Refraction

Purpose

When light encounters a new medium, such as a lens, it will either be reflected or it will enter the new medium, in which case it is refracted. Refraction is the process in which light "bends" as it moves from one medium to another. This process of refraction is what causes a lens to focus light to a point. In this lab, we will examine the reflection and refraction of light.

Theory

The law of reflection, Equation 1, is very simple. It states that the incident angle, θ_1 , is equal to the reflected angle, θ_2 , where both angles are measured relative to the "normal," an imaginary line perpendicular to the surface from which light is reflecting.

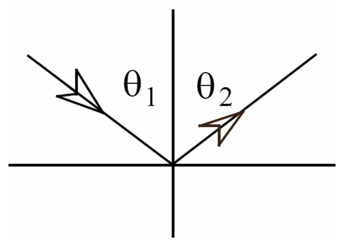

Figure 1

$$\theta_1 = \theta_2 \qquad (1)$$

Refraction occurs because the speed of light depends on the medium in which the light is traveling. To compare the speed of light in various media, one uses the ratio of the speed of light in vacuum to the speed of light in the medium. This quantity is always greater than one and is a property of the material. It is known as the index of refraction.

$$n = \frac{c}{v} \qquad (2)$$

where n is the index of refraction, v is the velocity of light in the medium and c is the speed of light in vacuum.

Suppose that a wave of light travels from one medium, having index of refraction n_1, into a second medium, having index of refraction n_2. If $n_2 > n_1$, the velocity of the wave in medium 1 is greater than the velocity in medium 2. This means that the wave fronts in medium 1 travel further than the wave fronts in medium 2 in the same period of time. As a result, we observe the light to "bend" as it moves from one medium to another.

This "bending" is described by Snell's Law, which relates the incident angle, θ_1, to the refracted angle, θ_2, given in Equation 3.

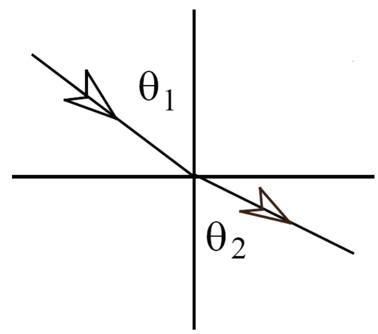

Figure 2

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 \qquad (3)$$

As a side note, the index of refraction, while a property of the medium, is not a constant in the medium. It also depends on the wavelength of light. This effect is known as dispersion and accounts for the rainbow and the spectrum that is produced by a prism.

Procedure

In order to get accurate results, it is important to have the laser carefully aligned, so that it passes over the center of the optical bench. Before you begin taking data, be sure to align the laser as described below - proper alignment of the laser is critical to the success of this lab.

1. Place the 2 mm aperture (Slide 9119) on the carrier approximately 10 cm from the laser. Adjust the laser until it lands squarely on the 2mm aperture.

2. Place the aperture slide on the carrier about 90 cm from the laser and again adjust the laser until it lands squarely on the 2mm aperture.

3. Repeat steps 2 and 3 until the laser falls on the 2mm aperture in both locations without further adjustment.

4. Place the aperture as close to the laser as possible.

You are now ready to begin this lab.

Part 1: Refraction in an Acrylic Plate

In this part, we examine what happens to light as it passes through an acrylic plate and use Snell's Law to determine the index of refraction of the acrylic plate.

According to Snell's Law, the light should refract at both the front and rear surfaces of the acrylic plate. Additionally, some light should be reflected at each surface. Thus, the light will follow paths similar to those seen in Figure 3.

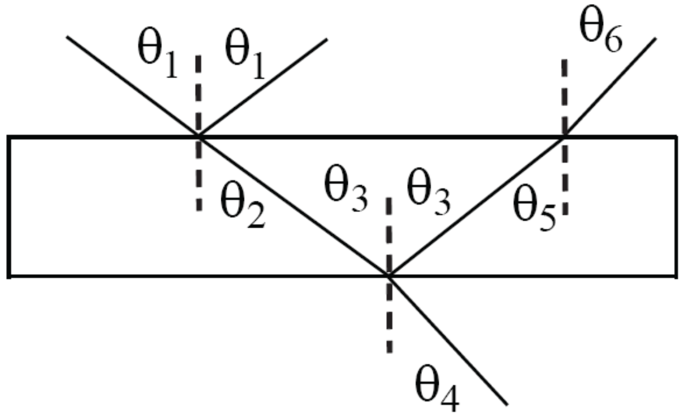

Figure 3

To find the index of refraction using Snell's Law, we need to measure both the incident and the refracted angle, *i.e.* θ_1 and θ_2 (or θ_3) and θ_4 (or θ_5) and θ_6. While it is possible to measure the incident angle directly as we did in Part 1, we cannot measure the refracted angle directly. However, we can calculate the refracted angle from easily-made measurements. From geometry, you should show that $\theta_2 = \theta_3 = \theta_5$.

