# Electrogyration in bismuth silicate

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The results of an experimental study of electrogyration in optically active crystals against a background of a strong Pockels effect are presented. Electrogyration and the Pockels effect can be observed separately. The electrogyration coefficient is determined in the visible region and in the near-IR region of the spectrum.

A linear electrogyration, which consists of a change in the specific optical activity, $\theta_a$, in an applied electric field, can occur in crystals with a sillenite structure.[1] Electrogyration is difficult to detect in crystals with a sillenite structure because both the ellipticity of the light wave and the azimuth of the polarization ellipse change due to the Pockels effect. The known experimental data on electrogyration in crystals with a sillenite structure are inconclusive. Miller,[2] for example, by using a procedure developed by him, did not detect electrogyration against the background of an electro-optic effect in crystals with a sillenite structure. Fox and Bruton[3] detected electrogyration in bismuth titanate but did not observe it in bismuth gallate. Vlokh and Tsarik[4] did not detect electrogyration in bismuth germanate, while the effect they observed in bismuth silicate (BSO) was assumed by them to be of electret origin, inconsistent with Zheludev's theory.[1] The problem of electrogyration in crystals with a sillenite structure thus remains unresolved.

It was found[4,5] that the electrogyration should be measured when the field and light are directed along the [111] axis, since there is no Pockels effect in this case.[4] In the case of longitudinal electrogyration, however, the angle of rotation of the polarization can be increased only by increasing the field, which in turn gives rise to an appreciable Pockels effect due to the weak transverse field components and thus complicates the measurement of electrogyration. On the other hand, transverse electrogyration is known[5] to occur in crystals with a sillenite structure; however, this type of electrogyration is accompanied by a strong Pockels effect.

Analysis based on the Jones matrices shows that electrogyration and the Pockels effect can be observed separately in the weak-signal approximation [$\Delta\beta \ll 2\theta_a$ and $\Delta\beta = (2\pi/\lambda)\Delta n(E)$ is the linear birefringence]. In the case of a linear input polarization, for example, a change in the azimuth due to the Pockels effect is proportional to the square of the field. On the other hand, a change in the azimuth due to electrogyration must be linear with respect to the field. A change in the ellipticity due to the Pockels effect under the condition $\theta_a z = \pi m$ (where $m = 1,2...$) is zero.[6] In this case the relative light intensity[6] is

$$\frac{I}{I_0} = \frac{1}{2}\left[1 - \sin 2\theta_e z + \frac{(\Delta\beta)^2 z}{4\theta_a} \cos 2\theta_e z\right], \tag{1}$$

where $\theta_e$ is the specific electrogyration; the analyzer is set up at angle $\pi/4$ to the polarizer.

We see that at $\theta_e z \ll 1$ a change in the intensity of light due to electrogyration is linear with respect to the field and a change in the light intensity due to the Pockels effect is quadratic. Because the signals are detected selectively in an alternating electric field, electrogyration can be separated from the Pockels effect in terms of frequency. An important feature of signal detection under these conditions is that the signal strength does not depend on the input polarization $\varphi_0$. If $\lambda$ is changed (if the length $z$ is changed), then the azimuth and the ellipticity will change, which gives rise to the necessity to taking $\varphi_0$ into account.

Experimental verification was carried out with undoped BSO samples in a transverse orientation: the field was directed along the [001] axis, and the light was directed along the [110] axis. In this case,

$$\theta_e = \frac{\pi}{\lambda n} \gamma_{41} E_{[001]}, \tag{2}$$

where $\gamma_{41}$ is the electrogyration coefficient, and $\Delta\beta = (\pi/\lambda) n^3 r_{41} E_{[001]}$. A control

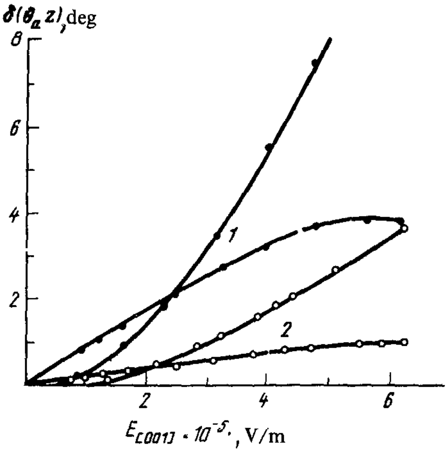

FIG. 1. Field-induced rotation of polarization. $\theta_a z_1 \simeq 540°$, $\theta_a z_2 \simeq 180°$.

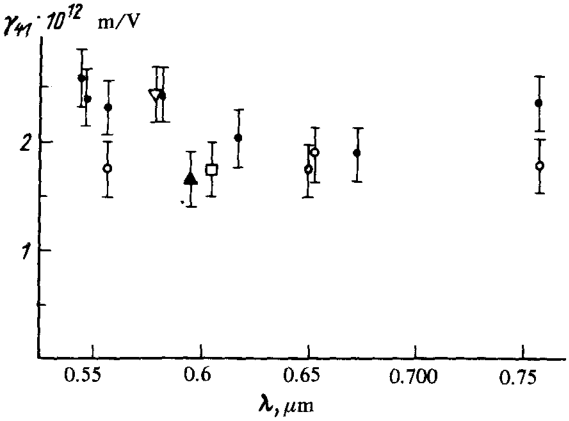

FIG. 2. Electrogyration coefficient. The length of BSO samples in mm. ●—36.9; ○—13.0; □—6.9; ▲—6.6; ∇—6.2.

voltage of ~1-kHz frequency was applied to silver-based contact-paste electrodes. Adjustment to the working wavelength $\lambda$ was accomplished by means of a monochromator. Figure 1 shows typical plots of the rotation of polarization as a function of the field at $\lambda \simeq 757$ nm for two samples, $\theta_a z_1 \simeq 3\pi$ and $\theta_a z_2 \simeq \pi$. In the neighborhood of zero, the first harmonic of the signal is linear with respect to the field, while the second harmonic is quadratic. The curves plotted for different values of $\varphi_0$ are essentially the same. At a constant field, the intensity depends on the angle $\varphi$ of the analyzer in accordance with $|\sin 2\varphi|$. When the analyzer is orthogonal to the exit state, the signal of each harmonic vanishes, i.e., the ellipticity does not change. Similar data were obtained in all experiments. The value of $\gamma_{41}$ is determined from the slope of the linear curve at the point $E = 0$ on the basis of relation (2). A more general case, in which $\theta_a(z) \simeq (m + 1/2)\pi$, was also tested. The signal depends on $\varphi_0$, and a change in the ellipticity is seen. The experimental values for the quadratic dependence are, on the average, ~80% of the calculated values, which is assumed to be a satisfactory agreement. The mean value of the electrogyration coefficient, according to the data in Fig. 2, is $\tilde{\gamma}_{41} = (2.0 \pm 0.1) \times 10^{-12}$ m/V.

We have thus shown that bismuth silicate exhibits electrogyration which was theoretically predicted by Zheludev.[1] The values of the electro-optical coefficient ($r_{41}$) and electrogyration coefficient ($\gamma_{41}$) are in order-of-magnitude agreement with each other. Electrogyration can, however, provide a modulation on the order of 1% in fields that provide 100% modulation of light because of the Pockels effect.

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