Lab 7: Refraction
Phys223 - Thursday (Ellis Roe)

Matt Forbes and Stuart(Partner)

March 5, 2012

Purpose

In this week's lab, we observe the behavior of light traveling between mediums which have a different "index of refraction." This index of refraction is a relation of how fast light can travel through a given medium. We first measure the effects of refraction by comparing the angles of incidence and refraction. Then we are able to produce total internal reflection, and determine the critical angle for which this phenomenon occurs. Next, we use Snell's law to find the index of refraction for both water and oil. And finally, we calculate the focal length of a concave lens in two ways, one of which is the lens makers formula.

Procedure

Exercise I: Prism

We shine white light through a prism (in our case, rhombus) in such a way that the refracted light has been separated in to individual colors. Noting that light with a larger frequency has a larger index of refraction for a given material, we are able to predict and verify which color will refract the most.

Exercise I: Slab

Using the same rhombus, but using two parallel surfaces this time, we calculate angle of incidence and refraction of an incident light ray. Making multiple measurements for different angles of incidence, we are able to calculate the index of refraction of the acrylic rhombus by averaging Snell's law.

Exercise II: Total Internal Reflection

In this exercise, we experimentally find the critical angle of the rhombus by finding the angle of incidence which results in only reflection at the surface; that is, no light passes through the incident surface on the rhombus. Using Snell's law, we can determine the theoretical critical angle by setting θ_2 to $90°$ and solving for θ_1.

Exercise III: Application

Here we measure the index of refraction of two substances contained in prisms. To do this, we shine a laser pointer through the prism, marking it's entrance and exit location. Then we find the angle between the incident ray and the refracted ray. With this angle, we can calculate the index of refraction using a given formula.

Exercise IV: The Lens Makers Formula

We shine five parallel rays at a double concave lens, and determine the focal length by finding the distance from the intersection of the reflected rays and the lens itself. Then, knowing the radius of curvature of the lens, we use the Lens Makers formula to find a second value for focal length.

Data/Analysis

Exercise I: Prism

Observing the refracted rays from the prism, we see the following colors: blue, green, yellow, orange, and red. Using Snell's law, we see that:

$$\theta_{\mathrm{r}} \approx \sin\theta_{\mathrm{r}} = \frac{n_1 \sin\theta_{\mathrm{i}}}{n_2}$$

Here, n_2 is 1, air, and n_1 is the index of refraction of the prism. We know that n_2 is proportional to the frequency of light, and since blue light has the largest frequency, we'd expect it to have the most refraction. This is what we see.

Shining the colored rays through the rhombus, we see that the refracted rays intersect, and thus are not parallel. Justification of this can be seen from Snell's law.

Exercise II: Slab

For the following three angles of incidence, we measure the angle of refraction and thus index of refraction.

θ_i	θ_r	n_2
18.0 ± 1	10.5 ± 1	1.69
40.5 ± 1	26.5 ± 1	1.46
26.0 ± 1	17.5 ± 1	1.45

When we average the index of refraction for each of these measurements, we get $\bar{n} = 1.53$. Compared to the actual value of 1.5, we say this is a pretty good method.

Exercise II: Total Internal Reflection

Using the angular part of the rhombus, we determined the minimum angle so that total internal reflection is achieved. Then, measuring the entrance and exit of the ray, we can measure the incident and reflected angle. Our measurements give:

$$\begin{aligned} \theta_c &= 44^\circ \pm 4^\circ \\ \theta_r &= 40^\circ \pm 4^\circ \end{aligned}$$

We would expect these two angles to be equal to each other, because this is just simple reflection as in mirrors. We can calculate the theoretical critical angle using Snell's law as follows:

$$\theta_c = \sin^{-1}\left(\frac{2}{3}\right) = 41.8^\circ$$

The percent difference in the experimental and theoretical values for the critical angle is 5%.

We observe the brightness of the internally reflected ray increase as the incident angle is increased past the critical angle. We know that the critical angle is inversely proportional to the index of refraction. n will be smaller for violet light, thus the critical angle will be greater.

Exercise III: Application

In this exercise, we need te measure the angle, δ, which is how much the refracted ray deviates from the incident angle in the prism. Using this angle and a provided geometric formula, we can determine the index of refraction for the substance:

$$n = \frac{\sin\left[\frac{1}{2}(\theta + \delta)\right]}{\sin\left[\frac{1}{2}(\theta)\right]}$$

For water, we measure $\delta = 22.5^\circ \pm 1^\circ$ using the procedure described above. Simply plugging in δ in to the formula, we find that $n = 1.39$ which is quite close to the known value of 1.33.

For the oil substance, we similarly measure $\delta = 38^\circ \pm 1^\circ$ and find $n = 1.51$.

Exercise IV: The Lens Makers Formula

First we measure the radius of convergence for the double concave lens as 13.6 cm and focal length of 6.8 cm using the technique from lab 6. Using $R_1 = R_2 = -6.8cm$ and $n = 1.5$ for the lens, we calculate the focal length with the Lens Makers formula:

$$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

Solving for f and plugging in our measurements:

$$\begin{aligned} f &= \frac{1}{(n-1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right)} \\ &= \frac{1}{\left(\frac{1}{2}\right)\left(\frac{2}{-6.8}\right)} \\ &= -6.8\text{cm} \end{aligned}$$

So the focal length of a concave lens is negative, as we found using the Lens Makers formula. The thickness of the lens could possibly change the radius of curvature, and thus the focal length.

Conclusion

We thoroughly investigated properties of light traveling between mediums and how different materials can change the angle for which light refracts. Throughout, we find Snell's law to be a very useful tool in predicting how light will react to an interface between two mediums. Also, we determine the conditions for refraction, the minimum angle called the critical angle. Finally, we find a new way to determine focal length using the index of refraction and radius of curvature of a lens.