Magnetic birefringence and magnetic dichroism of ultrasound in ferromagnets

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Birefringence and dichroism of ultrasound induced in polycrystalline nickel ferrite by a magnetic field **H** of strength 0–1 kOe and propagating perpendicular to this field have been observed experimentally. The ultrasound frequency 51 MHz was much lower than the magnetoelastic-resonance frequency. The phase velocities of the modes polarized parallel and perpendicular to **H** increase rapidly with increasing H, and their difference reverses sign at a certain field value H_1. A theoretical analysis shows that these phenomena are governed by two magnetoelastic-interaction mechanisms. One is due to the change of the magnetization **m** caused by the elastic stresses that accompany the mode that is polarized parallel to **H**. The other, common to both modes, is related to those magnetic-domain magnetization changes for which averaging over the change does not alter **m**.

1. Magnetic birefringence of transverse ultrasound in ferro- and ferrimagnets (magnetics for short) has been investigated both experimentally and theoretically, using as the example the acoustic analog of the Cotton-Mouton effect[1] in polarizing magnetic fields H_0 strong enough to produce magnetic saturation, and at frequencies close to that of magnetoelastic resonance. This birefringence arises because magnetoelastic interaction between the elastic and spin subsystems occurs in a wave propagating perpendicular to $\mathbf{H}_0$ and polarized parallel to $\mathbf{H}_0$. As a result, this wave becomes quasielastic and its velocity depends on H_0. The prefix "quasi" indicates that alternating elastic displacements in the wave are accompanied by an alternating magnetization **m** and an alternating magnetic-field strength **h** ($h \ll H_0$). No such interaction occurs in a wave polarized perpendicular to $\mathbf{H}_0$. The wave remains purely elastic and its velocity is independent of H_0.

Acoustic birefringence was theoretically described by a coupled system of electrodynamic, motion, elasticity, and magnetization equations, in which account was taken of the magnetoelastic interaction. It was assumed that the elastic tensor components c^M_{2323} and c^M_{1212} determined at constant magnetization and contained in the equations for transverse waves polarized parallel and perpendicular to $\mathbf{H}_0$, are independent of the polarization magnetization M_0 and are all equal: $c^M_{2323} = c^M_{1212} = c^0_{2323}$. We note that according to Ref. 2 the tensor c^M_{ijkl} for a magnetic in a single-domain state depends in the general case on M_0, but this dependence leads only to very weak effects.

In the case of magnetic fields corresponding to a multidomain state of a magnetic, the tensor components c^M_j contained in the material equations depend substantially on M_0. This leads to ΔE and ΔG effects.

Noting that the symmetry is lowered by magnetic polarization, one can expect the components c^M_{2323} and c^M_{1212} of a polycrystalline magnetic not only to depend on M_0, but also to differ from one another. This, too, should lead to magnetic birefringence and magnetic dichroism of ultrasound. The present paper is devoted to an experimental investigation of birefringence and dichroism of ultrasound in nickel ferrite in a wide magnetic-field range, and to a microscopic and phenomenological explanation of the observations.

2. The polycrystalline nickel ferrite ($NiFe_2O_4$) specimen, produced by sintering, was nearly ellipsoidal in shape (inset of Fig. 1a), with axes 24, 9.5 and 64 mm. The magnetic field was directed along the largest axis (z), and the ultrasound was propagated along the smallest (y). The measurements were made at frequencies ~51 MHz with a pulsed phase-sensitive setup based on a high-frequency acoustic bridge.[3] The phase shift of the investigated signal as a function of some parameter (magnetic field, temperature, etc.) that sets the state of the medium was determined from the change of the frequency of the master oscillator, while the change of the amplitude was determined from the readings N

