Experiment 15

DETERMINATION OF THE REFRACTIVE INDEX OFGLASS

The refractive index is measured for different types of glass using two methods: a travelling microscope method and a polarization method.

INTRODUCTION

1. In Geometric Optics the propagation of light is represented by rays which move along a line in the direction of travel of the light wave. In a homogeneous and isotropic material the rays are straight lines normal to the wave front. At a boundary between two materials the speed of light and the direction of the rays usually change. The refractive index (index of refraction) of an optical material is defined as the ratio of the speed of light c in vacuum to the speed v of light in the material

$$n = \frac{c}{v} \tag{15.1}$$

n is always greater than unity, n>1, as the light speed in a material is lower than in vacuum.

When a light strikes a surface separating two materials, a and b, it is partly reflected and partly refracted (transmitted) into the second material (figure 15.1).

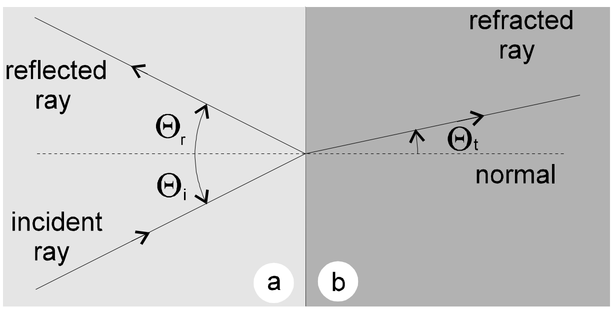

Fig. 15.1. Reflection and refraction of light striking a surface separating materials a and b. Θ_i is the angle of incidence, Θ_r is the angle of reflection and Θ_t is the angle of refraction

Experimental studies shows that the incident, reflected and refracted rays and the normal to the surface all lie in the same plane. The angle of reflection Θ_r is equal to the angle of incidence Θ_i (law of reflection)

$$\Theta_r = \Theta_i \tag{15.2}$$

The ratio of the sines of the angle of incidence Θ_i and the angle of refraction Θ_t is equal to the inverse ratio of the two refractive indexes (law of refraction or Snell's law)

$$\frac{\sin\Theta_i}{\sin\Theta_t} = \frac{n_b}{n_a} = n_{ba} \tag{15.3}$$

Here n_{ba} is the refractive index of material b with respect to material a. From equation (15.3) it is seen that if $n_b > n_a$, the angle Θ_t is smaller than Θ_i and the ray is bent toward the normal. When $n_b < n_a$, the ray is refracted away from the normal.

2. When the oscillations in the traveling wave occur only in one direction, that is perpendicular to the direction of propagation, the wave is linearly polarized in the direction of the oscillations. Polarization occurs only for transverse waves which include electromagnetic waves. Light from ordinary sources is not polarized but can be linearly polarized by using polarizing filters. These filters exploit dichroizm which is an ability of a material to absorb one of the polarized components much more strongly than the other. The direction of polarization of an electromagnetic wave is defined to be the direction of the electric field vector $\mathbf{E}$.

Unpolarized light can also be polarized during reflection from the surface between two optical materials. The reflected light is polarized in the direction parallel to the reflecting surface. For an arbitrary angle of incidence the light will be partially polarized. However for an angle Θ_p called the polarizing angle for which the reflected ray is perpendicular to the refracted ray, the reflected light is polarized completely. For this case, from law of refraction the following expression is obtained

$$\tan\Theta_p = \frac{n_b}{n_a} = n_{ba} \tag{15.4}$$

This is Brewster's law. The refracted light is always partially polarized with the degree of polarization being the greatest at an angle of incidence equal to Θ_p.

APPARATUS AND METHOD

In the first experimental method a travelling microscope with a vernier scale is used to find two positions where a marked cross is in focus. The first position corresponds to observation with the glass plate on the bench of the microscope and the second without it. For both positions of the telescope the readings of the vernier are taken. The principle of the measurement of the refractive index is illustrated in figure 15.2. The marked point P is observed through the glass plate.

