Once More about Magnetogyration (Case of the CdS, $(Ga_x In_{1-x})_2Se_3$, SiO_2 and $Li_2B_4O_7$ Crystals)

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Abstract

The paper is devoted to the study of induced gyrotropy (Faraday type and spatial dispersion type) by the magnetic field in crystals with different point groups of symmetry and different optical absorption. According to our experiments $Li_2B_4O_7$ and SiO_2 crystals do not possess magnetogyration because in the first case wavelength of 632.8nm is far from absorption age and in the second one magnetogyration is forbidden in such geometry of experiment. Coefficients of the Faraday effect for $Li_2B_4O_7$ and SiO_2 crystals are $\alpha_{33}=1.12\times10^{-10}Oe^{-1}$ and $\alpha_{33}=1.13\times10^{-10}Oe^{-1}$, respectively. But CdS and $(Ga_xIn_{1-x})_2Se_3$ (x = 0.3; 0.4) crystals that exhibit strong absorption at λ=632.8nm possess a sufficient magnetogyration effect. Determined coefficients of the Faraday effect and magnetogyration for CdS and $(Ga_xIn_{1-x})_2Se_3$ (x=0.3; 0.4) are $\alpha_{33}=5.05\times10^{-9}Oe^{-1}$, $\delta_{333}=5.7\times10^{-11}Oe^{-1}$ and $\alpha_{33}=9.27\times10^{-9}Oe^{-1}$, $\delta_{333}=2.45\times10^{-10}Oe^{-1}$ (x=0.3); $\alpha_{33}=9.29\times10^{-9}Oe^{-1}$,$\delta_{333}=2.43\times10^{-10}Oe^{-1}$ (x = 0.4) respectively. It is interesting to note that in contrary to the CdS crystals, $CdS_{0.22}Se_{0.78}$ and $CdS_{0.4}Se_{0.6}$ nanocrystals embedded in borosilicate glass matrix possess only the Faraday effect ($\alpha_{33}=2.06\times10^{-10}Oe^{-1}$ and $\alpha_{33}=2.29\times10^{-10}Oe^{-1}$, respectively) that is in good agreement with the symmetry conditions and our approach. Our present experiments show that a magnetogyration effect exists in crystals only due to sufficient absorption.

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Introduction

As it is known two types of optical activity differ in symmetry (gyration - ∞2 and Faraday effect - ∞/m) and in experimental manifestation. Experimentally this effect can be separated by a change of the sign of the wave vector that leads to a doubling of the Faraday rotation and compensation of the gyration rotation. However an observed optical rotation in pyroelectric crystals under application of the magnetic field [1] which was explained as magnetogyration [1,2] and then by the combined influence of electric and magnetic fields [3,4] was also separated from the Faraday rotation by the changing of the sign of the wave vector. In such a case it is reasonable to question: what is the symmetry and nature of the effect founded?

From the moment of finding the non-trivial optical activity which appeared in magnetic field in $LiJO_3$, CdS and $Pb_5Ge_3O_{11}$ crystals its description was clarified a few times. Firstly the difference in the polarization plane rotation angle at the opposite directions of wave vector was explained as the magnetogyration effect. The difficulties of this explanation were connected with the limiting of the Onzager principle. Then this effect was explained as optical activity induced by the combined influence of the magnetic field and electrical polarization since it was observed only in pyroelectrics and ferroelectrics and was separated by the change of the sign of polarization. However, such an effect should possess the symmetry ∞/m and its separation by the change of the sign of wave vector is not understandable. It is necessary to note that the Onzager principle can not be applied to the dissipate media while CdS pyroelectric crystals possess quite a strong interband absorption at the wavelength 632.8nm. This means that magnetogyration in these crystals is not forbidden.

The present report is devoted to the study of the Faraday effect and magnetogyration in the CdS (point group of symmetry 6mm), $(Ga_xIn_{1-x})_2Se_3$ (x = 0.3; 0.4) (point group of symmetry 6), SiO_2 (point group of symmetry 32) and $Li_2B_4O_7$ (point group of symmetry 4mm) crystals at the wavelength of 632.8nm (H||k||z). It is necessary to note that CdS and $(Ga_xIn_{1-x})_2Se_3$ crystals are wide band semiconductors and due to the point group of symmetry permit the existance of magnetogyration, in the $Li_2B_4O_7$ crystals magnetogyration is not forbidden due to the symmetry but these crystals are quite transparent at 632.8nm as well as in SiO_2 crystals at H||k||z magnetogyration is forbidden by the symmetry.

