Magnetoacoustic resonance phenomena in neutron scattering

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The intensity of the nuclear and magnetic scattering of neutrons by a high-quality, weakly ferromagnetic $FeBO_3$ crystal has been found to depend on the frequency of the magnetization-reversal field. On this frequency dependence there are resonant peaks which stem from the excitation of magnetoelastic vibrations.

During the interaction of radiation with high-quality crystals in which elastic vibrations are excited, we know that nontrivial resonance phenomena can arise. For example, an x-ray-acoustic resonance[1] may occur if the length of a sound wave coincides with the extinction length, or there may be resonance effects which are associated with the excitation of natural vibrations of the crystal and which are caused by a local defectiveness.[2]

It has recently been established that thin crystals of the weak ferromagnets $FeBO_3$ and α-Fe_2O_3 can have a quality high enough to allow the observation of those dynamic effects in both the nuclear scattering and magnetic scattering of neutrons which are properties of high-quality crystals.[3] For these crystals there are typically coupled magnetoacoustic waves, which arise during the magnetization reversal of the crystals[4] (high-quality crystals of iron borate are capable of undergoing magnetization reversal at frequencies up to 1 GHz in magnetic fields on the order of a few oersteds[5]). Such vibrations may be nonlinear, since the nonlinearity introduced by the magnetic subsystem in the elastic subsystem is very large in these crystals.[6] Our purpose in the present study was accordingly to determine the effect which a high-frequency magnetization reversal has on the magnetic and nuclear scattering of neutrons by a high-quality $FeBO_3$ crystal.

The neutron experiments were carried out on the MOND single-crystal diffractometer, installed at the IR-8 reactor of the Kurchatov Institute of Atomic Energy. We used a neutron beam with $\lambda = 2.4$ Å and $\Delta\lambda/\lambda = 1.5\%$, rendered monochromatic by reflection from two pyrolytic graphite crystals. In the experiments we used a high-quality $FeBO_3$ crystal: a wafer of irregular shape with transverse dimensions $\sim 4 \times 7$ mm and a thickness ~ 70 μm. We also used an $FeBO_3$ crystal of lower quality ($\sim 30''$), which was a wafer with dimensions $\sim 8 \times 10$ mm and a thickness ~ 120 μm. In each case the plane of the wafer coincided with the easy magnetization plane. A 180° magnetization reversal was carried out over the frequency range 0.1–1 MHz by means of a sinusoidally varying magnetic field, produced in a copper coil around the sample. The magnetic field strength was calculated from the current flowing through the coil; it ranged up to ~ 50 A/cm.

