Physics 197 Lab 5: Reflection and Refraction

Equipment:

Item	Part #	Qty per Team	# of Teams	Total Qty Needed	Storage Location	Qty Set Out	Qty Put Back
Basic Optics Light Source	PASCO OS-8517	1	8	8			
Power Cord for Light Source		1	8	8			
Ray Optics Set	PASCO Basic Optics	1	8	8			
Protractor		1	8	8			
Compass to draw circle		1	8	8			

Layouts:


Figure 1: Equipment


Figure 2: A-Dispersion


Figure 3: B-Total Internal Reflection


Figure 4: C-Snell's Law

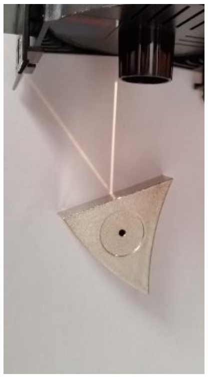


Figure 5: D-White Reflection


Figure 6: E-Color Reflection


Figure 7: F-Concave Mirror


Figure 8: G-Convex Mirror


Figure 9: H-Convex Lens


Figure 10: I-Concave Lens


Figure 11: J-Convex/Concave Lens

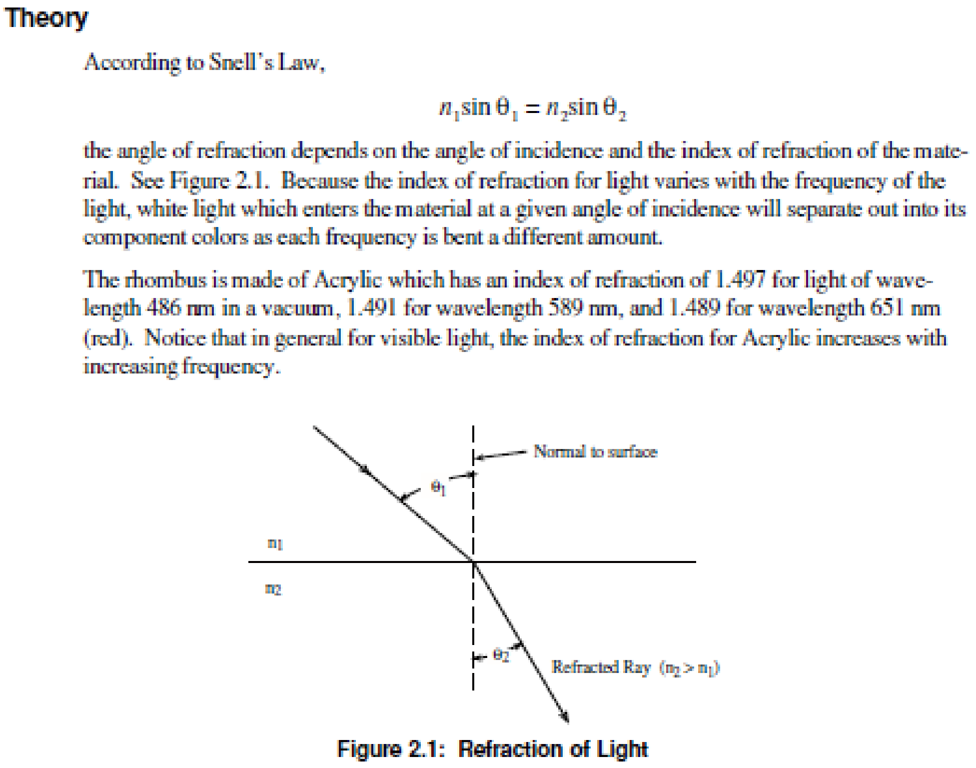
Summary:

In this lab, students will investigate the reflection and refraction of light. They will use a light source which can be configured to produce a single white ray of light, 3 parallel colored rays, or 5 parallel white rays of light. The single ray source will be transmitted through a trapezoidal prism to show dispersion and total internal reflection beyond the critical angle. Snell's Law will be investigated quantitatively by measuring the angle of incidence and the angle of refraction with the trapezoidal prism rotated through different angles. The single ray and the colored rays will be used to investigate reflection from a flat mirror. The 5 parallel rays will then be used to measure focal lengths (both positive and negative) for reflection off of a concave mirror, reflection off of a convex mirror, transmission through a convex lens, and transmission through a concave lens. Finally, the focusing characteristics of a convex lens coupled with a concave lens will be investigated.

