Demonstration of phenomena of conical refraction

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Phenomena of conical refraction in optically biaxial crystals together with the usual birefringence of light at the boundary of optically anisotropic media are amongst the most striking demonstrations of noncoincidence of directions of group and wave velocities of light in crystals when the whole cone of wave normals may correspond to one direction of the energy flux vector (the Poynting vector of a beam) and, vice versa, the whole cone of light beams—to one wave normal[1-2].

However, the possibility of observation of these phenomena was quite limited until the present day. It applies especially to the case of so-called external conical refraction (see below), and quantitative studies of these cases of light propagation are almost nonexistent though the phenomenon of conical refraction has been of interest in nonlinear optics recently[5,6].

Using contemporary crystals and contemporary light sources we, for the first time, made the lecture demonstration of the experiment on external conical refraction and repeated experiments on internal conical refraction. Quantitative studies of conical refraction are being introduced into laboratory and lecture courses of crystalloptics at the department of physics of crystals of the physics faculty of the Moscow university.

1. PHENOMENON OF EXTERNAL CONICAL REFRACTION

For the demonstration of this phenomenon the crystals of ammonium oxalate $[(NH_2)_2C_2O_4 \cdot H_2O]$ and lithium formate $(LiHCO_3 \cdot H_2O)$ were used, the latter being more accessible for experimentalists than the former. This choice was not done accidentally, for these crystals have relatively large vertex angle of the cone of refraction[7-10]. The crystal of ammonim oxalate has the angle $\varphi = 5°15'$ and that of lithium oxalate-$\varphi = -5°02'$. Let us note for comparison that $\varphi \approx 1°36'$ for aragonite.

All this allowed us to perform the demonstration rather simply and to observe a light ring at the screen situated on a distance ~3.5 m from the crystal with a diameter ~0.5 m (Fig. 1).

For evaluation of dimensions of the light ring on the screen, the hand of the lecturer explaining the demonstration has been photographed against the background of the ring. However, the rings with diameters of several meters can be observed by use of an argon laser.

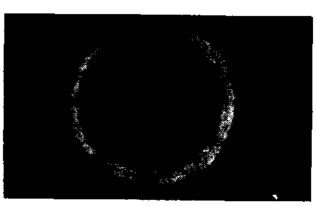

FIG. 1.

The diagram of the installation which was used in the experiment is shown in Fig. 2, where 1—He-Ne laser with power 20 mw; 2—$\lambda/4$ plate for transformation of linearly polarized light into circularly polarized light; 3—microscope objective with magnification 21 and aperture $D/r = 0.4$ focused onto the entrance surface of the crystal; 4—crystal; 5—aperture with a diameter 200 microns; 6—polaroid (for one of series of experiments); 7—screen.

The crystals were inserted into the special frame which pressed the aperture closely to the crystal. The frame was fastened to the mount which had four degree of freedom: rotation around the light beam axis and the axis perpendicular to the beam and translational movement in two orthogonal directions.

The crystals were oriented so that the light propagated along the biradial. For this purpose it was necessary to turn them by 3–4° because they were cut perpendicular to the binormal. The polarization of the light which passed through the crystal is a characteristic feature of the phenomenon of conical refraction, internal, as well as external.

Light is linearly polarized in every point of the light ring obtained on the screen, but at the same time there is no one pair of points with the same polarization of the light[3].

That is why, with use of a polaroid 6 in the optical scheme, a dark spot was formed in one place of the light ring observed on the screen; this moved along the ring upon rotation of the polaroid (Fig. 3).

Experiments with polaroid prove unambiguously that the phenomenon observed is conical refraction. Such a set of light polarizations distinguishes conical refraction from other optical phenomena connected with production of rings.

In conclusion, we note that the lecture demonstration of the phenomenon of external conical refraction is possible only with contemporary light sources possessing sufficient intensity of a collimated light beam.

2. INTERNAL CONICAL REFRACTION

Observation of this phenomenon was made with the same crystals of ammonium oxalate and lithium form-

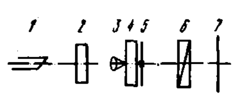

FIG. 2.

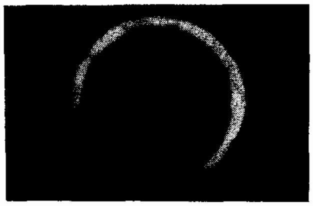

FIG. 3.

ate as in the previous experiment. The vertex angle χ of the cone of internal conical refraction of these crystals is relatively large. For ammonium oxalate, $\chi = 5°28'$ and for lithium formate, $\chi = 5°18'$, for aragonite, $\chi = 1°52'$.

In addition, it was possible to grow lithium formate crystals of large thickness (~2 cm) which is important for experiment because in this case it was possible to observe a light ring of sufficiently large diameter at the exit from the crystal (~2 mm for lithium formate).

The diagram of experimental installation is shown in Fig. 4, where 1—incandescent lamp, 2—aperture with $D = 100$ microns, 3—crystal, 4—measuring microscope with ocular magnification 15 and objective magnification 3.7 focused on the exit surface of the crystal, 5—polaroid. The same crystals and mounts were used as in the case of external conical refraction.

When a polaroid was installed, a dark spot was observed in a certain place of the light ring which moved along the ring. This was confirmation that the ring obtained was due to the conical refraction, because only in this case was such polarization of light transmitted through the crystal possible. Upon precise adjustment of the crystal it was possible to observe the characteristic dark region between two light rings.[11]

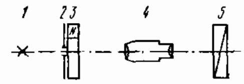

FIG. 4.

In both cases the comparison of calculated values of vertex angles of refraction cones according to the given values of ε_x, ε_y and ε_z with measured values of these angles comprised the quantitative part of the described experiments.

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