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ELECTROGYRATION EFFECTS IN QUARTZ CRYSTALS

O.G. Blokh
L'vov State University
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Among the nonlinear parametric effects produced in crystals by an external electric field, the linear and quadratic electro-optical effects, which are manifest in changes of the refractive properties of the crystals, are well known. In our investigations we observed an effect wherein the gyrational properties of a crystal are altered by an external electric field[1]. The investigations were carried out with quartz crystals cut perpendicular or parallel to the optical axis. In the former case we determined the value of the specific rotation of the plane of polarization of the radiation of a helium-neon laser (λ = 632.8 nm) under the influence of the field components E_x or E_y. In accordance with the symmetry conditions [1, 2], the specific rotation ρ_3 of the plane of polarization (gyration) can be represented by a series expansion in the even powers of the electric field $E_{x,y}$. In the first approximation we obtain

$$\rho_3 = \rho_3^0 + \beta_{31} E^2_{x,y} = \frac{\pi}{\lambda n_0}(g_{33} + \beta^*_{31} E^2_{x,y}), \quad \Delta\rho_3 = \frac{\pi}{\lambda n_0} \beta^*_{31} E^2_{x,y}, \tag{1}$$

where ρ_3^0 is the gyration in the absence of a field, connected with the component g_{33} of the axial gyration tensor of second rank, β_{31} and β^*_{31} are the coefficients of quadratic electrogyration or the components of the fourth-rank axial electrogyration tensor without and with allowance, respectively, for the ordinary refractive index n_0 [3], λ is the wavelength in vacuum, and $\Delta\rho_3$ is the gyration increment.

The linear electrogyration was investigated in a polarization system with a ZMR-3 monochromator, using the orientation of the ellipse of polarization produced [5, 6] when linearly polarized light is passed perpendicular to the optical axis through two identical x-cut samples of quartz with thickness d_x = 1 ± 0.01 mm, even when the incident beam is polarized parallel or perpendicular to the principal plane and the ordinary birefringence in the samples is cancelled out. Taking into account the influence of the field E_x, we can represent the angle ρ_1, which determines the orientation of the major axis of the polarization ellipse relative to the plane of polarization of the incident beam, in first approximation, in the form

$$\rho_1 = \rho_1^0 + \gamma_{11} E_x = \frac{1}{n_e^2 - n_0^2}(g_{11} + \gamma^*_{11} E_x), \quad \Delta\rho_1 = \frac{1}{n_e^2 - n_0^2} \gamma^*_{11} E_x, \tag{2}$$

where n_e is the extraordinary refractive index, g_{11} is the component of the second-rank axial tensor of the natural activity, and γ_{11} and γ^*_{11} are the components of the third-rank axial tensor of linear electrogyration without and with allowance for the refractive indices, respectively, and $\Delta\rho_1$ is the increment of the gyration (of the angle ρ_1).

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[1] The idea that a linear electrogyrational effect can occur in crystals was first advanced by I.S. Zheludev [1].

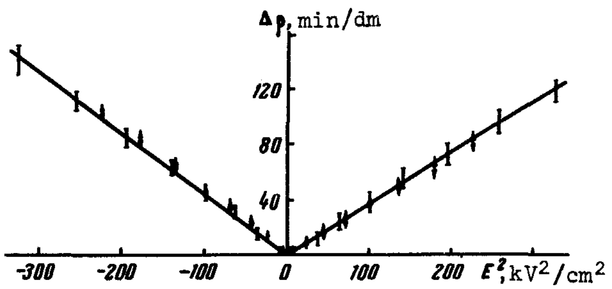

Fig. 1. Change of the rotating ability $\Delta\rho_3$ of quartz crystals as a function of the square of the electric field intensity. The arrows and the bars show the points for E_x and E_y, respectively. The figure indicates the scatter of the points obtained from multiple measurements in crossed polaroid filters mounted in a position where the polarization planes coincide with the axes x and y, at an angle ±45° to x and y, and also at arbitrary orientations such as to ensure 50% transmission without the field.

The investigations show that the sinusoidal dependences of ρ_1 on the wavelength at opposite directions of the constant field E_x (Fig. 2) are symmetrically shifted relative to the position without the field. No change of the period of the sinusoid as a result of piezoelectric deformation was observed. The amplitude of the oscillations of the polarization ellipse remains essentially unchanged, but these oscillations now occur relative to a new equilibrium position of the plane of polarization of the analyzer; in the absence of ellipticity and birefringence, this would correspond to a simple change in the rotation of the plane of polarization, depending on the sign of the field.