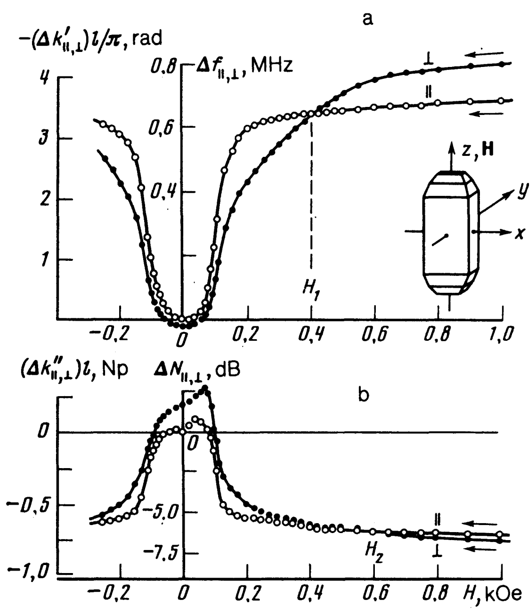

FIG. 1. Changes of the master-oscillator frequency (a) and attenuator readings (b), needed to restore the balance of the acoustic bridge, vs the intensity of the polarizing magnetic field, for wave polarized respectively parallel ($\Delta f_\parallel$, $\Delta N_\parallel$) and perpendicular ($\Delta f_\perp$, $\Delta N_\perp$) to **H** in nickel ferrite.

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of a calibrated attenuator with the bridge balanced. Linearly polarized transverse elastic oscillations were excited and received with X-cut lithium-niobate piezoconverters.

It can be shown that the changes of the real and imaginary parts of the y-component of the ultrasound wave vector $\mathbf{k} = (0, k' - ik'', 0)$ are given as functions of the external field by the relations

$$\Delta k'l = -2\pi\Delta f/\Delta f_\lambda, \quad \Delta k''l = \Delta\Gamma = \Delta N \; 0{,}05 \ln 10, \tag{1}$$

where l is the acoustic-path length, $\Delta f = f - f^0$, $\Delta\Gamma = \Gamma - \Gamma^0$, $\Delta N = N - N^0$ are the changes of the frequency, absorption (in nepers), and signal (in decibels) entering the receiver from the values f^0, Γ^0, and N^0 at the initial value of the parameter, Δf_λ is the modulus of the difference between the frequency f^0 and the frequency closest to it, corresponding to balance of the bridge at a fixed value of the parameter.

The piezoconverters were fastened to the specimen in such a way as to align the unit vectors $\mathbf{\Gamma}$ and $\mathbf{\Pi}$, respectively defining the directions of the excited and received transverse linearly polarized elastic oscillations. Two experiments were performed, with $\mathbf{\Gamma} \| \mathbf{\Pi} \| \mathbf{H}_0$ in the first and $\mathbf{\Gamma} \| \mathbf{\Pi} \perp \mathbf{H}_0$ in the second. The bridge was initially balanced at $H_0 = 0$ and $\mathbf{\Gamma} \| \mathbf{\Pi} \| z$. Next, the experimental values of

$$\Delta f_\| = f_\| - f_\|^0, \quad \Delta f_\perp = f_\perp - f_\|^0,$$
$$\Delta N_\| = N_\| - N_\|^0, \quad \Delta N_\perp = N_\perp - N_\|^0,$$

and Eqs. (1) were used to determine the values of $\Delta k'_{\|,\perp} l$ and $\Delta k''_{\|,\perp} l$. The subscripts $\|$ and $\perp$ pertain to two eigenwaves (modes) propagating along a certain direction (here—the y axis) perpendicular to $\mathbf{H}_0$, but polarized parallel and perpendicular to $\mathbf{H}_0$.

The differences $\Delta k'l = \Delta k_\|'l - \Delta k_\perp'l$ and $\Delta k''l = \Delta k_\|''l - \Delta k_\perp''l$ are parameters that characterize respectively the magnetic birefringence, i.e., the difference between the phase velocities, and the magnetic dichroism, i.e., the difference between the mode absorption coefficients.

3. The frequency changes $\Delta f_{\|,\perp}$ measured at 78 K as functions of H_0, and the values of $\Delta k_{\|,\perp} l$ calculated from them, are shown in Fig. 1a. Similar plots for $\Delta N_{\|,\perp}$ and $\Delta k''_{\|,\perp} l$ are shown in Fig. 1b. All the curves plotted with the magnetization tracking the hysteresis loop were "butterfly" shaped, but Fig. 1 shows only the sections corresponding to a decrease of the field from $H_{max} = 1$ to $H = 0.25$. The "butterfly" can be obtained by reflection about the ordinate axis. Figure 2 shows part of the magnetization hysteresis, obtained for the nickel ferrite sample used for the acoustic investigations.

