Antiferromagnetic effects in acoustics

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Several new acoustic effects associated with the antiferromagnetic vector order parameter are predicted. Their existence is derived from requirements imposed by the symmetry of the crystal lattice of an antiferromagnet and by the Onsager relationships applicable to components of the tensor of the elastic moduli.

The antiferromagnetic order, characterized by the antiferromagnetic vector $\mathbf{L} = \mathbf{M}_1 - \mathbf{M}_2$ in terms of the magnetizations $\mathbf{M}_1$ and $\mathbf{M}_2$ of two magnetic sublattices, gives rise to a number of specific physical properties the existence of which follows from the symmetry requirements and from other first principles of physics. Equilibrium properties of this type include weak ferromagnetism described by the total magnetization $\mathbf{M} = \mathbf{M}_1 + \mathbf{M}_2$, and also piezomagnetic and magnetoelectric effects.[1] Later many antiferromagnetic effects in transport phenomena and in optics have been theoretically predicted and confirmed experimentally (for information see the reviews in Refs. 2–5). We shall consider what can be regarded as analogs of these effects in acoustics, but there is a special feature of the acoustic effects which is formally due to the fact that the elastic properties are described by a fourth-rank tensor, in contrast to transport (galvanomagnetic) and optical properties which are described by second-rank tensors. Moreover, in acoustics we encounter not only transverse but also longitudinal waves.

Our aim will not be to establish the existence of some effect for antiferromagnetic (AFM) structures, but also to identify the laws governing the behavior of this effect as the magnetic state described by the direction of the vector $\mathbf{L}$ is varied. Therefore, we shall represent the tensor of the elastic moduli $C_{\alpha\beta}$ as an expansion in powers of the components of $\mathbf{L}$ and also of vectors representing the magnetic $\mathbf{B}$ and electric $\mathbf{E}$ fields, and of the wave vector $\mathbf{k}$ (in order to allow for possible spatial dispersion). The terms with $\mathbf{M}$, which are of the same form as those with $\mathbf{B}$, will not be written down because they do not give rise to effects of interest to us. The coefficients of this expansion will be determined from the requirement of invariance of the tensor $C_{\alpha\beta,\gamma\delta}$ under the transformation of the symmetry in accordance with the crystallographic space (Fedorov) group G. More accurately, instead of G we should use its subgroup $\widetilde{G}$, which is obtained from G by replacing all pure translations in this group with the identity element. This is due to the fact that we shall consider only those AFM structures which have coincident magnetic and crystallographic periods.

The time-reversal symmetry ($t \to -t$) should be allowed for by the Onsager relationships:

$$C_{\alpha\beta,\gamma\delta}(\mathbf{L}, \mathbf{B}, \mathbf{k}) = C_{\gamma\delta,\alpha\beta}(-\mathbf{L}, -\mathbf{B}, -\mathbf{k}). \quad (1)$$

A medium will be assumed to be transparent to sound, so that the tensor $C_{\alpha\beta,\gamma\delta}$ should be Hermitian:

$$C^{*}_{\alpha\beta,\gamma\delta} = C_{\gamma\delta,\alpha\beta}. \quad (2)$$

If the group $\widetilde{G}$ of the investigated crystal is known for a given AFM structure (i.e., when the atomic magnetic moments are divided into sublattices), it is sufficient to indicate the parity of the independent elements of this group.[6] We shall use the terms even and odd for the elements g^+ and g^- relating the magnetic atoms which belong to the same or to the different sublattices, respectively. It is important to recall the differences between the transformation properties of the antiferromagnetic vector $\mathbf{L}$ compared with the corresponding properties of the vector $\mathbf{B}$ (or $\mathbf{M}$). If $g^{\pm}\mathbf{B} = g\mathbf{B}$, then $g^{\pm}\mathbf{L} = \pm g\mathbf{L}$, where g is an element of the point symmetry acting on $\mathbf{B}$ and $\mathbf{L}$, in the same way as on the usual axial vector.