The variation of $\Delta\rho_1$ under the conditions of the extrema and of the mean values on the field intensity E_x acting on one or both samples (Fig. 3) indicates that the electrogyration has a linear character, and when the field acts on one sample $\Delta\rho_1$ is half as large as when it acts on both samples. Consequently, the electrogyration effect can be cumulative; this distinguishes it significantly from the rotation due to the linear electro-optical effect. In addition, it can be assumed that in an individual sample $\Delta\rho_1 = \gamma_{11} d_x E_x = \gamma_{11} V_x$, where V_x is the voltage on the crystal. Consequently, the linear electrogyration in quartz crystals consists of a general rotation of the polarization ellipse about the plane of polarization of linearly polarized light incident on the x-cut plate, and is proportional to the field intensity E_x. Taking (2) into account, we obtain from the data of Fig. 3 that $\gamma^*_{11} = (12.7 \pm 1.4) \times 10^{-7}$ cgs esu for $\lambda = 461$ nm.

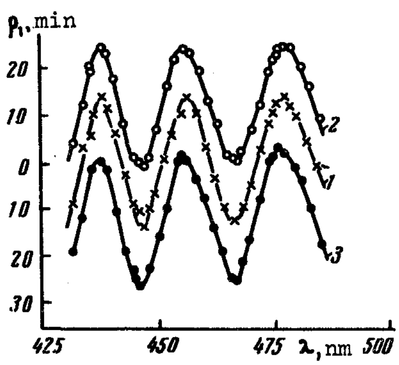

Fig. 2. Dependence of the orientation ρ_1 of the axis of polarization ellipse on the wavelength λ: 1 - without field; 2 and 3 - at a voltage of 12 kV on two samples.

On the basis of the presented experimental data we can conclude that in quartz crystal one observes in principle new parametric nonlinear optical effects (linear and quadratic electrogyration), consisting of changes in the gyration properties under the influence of the electric field. The observed effects are described by axial tensors of second and fourth rank, and can be observed also in other crystals, including non-gyration crystals, in directions that admit, in accordance with the symmetry conditions, of nonzero components of the axial tensors of third and fourth ranks. The quadratic electrogyration, unlike the electro-optical effect, is possible only in acentric crystals, while the linear electrogyration is possible in all media[1]. These effects can arise also spontaneously in the case of ferro- and antiferroelectric phase transitions.

[1]With the exception of crystals with symmetries m3m, $\bar{4}3m$, and 432 [1].

It is important that, in accordance with the symmetry conditions, only a linear spontaneous electrogyration effect can occur in ferroelectric crystals with centrally-symmetrical paraelectric phases, whereas the spontaneous electro-optical effect has a quadratic character in these crystals. In ferroelectrics with an initial acentric ferroelectric phase, the spontaneous electrogyrational effect (like the spontaneous electro-optical effect) can be either linear or quadratic. The conditions for the realization of either effect in the latter case are determined by the form of the axial tensors of the initial symmetry class and by the direction of the spontaneous polarization. When antipolarization occurs, the action of the internal field is equivalent [7] to the influence exerted on the crystal properties by a polar tensor of the third rank, i.e., only quadratic spontaneous electrogyration can be realized. Consequently, the crystal in the paraelectric phase should be acentric - in the case of antiferroelectric phase transitions there can occur only quadratic electrogyration, provided the crystal is acentric in the paraelectric phase. There are no such limitations on the occurrence of the quadratic electro-optical effect in the case of spontaneous antipolarization, i.e., the occurrence of spontaneous antipolarization is accompanied by a spontaneous quadratic electro-optical effect regardless of whether the initial paraelectric phase is centrally-symmetrical or acentric.

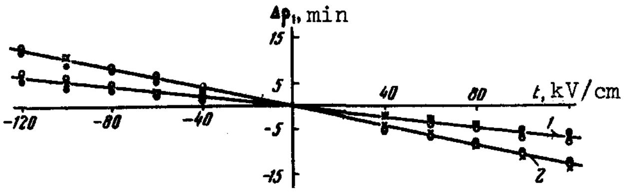

Fig. 3. Dependence of the increment of the angle of rotation of the polarization ellipse $\Delta\rho_1$ on the field intensity E_x: 1 - field on one sample; 2 - field on two samples.

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STUDY OF QUASI-TWO-PARTICLE REACTIONS IN PROTON-PROTON INTERACTIONS AT 10 GeV/c

Zh.S. Takibaev, E.G. Boos, L.A. San'ko, and T. Temiraliev
Institute of High Energy Physics, USSR Academy of Sciences

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In the study of four-prong proton-proton interactions in the Saclay 81-cm hydrogen bubble chamber irradiated at CERN by 10.01 ± 0.1 GeV/c protons, there were separated quasi-two-particle reactions of the type $pp \to pN^*$ (1), $pp \to p\Delta$ (2), $pp \to \Delta N^*$ (3), and $pp \to \Delta\Delta$ (4).

The procedure for separating quasi-two-particle reactions and the procedure for determining the cross section from the charge states are described in [1]. In this paper we consider certain properties of these reactions. It is of interest to compare the distributions with respect to the squares of the