Experiment 3: Reflection – Plane and Curved Mirrors

EQUIPMENT NEEDED

- Ray box (single and multiple white rays)  
- Protractor (SE-8732)  
- Metric rule  
- Plane and curved mirrors  
- Drawing compass (SE-8733)  
- White paper

Purpose

To study how rays are reflected and to determine the focal length and radius of curvature of different types of mirrors.

Part I: Plane Mirror

Procedure

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 the both the incident and reflected rays are clearly seen.

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. See Figure 3.1.

5. Measure the angle of incidence (θ₁) and the angle of reflection. Both these angles should be measured from the normal. Record the angles in Table 3.1.

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. Adjust the ray box so it produces the three primary color rays. Shine the colored rays at an angle to the plane mirror. 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.

![Figure 3.1](image)

Table 3.1 Plane Mirror Results

<table>
<thead>
<tr>
<th>Angle of Incidence</th>
<th>Angle of Reflection</th>
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Questions

① What is the relationship between the angle of incidence and the angle of reflection?

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

Part II: Cylindrical Mirrors

Theory

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. See Figure 3.2.

Procedure

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. See Figure 3.3. 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 in Table 3.2.

③ Use the compass to draw a circle that matches the curvature of the mirror. Measure the radius of curvature using a rule and record it in Table 3.2.

④ Repeat Steps 1 through 3 for the convex mirror. Note that in Step 2, the reflected rays are diverging for a convex mirror and they will not cross. Use a rule to extend the reflected rays back behind the mirror's surface. The focal point is where these extended rays cross.

<table>
<thead>
<tr>
<th>Table 3.2 Cylindrical Mirror Results</th>
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</thead>
<tbody>
<tr>
<td>Concave Mirror</td>
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<tr>
<td>Focal Length</td>
</tr>
<tr>
<td>Radius of Curvature using compass</td>
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</tbody>
</table>

Questions

① What is the relationship between the focal length of a cylindrical mirror and its radius of curvature? Do your results confirm your answer?

② What is the radius of curvature of a plane mirror?
Experiment 4: Snell’s Law

EQUIPMENT NEEDED
- Ray box (single white ray and colored rays)
- Rhombus
- Protractor (SE-8732)
- White paper

Purpose
To use Snell’s Law to determine the index of refraction of the acrylic rhombus.

Theory
Snell’s Law states

\[
\sin \theta_1 = \frac{n_2}{n_1} \sin \theta_2
\]

where \( \theta_1 \) is the angle of incidence, \( \theta_2 \) is the angle of refraction, and \( n_1 \) and \( n_2 \) are the respective indices of refraction of the materials. See Figure 4.1.

Procedure
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 4.2.
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 (\( \theta_1 \)) and the angle of refraction with a protractor. Both these angles should be measured from the normal. Record the angles in Table 4.1.
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.
Table 4.1 Data and Results

<table>
<thead>
<tr>
<th>Angle of Incidence</th>
<th>Angle of Refraction</th>
<th>n rhombus</th>
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<tbody>
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<td></td>
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<tr>
<td>Average index of refraction</td>
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</tbody>
</table>

Analysis

① 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 Table 4.1.

② Average the three values of the index of refraction and compare to the accepted value (n = 1.5) using a percent difference.

Question

What is the angle of the ray that leaves the rhombus relative to the ray that enters the rhombus?
Experiment 5: Total Internal Reflection

EQUIPMENT NEEDED
- Ray box (single ray)
- Rhombus
- Protractor (SE-8732)
- White paper

Purpose
To determine the critical angle at which total internal reflection occurs and to confirm it using Snell’s Law.

Theory
Snell’s Law states
\[ n_1 \sin \theta_1 = n_2 \sin \theta_2 \]
where \( \theta_1 \) is the angle of incidence, \( \theta_2 \) is the angle of refraction, and \( n_1 \) and \( n_2 \) are the respective indices of refraction of the materials. See Figure 5.1.

If a ray of light traveling from a medium of greater index of refraction to a medium of lesser index of refraction is incident with an angle greater than the critical angle \( \theta_c \), there is no refracted ray and total internal reflection occurs. If the angle of incidence is exactly the critical angle, the angle of the refracted ray is 90 degrees. See Figure 5.2. In this case, using Snell’s Law,

assuming the medium of lesser index of refraction is air with \( n = 1 \) and the medium of greater index of refraction is the Acrylic rhombus with \( n_1 = n = 1.5 \). Solving for the critical angle gives

Procedure
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 5.3. 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.

⑤ Remove the rhombus and draw the rays that are incident upon and that reflect off the inside surface of the rhombus. See Figure 5.4. 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 critical angle here: ____________________

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

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

\[
\text{% difference} = \frac{\text{measured value} - \text{theoretical value}}{\text{theoretical value}} \times 100
\]

Questions

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

② Is the critical angle greater for red light or violet light? What does this tell you about the index of refraction?
Experiment 6: Refraction – Convex and Concave Lenses

EQUIPMENT NEEDED

- Ray box (multiple white rays)
- Convex lens
- Concave lens
- Metric rule
- Second convex lens (optional)

Purpose

To explore the difference between convex and concave lenses and to determine their focal lengths.

Theory

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.

Procedure

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 6.1.

   \textbf{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 in Table 6.1.

\textbf{Table 6.1 Results}

<table>
<thead>
<tr>
<th></th>
<th>Convex Lens</th>
<th>Concave Lens</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focal Length</td>
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</tbody>
</table>

3. Repeat the procedure for the concave lens. 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.

4. Nest the convex and concave lenses together and place them in the path of the parallel rays. Trace the rays. What does this tell you about the relationship between the focal lengths of these two lenses?
5. 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.

6. 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?

7. If you have a second convex lens, place both convex lenses in the path of the five rays. The distance between the lenses should be less than the focal length of the lenses. Compare the quality of the focus of this two lens system to the focus of a single lens. Do all five rays cross in the same place?