By way of example we shall consider AFM structures of the type $\bar{1}^+3_z^+2_x^-$ (α-Fe_2O_3, $FeBO_3$, $MnCO_3$, etc. and $\bar{1}^-3_z^+2_x^-$ (Cr_2O_3) for rhombohedral crystals (group $R\,3c$) and a structure of the type $\bar{1}^+4_z^-2_d^+$ (CoF_2,MnF_2,etc.) for tetragonal crystals (group $P\,4/mnm$). Here, $\bar{1}$ represents inversion, 3_z is a threefold symmetry axis selected as the coordinate axis $\mathbf{z}$, 4_z is a fourfold screw axis (with translation by half a period), and 2_x and 2_d are twofold symmetry axes directed along the $\mathbf{x}$ axis or along the diagonal of the basal square ([110]), respectively.

The presence or absence of defects is affected decisively by whether the inversion $\bar{1}$ is an even or odd symmetry element. From the point of view of the magnetic symmetry, in the former case the magnetic structure has a center of symmetry, whereas in the latter it has a center of antisymmetry. We shall therefore consider separately centrosymmetric and anticentrosymmetric structures.

In the case of centrosymmetric structures the expansion of $C_{\alpha\beta,\gamma\delta}$ described above contains, firstly, terms which are even in respect of the magnetic vectors $\mathbf{B}$ and $\mathbf{L}$, for example those of the L_α, $L_\alpha B_\beta B_\gamma$, $L_\alpha E_\beta E_\gamma$ types and others. According to Eq. (1), such terms govern the antisymmetric part of $C_{\alpha\beta,\gamma\delta}$ and are responsible for the acoustic activity (which is an analog of the optical activity). Secondly, there should be terms which are even in respect of the set of the vectors $\mathbf{L}$ and $\mathbf{B}$ and these contribute to the symmetric part of $C_{\alpha\beta,\gamma\delta}$. Among them the greatest interest lies in terms of the $L_\alpha B_\beta$ type, which are responsible for birefringence characteristic because of its linearity with respect to the field $\mathbf{B}$. In the case of nonantiferromagnetic crystals the linear magnetic birefringence is usually quadratic in $\mathbf{B}$ or $\mathbf{M}$. The terms of both types of a centrosymmetric structure should be of even power in respect of the electric field $\mathbf{E}$.

In the case of anticentrosymmetric structures there are no terms which are linear (and generally odd) in respect of

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L. However, in the case of these structures the expansion of $C_{\alpha\beta,\gamma\delta}$ contains terms of the $L_\alpha E_\beta$ type in the antisymmetric part and terms of the $L_\alpha k_\beta$ type in the symmetric part. The former give rise to the antiferromagnetic-electric Faraday effect and the latter to an effect, the analog of which in optics is known as the gyrotropic linear birefringence.[7]

Knowing the form of the antiferromagnetic corrections to $C_{\alpha\beta,\gamma\delta}$, we can write down the stress tensor $\sigma_{\alpha\beta} = C_{\alpha\beta,\gamma\delta} e_{\gamma\delta}$ including them [$e_{\alpha\beta} = (\partial u_\alpha/\partial x_\beta + \partial u_\beta/\partial x_\alpha)/2$ is the strain tensor] and solve the equation of elastic dynamics for wave displacements $u \propto \exp(ikr - i\omega t)$:

$$\rho\ddot{u}_\alpha=\partial\sigma_{\alpha\beta}/\partial x_\beta. \tag{3}$$

We shall now give the results of such calculations for specific cases. We shall first consider antisymmetric structures and list the most characteristic effects.

1. Spontaneous antiferromagnetic acoustic activity associated with terms $\Delta C_{\alpha\beta,\gamma\delta} \sim L$

a) In the case of the $\bar{1}^+4_z^-2_d^+$ structure when $\mathbf{k}\|\mathbf{x}$, this effect is related to corrections to $\sigma_{\alpha\beta}$ corresponding to ΔC:;

$$\Delta\sigma_{xy}=-2i\alpha L_y e_{xz},\quad \Delta\sigma_{xz}=2i\alpha L_y e_{xy}, \tag{4}$$

where α is a real function of the frequency ω (and, generally of L^2).

