Refraction & Concave Mirrors

Equipment List

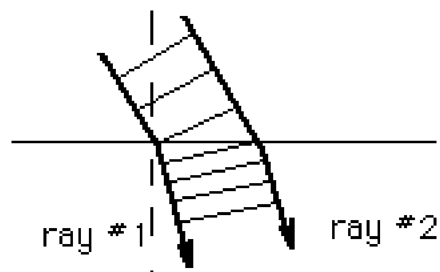
Qty	Items	Part Numbers
1	Light Source	OS-8517
1	Ray Optics Set	OS-8516
1	Optics Bench	OS-8518
1	50 mm Concave Mirror, and Half Screen	OS-8519
1	Viewing Screen	OS-8460
1	Vernier Caliper	
2	White paper, sheet	
1	Metric ruler	
1	Protractor	

Purpose

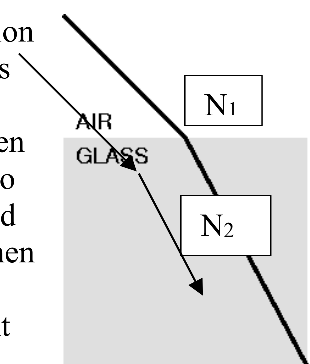
The purpose of part 1, and part 2 of this actvity is to examine the relationship of the angle of incidence and the angle of refraction for a light ray passing through a rhombus prism.

The purpose of part 3 of this activity is to exmaine some of the basic properties of a concave mirror by experimentally determining its focal length.

Background of Refraction



The most common example of refraction is the bending of light on passing from air to a liquid, which causes submerged objects to appear displaced from their actual positions. Refraction is also the reason that prisms separate white light into its constituent colors. Refraction is commonly explained in terms of the wave theory of light and is based on the fact that light travels with greater velocity in some media than it does in others. When, for example, a ray of light traveling through air strikes the surface of a piece of glass at an angle, one side of the wave front enters the glass before the other and is retarded (since light travels more slowly in glass than in air), while the other side continues to move at its original speed until it too reaches the glass.



As a result, the ray bends inside the glass, i.e., the refracted ray lies in a direction closer to the normal (the perpendicular to the boundary of the media) than does the incident ray. A light ray entering a different medium is called the incident ray; after bending, the ray is called the refracted ray. The speed at which a given transparent medium transmits light waves is related to its optical density (not to be confused with mass or weight density). In general, a ray is refracted toward the normal when it passes into a denser medium and away from the normal when it passes into a less dense medium.

The law of refraction relates the angle of incidence (angle between the incident ray and the normal) to the angle of refraction (angle between the refracted ray and the normal). This law, credited to Willebrord Snell, states that the ratio of the sine of the angle of incidence, θ_i, to the sine of the angle of refraction, θ_r, is equal to the ratio of the speed of light in the original medium, v_i, to the speed of light in the refracting medium, v_r. Snell's law is often stated in terms of the indexes of refraction of the two media rather than the speeds of light in the media. The index of refraction, n, of a transparent medium is the ratio of the speed of light in a vacuum, c, to the speed of light in the medium: $n = c/v$.

Using indexes of refraction, Snell's Law (also known as the Law of Refraction) takes the form $\sin\theta_i/\sin\theta_r = n_r/n_i$, or $n_i \sin\theta_i = n_r \sin\theta_r$.

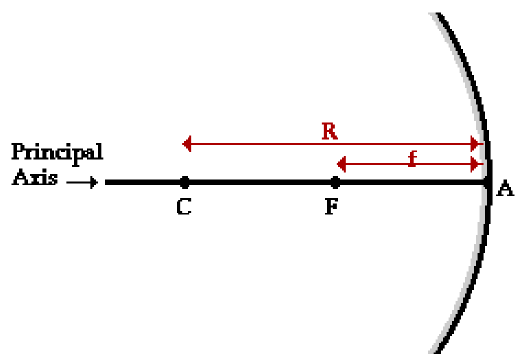
Snell's law has two special cases: critical angle and total internal reflection. When the angle of incidence makes a 90° angle of refraction, total internal reflection occurs. When there is total internal reflection, then you can obtain the critical angle. The critical angle is measured with respect to the normal at the refractive boundary and is equivalent to

$$\theta_r = 90° \rightarrow \ \theta_i = \theta_c = \arcsin\left(\frac{n_i}{n_r}\right).$$