Symmetry analysis and experiment

Let us analyze the reason of the manifestation of different effects of optical activity in greater detail. Since the Faraday effect consists in the inducing of the antisymmetrical part of dielectric permitivity with the symmetry ∞/m by the magnetic field, the symmetry of this effect should be ∞/m. According to the relation

$$D^{\omega}_i=\varepsilon^{o}_{ij}E^{\omega}_j+i\delta_{ikj}H_kE^{\omega}_j$$

$$\varepsilon_{ij}=\varepsilon^{o}_{ij}+i\delta_{ijk}H_k, \qquad (1)$$

where ε^{o}_{ij} - real part of the dielectric permitivity, D^{ω}_i and E^{ω}_j - electrical induction and strength of the electric field on the optical frequency, H_k - strength of the magnetic field, δ_{ijk} , δ_{ikj} - axial antisymmetric third rank tensors; it is visible that the existance of a flow of charges (due to the symmetry of the magnetic field and the Onzager principle) lead to the appearance of the imaginary part in dielectric permitivity. On the other hand it follows from the Ermit principle that the imaginary part of the dielectric permitivity should be only antisymmetrical. The antisymmetric part of the second rank polar tensor is dual to the axial vector ρ_n with the symmetry ∞/m. It means that the vector of the electrical induction

$$D^{\omega}_i =[\rho_n\times E^{\omega}_j], \qquad (2)$$

should turn in such media and elliptically eigen waves will exist. The sign of rotation of the polarization plane at Faraday effect does not depend on the sign of the wave vector but depends on the sign of the magnetic field. The gyration possesses the symmetry of the gyration tensor - ∞2 and according to

$$\varepsilon_{ij}=\varepsilon^{o}_{ij}+i\gamma_{ijk}k_k, \qquad (3)$$

depends on the sign of the wave vector.

Magnetogyration will lead to a change in the imaginary part of dielectric permitivity in the case of sufficient existing absorption

$$\rho_n=\delta_{nlk}H_lk_k, \qquad (4)$$

where δ_{nlk} – is a third rank polar tensor.

The separation of this optical activity from the Faraday rotation was made by the turning of the sample by 180^o around the axis that is perpendicular to the optical axis and in such a way changing the sign of δ_{nlk} tensor. During the described operation magnetogyrational rotation of the polarization plane $\rho_n\sim\delta_{nlk}H_lk_k$ will change the sign while the Faraday rotation should not change the sign.

The studying of the Faraday effect and magnetogyration was conducted by a polarimetric setup that permits to determine the polarization plane rotation with an accuracy not worth than 20″ and application of magnetic field up to 15kOe. The optical radiation of an He-Ne laser with the wavelength 632.8nm was propagated along the optical axis of uniaxial crystals and a magnetic field was applied along the same direction.

Experimental results

The $Li_2B_4O_7$ crystals belong to the point group of symmetry 4mm [8] and is transparent in the wide spectrum range - 0.2-3.5μm [9]. It means that according to symmetry these crystals could possess magnetogyration but at the wavelength 638.8nm they are transparent. As it is visible from Fig. 1 on turning the sample around the axis that is perpendicular to the optical one by 180° the induced magnetooptical rotation of the polarization plane is the same and is connected only with the Faraday rotation. The calculated coefficient of the Faraday effect is $\alpha_{33}=1.12\times10^{-10}Oe^{-1}$. The SiO_2 crystals belong to the point group of symmetry 32 and in these crystals due to the symmetry conditions magnetogyration is forbidden at the geometry of experiment k||H||z. The wavelength of 632.8nm is far from the absorption age of quartz crystals. As it is shown on Fig. 1 magnetooptical rotation of a polarization plane does not differ for the samples turned on 180°. The calculated value of the Faraday coefficient is $\alpha_{33}=1.13\times10^{-10}Oe^{-1}$.