The solution of the system (3) gives two elliptically polarized waves with the wave vectors[1)]

$$k_{1,2}=\left(\frac{\rho}{C_{66(44)}}\right)^{1/2}\omega\left[1\pm\frac{\alpha^2L_y^2}{2C_{66(44)}(C_{66}-C_{44})}\right]. \tag{5}$$

The polarization ellipses of the displacement vector ($\mathbf{u}\perp\mathbf{x}$) are described by

$$(u_z/u_y)_1=(u_y/u_z)_2=i\alpha L_y/(C_{66}-C_{44}). \tag{6}$$

In the paramagnetic range ($L=0$) these two modes would have been linearly polarized relative to the **y** and **z** axes, respectively. We are assuming in Eqs. (5) and (6) that $|\alpha L| \ll (C_{66}-C_{44})$. The effect is maximal for $\mathbf{L}\|\mathbf{y}$ and it disappears for $\mathbf{L}\|\mathbf{x}\|\mathbf{k}$.

b) For the $\bar{1}^+3_z^+2_x^-$ structure (which is the most popular in experimental studies), we shall write down all the components of $\Delta\sigma_{\alpha\beta}$:

$$\Delta\sigma_{xx}=-2i\alpha_1(L_ye_{yy}-L_xe_{xy})+i\alpha_2L_ye_{zz},$$

$$\Delta\sigma_{yy}=2i\alpha_1(L_ye_{xx}+L_xe_{xy})-i\alpha_2L_ye_{zz},$$

$$\Delta\sigma_{xy}=-i\alpha_1L_x(e_{xx}+e_{yy})+i\alpha_2L_xe_{zz},$$

$$\Delta\sigma_{zz}=2i\alpha_3(L_xe_{xz}+L_ye_{yz})-i\alpha_2[L_y(e_{xx}-e_{yy})+2L_xe_{xy}],$$

$$\Delta\sigma_{yz}=-i\alpha_3L_ye_{zz},$$

$$\Delta\sigma_{xz}=-i\alpha_3L_xe_{zz}.$$

However, the results of the calculations are given here only for the case when $\mathbf{k}\|\mathbf{z}$ in the state with $\mathbf{L}\perp\mathbf{z}$. The corresponding expressions for $\sigma_{\alpha\beta}$ (σ_{zz}, σ_{xz}, and σ_{yz}) which then occur in the system (3) are isotropic under rotation about the **z** axis, so that we can set the new axis **Y** to be the direction of the vector **L** (which means that $L_x=0$) and this can be done without any loss of generality. Finally, the wave vectors and polarizations of the three waves can be described by

$$k_1=(\rho/C_{44})^{1/2}\omega\equiv k,\quad \mathbf{u}_1\|\mathbf{X},$$

$$k_2=k\left[1+\frac{\alpha_3^2L^2}{2C_{44}(C_{33}-C_{44})}\right],\quad (u_X)_2=0,$$

$$\left(\frac{u_z}{u_Y}\right)_2=-\frac{i\alpha_3L}{C_{33}-C_{44}},$$

$$k_3=\left(\frac{\rho}{C_{33}}\right)^{1/2}\omega\left[1-\frac{\alpha_3^2L^2}{2C_{33}(C_{33}-C_{44})}\right],\quad (u_X)_3=0,$$

$$\left(\frac{u_Y}{u_z}\right)_3=-\frac{i\alpha_3L}{C_{33}-C_{44}}. \tag{7}$$

The first wave (with the wave vector unperturbed by the action of L) has a transverse polarization with $\mathbf{u}_1\perp\mathbf{L}$ (so that its polarization varies with rotation of **L** in the XY plane). The second wave, which is degenerate with the first for $L=0$, is combined with the longitudinal wave, which gives rise to two elliptically polarized waves. Then, in contrast to the preceding case, when the planes of the polarization ellipses are perpendicular to **k**, the plane identified here passes through the vectors **k** and **L**. This situation distinguishes acoustics from optics.

