4\pi M \frac{a - c}{2d} \right] \frac{d}{v_{\parallel}} \, ; \quad \phi_1 = g_n [4\pi M - H] \frac{c}{v_{\parallel}} \, .$$

The resonant depolarization is due to the unique interference of the small successive rotations of the vector $\vec{P}$ in the Bloch walls, resulting from its precession around the field $\vec{B}$ in the domains. Formula (5) is therefore similar to that for a diffraction grating. The principal diffraction maxima of depolarization appear when the condition $\phi_0 = 2\pi k$ (which coincides with the condition given above) is satisfied, when the vector $\vec{P}$ performs k revolutions within the period of the domain structure. The width of these resonances $\Delta\phi \sim 2\pi/N$

determines the requirements imposed on the monochromaticity of the neutron beam and on the perfection of the periodic structure, under which a maximum of order k can be observed:

$$\Delta v/v \leqslant 1/Nk , \quad \Delta d/d \leqslant 1/Nk . \tag{6}$$

The depth of the resonances depends quadratically on the number of traversed periods N, on the thickness c of the oppositely magnetized domains, on the width δ of the Bloch walls; it also depends on the neutron energy like v^{-4}.

With increasing temperature, the width of the walls increases appreciably ($\delta \sim \sqrt{A/K}$, where A(T) is the exchange constant and K(T) the magnetic-anisotropy constant) [2, 3], owing to the decrease of K(T), and consequently the depolarization maxima become more distinct.

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ESTIMATE OF LINE WIDTH OF STIMULATED MANDEL'STAM-BRILLOUIN AND RAMAN SCATTERING OF LIGHT IN SATURATION

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Stimulated Mandel'shtam-Brillouin Scattering. 1. It is known [1, 2] that at sufficiently low pump intensities I_L ($I_L < I^{MB}_{thr}$), the SMBS component reflected by the region $0 < Z < \ell$ has an intensity I_{MB} which is low compared with I_L (linear scattering regime), and the line width decreases with increasing pump intensity

$$\Delta\omega_{MB(lin)} = \Delta\omega\sqrt{\frac{\ln 2}{g\ell I_L}}, \tag{1}$$

where Δω is the line width of the thermal Mandel'shtam-Brillouin scattering and g is the gain. We present below estimates from which it can be concluded that in an essentially nonlinear SMBS regime ($I_{MB}(z=0) \leq I_L(z=0) >> I^{MB}_{thr}$) the line width tends to

$$\Delta\omega_{MB} \propto \Delta\omega\sqrt{\frac{\ln 2}{g\ell I^{MB}_{thr}}} = \Delta\omega\sqrt{\frac{\ln 2}{G}} \tag{2}$$