The critical angle only takes place when the light is traveling from a medium with a higher index of refraction to a medium with lower index of refraction. This is to say, we find the critical angle when the value of the incident theta is equal to 90° and thus $\sin(\theta_i)$ is equal to 1. The resulting value of the refracted theta will then be equal to the critical angle. For total internal reflection to occur, n_r must be greater than n_i.

Background to Spherical Concave Mirrors

Concave and convex mirrors are examples of spherical mirrors. Spherical mirrors can be thought of as a portion of a sphere which was sliced away and then silvered on one of the sides to form a reflecting surface. Concave mirrors are silvered on the inside of the sphere and convex mirrors are silvered on the outside of the sphere.

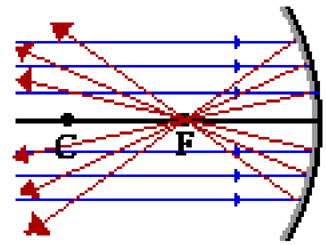


If a concave mirror is thought of as being a slice of a sphere, then there would be a line passing through the center of the sphere and attaching to the mirror in the exact center of the mirror. This line is known as the principal axis. The point in the center of sphere from which the mirror was sliced is known as the center of curvature and is denoted by the letter C in the diagram. The point on the mirror's surface where the principal axis meets the mirror is known as the vertex and is denoted by the letter A in the diagram. The vertex is the geometric center of the mirror. Midway between the vertex and the center of curvature is a point known as the focal point; the focal point is denoted by the letter F in the diagram. The distance from the vertex to the center of curvature is known as the radius of curvature (abbreviated by "R"). The radius of curvature is the radius of the sphere from which the mirror was cut. Finally, the distance from the mirror to the focal point is known as the focal length (abbreviated by "f").

$$\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$$

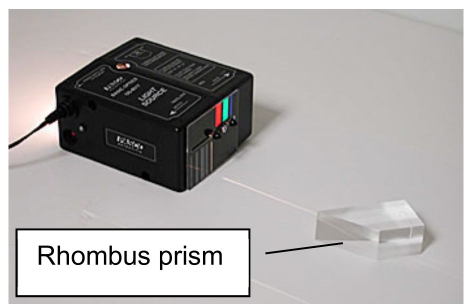
$$M_{exp} = \frac{h'}{h} = -\frac{q}{p}$$

The focal point is the point in space at which light incident towards the mirror and traveling parallel to the principal axis will meet after reflection. The diagram at the right depicts this principle. In fact, if some light from the Sun was collected by a concave mirror, then it would converge at the focal point. Because the Sun is such a large distance from the Earth, any light rays from the Sun which strike the mirror will essentially be traveling parallel to the principal axis. As such, this light should reflect through the focal point.



Setup for part 1: Refraction

1. Place the Light Source, label side up, on a new sheet of paper on a table. Adjust the mask on the end of the light source so one white ray is showing.
2. Place the rhombus on the paper so that the long side faces the light source and the textured side of the rhombus faces down. Also, position the rhombus so the ray passes through the parallel sides.