It is important to point out the following. Although the vector **L** is related linearly to the spontaneous weak ferromagnetic moment $\mathbf{M}_s$, the effects described above cannot be reduced to those due to the terms proportional to **M** in the expansion $C_{\alpha\beta,\gamma\delta}$ (**L**,**M**,...) This is demonstrated by the experiments involving an analog of the investigated (linear in **L**) effects in transport phenomena, which is the spontaneous antiferromagnetic Hall effect: when the field is altered by a factor of 8 (from 2 to 16 kG) the magnetization M of hematite increases by a factor of 2, whereas the Hall field which is proportional to L remains practically unchanged.[2] An analog of these effects had been discovered also in the case of optics (Ref. 8).[2)]

2. Antiferromagnetic Faraday effect in a transverse magnetic (electric) field

In the case of the $\bar{1}^+4_z^-2_d^+$ structure where $\mathbf{k}\|\mathbf{L}\|\mathbf{z}$ and $\mathbf{B}\|\mathbf{z}$, it is due to the following terms in $\sigma_{\alpha\beta}$:

$$\Delta\sigma_{xz}=-2i\eta L_zB_xB_ye_{yz},\quad \Delta\sigma_{yz}=2i\eta L_zB_xB_ye_{xz}.$$

Equation (3) then contributes circularly polarized waves with the wave vectors

$$k_\pm=k\left(1\pm\frac{\eta}{2C_{44}}L_zB_xB_y\right). \tag{8}$$

This means that the plane polarization of a transverse linearly polarized wave is rotated by an angle

$$\psi_\lambda=\frac{1}{2}(k_+-k_-)\lambda=\pi\frac{\eta}{C_{44}}L_zB_xB_y=\frac{\pi\eta}{2C_{44}}L_zB^2\sin2\varphi_B \tag{9}$$

when the distance traversed is one wavelength λ.

The features which distinguish this effect from the ordinary (linear in the field) Faraday effect are as follows: firstly, it is quadratic in respect of **B** and, secondly, it does not occur in a longitudinal (relative to the wave vector **k**) field but in a transverse field. The latter circumstance is important because this quadratic effect is not a correction to the linear effect but can be observed against zero background (when $\mathbf{B}\perp\mathbf{k}$). Moreover, the magnitude of the effect varies periodically (as $\sin 2\varphi_B$) with an azimuthal angle φ_B for the field $\mathbf{B}$.

The optical analog of this effect had been discovered recently[9] for CoF_2.

It should be noted that from the point of view of symmetry we can replace B in Eqs. (7)–(9) with the electric field E (this is also true of the optical analog of the effect). Moreover, we can replace B in these formulas with a static shear strain: $B_x B_y \to e_{xy}^{(0)}$.

3. Birefringence in a linear (in B) longitudinal field

a) In the case of the $\bar{1}^+4_z^-2_d^+$ structure it is interesting to consider the $\mathbf{k}\|\mathbf{B}\|\mathbf{L}\|\mathbf{z}$ configuration. Including relevant corrections of the $L_\alpha B_\beta$ type to $\sigma_{\alpha\beta}$, namely

$$\Delta\sigma_{xz}=2\beta_1 L_z B_z e_{yz},\quad \Delta\sigma_{yz}=2\beta_1 L_z B_z e_{xz},$$

we find that in this case there are two transverse linearly polarized waves:

$$k_{1,2}=k\left(1\mp\frac{\beta_1}{2C_{44}}L_z B_z\right)$$

which correspond to $\mathbf{u}_1\|[110]$ and $\mathbf{u}_2\|[1\bar{1}0]$ respectively. Clearly, this effect makes it possible to achieve direct "acoustic visualization" of antiferromagnetic domains which differ in the sign of L_z even in the case of crystals which are not transparent to light.

b) In the case of the $\bar{1}^+3_z^+2_x^-$ structure when $\mathbf{L}\perp\mathbf{z}$ and $\mathbf{k}\|\mathbf{B}\|\mathbf{z}$, we similarly find that

$$\Delta\sigma_{xz}=2\beta_2 B_z(L_y e_{yz}-L_x e_{xz}),\quad \Delta\sigma_{yz}=2\beta_2 B_z(L_y e_{xz}+L_x e_{yz}),$$

$$k_{1,2}=k\left(1\mp\frac{\beta_2}{2C_{44}}LB_z\right),$$

$$\left(\frac{u_x}{u_y}\right)_1=-\left(\frac{u_y}{u_x}\right)_2=\frac{L_y}{L+L_x}=\operatorname{tg}\frac{\varphi_L}{2}.$$

