Reflection of light from the boundary of chiral gyrotropic medium

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(Submitted 7 May 1990)
Pis'ma Zh. Eksp. Teor. Fiz. **51**, No. 11, 591–593 (10 June 1990)

It has been shown experimentally that there is no circular dichroism within 10^{-7} in a light reflected from an isotropic chiral gyrotropic medium. This circumstance makes it possible to determine whether the constitutive equations for these media have been chosen correctly.

The optics of chiral gyrotropic media attracts now considerable attention of physicists, because of the discovery of parity violation in weak interactions, and biologists, since active biological substances exhibit chiral properties. The final decision as to the correct choice of the constitutive equations for discribing the optical effects in such media has so far, however, not been made. Since the discussion of this topic has until now been of a purely theoretical nature,[1] we will describe here a simple experiment which would allow us to determine whether the constitutive equations for the chiral gyrotropic media are suitable equations. To the best of our knowledge, this is the first experiment of this kind.

Two types of constitutive equations for gyrotropic media have been discussed in the literature. The first type, proposed in Ref. 2 for the first time, can be described as follows. (For simplicity, we will restrict the analysis to the case of the isotropic chiral media.)

$$\begin{cases} \mathbf{D} = \epsilon \mathbf{E} - g\dot{\mathbf{H}} \\ \mathbf{B} = \mu \mathbf{H} + g\mathbf{E}, \end{cases} \tag{1}$$

where **D**, **B**, **E**, and **H** are respectively the electric induction and magnetic induction and the electric and magnetic fields of the light wave, and the parameter g is responsible for the chirality of the medium. The second type of constitutive equations was proposed by Born.[3] These equations are

$$\begin{cases} \mathbf{D} = \epsilon \mathbf{E} + p\dot{\mathbf{H}} \\ \mathbf{B} = \mu \mathbf{H}. \end{cases} \tag{2}$$

It was shown that these equations can be used to describe optical effects in homogeneous media without setting them at odds with each other. As to the propagation of light in inhomogeneous chiral media, however, the use of these equations gives fundamentally different results.[4] This case is most graphically illustrated in the calculation of the corrections for the Fresnel formulas at the boundary of the chiral medium.[5]

To experimentally verify this case, it would be useful to choose an optical arrangement that would permit the results predicted by these theories to be qualitatively different and that would eliminate to the maximum extent the accompanying interfering optical effects during the experiment. Such a case, in our view, is one in which light is reflected from a boundary of an isotropic chiral medium with a normal incidence.

The reflection coefficients of circularly polarized waves normally incident at a boundary of an isotropic chiral medium are, as was shown in Ref. 6, given by

$$r_{\mathrm{I}}^{\pm} = \frac{n_2 - n_1}{n_2 + n_1}; \qquad r_{\mathrm{II}}^{\pm} = \frac{n_2^{\pm} - n_1}{n_2^{\pm} + n_1}, \tag{3}$$

where n_1 and n_2 are the reflective indices of the boundary media, without allowance for the chiral gyrotropy, $r_{\mathrm{I}}^{\pm}$ are the reflection coefficients of the circular waves which correspond to Eq. (1), and $r_{\mathrm{II}}^{\pm}$ are the reflection coefficients of the circular waves which correspond to Eq. (2). We used the standard boundary conditions in each case. The refractive indices for the circular waves are

$$n_{\mathrm{I}}^{\pm} = n_2(1 \pm g); \qquad n_{\mathrm{II}}^{\pm} = n_2(1 \pm \frac{1}{2}p). \tag{4}$$

Equations (3) show that $r_{\mathrm{I}}^{\pm}$ is qualitatively different from $r_{\mathrm{II}}^{\pm}$, since in a linear approximation in the gyration parameter $r_{\mathrm{I}}^{\pm}$ does not depend on the chirality of the medium. This result was checked in our experiment which we will describe below.