An analysis of the results points to the following:

a) Birefringence and dichroism of transverse ultrasound propagating perpendicular to the magnetic field are observed in the entire range of H_0.

b) For birefringence there is a characteristic field value H_1 that demarcates the regions of the relatively weak and strong magnetic fields, in which $\Delta k_\perp'l > \Delta k_\|'l$ at $0 \leqslant H_0 < H$ and $\Delta k_\perp'l < \Delta k_\|'l$ for $H_1 < H_0$. A similar field H_2 exists also for the dichroism: $\Delta k_\perp''l > \Delta k_\|''l$ at $0 \leqslant H_0 < H_2$ and

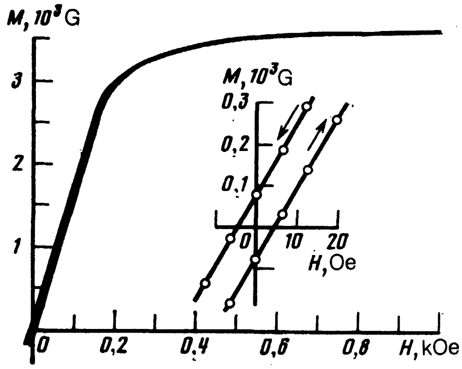

FIG. 2. Hysteresis loop of nickel ferrite magnetization.

$\Delta k_\perp''l < \Delta k_\|''l$ at $H_0 > H_2$. There is no birefringence and dichroism at $H_0 = 1$ and $H_0 = H_2$, respectively.

c) Birefringence and dichroism are preserved after preliminary magnetization even in the demagnetized state of the specimen. There apparently exists a magnetic texture that leads to anisotropy of the elastic properties in this state.

d) The presence of hysteresis on the plots of $\Delta k'_{\|,\perp} l$ and $\Delta k''_{\|,\perp} l$ not only vs H but also vs M indicates that the magnetoelastic state is not uniquely defined even when both H and M are given. The magnetoelastic state depends also on its prior history.

4. We consider now the physical processes that lead to the onset of magnetic birefringence and magnetic dichroism of ultrasound in ferro- and ferrimagnets.

For small oscillating magnetizations $\mathbf{m}$ ($m \ll M_0$), magnetic field strengths $\mathbf{h}$, elastic stresses τ_{ij}, and strains $\varepsilon_{ij} = (\partial u_i/\partial x_j + \partial u_j/\partial x_i)/2$, the following dynamic material equations hold:

$$\tau_{ij} = c^M_{ijkl}\varepsilon_{kl} + h_{ij,m}m_m,$$
$$h_n = h_{n,kl}\varepsilon_{kl} + \gamma_{nm}^\varepsilon m_m. \tag{2}$$

In these equations, the components of the elastic-modulus tensors c^M_{ijkl}, of the magnetostriction constants $h_{ij,m}$ and $h_{n,kl}$, and of the reciprocal susceptibility γ^ε_{nm} determined at constant stength, are all, in general, functions of the magnetic field H_0 and of the frequency f. The forms of these tensors for a magnetically polarized polycrystalline medium are given in Ref. 4.

Eliminating m_m and h_n from the system of coupled Maxwell equations written in the magnetostatic approximation, and from Eqs. (2) in the absence of an oscillatory magnetic field, we obtain, for the quantities that vary as $\exp[i(\omega t - \mathbf{k}\cdot\mathbf{r})]$, the relations

$$\tau_{ij} = c^H_{ijkl}\varepsilon_{kl}, \quad c^H_{ijkl} = c^M_{ijkl} - h_{ij,m}(\chi_{mn})_{\text{эфф}}h_{n,kl}, \tag{3}$$

where c^H_{ijkl} is the dynamic elastic modulus tensor defined for a constant field, $(\chi_{mn})_{\text{eff}}$ is the tensor of the effective magnetic susceptibility, $(\chi_{mn})^{-1}_{\text{eff}} = (\gamma_{mn})_{\text{eff}} = \gamma_{mn}^\varepsilon + (N_{mn})_\sim$, while $(N_{mn})_\sim = 4\pi k_i k_j k^{-2}$ and takes into account the oscillating magnetostatic field $\mathbf{h}$.

