Classroom

In this section of *Resonance*, we invite readers to pose questions likely to be raised in a classroom situation. We may suggest strategies for dealing with them, or invite responses, or both. "Classroom" is equally a forum for raising broader issues and sharing personal experiences and viewpoints on matters related to teaching and learning science.

Birefringence of Mica

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Low-cost and easy to setup experiment to determine birefringence of mica using a laser source and a quarter wave plate.

Theory: In an anisotropic crystal, the direction of electric displacement vector **D** is generally different from that of the electric field **E** except in three mutually orthogonal directions designated as X, Y and Z. The dielectric constants along X, Y and Z, designated as ε_a, ε_b and ε_c are the three *principal dielectric constants.* For any direction of the wave front, there are two velocities for vibrations of **D** in two mutually perpendicular directions. The existence of two velocities along a direction, gives rise to the phenomenon of *double refraction*, also known as *birefringence.*

The above can be visualized with the help of a *dielectric ellipsoid* (*Figure* 1) which can be described by the equation

$$\frac{x^2}{\varepsilon_a} + \frac{y^2}{\varepsilon_b} + \frac{z^2}{\varepsilon_c}\ . \qquad (1)$$

The three velocities and refractive indices corresponding

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Birefrigence, retarding plate, dielectric axis, biaxial crystal, double refraction, negative birefringent material.

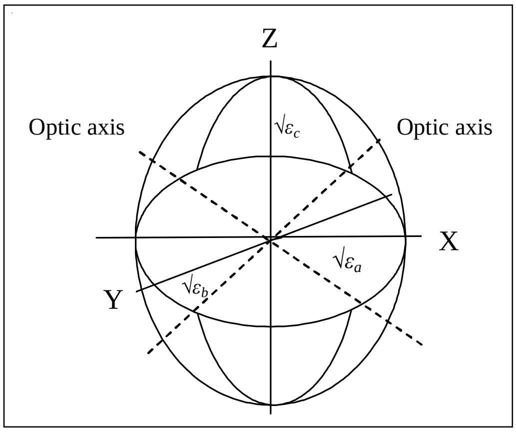

Figure 1. Dielectric ellipsoid of biaxial crystal.

to ε_a, ε_b and ε_c are given by the following equations:

$$v_a = \frac{c}{\sqrt{\varepsilon}_a}, \quad v_b = \frac{c}{\sqrt{\varepsilon}_b}, \quad v_c = \frac{c}{\sqrt{\varepsilon}_c}\ , \tag{2}$$

$$n_a = \sqrt{\varepsilon}_a, \quad n_b = \sqrt{\varepsilon}_b, \quad n_c = \sqrt{\varepsilon}_c\ , \tag{3}$$

where c is the velocity of light in vacuum.

The values of the refractive indices depend on the frequency of light.

Mica is a negative biaxial birefringent crystal which splits most easily along the YZ cleavage plane. In case of mica, $n_b = 1.5936$ and $n_c = 1.5977$ for sodium light. Therefore, v_b (called the fast ray) has a value higher than v_c (called the slow ray). When a plane polarized light of wavelength λ is incident on a mica sheet of thickness d, the two rays, fast and slow, will emerge with a phase difference δ given by the equation

$$\delta = 2\frac{\pi}{\lambda}(n_c - n_b)d\ . \tag{4}$$

Thus the emerging light becomes elliptically polarized, of which linearly polarized and circularly polarized are special cases. According to Fresnel's theory of optical rotation, the vibration of a linearly polarised light, on passing through a retarding plate, gets rotated through an angle $\theta = \delta/2$. Hence,

$$\theta = \frac{\pi}{\lambda}(n_c - n_b)d \ . \quad (5)$$

When the polarizer and analyzer are set at right angles to each other, no light is transmitted. On inserting a mica sheet between the crossed polarisers, light passes through the combination. This is so because light emerging from the mica sheet is elliptically polarised which has a component parallel to the transmitting plane of the analyser. However, if the vibration direction of the plane polarised light incident on the mica sheet makes an angle of 45° with the Y and Z axes, then the component parallel to the transmitting plane of the analyser is zero and hence no light passes through it.

Principle: By measuring the rotation produced by the mica sheet of a given thickness, the difference between the refractive indices can be determined.