PreLab:

In Lab C you will investigate Snell’s Law by allowing a white ray of light to pass through a piece of acrylic (in the shape of a trapezoidal prism). For this experiment the light will enter the acrylic from air, and then exit back into air through a second interface parallel to the first. Assume that the index of refraction of the acrylic is about 1.493, and the two parallel sides are separated by an acrylic thickness of 31 mm. Using Snell’s Law, calculate the angle of refraction in the acrylic for incident angles of 0, 10, 20, 30, 40, 50, 60, 70 and 80 degrees. Plot the angle of refraction versus the angle of incidence. (Please make the plot carefully, taking up about half of a lab notebook page).

Laboratory: Much of the following text is pasted from the PASCO Experiment manual for the Basic Optics Kit,Part number O12-05628C. (What is called a rhombus below is actually a trapezoid)



Theory

According to Snell’s Law,

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

the angle of refraction depends on the angle of incidence and the index of refraction of the material. See Figure 2.1. Because the index of refraction for light varies with the frequency of the light, white light which enters the material at a given angle of incidence will separate out into its component colors as each frequency is bent a different amount.

The rhombus is made of Acrylic which has an index of refraction of 1.497 for light of wavelength 486 nm in a vacuum, 1.491 for wavelength 589 nm, and 1.489 for wavelength 651 nm (red). Notice that in general for visible light, the index of refraction for Acrylic increases with increasing frequency.

Figure 2.1: Refraction of Light

Experiment A: Dispersion.

① Place the ray box, label side up, on a white sheet of paper on the table. Adjust the box so one white ray is showing.

② Position the rhombus as shown in Figure 2. The triangular end of the rhombus is used as a prism in this experiment. Keep the ray near the point of the rhombus for maximum transmission of the light.

③ Rotate the rhombus until the angle (θ) of the emerging ray is as large as possible and the ray separates into colors.

(a) What colors are seen and in what order are they?

(b) Which color is refracted at the largest angle?

(c) According to Snell’s Law and the following information given about the wavelength dependence of the index of refraction for Acrylic, which color is predicted to refract at the largest angle? (Blue n=1.497, Green n=1.493, Red n=1.489)

④ Rotate the front aperture of the ray box and shine the three primary color rays into the rhombus at the same angle used for the white ray. Do the colored rays emerge from the rhombus parallel to each other? Why or why not?

Experiment B: Total Internal Reflection (TIR).

The critical angle is the angle going from the acrylic (material with higher index of refraction) to air (material with lower index of refraction) where the refracted ray (in the air) would be at an angle of 90 degrees. At incident angles larger than the critical angle (again, going from the acrylic to the air) the light ray will experience total internal reflection.

① Place the ray box, label side up, on a white sheet of paper on the table. Slide the ray mask until only one white ray is showing.

② Position the rhombus as shown in Figure 3 (without the protractor). Do not shine the ray through the rhombus too near the triangular tip.

③ Rotate the rhombus until the emerging ray just barely disappears. Just as it disappears, the ray separates into colors. The rhombus is correctly positioned if the red has just disappeared.

④ Mark the surfaces of the rhombus. Mark exactly the point on the surface where the ray is internally reflected. Also mark the entrance point of the incident ray and mark the exit point of the reflected ray.

⑤Remove the rhombus and draw the rays that are incident upon and that reflect off the inside surface of the rhombus. Measure the total angle between these rays using a protractor. If necessary, you may extend these rays to make the protractor easier to use. Note that this total angle is twice the critical angle because the angle of incidence equals the angle of reflection. Record the measured critical angle

⑥ Calculate the critical angle using Snell's Law and the given index of refraction for Acrylic. Record the theoretical value.

⑦ Calculate and record the percent difference between the measured and theoretical values:

Questions

① How does the brightness of the internally reflected ray change when the incident angle changes from less than θc to greater than θc?

② Is the critical angle greater for red light or violet light? What does this tell you about the index of refraction?

Experiment C: Snell's Law.

① Place the ray box, label side up, on a white sheet of paper on the table. Slide the ray mask until only one white ray is showing.

② Place the rhombus on the table and position it so the ray passes through the parallel sides as shown in Figure 4.

③ Mark the position of the parallel surfaces of the rhombus and trace the incident and transmitted rays. Indicate the incoming and the outgoing rays with arrows in the appropriate directions. Mark carefully where the ray enters and leaves the rhombus.

④ Remove the rhombus and on the paper draw a line connecting the points where the ray entered and left the rhombus.

⑤ Choose either the point where the ray enters the rhombus or the point where the ray leaves the rhombus. At this point, draw the normal to the surface.

⑥ Measure the angle of incidence (θi) and the angle of refraction with a protractor. Both these angles should be measured from the normal. Record the angles in a table.

⑦ Change the angle of incidence and measure the incident and refracted angles again. Repeat this procedure for a total of three different incident angles.

