Physics of the Solid State, 2025, Vol. 67, No. 5

04,05,16

Features of the spectrum of the faraday effect in $FeBO_3$ caused by the magnetization component of the parallel C_3 axis

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Received May 26, 2025
Revised May 27, 2025
Accepted May 27, 2025

For the first time, the spectral dependence of the Faraday effect caused by the magnetization of the parallel C_3 axis of the crystal was measured in the area of its transparency in iron borate. Based on the spectral dependence, the peak of the effect was observed at a wavelength of light equal to 475 nm. The origin of the peak in the spectral dependence of the effect is associated with the transition $({}^6A_{1g} \to {}^4A_{1g}, {}^4E_g)$ in the Fe^{3+} iron borate ion.

Keywords: Faraday effect, spectral dependence, iron borate, C_3 axis.

DOI: 10.61011/PSS.2025.05.61492.143-25

Weak ferromagnetic, iron borate $FeBO_3$ has been studied well to this time, but still attracts the attention of the researchers as a model object for the study of new magnetic properties, which manifest, in particular, in the experiments of superfast magnetic dynamics [1] and at superhigh pressures [2,3]. Besides, the studies of the magnetic properties of crystals $FeBO_3$ as model objects help to deepen our knowledge on the nature of magnetic anisotropy, in particular, on Dzyaloshinski-Moriya interaction. The review of the recent results on the study of the magnetic properties of iron borate is presented in paper [4]. Magnetooptical properties of iron borate have been studied in detail, in particular, linear magnetooptical effects (see [5,6]). In paper [7] when the iron borate specimens were illuminated with white light, Faraday effect (FE) was observed for the first time, being provided for by the magnetization component of the parallel axis C_3 of the crystal.

Appearance of low spontaneous magnetization (m_D) in the basal plane of rhombohedral antiferromagnetics is the natural effect of symmetry of these crystals [8]. Magnetization m_D occurs when the thermodynamic potential of antiferromagnetic in the members of not higher than the second order is taken into account in the decomposition of sublattice magnetization by components. Spontaneous magnetization is due to relativistic interactions of spin-lattice crystal. Ratio of value m_D to the sum of the antiferromagnetic sublattice magnetization values is proportionate to the squared ratio of the electron speed in the crystal to the light velocity $(v/c)^2$ and amounts to $10^{-2}-10^{-5}$. If the members of the fourth order are taken into account in the thermodynamic potential by components of sublattice magnetization, the theory predicts the presence of spontaneous magnetization (m_z) along the axis of the third order C_3 of the perpendicular basal plane crystal. Relative value m_z is proportionate to $(v/c)^4$. Angular dependence m_z in rotation m_D around axis C_3 is described with the equation $m_z = m_{z0} \cdot \cos 3\varphi$, where φ — angle in the basal plane between the direction m_D and line of basal plane crossing with the mirror plane of symmetry. Existence of the component m_z was found in the iron borate by Flanders method of specimen rotation around axis C_3 in the constant magnetic field parallel to the basal plane and measurement of component m_z at the frequency that exceeds the rotation frequency three times [9]. The measured value m_z turned out to be two and half thousand times less than m_D. Note significant differences between components m_D and m_z:

- high difference in the values;
- m_D lies in the basic plane of iron borate, and its value does not depend on orientation in this plane;
- m_z is perpendicular to the basal plane, and in rotation of magnetic sublattice spins around axis C_3 by 360° the component m_z changes the sign 6 times.

