Construct, Conduct & Comprehend Physics Experiments

LEOK-3-27 Analyse Polarization Status and Verifying Malus' Law

- *Complete set*
- *Cost effective solution*
- *Detailed instructional manual*
- *Easy alignment*

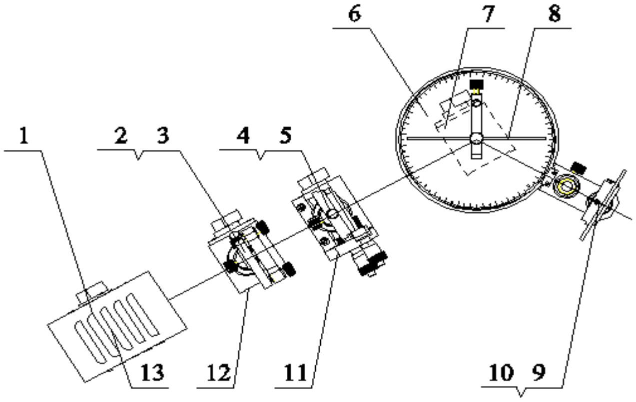

Figure 27-1 Schematic of experiment setup

1: Bromine Tungsten Lamp (LLC-3)
2: Lens (*f'* =150 mm)
3: Two-Axis Mirror Holder (SZ-07)
4: Adjustable Slit (SZ-27B)
5: Lens Holder (SZ-08)
6: Optical Goniometer (SZ-47)
8: Lloyd Mirror (black glass)
9: Polarizer
10: Rotary Lens Holder (SZ-06A)
7, 11, 12, 13: Magnetic Base (SZ-04)

* Other parts needed: sodium lamp (LLE-2), He-Ne laser (LLL-2), 1/4-wave plate, iceland crystal (SZ-48), lens (*f'* = 4.5 mm), kinematic mount (SZ-07).

Theory

a) Brewster's Angle

When unpolarized light travels from a transparent medium with a refractive index n_i to another one with a higher refraction index n_t, part of the light is refracted into the second medium while the other part of the light is reflected back into the first medium, as shown in Figure 27-2.

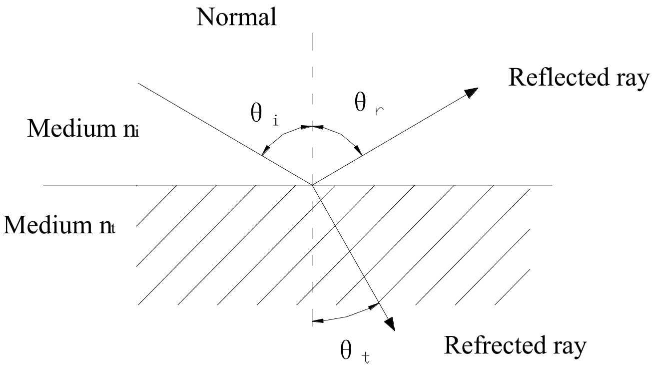

Figure 27-2 Reflection & refraction of light between two media

If the angles of incidence and refraction are θ_i and θ_t, respectively, the following condition exists, known as Snell's law

$$n_i \sin\theta i = n_t \sin\theta t \qquad (27\text{-}1)$$

According to Sir David Brewster, at a specific angle of incidence, q_b, called Brewster's angle, the reflected ray and the refracted ray are perpendicular to each other, so the sum of the incident angle and the refractive angle is 90° as

$$\theta_b + \theta t = 90^\circ \text{, namely } \theta_t = 90^\circ - \theta_b \qquad (27\text{-}2)$$

By substituting equation (27-2) into equation (27-1), we get

$$n_i \sin\theta_b = n_t \sin(90^\circ - \theta_b) = n_t \cos\theta_b$$

$$\tan\theta_b = \frac{n_t}{n_i} \qquad (27\text{-}3)$$

Then the Brewster's angle is:

$$\theta_b = \arctan\frac{n_t}{n_i} \qquad (27\text{-}4)$$

b) Birefringence

Put an iceland spar on a piece of print paper, and we will see two distinct images of words. One image will remain fixed as the crystal is rotated, and the light ray through the crystal is called "ordinary ray" since it behaves just as a ray through glass. However, the other image will rotate with the crystal, tracing out a small circle around the ordinary image. This light ray is called "extraordinary ray". This is the phenomenon of birefringence.

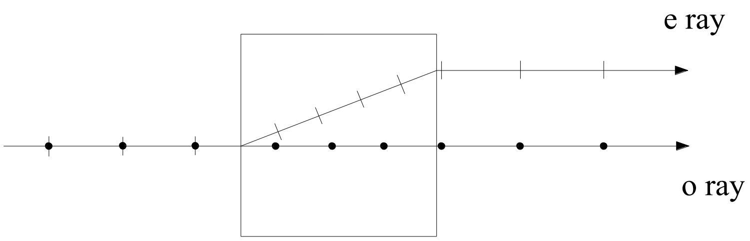

Figure 27-3 Schematic of birefringence

c) Malus' Law

When a light ray passes through a polarizer, then another polarizer, called analyzer, the transmitted light intensity $I(\vartheta)$ leaving out of the second polarizer, is given by Malus' Law

$$I(\theta) = I_0 \cos^2 \theta \tag{27-5}$$

Where I_0 is light intensity incident on the first polarizer, ϑ is the angle of two polarizer axes.