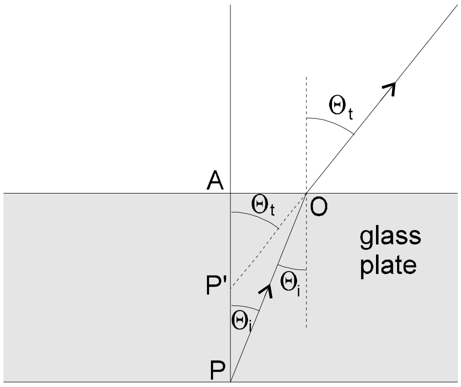

Fig. 15.2. Illustration of the principle of the measurement of the refractive index of a glass plate

Rays coming from P refract at the surface. Consequently an observer sees the image of P at P´ and it is shifted upwards by a distance PP´ = h for a given thickness of the glass plate AP = d. From the law of refraction

$$\frac{1}{n} = \frac{\sin\Theta_i}{\sin\Theta_t} = \frac{P'O}{PO} \tag{15.5}$$

For a small angle of incidence Θ_i P´O and PO can be approximated by AP and AP' respectively. Then from (15.5) the refractive index is given by,

$$n = \frac{d}{d - h} \tag{15.6}$$

In the second method to measure the refractive index the experimental arrangement shown in figure 15.3 is used. The light reflected from the glass plate

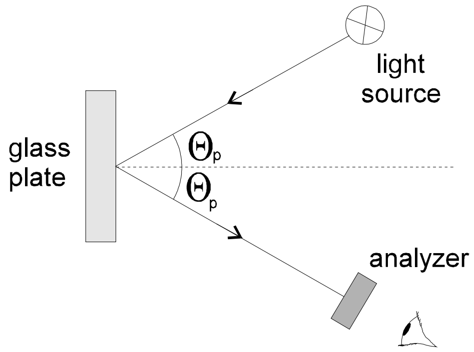

Fig. 15. 3. Schematic diagram of the apparatus to measure the refractive index of a glass plate using the polarization method

is observed at different angles of reflection Θ_r ($\Theta_r = \Theta_i$) and the degree of polarization is recorded for different values of Θ_r using an analyzer. The analyzer is rotated around its axis and for incident light with complete polarization the intensity of light transmitted by the analyzer is (Malus's law)

$$I = I_m \cos^2 \varphi \tag{15.7}$$

where I_m is the maximum intensity and φ is the angle between the direction of polarization of light and the polarizing axis of the analyzer. For $\varphi = \frac{\pi}{2}$ the intensity of the transmitted light is zero, which is also an indication of the complete polarization of the incident light. Thus in the experiment for $\Theta_r = \Theta_p$ zero intensity will be observed while rotating the analyzer. However for other angles of incidence there will be only a minimum in the intensity as the reflected light is partially polarized. Knowing Θ_p the refractive index is calculated from equation (15.4) (Brewster's law).

MEASUREMENTS

1. Find the refractive index of the glass plates provided using the travelling microscope method. Make the measurements of the distance h and the thickness of the plate d 7 times and find the mean value with the standard deviation (see (6) for the expression used to calculate the standard deviation). Calculate n using the mean values of h and d. Note that readings of the vernier scale are taken with an accuracy of 0.01mm.

2. Find the refractive index of the glass plates provided using the polarization method. Make the measurements of the polarizing angle Θ_p 7 times and find the mean value with its standard deviation. Calculate n using that value of Θ_p.
3. Compare the obtained results with the values of refractive index given in table 9.

ANALYSIS OF ERRORS

The errors in the measurements of n are expressed as standard deviations σ_n and are calculated from the following formulae. For the first method

$$\sigma_n = \sqrt{\left(\frac{\partial n}{\partial d}\right)^2 \sigma_d^2 + \left(\frac{\partial n}{\partial h}\right)^2 \sigma_h^2} = \sqrt{\left(\frac{h}{(d-h)^2}\right)^2 \sigma_d^2 + \left(\frac{d}{(d-h)^2}\right)^2 \sigma_h^2} \tag{15.8}$$

and for the second method

$$\sigma_n = \left(\frac{\partial n}{\partial \Theta_p}\right) \sigma_\Theta = \frac{1}{\cos^2 \Theta_p} \sigma_\Theta \tag{15.9}$$

Here σ_d, σ_h and σ_Θ are the standard deviations in the measurements of d, h and Θ_p respectively. σ_Θ should be expressed in radians.

QUESTIONS

1. Describe total internal reflection and find the critical value of the angle of incidence.
2. Prove that a ray of light reflected from a plane mirror rotates through an angle 2α when the mirror rotates through an angle α about an axis perpendicular to the incident and reflected rays.
3. What does the refractive index of a given material depends on?
4. Describe the concept of wave polarization for the case of mechanical and electromagnetic waves.