Let the waves propagate perpendicular to $\mathbf{H}_0$. Two linearly polarized modes, with polarization unit vectors parallel and perpendicular to **H**, can then exist in the medium. The real and imaginary components of the wave vectors of these modes are given by

$$k_\parallel'=\omega(\rho/c_{2323}^{\prime H})^{1/2},\qquad k_\perp'=\omega(\rho/c_{1212}^{\prime H})^{1/2},$$
$$k_\parallel''=\frac{1}{2}k_\parallel'\frac{c_{2323}^{\prime\prime H}}{c_{2323}^{\prime H}},\qquad k_\perp''=\frac{1}{2}k_\perp'\frac{c_{1212}^{\prime\prime H}}{c_{1212}^{\prime H}},\tag{4}$$

where ρ is the density of the medium. Here

$$c_{2323}^{\prime H}=c_{2323}^{\prime M}(1-\alpha\,\mathrm{Re}\,K_\parallel^2),\tag{5}$$

$$\frac{c_{2323}^{\prime\prime H}}{c_{2323}^{\prime H}}=\left[\frac{c_{2323}^{\prime\prime M}}{c_{2323}^{\prime M}}+\alpha\frac{\chi_{22}^{\prime\prime\varepsilon}}{\chi_{22}^{\prime\varepsilon}}\mathrm{Re}\,K_\parallel^2\right](1-\alpha\,\mathrm{Re}\,K_\parallel^2)^{-1},\tag{6}$$

where the real part of the magnetomechanical-coupling coefficient is

$$\mathrm{Re}\,K_\parallel^2=h_{23,2}\chi_{22}^{\prime\varepsilon}h_{2,32}/c_{2323}^{\prime M},\tag{7}$$

and $\chi_{22}^{\prime\varepsilon}$ and $\chi_{22}^{\prime\prime\varepsilon}$ are the real and imaginary components of the transverse magnetic susceptibility. The attenuation coefficient $\alpha=(1+4\pi\chi_{22}^{\prime\varepsilon})^{-1}$ takes into account the magnetostatic field **h** produced when a quasielastic wave propagates with polarization parallel to $\mathbf{H}_0$. It was assumed here and in Ref. 5 that the components $h_{23,2}$ and $h_{2,32}$ of the magnetostriction-constant are equal and are real. Like α, they depend on the polarization of the magnetization M_0.

Since $h_{12,1}=0$ (see, e.g., Ref. 4), we have $K_\perp^2=0$,

$$c_{1212}^{\prime H}=c_{1212}^{\prime M},\qquad c_{1212}^{\prime\prime H}=c_{1212}^{\prime\prime M},\tag{8}$$

and the wave polarized perpendicular to $\mathbf{H}_0$ is elastic. The difference between c_{1212}^H and c_{2323}^H determines the anisotropy of the shear modulus G^H.

In magnets having a domain structure, the components $c_{2323}^{\prime M}$, $c_{1212}^{\prime M}$, $c_{2323}^{\prime\prime M}$ and $c_{1212}^{\prime\prime M}$ also depend on M_0. Assume that $c_{1212}^0=c_{2323}^0$; we can then write

$$c_{2323}^{\prime M}(M_0)=c_{2323}^0[1-\Delta_{2323}(M_0)],\ c_{1212}^{\prime M}(M_0)=c_{2323}^0[1-\Delta_{1212}(M_0)],\tag{9}$$

where c_{2323}^0 is the elastic-modulus of the magnetic in the magnetic-saturation state. The components Δ_{2323} and Δ_{1212} vary, from zero at the saturation magnetization to their maximum values $\Delta_{2323}(0)$ and $\Delta_{1212}(0)$, for the ΔG effect. The possible inequality $\Delta_{2323}(M_0)\neq\Delta_{1212}(M_0)$ causes anisotropy of the shear modulus G^M.