The polarization of normal modes is now governed by the azimuthal angle φ_L for the vector $\mathbf{L}$. Therefore, transmitted transverse sound reflects to some degree the distribution of the vector $\mathbf{L}$ in the xy plane, i.e., it reflects the domain structure.

c) For the same $\bar{1}^+3_z^+2_x^-$ structure in the same state with $\mathbf{L}\perp\mathbf{z}$ and for $\mathbf{k}\|\mathbf{z}$, but $\mathbf{B}\perp\mathbf{z}$, the expressions for the components $\sigma_{\alpha\beta}$ corresponding to such value of $\mathbf{k}$ are again invariant under arbitrary rotation about the $\mathbf{z}$ axis. Taking in this case the field $\mathbf{B}$ to be the new $\mathbf{X}$ axis on condition that the field is sufficiently strong to ensure $\mathbf{L}\perp\mathbf{B}$ we find that

$$\sigma_{Xz}=2(C_{44}+\beta_3 L_Y B_X)e_{Xz},\quad \sigma_{Yz}=2(C_{44}-\beta_4 L_Y B_X)e_{Yz}.$$

Consequently, we now obtain two linearly polarized waves:

$$k_1=k\left(1-\frac{\beta_3}{2C_{44}}L_Y B_X\right)\quad \text{for}\quad \mathbf{u}\|\mathbf{X}\|\mathbf{B}$$

and

$$k_2=k\left(1+\frac{\beta_4}{2C_{44}}L_Y B_X\right)\quad \text{for}\quad \mathbf{u}\|\mathbf{Y}\|\mathbf{L}.$$

We must draw attention to the fact that in the last three cases (3a, 3b, and 3c) the difference between the phases of two normal modes (and we can always expand a linearly polarized wave entering a medium into such modes) depends on the field $\mathbf{B}$. In particular, in the case c, we have

$$(k_2-k_1)z=k\left(\frac{\beta_3+\beta_4}{2C_{44}}\right)L_Y B_X z. \tag{10}$$

This means that when a wave traverses a plate of thickness z, the elastic displacement along this direction oscillate at the exit in the same was as $\mathbf{B}$ and the period is

$$\Delta B_X=2\pi C_{44}/k(\beta_3+\beta_4)L_Y z. \tag{11}$$

d) In the case of $\mathbf{L}\|\mathbf{z}$ and the $\bar{1}^+3_z^+2_x^-$ structure, the terms of the $L_\alpha B_\beta$ type in $\sigma_{\alpha\beta}$ appear for $\mathbf{B}\perp\mathbf{z}$ and they are related to the birefringence of waves with $\mathbf{k}\perp\mathbf{z}$. We shall not give the relevant solutions because for these values of $\mathbf{k}$ the normal modes in a rhombohedral crystal are usually neither longitudinal nor transverse even in the absence of the terms with $\mathbf{L}$. Inclusion of these terms complicates the situation even further. A fairly simple case is obtained only for $\mathbf{B}\|2_x$, when $\mathbf{k}\|\mathbf{B}$ or $\mathbf{k}\perp\mathbf{B}$. In such cases the terms with $L_\alpha B_\beta$ result in simple renormalization of the dynamic modulus C_{14} (responsible for the anisotropy of the elastic properties in the xy plane) which reduces to the replacement $C_{14}\to C_{14}+\beta_5 L_z B_x$ in the case $\mathbf{k}\|\mathbf{B}\|\mathbf{x}$ and $C_{14}\to C_{14}-\beta_5 L_z B_x$ in the case $\mathbf{k}\|\mathbf{y}$.

It should be noted that phenomenological theoretical parameters β_i are not generally constant, but are functions of the frequency ω and of the absolute value of the magnetic field $\mathbf{B}$.

Some analogs of the above effects in transport phenomena and in optics of centrosymmetric antiferro-magnets can be found in the reviews given in Refs. 2 and 5.