The paper studied the spectral dependence of FE provided for component m_z, in the transmission region of iron borate. The studied specimens are thin green wafers parallel to the basal plane with transverse dimensions of ~ 3 mm. The thickness of the specimens was 4.2 and 6.6 μm. The thinnest specimens were selected among the available specimens, since they have high optical homogeneity and perfect faces. Perfect flat surfaces of the specimen and volume homogeneity play a significant role in this study. The source of light was an arc xenon lamp, whose light arrived to a monochromator. The ray of light was oriented perpendicularly to the plane of the specimen along its axis C_3. Precise orientation of light along axis C_3 is important, since the deviation of the ray from the axis causes FE, provided for by component m_D, which is greater than

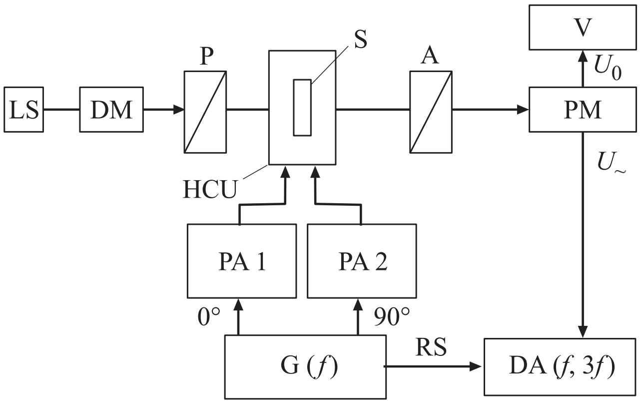

Figure 1. Block diagram of the installation.

FE provided for by component m_z by orders of magnitude. The specimen was placed into a rotary magnetic field, the rotation plane of which coincided with the basal plane of $FeBO_3$ crystal. The rotary magnetic field was created by two pairs of identical Helmholtz coils oriented perpendicularly to each other. Current phase in the coil pairs differed by 90°. The frequency of the rotary magnetic field was specified as $f = 265\,\text{Hz}$, and the field value was 10 Oe, which exceeded the saturation field in the basal plane of specimens by an order of magnitude [10]. Measurements of the Faraday effect were carried out at tripled frequency $3f$ using a digital measurement amplifier Saluki-SE1022, which makes it possible to do the simultaneous measurement of signals in frequencies f and $3f$ using digital phase detection. A sinusoidal signal is sent as a reference to the amplifier from the generator at frequency f. The reference signal at frequency $3f$, matched in phase with the signal at frequency f, is created in the amplifier itself.

The block diagram of the setup is shown in Figure 1. LS — light source, DM — double monochromator, P — polarizer, S — specimen, HCU — Helmholtz coil unit, A — analyzer, PM — photomultiplier, V — voltmeter, DA — digital amplifier, G — generator, PA 1 and PA 2 — power amplifiers, RS — reference signal.

The analyzer's polarization plane is rotated towards the plane of polarizer's polarization, which makes it possible to convert the rotation of the light polarization plane created by the specimen into the change of the light intensity proportionate to the rotation angle. The angle between the polarizer and analyzer polarization planes is 45°.

The operation of the measurement amplifier at various frequencies of the sound range was tested by sending a rectangular signal to its inlet with the known amplitude that changed by 5 orders to cover the range of the measured signals. Amplitudes of the first and third harmonics of the measured rectangular signal were recorded at the amplifier's outlet. The testing results demonstrated good compliance of the amplitudes of specified harmonics with the expected values obtained as a result of decomposition of the rectangular signal into the Fourier's series.

As a result of significant difference in FE values provided for by the magnetization components m_D and m_z, a question arises on the possible effect of the first FE on the results of the measurement of the second one. Deviation of the ray of light from axis C_3, and divergence of the beam result in FE in the rotary magnetic field, with Fe being provided for by magnetization m_D and having frequency f. Divergence of the beam of light was minimized using diaphragms. The ray diameter was $\sim 1\,\text{mm}$, the angular divergence of the beam was less than 10^{-2} radian. For the accurate setup of the ray of light along axis C_3 the specimen was rotated relative to two mutually perpendicular axes perpendicular to the ray of light incident on the specimen using micrometric inputs at simultaneous measurement of FE on the first harmonic with the purpose of its minimization.