We obtain thus from (5), (8), and (9)

$$c_{2323}^{\prime H}=c_{2323}^{\prime M}(1-\alpha\,\mathrm{Re}\,K_\parallel^2)\approx c_{2323}^0(1-\alpha\,\mathrm{Re}\,K_\parallel^2-\Delta_{2323}),$$
$$c_{1212}^{\prime H}=c_{1212}^{\prime M}=c_{2323}^0(1-\Delta_{1212}).\tag{10}$$

The difference between the components $c_{2323}^{\prime H}$ and $c_{1212}^{\prime H}$, which leads to birefringence, is due consequently to two factors:

a) the presence of a magnetoelastic coupling, characterized by $K_\parallel^2$, in both the multidomain and the single-domain states,

b) the anisotropy of the shear modulus G^M in the multidomain state of the magnetic.

Both factors are due to a local (within the domain) magnetoelastic coupling: in volumes that are small in terms of the wavelength but exceed the characteristic domain sizes, the uniform elastic stresses produce nonuniform changes in the local magnetization of each domains. These changes produce in turn local nonuniform strains, which yield additional strains of the magnetic after averaging over a physically small volume that contains many domains.

The effect described by the magnetomechanical-coupling coefficient $K_\parallel^2$ is due to the alternating magnetization **m** that characterizes the magnetic state of a physically small volume. The effect described by the components Δ_{2323} and Δ_{1212} is due to those magnetization changes in each domain which yield zero when averaged over the domains in a physically small volume.

We clarify now the character of the dependence of Δ_{2323} and Δ_{1212} on M_0 in a field region which, judging from the magnetization curve, contains the field H_1 and in which the main processes are rotations of the spontaneous magnetization vectors and no domains with a magnetization "reversed" relative to $\mathbf{H}_0$ is produced. For a crystalline magnetic numbered ν, having cubic crystallographic symmetry and containing a domain numbered $\varkappa$, the density of the local free magnetoelastic-interaction energy $F_{\mathrm{me}}^{\varkappa,\nu}$ is equal, in the crystallographic coordinate frame, to

$$F_{\mathrm{me}}^{\varkappa,\nu}=M_s^{-2}b_{1111}[\varepsilon_{11}^{\varkappa,\nu}(M_1^{\varkappa,\nu})^2+\varepsilon_{22}^{\varkappa,\nu}(M_2^{\varkappa,\nu})^2+\varepsilon_{33}^{\varkappa,\nu}(M_3^{\varkappa,\nu})^2]$$
$$+M_s^{-2}b_{1212}[\varepsilon_{12}^{\varkappa,\nu}M_1^{\varkappa,\nu}M_2^{\varkappa,\nu}+\varepsilon_{13}^{\varkappa,\nu}M_1^{\varkappa,\nu}M_3^{\varkappa,\nu}+\varepsilon_{23}^{\varkappa,\nu}M_2^{\varkappa,\nu}M_3^{\varkappa,\nu}],\tag{11}$$

where $M_s=|M^{\varkappa,\nu}|$, b_{1111} and b_{1212} are the magnetoelastic-interaction constants, and $M_i^{\varkappa,\nu}$ are the spontaneous-magnetization components of domain $\varkappa$ of crystallite ν.

For small changes $\mathbf{m}^{\varkappa,\nu}$ of the magnetization $(M^{\varkappa,\nu})_i=(M_0^{\varkappa,\nu})_i+m_i^{\varkappa,\nu}$ relative to the initial $\mathbf{M}_0^{\varkappa,\nu}$, the local free energy changes and

$$\Delta F_{\mathrm{me}}^{\varkappa,\nu}=h_{ij,k}^{\varkappa,\nu}\varepsilon_{ij}^{\varkappa,\nu}m_k^{\varkappa,\nu},\tag{12}$$

where the following components of the local magnetostriction-constant tensor are off-diagonal in the pair of indices ij:

$$h_{13,3}^{\varkappa,\nu}=h_{12,2}^{\varkappa,\nu}=M_s^{-2}b_{1212}(M_0^{\varkappa,\nu})_1,\quad h_{23,3}^{\varkappa,\nu}=h_{12,1}^{\varkappa,\nu}=M_s^{-2}b_{1212}(M_0^{\varkappa,\nu})_2,$$
$$h_{23,2}^{\varkappa,\nu}=h_{13,1}^{\varkappa,\nu}=M_s^{-2}b_{1212}(M_0^{\varkappa,\nu})_3.\tag{13}$$