It can be seen from Fig. 1 that when an alternating magnetic field of sufficient

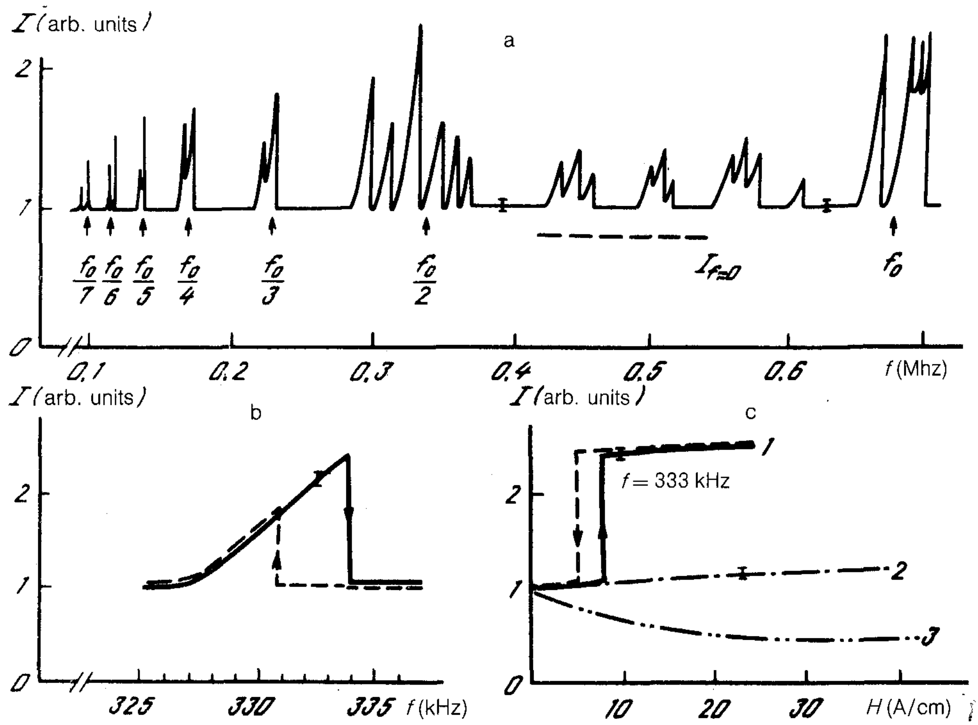

FIG. 1. a—Intensity of the (222) reflection of neutrons by a high-quality $FeBO_3$ crystal versus the frequency of the magnetization-reversal field; b—hysteresis; c—amplitude dependence of the intensity of the nuclear (222) scattering of neutrons by (1) a high-quality crystal and (2) a mosaic crystal, and (3) that of the magnetic (100) scattering by the mosaic $FeBO_3$ crystal.

amplitude is applied to the high-quality $FeBO_3$ crystal, several groups of resonant peaks appear on the frequency dependence of the intensity of the nuclear (222) reflection of neutrons. One of these peaks lies near the frequency $f_0 \sim 680$ kHz, while the others lie near multiples of this frequency. For each of the resonant peaks, a coil detected magnetic oscillations in the crystal after the applied voltage was turned off rapidly (in $\sim 30\ \mu s$). These magnetic oscillations had frequencies on the order of f_0 and decayed over a time ranging up to 400 μs. In addition to the strong peaks on the frequency dependence we also observed some weaker resonances, which corresponded to harmonics of other frequencies, higher than f_0. It was established that the height of the resonant peaks decreases as the crystal is mounted more rigidly. When the crystal is heated to the temperatures above the Néel point ($T_N = 348$ K),or if an additional magnetization is introduced by a static field several times as strong as the alternating magnetic field, the scattering intensity becomes independent of the frequency. A change in the mounting of the sample may lead to a change in the magnitudes and positions of the individual resonant peaks, but the average position of each group of peaks remains the same.

Similar effects were observed in other nuclear and magnetic, Laue and Bragg, reflections of neutrons from the high-quality $FeBO_3$ crystal, but they were not seen in the neutron scattering by the mosaic $FeBO_3$ crystal. In the latter case the scattering intensity was independent of the frequency of the magnetization-reversal field, at field strengths up to 50 A/cm, but this scattering intensity varied with the amplitude of the magnetic field (Fig. 1c).

The heights of the resonant neutron peaks increase linearly with increasing optical thickness of the crystal. This thickness was increased by tilting the crystal around the normal to the reflecting plane.

Taken together, these facts suggest that the reason for the growth of the scattering intensity is a degradation of the quality of the crystal caused by a resonant excitation of magnetoelastic vibrations. Natural frequencies on the order of f_0 are characteristic of membrane vibrations of $FeBO_3$ samples with transverse dimensions ~ 5 mm (Ref. 7). The distinctive shape of all of the resonant peaks (an abrupt decrease in the scattering intensity when the frequency exceeds a certain threshold), the threshold which is required for the appearance of the effect upon a variation of the magnetic field amplitude (Fig. 1c), and the hysteresis on both of these curves strongly suggest that these oscillations are nonlinear.

We observed corresponding magnetoacoustic resonance phenomena in the (200) scattering of $\mathrm{Cu}K_\alpha$ *x* radiation in the high-quality $FeBO_3$ crystal. Such phenomena should also be expected when other types of radiation are used (Mössbauer, synchrotron, etc.)

One can hope that experiments in neutron and x-ray magnetoacoustics similar to those described above will yield information on the oscillations of the nuclear and spin subsystems of a crystal (in particular, that they will reveal the amplitudes of oscillations, through measurements of the intensities of resonant peaks) of a more-detailed nature than is furnished by other methods available. One can also hope that such experiments will open new fields of application for diffraction methods.

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