The CdS and $(Ga_xIn_{1-x})_2Se_3$ crystals belong

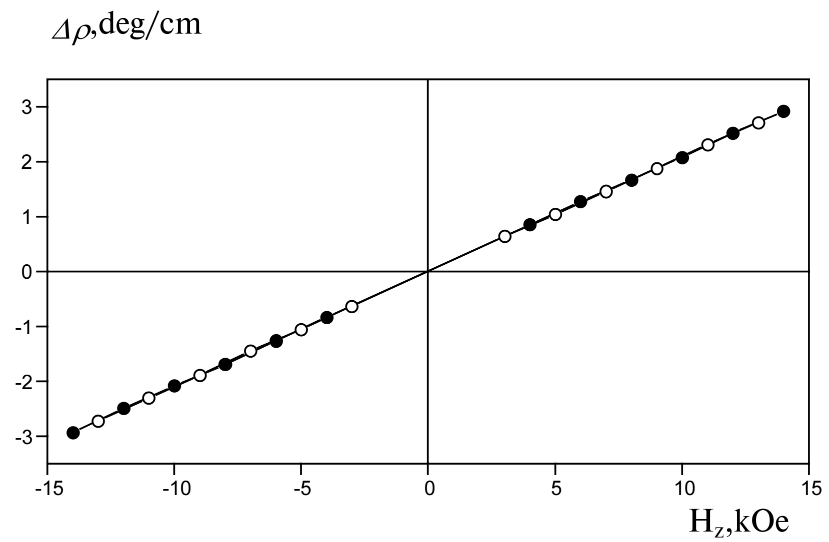

Fig.1. The dependence of the rotation of polarization plane in $Li_2B_4O_7$ and SiO_2 crystals on magnetic field (λ=632.8nm, T=20°C); full and empty circuits indicate results for different positions of the sample.

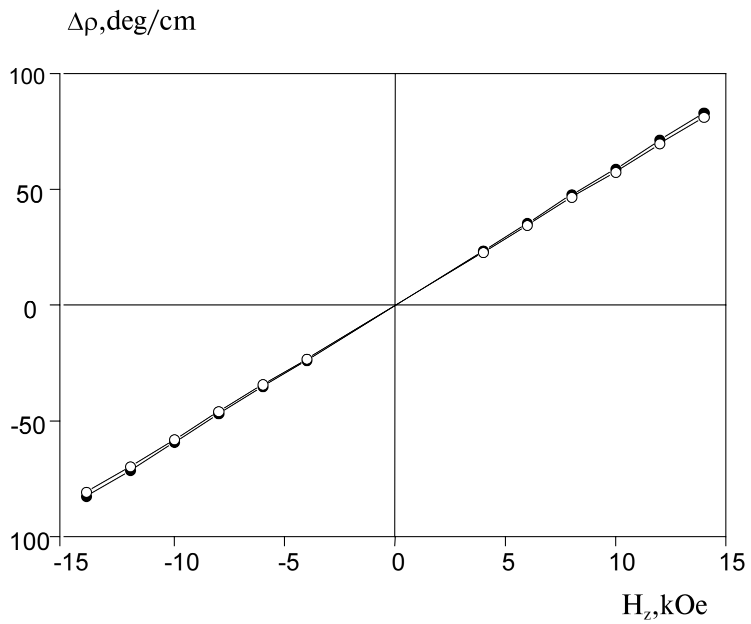

Fig.2. The dependence of the rotation of the polarization plane in CdS crystals on the magnetic field (λ=632.8nm, T=20°C); full and empty circuits indicate results for different positions of the sample.