We shall now consider some effects in anticentrosymmetric structures of the $\bar{1}^-3_z^+2_x^-$ (Cr_2O_3) type.

1. Gyrotropic (i.e., dependent on k_z) linear birefringence associated with the symmetric part of $C_{\alpha\beta,\gamma\delta}$

If $\mathbf{L}\perp\mathbf{z}$ and $\mathbf{k}\|\mathbf{z}$, then the terms in $\sigma_{\alpha\beta}$ responsible for this effect are

$$\Delta\sigma_{xz}=2\gamma k_z(L_y e_{yz}-L_x e_{xz}),\quad \Delta\sigma_{yz}=2\gamma k_z(L_y e_{xz}+L_x e_{yz}).$$

Consequently, we obtain two transverse linearly polarized waves with phase velocities and polarizations given by the relationships

$$v_{1,2}=\left(\frac{C_{44}}{\rho}\right)^{1/2}\left(1\pm\frac{\gamma}{2C_{44}}Lk_z\right),$$

$$\left(\frac{u_x}{u_y}\right)_1=-\left(\frac{u_y}{u_x}\right)_2=\operatorname{tg}\frac{\varphi_L}{2}.$$

The polarization of the modes is again determined by the angle φ_L and the velocity of each of the modes changes as a result of reversal of the sign of k_z (these modes transform into one another).

It should be noted that our assumption about the spatial dispersion (dependence of $C_{\alpha\beta,\gamma\delta}$ on the wave vector $\mathbf{k}$) for magnetic materials is not in any way unusual. It is known[2] that near the points of magnetic orientational phase transitions an inhomogeneous exchange contributing to the effective dynamic moduli $C_{\alpha\beta,\gamma\delta}$ of a quasiacoustic mode due to the magnetoelastic coupling can make these moduli indeed functions of $\mathbf{k}$.

2. Antiferromagnetic-electric Faraday vector linear in the vector L and in the electric field E

We shall consider only the simplest situation, $\mathbf{k}\|\mathbf{E}\|\mathbf{L}\|\mathbf{z}$, for which the necessary terms in $\sigma_{\alpha\beta}$ are

$$\Delta\sigma_{xz}=2i\delta L_zE_ze_{yz},\quad \Delta\sigma_{yz}=-2i\delta L_zE_ze_{xz}. \tag{12}$$

We thus obtain two transverse circularly polarized waves with the wave vectors

$$k_\pm=k\left(1\pm\frac{\delta}{2C_{44}}L_zE_z\right),\quad \left(\frac{u_x}{u_y}\right)_\pm=\pm i. \tag{13}$$

3. Acoustic Faraday effect quadratic in L

Without altering the symmetry requirements, we can make the substitution $E_z=aL_zB_z$ in Eqs. (12) and (13) (here, a is a constant). This relationship is invariant under the symmetry transformations $\bar{1}^-$, 3_z^+, and 2_x^-, and it represents one of the equations governing the inverse magnetoelectric effect.[10] Consequently, instead of Eq. (13), we obtain

$$k_\pm=k\left(1\pm\frac{\nu_1}{2C_{44}}L_z^2B_z\right),\quad \left(\frac{u_x}{u_y}\right)_\pm=\pm i, \tag{14}$$

where ν_1 is a new parameter. This is the acoustic Faraday effect which appears in this situation if $\mathbf{k}\|\mathbf{B}\|\mathbf{L}\|3_z$.

It is interesting to note that the acoustic activity of waves with $\mathbf{k}\|\mathbf{L}\|3_z$, which is quadratic in $\mathbf{L}$ and linear in $\mathbf{B}$, should exist also for $\mathbf{B}\perp\mathbf{z}$. In this case, we find that

$$\Delta\sigma_{zz}=2i\nu_2L_z^2(B_xe_{yz}-B_ye_{xz}),$$

$$\Delta\sigma_{xz}=i\nu_2L_z^2B_ye_{zz},\quad \Delta\sigma_{yz}=-i\nu_2L_z^2B_xe_{zz}.$$

Here, as in the case of a centrosymmetric structure described by the system of Eq. (7), the acoustic activity mixes one of the transverse waves (with the polarization $\mathbf{u}\perp\mathbf{B}$) with a longitudinal wave, giving rise to two elliptically polarized modes. Both polarization ellipses lie in a plane perpendicular to $\mathbf{B}$ and passing through $\mathbf{k}$. If we take the direction of $\mathbf{B}$ as the new X axis, then we find that these waves are described by formulas of the type given by Eq. (7) provided α_3L is replaced with ν_2L^2B.