Formula

$$n_c - n_b = \frac{\lambda\theta}{\pi d} \ .$$

Apparatus

Figure 2. Mica in a ring.

- A sheet of mica of known thickness mounted on a circular frame covering half the circle (made in the laboratory by oneself). (See *Figure* 2.)
- Two polaroids P and A mounted on a circular graduated scale.
- Quarter wave plate, which produces a phase difference of $\pi/2$ between the slow and fast components for the wavelength of the incident light.
- Laser ($\lambda = 625$ nm).

Procedure

- Laser light, polariser (P), analyzer (A), quarter wave plate (QWP) and mica sheet are all mounted on stands of the same height and placed in a line as shown in the photograph. (See *Figure* 3.)
- Laser light passes through the polariser P and analyser A and is incident on a white screen.
- The A is rotated till the spot on the sheet vanishes. Now the polariser and analyser are *crossed*.
- The mica sheet is inserted between P and A. The light spot on the screen is visible.
- The mica is rotated till the light spot vanishes again. (Now the electric vibration of the incident ray is at 45° to both Y and Z axes.)
- The P and A are rotated through 45° each in the same direction.
- The QWP is inserted between the mica and analyser and the mica sheet is removed from the path of light. The light spot is visible on the screen.

All the instruments are available at Kamaljeeth Instrument and Services Unit, No.610, 5th Main, 8th Cross, JRD Tata Nagar, Bangalore 560092.
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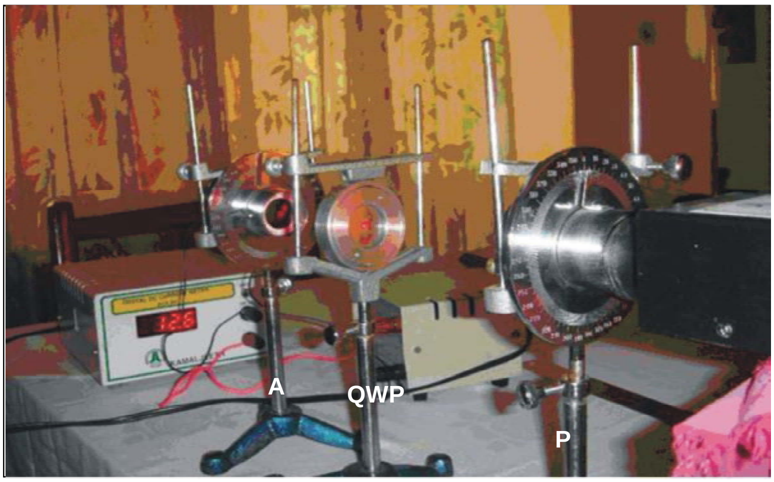

Figure 3.

- The QWP is rotated till the spot vanishes again. The reading on the analyzer is noted as R_1.
- The mica sheet is inserted in the path of light (the light spot is visible again) and the analyzer is rotated till the light spot vanishes.
- The reading on the analyzer is noted as R_2.
- The difference between R_1 and R_2 gives the angle of rotation of the electric vibration emitted by mica ($\theta = R_2 - R_1$).

The birefringence of the mica (of a given thickness) is calculated using the formula given above.

Calculation: The average rotation obtained was 163.5° with a semiconductor laser (λ= 625 nm) for a mica sheet of 0.12 mm thickness.

$$\Delta n = \frac{\theta\lambda}{\pi d} = \frac{163.5 \times 625 \times 10^{-9}}{180 \times 0.12 \times 10^{-9}} = 0.0047\,.$$

Error in measurement of d is the main contributor to estimated error in Δn, which is 8%.

Thus, $\Delta n = .0047 \pm .0004$.

Result: Δn of mica for λ = 625 nm is 0.0047 $\pm$ .0004

Discussion: The expected Δn of mica for sodium light (λ = 589.6 nm) is 0.0041 ([1], p.554). The measured value of Δn for λ =625 nm is reasonable (within the measurement error).

Conclusions: The experiment is useful in demonstrating the following:

• Retarding plates and their function (quarter wave plates and mica). • Optical rotation. • A biaxial crystal has 3 velocities but only 2 rays in any direction.

Suggested Reading

[1] Francis A Jenkins and Harvey E White, *Fundamentals of Optics*, 4th Edition, McGraw-Hill International Edition, 1981.