Acoustomagnetic resonance in neutron diffraction

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The effect of elastic resonant vibrations on the intensity of magnetic scattering of neutrons by a $FeBO_3$ crystal has been observed. This effect is linked with the excitation of vibrations of the magnetic moments. The amplitude of magnetic oscillations has been measured. The dependence of this amplitude on the magnetic field strength and on the sound amplitude has also been measured.

Weak ferromagnets with an "easy-plane" anisotropy are characterized by a strong, magnetically elastic coupling, whose presence gives rise to vibrations in one subsystem (elastic or magnetic) which causes the other subsystem to vibrate.[1,2]

In Refs. 3 and 4 we observed resonant magnetoacoustic effects in the diffraction of neutrons and x-rays by perfect crystals of weak ferromagnets: the intensity of the reflections in the crystal increased as a result of application of an alternating magnetic field. The reflections stemmed from the elastic distortions which caused the perfect crystal to scatter as a mosaic crystal. Excitation of the acoustic waves in the crystal will lead, as can be expected, to a vibration of the magnetic moments as a result of the presence in it of a magnetoelastic coupling. These magnetic moments can be recorded directly from the change in the intensity of the elastic magnetic scattering of neutrons. These acoustomagnetic effects can, however, be observed only if the scattering intensity does not depend on the mosaic characteristics introduced by the elastic vibrations. Such an effect can occur, for example, in a diffraction in the kinematic limit: in crystals which are thin in comparison with the extinction length. In the case of a thin crystal the intensity of the magnetic scattering of neutrons is proportional to the square of the sine of the angle between the scattering vector and the antiferromagnetism vector[5] and for an easy-plane sample can be represented in the form

$$I(\varphi) \sim (1 - (\sin(\varphi) \cdot \cos(\Delta))^2), \tag{1}$$

where φ is the angle which determines the easy-plane orientation of the antiferromagnetism vector, and Δ is the angle between the normal to the reflecting plane and the easy plane. In the absence of vibrations, the orientation of the magnetic moments is given by the direction (which is characterized by the angle φ_0) of the scattering magnetic field applied in the easy plane: the weakly ferromagnetic vector is oriented parallel to the direction of the field and the antiferromagnetic vector is oriented perpendicular to it.

If the antiferromagnetic vector begins to execute angular oscillations with an amplitude φ^*, then the time-averaged, t, intensity of the magnetic scattering will change. In the case of harmonic vibrations the intensity can be written in the form

$$I^*(\varphi_0,\varphi^*) \sim \int_0^{2\pi} I(\varphi_0 + \varphi^* \sin(t))dt. \qquad (2)$$

The intensity of the magnetic scattering of neutrons can thus be used to determine the presence or absence of oscillations of the antiferromagnetism vector and the magnitude of the amplitude φ^*. The experiments were carried out on the MOND diffractometer situated at the IR-8 reactor in the Kurchatov Atomic Energy Institute. A beam of neutrons with $\lambda = 1.2$ Å was rendered monochromatic by means of a double monochromator[6] of pyrolytic-graphite crystals (the 002 reflection). The sample was a $FeBO_3$ plate 6×2 mm in size, whose plane was the same as that of easy magnetization; after saturation the field was ≈ 10 Oe. The thickness of the sample, $t_0 \approx 40$ μm, was 0.25 (for $\varphi_0 = 0$) and 0.06 (for $\varphi_0 = 90°$) of the extinction length. An ultrasonic $LiNbO_3$ transducer with a resonant $f_0 \simeq 4.3$ MHz was cemented to the edge of the crystal. We studied the intensity of magnetic scattering of neutrons [the (100) reflection with $\Delta = 15.5°$] as a function of φ_0, of the frequency f, of the voltage V_0 across the transducer, and of the magnetic field strength.

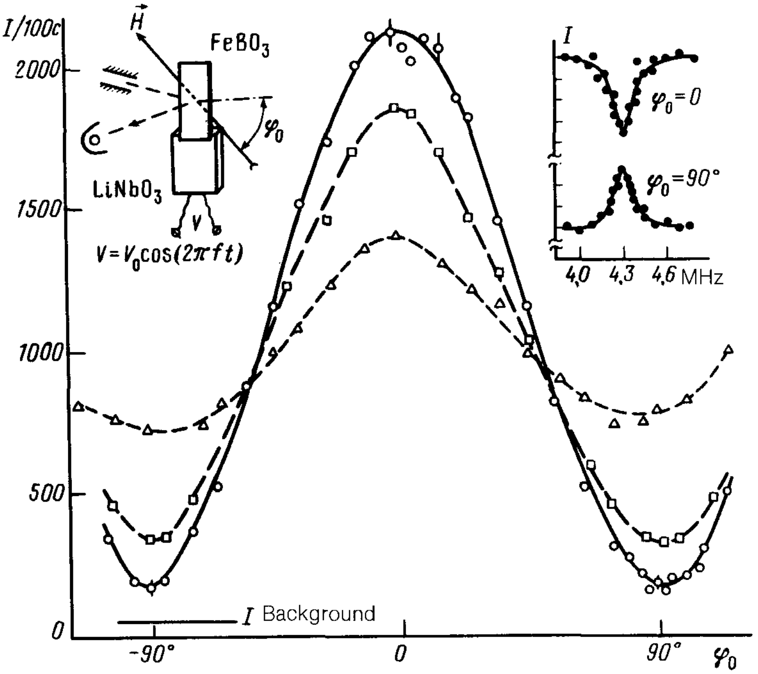

FIG. 1. Intensity of the magnetic scattering of neutrons versus the orientation of the external magnetic field when the following voltages are applied to the piezoelectric transducer: O—0; ◇—2.5 V; Δ—7 V. Solid line — Result of calculations based on Eq. (1). Insets—Experimental layout and the scattering intensity versus the signal clarity of the piezoelectric transducer.