Measurements of spectral dependence of FE provided for magnetization component m_z, in the range of light wavelengths (λ) 450−670 nm in both studied specimens demonstrated similar results. Figure 2 presents the FE spectrum provided for component m_z and measured in the specimen with thickness of $4.2\,\mu\text{m}$.

From the figure you can see that as the light wavelength increases, the effect value rises sharply from 1.5 deg/cm at $\lambda = 450\,\text{nm}$ to the maximum of 4 deg/cm at $\lambda = 475\,\text{nm}$ and then again first sharply, and then monotonously drops down to 1 deg/cm at $\lambda = 670\,\text{nm}$ (note that due to the incorrect operation of the constant signal measurement channel U_0 in paper [7], the FE value in paper [7], provided for by component m_z, is significantly less than in Figure 2).

Qualitatively the behavior of FE provided for by magnetization component m_z, in the studied range λ agrees with the FE behavior provided for by magnetization component m_D and presented in paper [11]. Moreover, the FE peak observed in this paper practically matches the position of the FE peak observed in [11] at $\lambda = 472\,\text{nm}$. FE peak at $\lambda = 472\,\text{nm}$ was related by authors of paper [11] to the electronic transition inside d-shell of ion Fe^{3+} of iron borate ($^6A_{1g} \rightarrow {}^4A_{1g}, {}^4E_g$). Due to the analogy in behavior of FE spectra provided for by components m_D and m_z, it is natural to bind the appearance of the peak on FE curve at

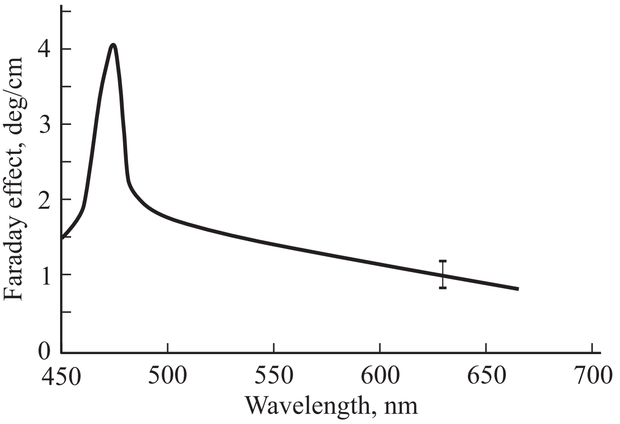

Figure 2. EF spectrum provided for component m_z.

$\lambda = 475$ nm, provided for by component m_z, with the same electronic transition in ion Fe^{3+}. FE value provided for by m_D, in the peak maximum is approximately 4000 deg/cm, while the FE value provided for by component m_z, in the peak maximum is around 4 deg/cm. In the second case the effect value is 1000 times less than in the first one. Above it was noted that the magnetization value m_z in the iron borate is less than value m_D 2500 times. I.e., no proportionality is observed between the values of the magnetization components m_z and m_D and FE values provided for by these components.

In the general case there should be no proportionality between values m_D and m_z and FE values determined by these magnetizations. It is related to the fact that spontaneous magnetization in the basal plane m_D occurs when the thermodynamic potential of iron borate in the members of not higher than the second order is taken into account in the decomposition of sublattice magnetization by components. And only when the members of the fourth order are taken into account in the thermodynamic potential by components of sublattice magnetization, the theory predicts and the experiment confirms the presence of spontaneous magnetization m_z along the axis of the third order. Effective fields determining the existence of magnetizations m_D and m_z, are mutually perpendicular and vary differently when the antiferromagnetism vector turns in the basal plane. Therefore, the microscopic mechanisms determining the occurrence of these fields vary. And mechanisms determining appearance of FE in two discussed cases also vary.

Funding

The study was performed under the state assignment of the Lomonosov Moscow State University.

Conflict of interest

The authors declare no conflict of interest.

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Translated by M.Verenikina