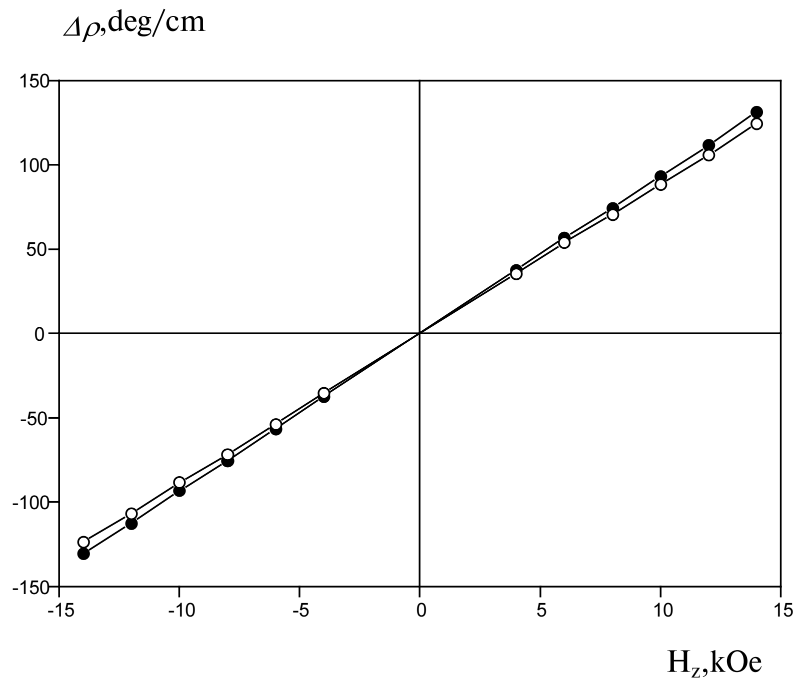

Fig.3. The dependence of the rotation of polarization plane in $(Ga_xIn_{1-x})_2Se_3$ (x = 0.3; 0.4) crystals on magnetic field (λ=632.8nm, T=20°C); full and empty circuits indicate results for different positions of the sample.

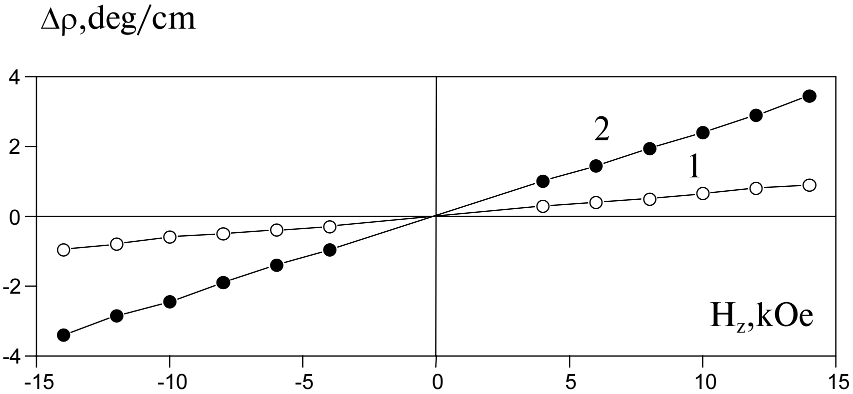

Fig.4. The dependence of the magnetogyration rotation of the polarization plane in CdS (1) and $(Ga_xIn_{1-x})_2Se_3$ (x = 0.3; 0.4) (2) crystals on magnetic field (λ=632.8nm, T=20°C).

to the point group of symmetry 6mm and 6, respectively and exhibit strong absorption at λ=632.8nm [10]. As it is visible from Fig. 2,3 these crystals possess different magnetooptical rotation in the turned samples. This additional rotation of the polarization plane is connected with magnetogyration (Fig. 4).

Determined coefficients of Faraday effect and magnetogyration for CdS and $(Ga_xIn_{1-x})_2Se_3$ (x=0.3;0.4) are $\alpha_{33}=5.05\times10^{-9}Oe^{-1}$, $\delta_{333}=5.7\times\times10^{-11}$ Oe^{-1} and $\alpha_{33}=9.27\times10^{-9}$ Oe^{-1}, $\delta_{333}=2.45\times\times10^{-10}$ Oe^{-1} (x=0.3); $\alpha_{33}=9.29\times10^{-9}Oe^{-1}$, $\delta_{333}=2.43\times10^{-10}$ Oe^{-1} (x=0.4) respectively. It is interesting to note that in contrary to the CdS crystals, $CdS_{0.22}Se_{0.78}$ and $CdS_{0.4}Se_{0.6}$ nanocrystals embedded in borosilicate glass matrix in which magnetogyration effect is forbidden due to the symmetry but which possesses strong absorption, show only the Faraday effect (Fig. 5) ($\alpha_{33}=2.06\times10^{-10}Oe^{-1}$ and