To understand the qualitative picture of the phenomenon and to simplify the problem, we consider a magnetic that is anisotropic in its magnetic properties but isotropic in its magnetoelastic properties. We neglect by the same token the coupling-coefficient differences between the elastic and spin waves, taken into account in Ref. 6. This is permissible for qualitative conclusions in the case of nickel ferrite, since its constants b_{1111} and b_{1212} are positive and do not differ by more than fifty percent.[7] We can then introduce for the description of the local magnetoelastic energy of the regions occupied by individual domains a common coordinate frame connected with the polarizing magnetic field and having a z axis oriented along $\mathbf{H}_0$. The components of the tensors $h_{ij,m}^{\varkappa,\nu}$ also take in this case the form (13), where $(M_0^{\varkappa,\nu})_i$ are now the components of the vectors $\mathbf{M}_0^{\varkappa,\nu}$ in this new coordinate frame.

If $H_0 > H_s$, where H_s is the magnetic-field intensity at which magnetic saturation is reached, then $(M_0^{\varkappa,\nu})_1 = (M_0^{\varkappa,\nu})_2 = 0$ and $(M_0^{\varkappa,\nu})_3 = M_s$. With decreasing magnetic field strength, the magnetic anisotropy causes the magnetic to break up into domains whose magnetization $\mathbf{M}_0^{\varkappa,\nu}$ approaches the direction of the nearest easy-magnetization axis of the crystallite and makes acute angles with $\mathbf{H}_0$. Components $(M_0^{\varkappa,\nu})_1$ and $(M_0^{\varkappa,\nu})_2$ are produced and grow in each domain, taking on both positive and negative values, while $(M_0^{\varkappa,\nu})_3$ decreases and remains initially positive.

A wave polarized parallel to $\mathbf{H}_0$, which causes the strain ε_{23}, produces according to (13) in each domain magnetization changes $m_2^{\varkappa,\nu}$ due to the magnetostriction-constant component $h_{23,2}^{\varkappa,\nu}$ proportional to $(M_0^{\varkappa,\nu})_3$. They cause magnetostriction strains that lead, on averaging over the domains, to additional strains in the magnetic. Since $(M_0^{\varkappa,\nu})_3$ is initially positive in all domains, the local changes of the magnetization $m_2^{\varkappa,\nu}$ yield, on averaging over the domains, a magnetization change m_2 that is proportional to the averaged (over the physically small volume) component $h_{23,2}$ that decreases with decreasing H_0. This process is described according to (7) by the magnetomechanical-coupling constant $K_\parallel^0$ and determines the difference between the values of the components c_{2323}^H and c_{2323}^M.

In addition, the same wave alters the magnetizations $m_3^{\varkappa,\nu}$ due to the component $h_{23,3}^{\varkappa,\nu}$. When averaged over the domains they do not give rise to the magnetization m_3, since the component $h_{23,3}^{\varkappa,\nu}$ is odd in $(M_0^{\varkappa,\nu})_2$. Therefore $h_{23,3} = 0$. The strains averaged over the domains, however, lead to additional strains described by the component Δ_{2323}. The component Δ_{2323} should increase with decreasing H_0, in view of the increase of the components $(M_0^{\varkappa,\nu})_2$.