As a sample to be tested we used a wedge-shaped α-$\mathrm{LiIO_3}$ crystal (lithium iodate), whose working surface was normal to its optical axis. This crystal is known[7] to have a large rotation coefficient $\theta = 86.8°/\mathrm{mm}$ for $\lambda = 0.63\ \mu\mathrm{m}$ and $n_2 = 1.9$. Using these data and Eqs. (3) and (4), we find for case $n_1 = 1$ (air)

$$\begin{aligned} R_{\mathrm{I}}^{\pm} &= |r_{\mathrm{I}}^{\pm}|^2 = \left(\frac{n_2 - n_1}{n_2 + n_1}\right)^2 = 9.6 \cdot 10^{-2} \\ R_{\mathrm{II}}^{\pm} &= |r_{\mathrm{II}}^{\pm}|^2 = \left(\frac{n_2 - 1}{n_2 + 1}\right)^2 \pm \frac{4(n_2 - 1)}{(n_2 + 1)^3}\,\frac{\lambda\theta}{360} = 9.6\times 10^{-2} \pm 2.24\times 10^{-5}. \end{aligned} \tag{5}$$

We see that a circular dichroism occurs in the second case upon reflection and there is no such dichroism in the first case,

$$\Delta R = R_{\mathrm{II}}^{\pm} - R_{\mathrm{I}}^{-} = \frac{8(n_2 - 1)}{(n_2 + 1)^3}\,\frac{\lambda\theta}{360} = 4.5\times 10^{-5}. \tag{6}$$

We have used a modulation method of measuring circular dichroism.[8] The experimental setup is shown schematically in Fig. 1. As a light source we used a stabilized LGI-302 laser with $\lambda = 0.63\ \mu\mathrm{m}$ ($P = 1$ mW). To eliminate the effect of the reflected beam on the laser, the incidence angle was changed by ≈2° from the normal angle. Estimates showed that this adjustment has only a slight effect on the results of the measurements. As the ellipticity modulator we used an electrooptic ML-102 mod-

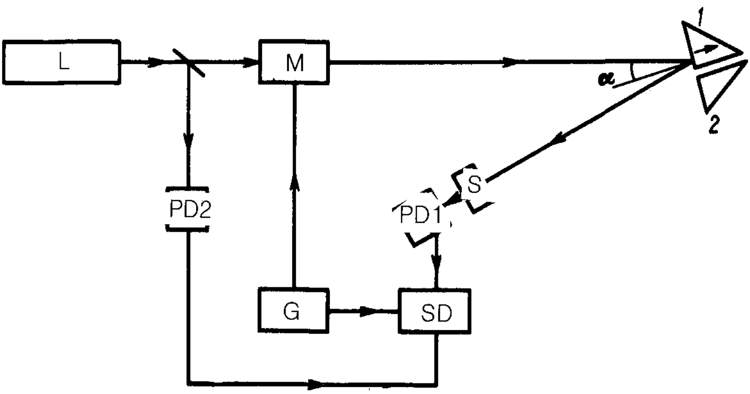

FIG. 1. Experimental setup. L—Laser; M—modulator; G—generator; SD—synchronous detector; S—scatterer; PD1—photodetector PD1; PD2—photodetector PD2; $\alpha < 2°$; *1*—α-LiIO$_3$ crystal; *2*—glass prism.

ulator whose voltage supply source was a GZ-56/1 audio-frequency oscillator. Differential on–off switching of the FP1 and FP2 photodetectors has made it possible to decrease the effect of the amplitude noise of the laser upon separating out the circular dichroism signal in the photocurrent of the photodetector FP2. To cancel the effect of the anisotropy of the photodiode, we have placed a light scatterer LS in front of it. To eliminate the systematic errors, we compared the crystal reflection dichroism with the dichroism which occurs at the boundary of the glass wedge which was placed next to the crystal. This allowed us to change them quickly without offsetting the optical arrangement. Averaging over many measurements has shown that circular dichroism is absent, within 10%, in each case. It can thus be asserted that the constitutive equations (1) are more suitable for describing the interaction of light with chiral media.

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Translated by S. J. Amoretty