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First Correct Experimental Discovery of the "Weak" Gyrotropy-Phenomenon of "Non-Gyrotropic" Crystals of 3 m, 4 mm, 6 mm Symmetry Classes, Using the $LiNbO_3$ Crystal as an Example

Alexander Kh. Zilbershtein[1,2]

[1]Institute of Precambrian Geology and Geochronology (Russian Academy of Sciences), Saint-Petersburg, Russia
[2]University of Cologne, Cologne, Germany
Email: silver.48@mail.ru

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Abstract

The purpose of the work was the correct experimental discovery of the effect of "weak" gyrotropy of the "non-gyrotropic" transparent crystals. The original experiment was based on the study of the light transmission (T) of the system: Polarizer—wedge-shaped Crystal's sample—Analyzer (orthogonal to Polarizer). It was shown that: if the optical axis of the crystal is parallel to the rib of the wedge and to the polarization of the linear-polarized incident light, then the transmission T of the system can be not equal to zero (due to existence of nonzero components (G_{12}) of the antisymmetric pseudotensor of gyration $\{G\}$ described the "weak" gyrotropy). Using the $LiNbO_3$ crystal as an example, such nonzero T was at the first time experimentally discovered. Absolute value of components G_{12} of the $LiNbO_3$ crystal was first estimated: ($[G_{12}] = (1.50 +/- 0.51)\ 10^{-6}$).

Subject Areas

Physics & Mathematics

Keywords

Crystals, Light, Polarization, Weak Gyrotropy, Wedge-Shaped Sample, Vector of Electric Field Strength, Wave Vector, Optical Axis, Nonzero Transmission

1. Introduction

The phenomenon of weak gyrotropy of non-gyrotropic crystals of pyroelectric symmetry classes: 3 m, 4 mm, 6 mm, was predicted [1] and theoretically described [2] [3] [4] [5].

In according to the theory, these optically uniaxial crystals can transform the incident light, which is linear-polarized parallel to the optical axis **C**, into elliptically polarized one.

It is very important that this ellipse into the crystal takes place in the plane which is parallel to the optical axis **C** and to the wave vector of the light **k**. Thus, as light wave passes in the crystall, the vector of its electric field strength **E** is rotated from the normal direction (orthogonal to **k**) to the direction of the wave vector **k**.

The value (ϕ) of the angle of the rotation in non-absorptive crystals can be approximately presented in the form analogical to the well-known Equation (81.24) [6]:

$$\phi = \left(\pi G_{12} d n_e^3\right) / \lambda_0 \tag{1}$$

where: d is the path of the light in the crystal; n_e is the corresponding principal refractive index; λ_0 is the wavelength of the incident light; G_{12} is the component of the pseudotensor $\{G\}$ of gyration. For the above three symmetry classes the pseudotensor $\{G\}$ is antisymmetric rank-two tensor, where only two components ($G_{12} = -G_{21}$) are not equal to zero (see [4] [5] [6]).

In the theoretical papers [1] [2] there was proposed the scheme of the experiment for observation of the weak gyrotropy. The idea of this experiment was to study the polarization state of the reflected light on condition that the direction of propagation of the incident linear—(parallel to the optical axis **C**)—polarized light is not normal to the reflecting surface (boundary of the crystal under study).

In this case the described above ellipse has nonzero projection on the reflecting face. Then the some (nonzero) reflected light can be observed in the polarization, which is orthogonal to the polarization of the incident light.

There is only one known attempt [7] of experimental observation of the phenomenon of weak gyrotropy of the crystals. The authors [7] used the proposed theoretically [1] [2] experimental sheme (see above) and studied the CdS single crystal (class 6 mm). They observed the nonzero reflected light in the polarization, which was orthogonal to the polarization of the incident light, and interpreted this fact as the effect of weak gyrotropy.

However the existence of such nonzero light can be caused by the other well-known effects too, as: the influence of a subsurface layer of crystals [8]; the change of polarization state of light reflected from the real crystal boundary [9]. These known effects can and have to mask the effect of weak gyrotropy, but such masking was not taking into account in the paper [7]. So the cause of obtained in [7] experimental data is not sufficiently clear. The criticism of the presented in the paper [7] interpretation of the obtained data one can find in the book [8] and in the paper [9].

