Investigation of the resonance Faraday effect in a pulsed magnetic field up to 10 MG

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The Faraday effect (FE) in $Er(PO_3)_3$ glass is investigated in a magnetic field of ≈ 10 MG. A resonance enhancement of the FE in ≈ 8-MG field and an electron paramagnetic resonance at the optical frequency in ≈ 3-MG field were observed.

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The study of solids in $\sim 10^7$-G magnetic fields when the energy of interaction of ions with the field is comparable to the energies of the spin-orbit and exchange interactions and also to the energy of the crystal field is of obvious interest. This paper is devoted to an investigation of the Faraday effect (FE) in $Er(PO_3)_3$ glass and at the same time reports one of the first attempts to make practical use of 10-MG range magnetic fields.

A type MK-1 magnetic compression generator[1] was used as the source of the magnetic field. After modifying the design of the generator, we were consistently able to generate magnetic fields up to 10 MG in our experiments. An optical measurement procedure[2] based on the FE in the TF-5 heavy flint glass was used to obtain reliable measurement results. The measuring channel had to be spatially separated from the experimental channel because the optical technique was used simultaneously for measuring the field and studying the magnetic-optical effects in the material being investigated. We were able to do this because of the large (up to 9 mm) diameter of the region of maximum field, a noteworthy property of the modified generator. Such separation was possible because the measuring assembly consisted of three compactly arranged 3.6-mm-diam porcelain tubes. The tube axes were separated at an angle approximately equal to the divergence angle of the probing ray of the helium-neon laser ($\lambda = 632.8$ nm).

The samples were arranged in the tubes as follows: and $Er(PO_3)_3$ glass sample of length $l = 1.03$ mm was placed in the first tube, a similar $Er(PO_3)_3$ sample and a TF-5 flint glass sample ($l = 2.5$ mm) were placed in tandem in the second tube, and only a TF-5 sample ($l = 2.5$ mm) was placed in the third tube for measuring the field. The induction probes of the derived field were placed above and between the tubes. The outer diameter of the measuring assembly was 8.3 mm. The light beams from the second and third tubes were directed to their individual recording channels which contained a light filter, a polarizer-analyzer, a photomultiplier, and an oscillograph, while the light beam from the first tube was directed at the photodiode for measuring the transmission coefficient of $Er(PO_3)_3$ during the experiment. We conducted two identical explosive experiments with $Er(PO_3)_3$, whose results coincide to within 5%.