The wave polarized perpendicular to $\mathbf{H}_0$, which causes the strain ε_{12}, gives rise only to changes of $m_1^{\varkappa,\nu}$ and $m_2^{\varkappa,\nu}$, due to the components $h_{12,2}^{\varkappa,\nu}$ and $h_{12,1}^{\varkappa,\nu}$ odd in $(M_0^{\varkappa,\nu})_1$ and $(M_0^{\varkappa,\nu})_2$. Averaging over these magnetization changes does not lead to changes of the magnetizations m_1 and m_2. Hence $h_{12,2} = h_{12,1} = 0$. Accordingly, $c_{1212}^H = c_{1212}^M$. These local magnetization changes, however, produce strains which, when averaged over the domains, give rise to additional strains described by a component Δ_{1212} that increases with decreasing H_0.

We should have $\Delta_{1212} > \Delta_{2323}$, since propagation of a wave polarized parallel to $\mathbf{H}_0$ produces only changes $m_3^{\varkappa,\nu}$, and propagation of a wave polarized perpendicular to $\mathbf{H}_0$ produces $m_1^{\varkappa,\nu}$ and $m_2^{\varkappa,\nu}$. In addition, $m_3^{\varkappa,\nu} < m_{1,2}^{\varkappa,\nu}$. This circumstance determines the anisotropy of the shear modulus G^M.

It should be noted that as $H_0 \to H_s$ the component $h_{23,2}$ reaches a maximum, while χ_{22}, in contrast to χ_{33}, tends not to zero but to a value of the order of M_s/H_s. In fields $H_0 \sim H_s$ the coefficient $K_\parallel^2$ is therefore finite according to (7).

The aggregate of the described effects is schematically illustrated in Fig. 3. From relations (4) and Fig. 3 it follows

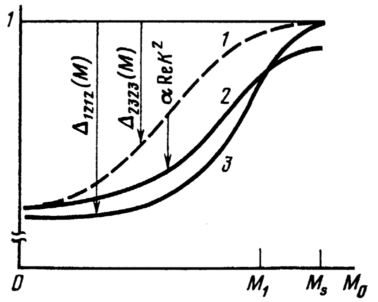

FIG. 3. Schematic dependence of relative values of the real components of the elastic-modulus tensor, determined at constant magnetization and magnetic field intensity, on the polarization magnetization M_0: 1—$c_{2323}'^M/c_{2323}^0$, 2—$c_{2323}'^H/c_{2323}^0$, 3—$c_{1212}'^H/c_{2323}^0 = c_{1212}'^M/c_{2323}^0$.

that the previously introduced field H_1 distinguishes the region $H_0 > H_1$, in which not only $\Delta k_\parallel' l > \Delta k_\perp' l$ but also $c_{1212}'^H > c_{2323}'^H$, from the region $H_1 > H_0 \geqslant 0$, in which not only $\Delta k_\parallel' l < \Delta k_\perp' l$ but also $c_{1212}'^H < c_{2323}'^H$. According to (10), the field H_1 can be obtained from the equation

$$\Delta_{1212}(M_0) - \Delta_{2323}(M_0) = \alpha \mathrm{Re} K_\parallel^2, \qquad (14)$$

where $\alpha \mathrm{Re} K_\parallel^2$ and M_0 are functions of H_0.

The birefringence is due to anisotropy of the shear modulus G^H. In the region $H_0 > H_1$ it is caused mainly by the difference in $c_{2323}'^H$ and $c_{2323}'^M$ due to the macroscopic (within the confines of the physically small volume) magnetoelastic interaction characterized by the small quantity $\alpha \mathrm{Re} K_\parallel^2$. In the region $H_1 > H_0 \geqslant 0$ this anisotropy is due primarily to the anisotropy of the shear modulus G^M, an anisotropy caused by microscopic (on a domain scale) interaction.

A similar explanation can be offered for the intersection of the $\Delta k_\parallel'' l$ and $\Delta k_\perp'' l$ curves, for in accordance with the definition (6) the value of $c_{2323}''^H$ besides being determined by $c_{232}''^M$, is determined also, because of the magnetoelastic interaction, by the quantity $\chi_{22}''^\varepsilon$ which is characteristic of the electromagnetic losses. When magnetic saturation is reached, the difference between $c_{1212}''^M$ and $c_{2323}''^M$ vanishes, but $\chi_{22}''^\varepsilon$ does not.

