Methodological Notes

EXPERIMENTS ON REFRACTION AND REFLECTION OF POLARIZED LIGHT

D. I. SAKHAROV

Usp. Fiz. Nauk **74**, 177-179 (May, 1961)

As is well known, the direction of the plane of polarization changes upon reflection and refraction of linearly polarized light. It follows from Fresnel's formulas* that there is no rotation of the plane of polarization when the angle of incidence is equal to zero, and also in cases in which the angle between the plane of polarization of the incident ray and the plane of its incidence is equal to 0° or 90°. It can be seen from these formulas that the angle through which the plane of polarization is rotated in reflection or refraction depends little on the wavelength of the incident light. It is also known that in the case of total reflection from the boundary between two dielectrics, or for reflection from a metallic surface, linearly polarized light becomes elliptically polarized. If at the same time the angle between the plane of polarization of the incident wave and the plane of its incidence is close to 0 or to 90°, then the reflected light remains practically linearly polarized.

As a consequence, linearly polarized light becomes depolarized on passing through a transparent medium containing a large number of fine inclusions of transparent material with an index of refraction which is different from the index of refraction of the medium. This effect is the greater the larger the number of reflections and refractions that take place in the transmission of the light through this medium.

The rotation of the plane of polarization in reflection and refraction, and the depolarization in light scattering can be illustrated by the following simple demonstrations. To carry them out, two polaroids are necessary (for example, in the form of two discs 20 cm in diameter). The polaroids are set parallel to one another and to a screen, and are illuminated from the reverse side by white light. In the space between the polaroids, the light should be incident only through the polaroid closest to the illuminated screen. Observations (or photography) are carried out through the second polaroid. The experiments are conducted in a darkened room.

*The formulas have the form

$$\tan \beta = \tan \alpha \frac{\cos (i_1 + i_2)}{\cos (i_1 - i_2)},$$

$$\tan \gamma = \tan \alpha \frac{1}{\cos (i_1 - i_2)}.$$

Here α, β and γ are the angles between the plane of incidence of the ray and the plane of vibration in the incident, reflected and refracted rays, while i_1 and i_2 are the angles of incidence and refraction.

1) A glass tube (an empty test tube) is placed between the polaroids. It is shown that for parallel principal planes of the polaroids the tube appears light in the center and dark at the edges. The polaroids are then crossed and the tube rotated about an axis perpendicular to the direction of the polaroids. In this case, there are two mutually perpendicular positions of the tube for which it appears dark (the light does not pass through the second polaroid). When the tube makes an angle of 45° to these positions, the walls of the tube are bright while the center remains dark (Fig. 1). This is explained by the fact that the light

FIG. 1

passing through the first polaroid, upon refraction in the walls of the tube, changes the direction of the plane of polarization and therefore passes through the second polaroid; in the center of the tube, where the angle of incidence of the light is close to 0°, the direction of the plane of polarization remains unchanged and the second polaroid blocks the light. For those positions of the tube for which the edge of the tube as well as the middle appear dark, the angle between the plane of polarization and the plane of incidence is 0 or 90°, and there is likewise no rotation of the plane of polarization.

2) A round glass bulb (or soap bubble) is placed between the crossed polaroids. The center of the bulb and four regions on the edges appear dark, forming a figure that is approximately cross-shaped. Bright parts of the glass bulb appear between the dark regions of the cross (Fig. 2). Upon rotation of the bulb

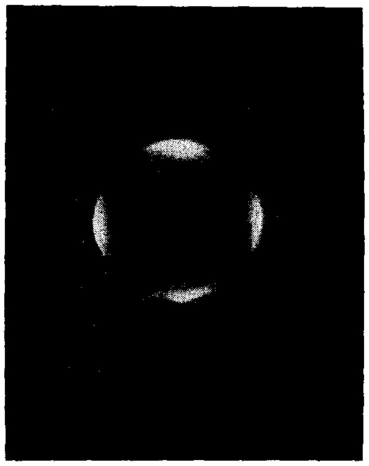

FIG. 2

about an axis perpendicular to the direction of the polaroids, the direction of the dark cross is maintained. Upon transition from the crossed position of the polaroids to parallel, the cross is replaced by two dark bands which disappear upon further rotation of one of the polaroids. The explanation of these phenomena is similar to that for the case of the tube.

3) If a blown glass sphere is put in contact prior to hardening with a cold metallic surface, then a small region is formed in the glass at the point of contact, the index of refraction of which differs from that of the surrounding glass. When such a sphere is placed between crossed polaroids, a small dark cross is seen in addition to the large one (or the sort shown in Fig. 2); the small cross is sometimes very regular in shape. The direction of this cross is identical with the direction of the large cross and also remains unchanged upon rotation of the tube about an axis perpendicular to the plane of the polaroids. At the base of a test tube, which is heated to softening and deformed by direct contact with a cold plane surface, a dark cross is seen against a bright background (Fig. 3) upon observation between crossed polaroids. Complicated figures of several dark crosses or dark rings, parallel to the fused edges of the tube, are seen close to these ends. The reason for the appearance of the dark crosses is the same: rotation of the plane of polarization upon refraction at the boundaries of regions with a change in the index of refraction.

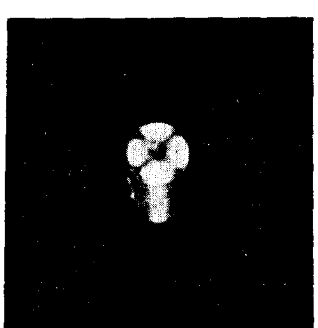

FIG. 3

4) A metallic tube of conical shape with a polished inner surface is placed between the polaroids. Four dark bands are seen (through crossed polaroids) at the inner surface of the tube (Fig. 4). The position of the dark bands is the same as in the case of a circular tube. Upon rotation of one of the polaroids, the dark bands rotate in the same direction and are weakened. For parallel polaroids, bright bands are observed at those places where there were dark bands for crossed polaroids; they are barely visible against a general bright background.

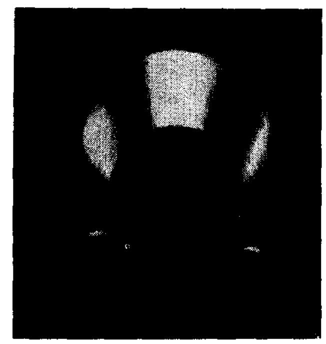

FIG. 4

In contrast with the phenomena observed in placing anisotropic bodies between the polaroids, the pictures observed in experiments (1) — (4) are in black and white; no color is observed.

5) A thin sheet of white or colored paper, white bird feathers, a layer of white powder or soap suds, opal or frosted glass, flowers of different colors, were also placed between the crossed polaroids. All such bodies are self-luminous, while the coloring of the bodies is in no way changed. The intensity of their illumination in the rotation of one of the polaroids remains unchanged, which demonstrates the almost complete depolarization of the light that passes through these bodies.

6) A vertical cuvette with plane-parallel sides is placed between two polaroids. The cuvette is filled with a weak solution of milk and water. A thick glass plate is placed so that the light in different parts of the cuvette passes through layers of milk of different thickness. If a suitable concentration of milk solution is chosen, then the layer of milk in the case of parallel polaroids is brighter the thicker the layer, while the opposite is the case for crossed polaroids. This means that for a given concentration of the solution, an increase in the number of particles producing the depolarization, in the transition to a thicker layer, has more importance than the increase in the absorption of the light.

Translated by R. T. Beyer