Oscillograms from one of the experiments are shown in Fig. 1, and the experi-

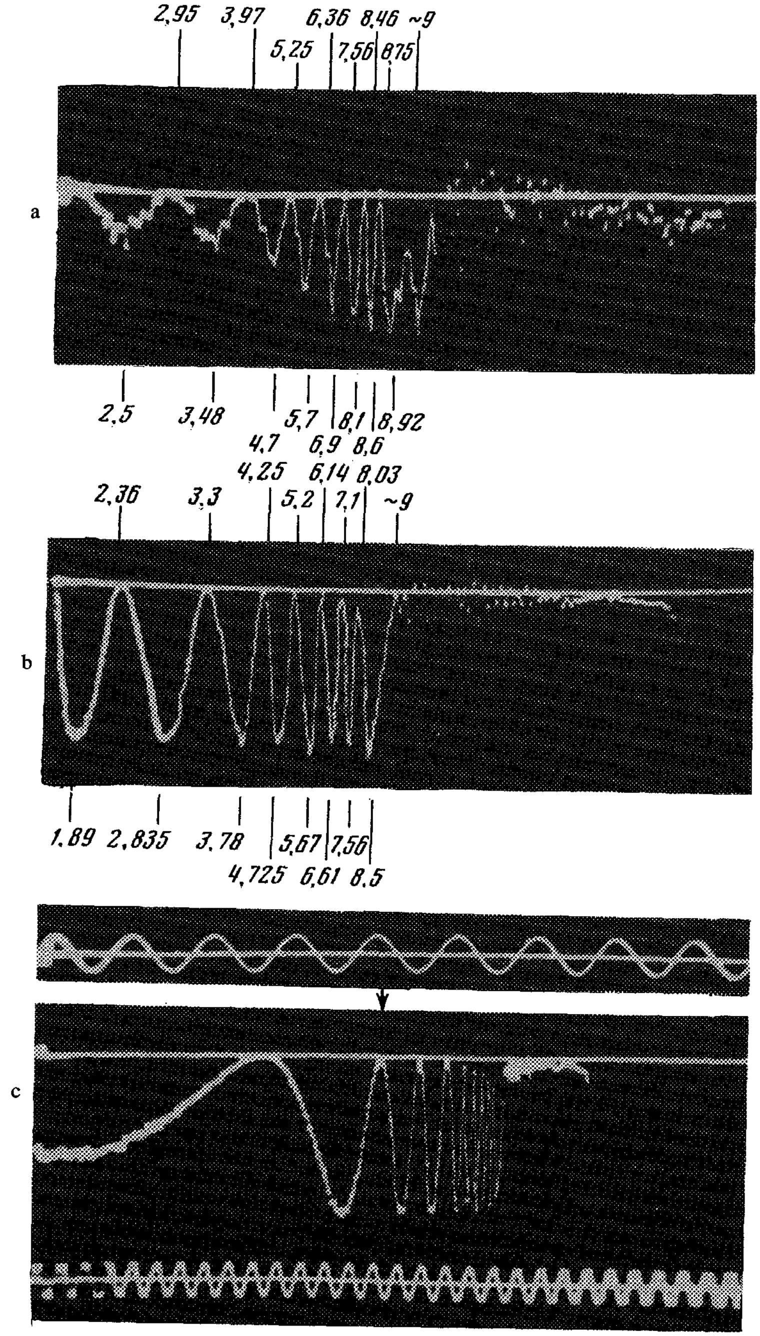

FIG. 1. Oscillograms of the Faraday rotation: a, $Er(PO_3)_3$ + TF-5 glass; b and c, TF-5. The two upper oscillograms were taken 14 μsec after the start of the measurement and the lower one extends over the entire time interval. The numbers denote the field in MG. The calibration sine curve has a period of 1 μsec. The arrow in oscillogram *c* indicates the origin of the upper oscillograms. The Verdet constant of TF-5 is 0.0457 min/cm·G at room temperature.

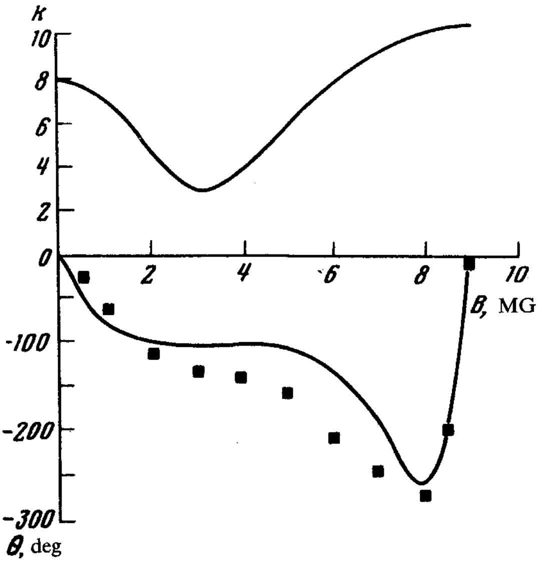

FIG. 2. The transmission coefficient K (experiment) and rotation of the plane of polarization relative to the field **B** (the points represent the experiment and the solid line denotes theory) of the $Er(PO_3)_3$ sample.

mental field dependences of the angle of turn θ of the polarization plane and of the transmission coefficient k, are shown in Fig. 2. As Fig. 2 demonstrates, the $\theta(B)$ dependence has a complex form: the rotation is negative, with saturation in a field of 2–4 MG; then θ increases again, peaks at 8 MG, and changes sign at 9 MG.

The general equation for the FE can be broken down into two parts: a paramagnetic part $\theta_p = C_p B(x)l$ due to the Er^{3+} ions and a diamagnetic part $\theta_d = V_d\, lB$ due to the matrix ions. The constants $C_p = -1.01\times 10^5$ min/cm and $V_d = 0.019$ min/cm·G can be determined from experiments in fields up to 2 MG (an MK-2 generator).[3] If only these contributions were in effect, then in fields up to 4 MG we would have $|\theta_p| > \theta_d$ and $\theta < 0$. However, the terms should be compensated and the sign of the FE should be reversed in strong fields due to the saturation of θ_p in fields of ≈ 3.8 MG.

As shown by Fig. 2, these ideas are inconsistent with the experiment, a fact which we attribute to the resonance contributions to θ because the probing frequency ω falls in the region of the absorption lines. The $Er(PO_3)_3$ spectrum near ω has transitions at 650 nm, which corresponds to the ${}^4I_{9/2}$ level according to the classification,[4] and at ≈ 530 nm. If the Zeeman components of the level at 530 nm cross ω, then a resonance enhancement of θ_r should occur (in the standard notation used previously[2]):

$$\theta_r = C_r \{[\omega^{\circ}_{ba} = aB - \omega]/[(\omega^{\circ}_{ba} - aB - \omega)^2 + \Gamma^2] + D\}l \, .$$

From the measurements of the spectrum $\Gamma \approx 6\times 10^{13}$ rad/sec. Setting $\alpha = 0.639\times 10^8$ rad/sec·G (an estimate of the Zeeman splitting) and taking into account that in relatively weak (up to 2 MG) fields $\theta_r \approx 0$, we obtain $C_r D = 1.05\times 10^3$ deg/cm. Assuming that $C_r = -3.49\times 10^{19}$ min·rad/cm·sec, we can calculate the dependence $\theta = \theta_p + \theta_d + \theta_r$ shown in Fig. 2. Notice that the calculation closely fits the experiment. The fact that the transmission does not decrease in the resonance region can be attributed to the increase in the strength of the oscillators of the electric dipole transitions as a result of variation of the "mixing" of the levels in the strong magnetic field, which is due to the crystal field. Such an effect was observed by Boĭko and Soĭka.[5]

The dispersion dependence[6] $\theta(\lambda)$ indicates that the $^4I_{15/2} \rightarrow {}^4I_{9/2}$ (650 nm) transition is a magnetic dipole transition and the frequency of the transition $-15/2 \rightarrow -9/2$ between the sublevels increases by $[g(^4I_{15/2})(15/2) - g(^4I_{9/2})(9/2)]\mu_B B$ due to splitting in the magnetic field. The spectroscopic values of the g factors show that in $\approx$3-MG fields the frequency of this transition coincides with the emission frequency. We accordingly attribute to this transition the enhanced absorption in a $\approx$3-MG field (Fig. 2) observed in the experiment; moreover, since it is a magnetic-dipole transition (the removal of forbiddenness is due to the crystal field), it can be classified as an electron paramagnetic resonance at the optical frequency.

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