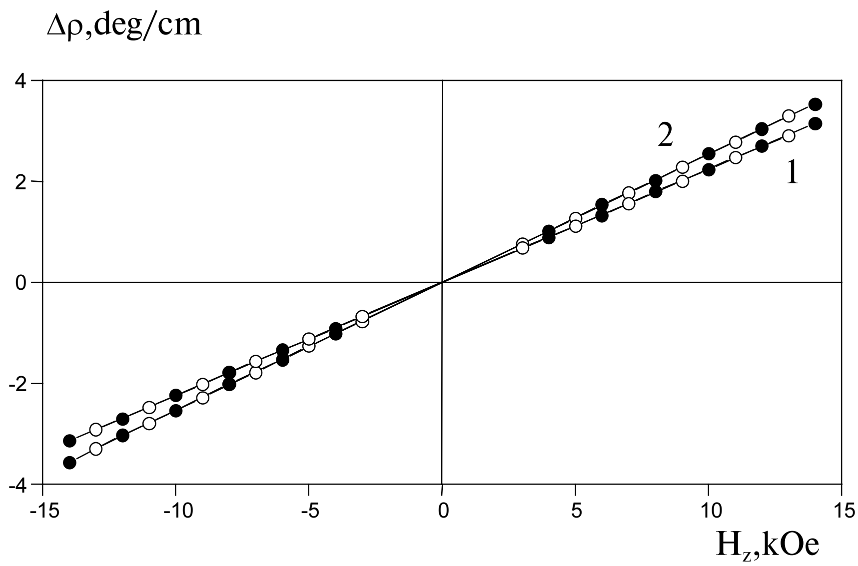

Fig.5. The dependence of the rotation of polarization plane in $CdS_{0.22}Se_{0.78}$ (1) and $CdS_{0.4}Se_{0.6}$ (2) nanocrystals embedded in borosilicate glass matrix on magnetic field (λ=632.8nm, T=20°C); full and empty circuits indicate results for different positions of the samples.

α_{33}=2.29×10^{-10}Oe^{-1}, respectively) which is in good agreement with the symmetry conditions and our approach.

Conclusions

1.The magnetooptical rotation of the polarization plane in $Li_2B_4O_7$, SiO_2, CdS and $(Ga_xIn_{1-x})_2Se_3$ (x=0.3; 0.4) crystals as well as in $CdS_{0.22}Se_{0.78}$ and $CdS_{0.4}Se_{0.6}$ nanocrystals embedded in borosilicate glass matrix was studied. The $Li_2B_4O_7$, SiO_2 crystals and $CdS_{0.22}Se_{0.78}$ and $CdS_{0.4}Se_{0.6}$ nanocrystals embedded in borosilicate glass matrix do not possesses magnetogyration as well as CdS and $(Ga_xIn_{1-x})_2Se_3$ crystals possess both the Faraday effect and magnetogyration as well .

2. The calculated values of Faraday coefficients and components of magnetogyration tensor are: for SiO_2 crystals α_{33} =1.13×10^{-10} Oe^{-1}; for crystals $Li_2B_4O_7$ α_{33} = 1.12×10^{-10} Oe^{-1} ; for CdS crystals α_{33}=5.05×10^{-9}Oe^{-1}, δ_{333}=5.7×10^{-11}Oe^{-1}; for $(Ga_xIn_{1-x})_2Se_3$ (x = 0.3; 0.4) crystals α_{33}=9.27×10^{-9} Oe^{-1}, δ_{333} =2.45×10^{-10} Oe^{-1} (x = 0.3); α_{33}=9.29×10^{-9} Oe^{-1}, δ_{333}=2.43××10^{-10} Oe^{-1} (x = 0.4); for $CdS_{0.22}Se_{0.78}$ and $CdS_{0.4}Se_{0.6}$ nanocrystals embedded in borosilicate glass matrix α_{33}=2.06×10^{-10}Oe^{-1} and α_{33}=2.29×10^{-10}Oe^{-1}, respectively.

3.Our present experiments show that magnetogyration effect exist in crystals only due to the sufficient absorption.

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