Thus the presented in the paper [7] data cannot be recognized as the correct observation of weak gyrotropy (see [8] [9]).

2. Correct Experimental Discovery of the Weak Gyrotropy Phenomenon

In present paper the other idea and scheme of the experiment for the observation of the effect of weak gyrotropy are proposed (see **Figure 1**).

The researched sample of the crystal represents the wedge whose rib is parallel to the optical axis **C** of the crystal; The direction of propagation of the incident light (**k**) is normal to the nearest (to the light source) surface of the wedge; The incident light is linear-polarized, the polarization is parallel to the optical axis **C**; The polarization state of the light passed through the sample is analysed.

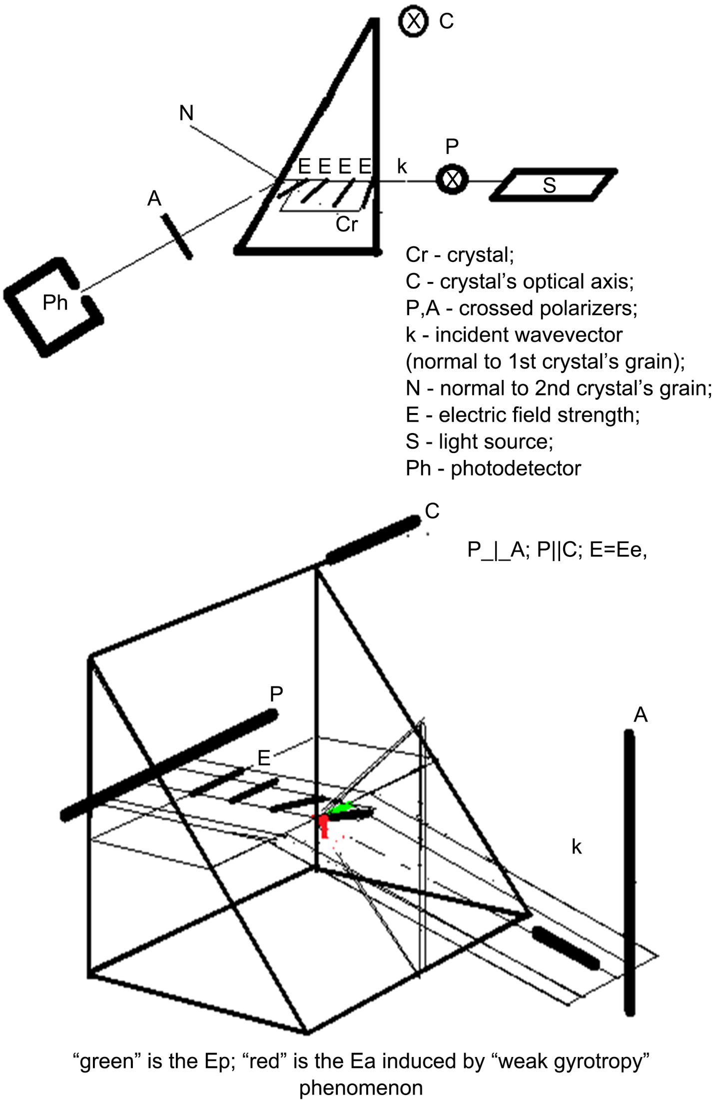

Figure 1. Experiment scheme of observation of weak gyrotropy. **C** is the optical axis of crystal; **k** is the wave vector of the incident light; **E** is the vector of light's electric field strength; P, A are permitted polarizations of polarizer (P), analyzer (A).

Compliance with the well-known boundary condition of continuity of the tangential component of the vector of light's electric field strength (**E**) provides the existence of a nonzero light in the polarization, which is orthogonal to the polarization of the incident light (see **Figure 1**).

In given case the light transmission (T) of the system: Polarizer (parallel to the optical axis **C**)-Crystal-Analyzer (orthogonal to Polarizer), which is corresponding to the above nonzero light, can be expressed in the simple form:

$$T = \left(\left(\sin\phi\right)\left(\sin\alpha\right)\right)^2 \left(i.e.\ \phi = \left(\arcsin\left(T^{1/2}/\left(\sin\alpha\right)\right)\right)\right) \tag{2}$$

where: α is the wedge angle; ϕ is presented in the Equation (1).