In the absence of sound, the dependence $I^*(\varphi_0)$ is described by Eq. (1) within the statistical errors (Fig. 1). Upon increasing V_0 the $I^*(\varphi_0)$ curve flattens out: At $\varphi \simeq 0$ the scattering intensity decreases and at $\varphi \simeq \pm 90°$ it increases, as follows from Eq. (2), as the amplitude φ^* is increased. The frequency dependence of the scattering intensity in this case exhibits a peak at $\varphi_0 = 90°$ and a trough at $\varphi_0 = 0$, suggesting that the effect we have observed is resonant in nature. In the first approximation the resonance curve is symmetric in shape relative to the resonance frequency f_0 of the transducer. The amplitude of magnetic oscillations was determined from the ratio of the scattering intensities of the excited and unexcited crystals. It was established that this amplitude is proportional to V_0, and that it decreases with increasing N (Fig. 2).

The maximum value of φ^* is on the order of 1 rad. In the control experiment the crystal was detached from the piezoelectric transducer and placed a distance of $\simeq 1$ mm from it. The effect of ultrasound on the distance was absent in this case.

In a linear approximation the amplitude of the magnetic oscillations can be expressed in terms of the elastic strain tensor[1] $\hat{u}$:

$$\varphi^* = \frac{2H_e}{M} \frac{\hat{B}\hat{u}}{(H(H + H_d) + 2H_eH_{ms})}, \tag{3}$$

where M is the magnetization of the sublattices, N_e and N_dN_{ms} are the effective fields of the intrasublattice Dzyaloshinskiĭ exchange of the spontaneous striction, and $\hat{B}$ is the magnetoelastic tensor. The theoretical dependence $\varphi^*(H)$ which was calculated with use of the values of the constants for $FeBO_3$ from Ref. 7, is in agreement with the experimental data (Fig. 2). Assuming that $\hat{B} = B \simeq 5 \times 10^6$ erg/cm (Ref. 7), we can

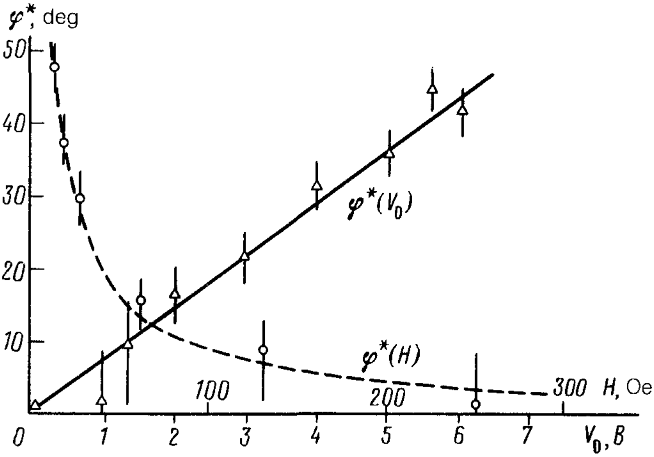

FIG. 2. Oscillation amplitude of the magnetic moments versus the magnetic field strength (at $V = 6$ B) and the voltage on the piezoelectric transducer (at $H = 10$ Oe). Dashed line—Calculation based on Eq. (3) for $2H_eH_{ms}/H_d = 8.7$ Oe (Ref. 7).

determine the elastic strain which at $V \simeq 5$ B is $u \simeq 10^{-5}$, which is close to the magnetostriction constant of weak ferromagnets.[8]

The excitation of resonance elastic vibrations of a $FeBO_3$ crystal with a strong magnetoelastic coupling thus leads to a change in the time-averaged intensity of the magnetic scattering of neutrons, which can naturally be linked with the appearance of rf resonance vibrations of the magnetic moments and with the corresponding change of the scattering amplitude. The data taken collectively (the symmetric shape of the frequency characteristic, linear coupling of the amplitude of magnetic and acoustic waves, absence of a threshold) show that despite the large amplitude of magnetic vibrations ($\simeq 1$ rad), the acoustomagnetic resonance for the amplitudes of the ultrasonic waves used in the experiment is a linear effect in contrast with the nonlinear magnetoacoustic resonance.[3]

Because of its ability to directly and simultaneously analyze the elastic and magnetic excitations and the interaction between them, neutron scattering is a promising method of investigation in the region of linear and nonlinear magnetoacoustics.

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