In earlier investigations[1] magnetic birefringence was observed in single crystals magnetized to saturations, at frequencies close to resonance. Under these conditions there is no birefringence mechanism caused by anistropy of the shear modulus G^M. The results of the earlier studies can be described by relations (5), (7), and (8), by putting $c_{2323}'^M = c_{1212}'^M = c_{2323}^0$, by replacing the components $h_{23,2}$ of the magnetostriction constant by its value in the magnetic saturation state $b_{1212} M_s^{-1}$, and by taking into account the frequency dependence of $\chi_{22}'^\varepsilon$; in a magnetic having cubic crystallographic symmetry, under the conditions of the earlier experiments this dependence takes the form $\chi_{22}'^\varepsilon = \chi_\perp (1 - \omega^2/\omega_m^2)^{-1}$, where

$$\chi_\perp = M_s (H_0 + 2\mathscr{K}_1/M_s)^{-1}, \quad \omega = 2\pi f, \quad \omega_m^2 = \gamma^2 M_s^2 (\alpha \chi_\perp)^{-1},$$

$\mathscr{K}_1$ is the crystallographic magnetic-anisotropy constant and γ is the spectroscopic-splitting factor.

5. Magnetic birefringence and magnetic dichroism of transverse sound propagating perpendicular to a magnetic field $\mathbf{H}_0$ have thus been observed in a polycrystalline ferrite in a wide range of the magnetic field and at a frequency (51 MHz) lower than that of the magnetoelastic resonance. There are two regions of H_0 variation: a region of relatively weak fields, in which the phase velocity $v_\perp$ of the mode polarized perpendicular to $\mathbf{H}_0$ is less than its value $v_\parallel$ for the mode polarized parallel to $\mathbf{H}_0$, and a region of relatively strong fields, where $v_\perp > v_\parallel$.

It follows from a theoretical analysis of the results, an analysis extended also to the region of resonance frequencies, that these phenomena are due to two mechanisms that produce magnetoelastic interaction.

The first mechanism, acting in both the polydomain and single-domain states, and therefore effective under the conditions of the earlier investigations,[1] predominates in the region of relatively strong fields. It manifests itself for a mode polarized parallel to H_0 and is due to the change, induced by the elastic stresses accompanying the wave of the magnetization $\mathbf{m}$ averged over physically small (relative to the wavelength) volumes that contain many domains. This mode is therefore quasielastic and its phase velocity depends on H_0. This mechanism is not active in the mode polarized perpendicular to $\mathbf{H}_0$. This mode therefore becomes purely elastic and its velocity is independent of H_0 in fields in which the domain structure is already eliminated and only the first mechanism remains.

The second mechanism, acting only in the multidomain state and predominant at relatively weak fields, is due to magnetoelastic interaction on a microscopic (domain) scale. It is due to those local magnetization changes that characterize the magnetic state of each domain and which, when averaged over a physically small volume, do not give rise to a change of the macroscopic magnetization $\mathbf{m}$. The existence of the second mechanism leads not only to the dynamic ΔG effect, but also to anisotropy of the dynamic shear modulus G^M determined at constant magnetization, and also to the different H_0-dependences of the phase velocities and of the absorption of modes polarized parallel and perpendicular to $\mathbf{H}$.

When the medium is magnetically polarized by the field H_0, the first mechanism is phenomenologically related to the increase of the number of independent components of the dynamic elastic modulus tensor c^H_{ijkl} that determines the phase velocity and the mode absorption, since it differs from the tensor c^M_{ijkl} that characterizes the change of the elastic state of the medium when its external (macroscopic) magnetic state is preserved ($\mathbf{m} = 0$).

The second mechanism, on the other hand, is brought about by the fact that in a polydomain state not only the value of the tensor c^M_{ijkl} but also the number of its independent components is determined by the internal (microscopic) magnetoelastic state—by the domain texture which results from the magnetic polarization by the field H_0, but can be preserved also in the demagnetized state.

In conclusion, we thank I. P. Galyamina for supplying the nickel ferrite specimens.

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