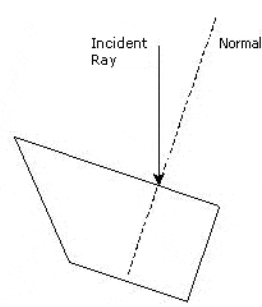


Procedure Part 1: Refraction

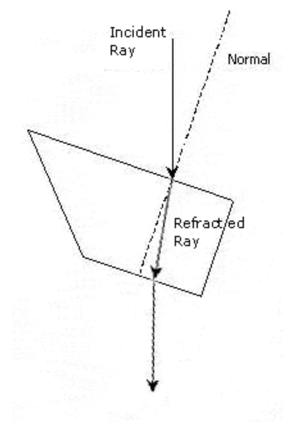
1. Trace the shape of the rhombus and then position the light ray entering the rhombus at 30 degrees such that the light enters and exits the rhombus through parallel sides. Then trace the incoming and outgoing rays with arrows in the appropriate directions.
2. Reposition the light source so the light strikes the rhombus at a 45 degree angle of incidence and trace the incoming and outgoing light rays.
3. Repeat step 2 but with a 60 degree angle of incidence.

Analysis Part 1: Refraction

1. Remove the paper from under the light and rhombus.
2. Using your protractor and ruler, draw a line perpendicular to and through the surface of the rhombus at the point where the ray of incidence strikes the rhombus. This line is the normal.



3. Trace the path of the light ray as it moves through the rhombus. This is the line that connects the point where the light ray enters the rhombus to the point the light ray exits the rhombus.
4. Measure the angle of incidence (angle of the incoming ray relative to the normal) and the angle of refraction (angle of the ray transmitted through the rhombus relative to the normal) and record the value in the chart.
5. Repeat steps 2-4 for each trial. Record the values in the Lab Report.

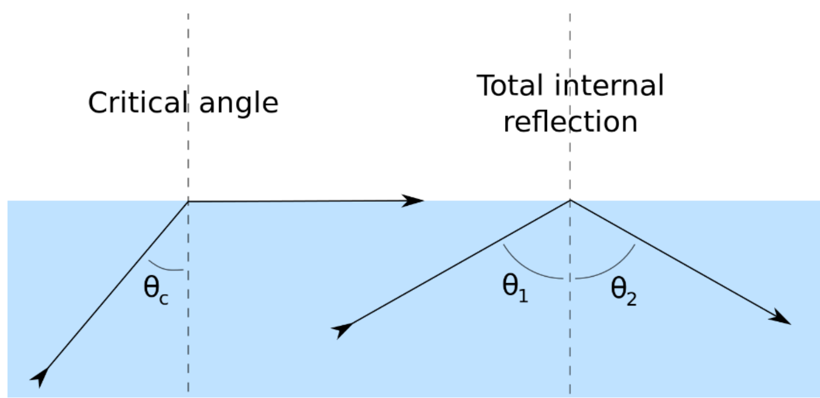


Setup Part 2: Refraction at Critical Angle

1. Place the Light Source, label side up, on a new sheet of paper on a table. Adjust the mask on the end of the light source so one white ray is showing.
2. Place the rhombus on the paper so that the long side faces the light source and the textured side of the rhombus faces down. Also, position the rhombus so the ray passes through the parallel sides.

Procedure Part 2: Refraction at Critical Angle

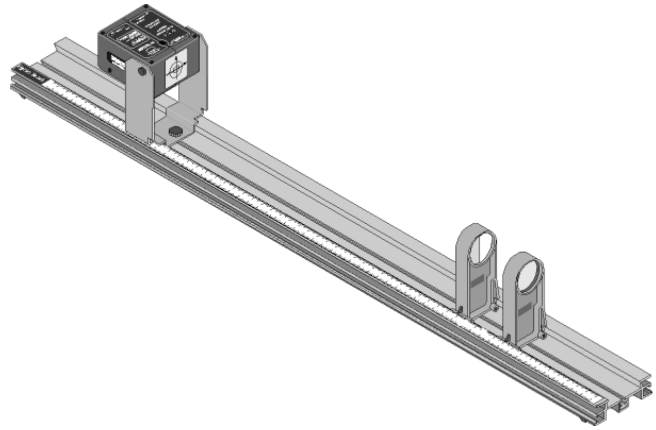
1. Trace the shape of the rhombus.
2. Shine a single slit light source into the rhombus, increasing the angle of incidence until total internal reflection occurs.
3. Trace the incoming light ray and mark the position on the opposite side of the rhombus where the internal light beam strikes the side of the rhombus.