8. Using Snell's Law and your data, calculate the index of refraction for the Acrylic rhombus, assuming the index of refraction of air is one. Record the result for each of the three data sets in the table.

9. Average the three values of the index of refraction and compare to the accepted value ($n = 1.493$) using a percent difference.

Experiment D: Reflection off of a flat surface.

① Place the ray box, label side up, on a white sheet of paper on the table. Adjust the box so one white ray is showing.
② Place the mirror on the table and position the plane surface of the mirror at an angle to the ray so that both the incident and reflected rays are clearly seen. (See figure 5).
③ Mark the position of the surface of the plane mirror and trace the incident and reflected rays. Indicate the incoming and the outgoing rays with arrows in the appropriate directions.
④ On the paper, draw the normal to the surface.
⑤ Measure the angle of incidence (θi) and the angle of reflection. Both these angles should be measured from the normal. Record the angles in a table.
⑥ Change the angle of incidence and measure the incident and reflected angles again. Repeat this procedure for a total of three different incident angles.
7. What is the relationship between the angle of incidence and the angle of reflection?

Experiment E: Reflection of Colored Light.

1. Adjust the ray box so it produces the three primary color rays. Shine the colored rays at an angle to the plane mirror. (See figure 6). Mark the position of the surface of the plane mirror and trace the incident and reflected rays. Indicate the colors of the incoming and the outgoing rays and mark them with arrows in the appropriate directions.

2. Are the three colored rays reversed left to right by the plane mirror?

Experiment F: Focal Length of a Concave Mirror.

A concave cylindrical mirror will focus parallel rays of light at the focal point. The focal length is the distance from the focal point to the center of the mirror surface. The radius of curvature of the mirror is twice the focal length.
① Using five white rays from the ray box, shine the rays straight into the concave mirror so the light is reflected back toward the ray box as in figure 7. Draw the surface of the mirror and trace the incident and reflected rays. Indicate the incoming and the outgoing rays with arrows in the appropriate directions.
② The place where the five reflected rays cross each other is the focal point of the mirror. Measure the focal length from the center of the concave mirror surface to the focal point. Record the result.
③ Use the template on the next page to estimate the radius of curvature of the mirror. (Place the mirror on the template to find the circle segment that matches the curvature the best. Measure the radius of that circle segment by measuring the distance to the center dot. Feel free to interpolate between the plotted concentric circle segments.)
4. What is the relationship between the focal length of the concave mirror and its radius of curvature? Do your results confirm your answer?
5. What is the radius of curvature of a plane mirror?

Experiment G: Focal Length of a Convex Mirror.

1. Repeat the Concave Mirror Steps 1 through 3 for the convex mirror (See figure 8). Note that in Step 2, the reflected rays are diverging for a convex mirror and they will not cross. Use a ruler to extend the reflected rays back behind the mirror's surface. The focal point is where these extended rays cross.
2. What is the relationship between the focal length of the convex mirror and its radius of curvature? Do your results confirm your answer?

Experiment H: Focal Length of a Convex Lens.

Parallel rays of light passing through a thin convex lens cross at the focal point of the lens. The focal length is measured from the center of the lens to the focal point.

① Place the ray box on a white piece of paper. Using five white rays from the ray box, shine the rays straight into the convex lens. See figure 9.
NOTE: Concave and Convex lenses have only one flat edge. Place flat edge on surface. Trace around the surface of the lens and trace the incident and transmitted rays. Indicate the incoming and the outgoing rays with arrows in the appropriate directions.
② The place where the five refracted rays cross each other is the focal point of the lens. Measure the focal length from the center of the convex lens to the focal point. Record the result.
3. Place the convex lens in the path of the five rays. Block out the center 3 rays (the mirror on edge works well) and mark the focal point for the outer two rays. Next, block out the outer two rays (or slide the mask to the position that gives 3 rays) and mark the focal point for the inner 3 rays. Are the two focal points the same? (Note, this experiment will not work well if the rays coming out of the lightbox are not sufficiently parallel).

Experiment I: Focal Length of a Concave Lens.

1. Repeat the convex lens procedure for the concave lens. See figure 10. Note that in Step 2, the rays leaving the lens are diverging and they will not cross. Use a rule to extend the outgoing rays straight back through the lens. The focal point is where these extended rays cross. The focal length of this concave lens is taken to be negative.

Experiment J: Combination of a Convex and Concave Lens.

1. Nest the convex and concave lenses together and place them in the path of the parallel rays. (See figure 11). Trace the rays. What does this tell you about the relationship between the focal lengths of these two lenses?
2. Slide the convex and concave lenses apart to observe the effect of a combination of two lenses. Then reverse the order of the lenses. Trace at least one pattern of this type.

Template for concave mirror radius of curvature, experiment F: