EXPERIMENTAL DETECTION OF ELECTRIC GYROTROPY IN SrMoO_4 CRYSTALS

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EXPERIMENTAL DETECTION OF ELECTRIC GYROTROPY IN $SrMoO_4$ CRYSTALS

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Taking spatial dispersion into account leads to qualitatively new phenomena (^{1}), among which one should include the effect of the appearance of gyrotropy in crystalline media placed in an external electric field. Phenomenologically, the effect of electric gyrotropy can be described by taking into account terms of the form $\alpha_{ijkl}E_k k_l$ in the expansion of the tensor*

$$\varepsilon_{ij}^{-1}(E) = \varepsilon_{0ij}^{-1} + \alpha_{ijkl}E_k k_l + o(\beta), \tag{1}$$

the inverse tensor of dielectric permittivity ε_{ij}, in the approximation of a weak external perturbation. From the symmetry principle for kinetic coefficients it follows that the components of the tensor α_{ijkl} are antisymmetric in the first two indices and, in the absence of absorption in the medium, are purely imaginary. Taking this into account, the correction to the quantity ε_{0ij}^{-1} due to the external electric field may be written as follows: $\alpha_{ijkl}E_k k_l = e_{ijm}a_{mkl}E_k k_l$, where e_{ijm} is the completely antisymmetric unit pseudotensor of rank 3. In turn, a_{mkl}, skew-symmetric in the indices kl, after the symmetrization operation takes the form $a'_{mkl} = a_{mkl} + e_{min}B_{mn}$, where B_{mn} is a tensor of rank 2. Then we obtain that

$$\alpha_{ijkl}E_k k_l = e_{ijm}a'_{mkl}E_k k_l + e_{ijm}e_{kln}B_{mn}E_m k_n.$$

In this expression the first term describes the electric gyrotropy of crystals, and the second describes the electro-optic effect linearized with respect to k_n.

The character of the symmetry of crystals imposes definite restrictions both on the very fact of observing the effects and on the number of linearly independent coefficients of tensors of the form a_{mkl} (^{2}) and B_{mn} (^{3}). The consequences following from the symmetry conditions are only sufficient, but not yet necessary, for the observation of electric gyrotropy, since, according to (^{4}), the propagation conditions of an electromagnetic wave are affected not by the gyration vector G_i itself, but by its projection onto the wave normal. Therefore, the attempts of the authors of (⁵) to interpret the effect they discovered—the influence of an electric field on the specific rotation of the polarization plane of a light beam in cubic crystals of bismuth germanate (point group 23)—as an effect of electric gyrotropy are erroneous in view of what has been said; moreover, the magnitude of the effect itself suggests that in the investigated $GeBi_{12}O_{20}$ crystals, under the action of the electric field and light, photochemical reactions occur that lead to a substantial rearrangement of the electronic absorption bands (⁶).

From the standpoint of setting up the experiment, greatest interest is presented by those classes of optically inactive crystals in which electric gyrotropy will not be masked by linear and k_n-linearized electro-optic effects. In choosing the object of investigation we settled on optically uniaxial crystals of the $SrMoO_4$ type, crystallizing in the class $4 : m$. It can be shown that the magnitude of rotation of the plane of polarization of a light beam propagating along the z axis

$$\rho_z = \frac{\pi}{\lambda_0 n_0^2} \alpha'_{zzz} E_z k_z l,$$

where λ_0 is the wavelength of the light, n_0 is the refractive index for the ordinary light ray, E_z is the component of the electric field, and l is the length of the specimen in the direction of light propagation.

Fig. 1. Block diagram of the experimental setup for observing the effect of electric gyrotropy. 1 —helium-neon laser; 2 —$\lambda/4$-plate; 3 —$SrMoO_4$ crystal specimen; 4 —analyzer; 5 —photodetector; 6 —ORION TT-1301 selective voltmeter; 7 —VK-79 voltmeter; 8 —sinusoidal-voltage generator

The block diagram of the experimental setup for measuring the rotation of the plane of polarization of light caused by electric gyrotropy is shown in Fig. 1. The maximum sensitivity of the recording system, consisting of an M12FD 35 photomultiplier tube (5), an ORION TT-1301 selective amplifier (6), and a VK-79 voltmeter (7), was achieved by rotating the analyzer (4) by an angle of 45° relative to the direction of polarization of the light beam. The electric field on the crystal specimen (3), which had a cylindrical shape, was produced by means of semitransparent SnO_2 electrodes deposited on thin plates of fused quartz. The distribution of the electric field in the gap of such a capacitor was chosen to be asymmetric with respect to ground.

When an electric field acts on the specimen, the plane of polarization of the linearly polarized light beam is rotated; then, by means of the analyzer, this is transformed into a change in intensity at the frequency of the electric field. Then the magnitude of the useful signal, for $\rho_z \ll 1$, is determined by the expression

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* The remaining corrections to ε_{0ij}^{-1} may be regarded as small.

$$v_{\sim} = v_{=} \left(\frac{\pi}{\lambda_0^2 n_0^2} \alpha'_{zzz} E_z k_z l \right),$$

linearly dependent on the magnitude of the potential difference on the specimen, since $E_z l = U_z$ (see Fig. 2). Measuring the dc $v_{=}$ and ac $v_{\sim}$ components of the voltage at the output of the photodetector and determining from the experimental data $\operatorname{tg} \alpha = v_{\sim}/U_z$, one can calculate the values of the coefficient a_{333} by the formula

$$\alpha'_{333} = \frac{\lambda_0^2 n_0^2}{2\pi^2} \frac{\operatorname{tg} \alpha}{v_{=}}.$$

Fig. 2. Voltage of the useful signal $v_{\sim}$ as a function of the magnitude of the voltage U_m applied to the crystal specimen. $\operatorname{tg} \alpha = 2.7 \cdot 10^{-6}$

As a result of processing the experimental data, it was found that $\alpha_{333} = 9 \cdot 10^{-15}$ cm^2/V at a wavelength of 6328 Å, if $n_0 \sim 2.15$ is assumed. To confirm the data indicating that the effect of electric gyrotropy is observed in the described experiment, a control was performed

experiment: a circularly polarized beam of light was passed through the specimen by means of a $\lambda/4$-plate (2). In this case the effect disappeared, as was to be expected.

To compare the experimental data with theory one may use the following considerations: in hypothetical fields of the order of atomic fields, the corrections to the value of ε_{0ij}^{-1} due, for example, to the linear electro-optic effect and to electric gyrotropy should be of the same order. Then it is not difficult to obtain an estimate of the magnitude of the effect from experimental data on the magnitude of the electro-optic effect in crystals (7). It turned out that the estimate obtained for α_{333} lies in the range 10^{-14}–10^{-15} cm^2/V and is in satisfactory agreement with experiment.

Thus, it may be stated that, in addition to natural and magnetic gyrotropy, electric gyrotropy also exists in crystals, leading to the rotation of the plane of polarization of light in an external electric field.

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