The system of the equations the Equation (1) and the Equation (2) permits to obtain the expression for estimation of the value of nonzero components (+/– G_{12}) of the pseudotensor of gyration $\{G\}$, which provide the effect of weak gyrotropy, in the following form:

$$G_{12} = \left(\lambda_0/\left(\pi d n_e^3\right)\right)\left(\arcsin\left(T^{1/2}/\left(\sin\alpha\right)\right)\right) \tag{3}$$

The optically homogeneous and transparent large single $LiNbO_3$ crystal (class 3 m) was studied as an example. The crystal was kindly provided by Professor L. Bohaty (Koeln University, Germany).

The wedge-shaped sample with wedge angle equal to 23 degrees was produced from this crystal.

The light-emitting diode with interference filter was used as the source of light. The light source provided the parallel beam with diameter of cross-section about 10 mm and wavelength (λ_0) equal to (550 +/– 6.0) nm.

The homogeneous polarizing filters were used as the polarizer and the analyzer.

The stabilized homogeneous photocell was used as the photodetector.

The described above original set-up (stabilized polarization precise photometer) permited at the first time to observe and to measure the nonzero transmission (T) of the light passed through the crystal placed between crossed (orthogonal) polarizers (polarizer and analyzer). This study was produced on the condition, that the polarization of the incident light was parallel to the optical axis **C** of the crystal.

For the orthogonal orientation of the polarizers (when the polarization of the incident light is orthogonal to the optical axis **C** of the crystal) the transmission of the system Polarizer-Crystal-Analyzer was equal to zero to the accuracy of measurement.

That is, the observed nonzero transmission was caused namely by the weak gyrotropy.

It is important to note that it was the first correct experimental observation of the weak gyrotropy phenomenon of crystals.

In given case the value of this nonzero transmission (T) was equal to 0.14 +/– 0.10.

By use of the Equation (3) the obtained value of the transmission (T) permits to estimate the absolute value $[G_{12}]$ of the nonzero components of antisymmetric pseudotensor of gyration {*G*} provided the weak gyrotropy.

For the “nongyrotropic” $LiNbO_3$ crystal the estimation of the absolute value of the $[G_{12}]$ was obtained at the first time:

$$[G_{12}] = (1.50+/-0.51)10^{-6}$$

(this estimation of the $[G_{12}]$ was obtained for: $\lambda_0 = 550$ nm, $n_e = 2.30$, $d = 10$ mm and room conditions (about 293 K, 1 bar)).

3. Conclusion

The new idea and scheme of the experiment for observation of the weak gyrotropy phenomenon were first proposed;

The original precise set-up for this experiment was constructed;

It was first proposed the expression (Equation (2)) for nonzero transmission (T) induced by “weak” gyrotropy of “nongyrotropic” crystals;

By use of this expression, the scheme and the constructed original set-up, it was produced the first correct experimental observarion (discovery) of the “weak” gyrotropy of “nongyrotropic” crystals (using the single crystal $LiNbO_3$, as an example);

The obtained experimental data permitted in part at the first time to estimate the absolute value of the nonzero components of antisymmetric pseudotensor of gyration of the $LiNbO_3$ crystal.

It should be noted that transparent crystals of 3 m, 4 mm, 6 mm symmetry classes are the medium with spatial dispersion, such medium can be a possible source of longitudinal electromagnetic waves [4].

Indeed, the transparent crystal’s plates parallel to the optical axis (**C**) with the thickness (d_l) equal to:

$$d_l = \lambda_l \Big/ \left[2n_e^3(\lambda_l) G_{12}(\lambda_l) \right],$$

can provide the rotation of the vector of electric field strength of passed light wave equal to $\pi/2$.

So for the plates with the thickness d_l can take place $\phi = \pi/2$ (see the Equations (1), (2)), *i.e.* the wave at the exit of the plate can be a longitudinal light wave at the wavelength λ_l

Thus such crystals can be used as a possible source of the longitudinal electromagnetic light waves, whereas only longitudinal electromagnetic microwaves are known now (see [10] [11])

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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