Experiment Procedures

1) Measure Brewster's angle and determine the polarization direction of a polarizer

Let the filament of the Tungsten light source locating on the front focal plane of the lens to create a collimated beam (the distance between the two magnetic bases is about 162 mm). After passing through the slit, the beam is incident onto the black glass at the center of the goniometer disk and light leaves a track along the radial direction on the disk. Rotate the goniometer disk, let the beam have a specific angle incident on the black glass. Then rotate the polarizer one full turn, observe the beam behind the polarizer and let the polarizer stop at the darkest angle position. Then rotate the goniometer disk and the polarizer alternatively, let the observed light becoming dark and dark till the darkest (finely adjust the polarizer angle at the same time). Finally, the polarizer axis lays in the plane of incident and reflection beams of the black glass, and the angle of the incident beam on the surface of the black glass plate is the Brewster's angle (for this black glass, n=1.51, so $i_B \approx 57^o$);

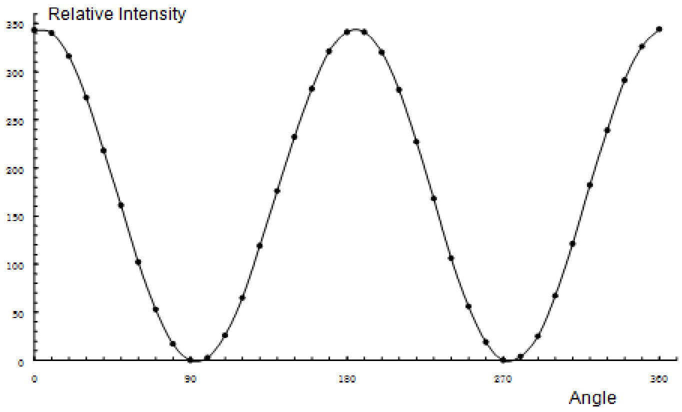

Figure 27-4 Plot of transmitted intensity vs relative angle

2) Analyze linear polarized light and verify Malus' law

Use the He-Ne laser as light source, let the light beam sequentially pass two polarizers and illuminate on the sensor of the light meter. Rotate the second polarizer (i.e. analyzer) until the transmitted laser intensity reaches a minimum value on the light meter. Now the axes of the polarizer and the analyser are perpendicular to each other.

Continue to rotate the analyser until the transmitted laser intensity reaches another minimum value. Check the angular reading of the analyzer, it should be rotated by 180° from the previous angle.

Rotate the analyzer step by step with interval 10º, record the transmitted intensities of the laser and corresponding angle values in a table.

Plot the curve of intensity vs relative angle, as shown in Figure 27-4. This curve verifies the Malus' law.

3) Analyze elliptical polarized beam:

Use the He-Ne laser as light source, insert the ¼ λ wave plate between two orthogonal polarizers with known axis directions (axis direction can be determined in Step 1), let the axis of the ¼ λ wave plate at an arbitrary angle, rotate the analyzer in a full turn (360°), the transmitted light will present dark and bright twice alternatively (use a white screen to receive the transmitted light), at the dark position, the transmission direction of the analyzer is the direction of the short axis of the ellipse.

4) Analyze circularly polarized light and determine the axis of ¼ λ wave plate

Use the He-Ne laser as light source, insert the ¼ λ wave plate between two orthogonal polarizers with known axis directions, when the angle between polarizer and ¼ λ wave plate is 45° or 135°, rotate the analyser and output light intensity doesn't change (use a white screen to receive the transmitted light), therefore the axis of ¼ λ wave plate will be at 45° or 135° with respect to the polarizer axis; the transmitted light from the analyzer is therefore circularly polarized.

Note: the axis of the ¼ λ wave plate is marked on its mount. However, the actual axis direction may be deviated from the mark line. To determine the actual axis direction, place the ¼ λ wave plate in between two crossed polarizers which is illuminated by the He-Ne laser. Rotate the ¼ λ wave plate till the minimum laser output is achieved. At this time, the axis of the ¼ λ wave plate is parallel to the axis of either of the two polarizers.

5) Demonstrate birefringence phenomenon

Hold the Iceland crystal (SZ-48) and look into the aperture from the side of large hole. Two bright spots can be observed. This means the light ray entering the small hole on the front side are split into two rays of slightly different paths. This phenomenon demonstrates the crystal is optically anisotropic or is birefringent. Furthermore, illuminate a He-Ne laser beam into the input aperture of the Iceland crystal, the transmitted beam will be split into two beams, rotate the crystal, *o* beam and *e* beam as well as their polarization directions can be determined using a polarizer.

Note: since this is a natural crystal of educational grade, there might be some cracks inside, which might blur the laser beams.