You should see two dots on the front surface of the acrylic plate. The brighter dot corresponds to the incident light and the dimmer dot corresponds to the light reflected from the back surface of the acrylic plate. Using trigonometry, you should be able to show that:

$$\theta_2 = \tan^{-1}\left(\frac{d}{2\mathrm{t}}\right) \qquad (4)$$

where *d* is the spacing between the dots, *t* is the thickness of the acrylic plate and θ_2 is the refracted angle.

Using the angle table, set the incident angle and measure the spacing between the dot made by the incident beam and the dot made by the reflected beam, *d*. Make this measurement for ten different incident angles.

What is the mean experimental value for the index of refraction of the acrylic plate? How does this compare to the value reported by the manufacturer, n = 1.51?

What might be the cause for any observed differences?

Part 2: Refraction in a Prism

In this part, we examine what happens to light as it passes through a 45-45-90 prism. According to Snell's law, the light should follow a path similar to what seen in Figure 4.

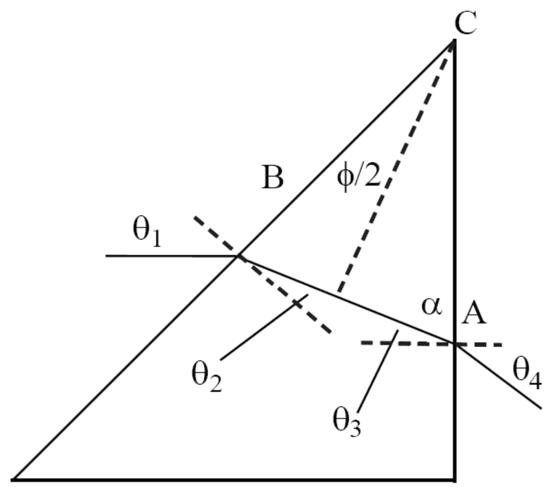

Figure 4

We can measure the incident angle as we did before, but we are unable to measure the refracted angle directly.

Fortunately, there is a way to measure this angle indirectly. At a certain incident angle, the light will traverse the prism "symmetrically," forming the same angle with respect to the normal at each surface (*i.e.* in Figure 4, $\theta_1 = \theta_4$). This occurs at what is known as the "angle of minimum deviation." At the angle of minimum deviation, it is also the case that $\theta_2 = \theta_3$. Why?

From the geometry of the experiment, we can relate the refracted angles (θ_2 and θ_3) to the apex angle of the prism, ϕ.

1. ΔABC is an isosceles triangle. If we draw a line segment CD that bisects the angle ϕ, the resulting triangle, ΔACD, is a right triangle. Thus

$$\alpha + \frac{\varphi}{2} + 90 = 180$$

2. Since θ_2 is measured with respect to the normal,

$$\alpha + \theta_2 = 90$$

3. Combining these results, we find that, at minimum deviation,

$$\frac{-\varphi}{2} + 90 + \theta_2 = 90$$

Or

$$\theta_2 = \frac{\varphi}{2} \qquad (5)$$

And, Snell's Law reads:

$$n_2 = n_1 \frac{\sin\theta_1}{\sin\left(\frac{\varphi}{2}\right)} \qquad (6)$$

To locate the angle of minimum deviation, place the prism on the angle table with the hypotenuse along the centerline. Rotate the angle table so the beam enters from the hypotenuse. As you rotate the angle table, track the motion of the beam on the other side of the prism. At some point, the beam will change directions. When this occurs, the angle of minimum deviation has been reached. Once minimum deviation has been reached, record the position of the table. The incident angle, as always, should be measured from the normal to the incident surface.

What is the mean experimental value for the index of refraction of the prism plate? How does this compare to the value reported by manufacturer, n = 1.518?

What might be the cause for any observed differences?