We shall now consider experimental investigations of the magnetic birefringence of sound in antiferromagnets. Unfortunately, the present author is aware of only two such investigations,[11,12] which are discussed in the review of Ref. 13. We shall consider the results of these investigations on the basis of the above representations

The acoustic birefringence in a centrosymmetric antiferromagnetic $MnCO_3$ was discovered in Ref. 11 in a situation corresponding to Eqs. (10) and (11) ($\mathbf{L}$ and $\mathbf{B}\perp\mathbf{z}$, $\mathbf{k}\|\mathbf{z}$,). The theory is in agreement with the experimental results, with the exception that the experimental period of oscillations of the intensity of the transmitted hypersound (104 and 204 MHz) increases strongly on increase in the field $\mathbf{B}$, whereas the theoretical formula (11) does not include an explicit field dependence. This is due to the fact that oscillations were observed in the range of fields ($B<4$ kG) in the vicinity of an orientational phase transition (see Chap. 3 in Ref. 2), for which the effective magnetoelastic coupling parameter ζ depends strongly on the field, falling rapidly on increase in B away from this point. There are grounds for expecting the phenomenological parameters β_3 and β_4 occurring in Eqs. (10) and (11) to be proportional to ζ. In any case, this is true if the effect under consideration is due to the interaction of elastic and spin waves, as assumed in Ref. 11 (although generally speaking there may be other mechanisms).

The acoustic Faraday effect in the state with $\mathbf{B}\|\mathbf{L}\|3_z$ for the waves $\mathbf{k}\|\mathbf{z}$ was observed in an anticentrosymmetric antiferromagnet Cr_2O_3 (Ref. 12). This case corresponds to Eq. (14). The experiments were carried out right up to high fields ($\sim10^5$ G) which included the point of the spin flop transition ($B_{sf}\approx60$ kG). A strong increase in the Faraday rotation angle was observed on approach to this point. (The rotation was measured in tens of π for a sample 4.4 mm long.) This indicated that the parameter ν_1 in Eq. (14) was again proportional to the effective parameter of the magnetoelastic coupling, which increased in the phase transition region.

These two investigations thus demonstrated that the birefringence and acoustic activity effects in antiferromagnets were not weak at all. Therefore, systematic investigations of these effects and experimental discovery of some new effects predicted in the present note would be of interest not only in the physics of antiferromagnets (particularly in connection with the studies of the nature of the magnetoelastic coupling and laws governing orientational transitions), but may possibly be useful from the point of view of applications of antiferromagnets in acoustoelectronics. One could hope that such systematic investigations would be helped by the above symmetry analysis, which predicts a number of new effects (or some new features of the known effects) typical specifically of antiferromagnets. It should be mentioned here that the present note does not deal at all with the effects of the $L_\alpha L_\beta$ type, which from the point of symmetry do not differ from the effects of the $M_\alpha M_\beta$ or $B_\alpha B_\beta$ type, characteristic of ferromagnets and paramagnets.

Further progress in this field of magnetoacoustics of antiferromagnets would involve not only experimental investigations of the predicted effects, but further developments of the theory on the basis of specific model representations. There are grounds for assuming[14] that it would be of considerable interest to extend such investigations to nonlinear phenomena.

[1)] Here and later we shall ignore the waves which are not affected by the vector $\mathbf{L}$ in this geometry. Here, C_{ij} is the usual abbreviated form used for the moduli $C_{\alpha\beta,\gamma\delta}$ $(i,j=1,2,...,6)$.

[2)] Unfortunately, when Vonsovskiĭ and the present author wrote the monograph on dynamic and transport properties of magnetic materials,[2] they were not aware of Ref. 8 and did not refer to it, and apologies are due for this omission.

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