Analysis Part 2: Refraction at Critical Angle

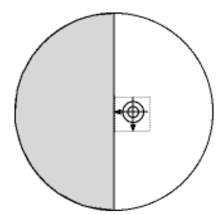
1. Remove the rhombus, connect the incoming ray to the position just marked.
2. Trace a line in the internal normal direction where the internal light ray struck the rhombus.
3. The angle formed from this normal and the internal light ray formed is the critical angle for the rhombus.

Setup for Part 3: Concave Mirror



1. Mount the Light Source at one end of the Optics Bench so its front is at location 0.0 cm. Turn on the Object Source.
2. Place the Concave Mirror at the 100.0 cm mark of the Optics Bench, with the mirror facing the image source.
3. Make sure the crossed-arrow 'object' is illuminated and pointing toward the mirror.
4. Place the Half-Screen on the Optics Bench between the Object Source, and the mirror.
5. With the Vernier Caliper measure the size of the crossed-arrowed object, and record this as the *height of the object* for Table 3.

Procedure for Part 3: Concave Mirror



1. With the Object Source, and mirror in their current locations move the Half-Screen closer to or farther from the Concave Mirror until the reflected image of the crossed arrow target on the white screen is focused.
2. Determine the distance between the position indicators on the Half-Screen and the Concave Mirror, and record that distance in Table 3 for q for position 100 cm.
3. Using the Vernier Caliper measure the size of the image and record it in Table 3 under h'.
4. Reposition the mirror to the next position listed in Table 3, and repeat procedure for all the listed object positions, p.
5. Preform calculations to complete Table 3. Show work in the space provided below Table 3.

<u>Analysis of Refraction & Concave Mirrors Lab</u>

Name____ Group#________
Course/Section_____________________________________
Instructor____

Analysis Part 1 and 2: Refraction

Data Table (10 Points)

Rhombus Prism		
Angle of Incidence (degrees)	Angle of Refraction (degrees)	Critical Angle (degrees)

1. Use *Excel* to graph the sine of the angle of incidence and the sine of the angle of refraction. From this graph determine the Index of Refraction of the material the rhombus prism is made from. (10 points)

2. As the ray of light enters the rhombus, describe what happens. (5 points)

3. Describe the relationship between the angle of incidence and angle of refraction. (4 points)

4. Using the measured index of refraction, calculate the critical angle for the rhombus surrounded by air. Show work. (4 points)

5. What is the percent error between the measured and calculated values of the critical angle? Use the calculated as the theoretical value. Show work. (4 points)

6. Using Snell's Law, explain why the index of refraction is a dimensionless quantity. (5 points)

Analysis Part 3: Concave Mirror

Table 3: Spherical Concave Mirror

Object Height, h________ **Mirror Focus Length________**

p(cm)	q(cm)	$f = \dfrac{q \cdot p}{q + p}$	h'(cm)	M = h'/h	M = -q/p
100					
75					
50					
40					
35					
30					
25					
20					
17.5					
15					
13					
Average f					

Show calculations. (10 points)

1. Calculate the % Error between the given focus length of the mirror and your average experimental value. Show work. (3 points)

2. Using Excel, or some other graphing program, graph $\frac{1}{q}\,vs.\frac{1}{p}$ from the data from Table 3. (5 points)

3. What physical property of the mirror does the y-intercept represent? (5 points)

4. Were the images, compared to the object, upright or inverted? (5 points)

5. Would the image be upright or inverted if the object was placed ‘inside’ the focus length of the mirror? (5 points)

6. Using Excel, or some other graphing program, graph M vs. p. (5 points)

7. As the object position value gets larger what value does the magnification go to? (5 points)

8. How does the radius of curvature, R, relate to the focal length, f, of a concave mirror? (5 points)

9. Very briefly explain what happens when light rays strike a concave mirror. (5 points)

10. Do the results of the experiment confirm the theory? Explain your answer. (5 points)