Reflection and Refraction with the Ray Box

OBJECTIVES

- ☐ Investigate for reflection from a plane surface, the dependence of the angle of reflection on the angle of incidence.
- ☐ Investigate refraction of rays from air into a transparent plastic medium.
- ☐ Determine the index of refraction of a plastic prism from direct measurement of incident and refracted angles of a light ray.
- ☐ Investigate the focal properties of spherical reflecting and refracting surfaces.

EQUIPMENT LIST

- Ray box, 60.0° prism, plano-convex lens, circular metal reflecting surfaces
- Converging lens, diverging lens, protractor, straightedge, compass
- Sharp hard-lead pencil, black tape, several sheets of white paper

THEORY

Reflection

The reflection of light from a plane surface is described by the **law of reflection,** which states that the angle of incidence θ_i is equal to the angle of reflection θ_r.

The angles are measured with respect to a line perpendicular to the surface. Reflection from a plane mirror or a plane piece of glass are examples of the law of reflection.

In Figure 40-1(a) several incident rays and reflected rays are shown for a plane surface. The angle of incidence θ_i is seen to be equal to the angle of reflection θ_r.

Refraction

In general, light rays incident on a plane interface will be partially reflected and partially transmitted into the second medium. The transmitted ray undergoes a change in direction because the speed of light is different for different media. The ray is said to be **refracted.** This is illustrated in Figure 40-1(b). The angle of incidence is θ_1, and the angle of refraction is θ_2.

The speed of light in a vacuum is c ($\approx 3.00 \times 10^8$ m/s), the maximum possible speed of light. For any material the speed of light is v where $v \le c$. A quantity called **the index of refraction** n for any medium is

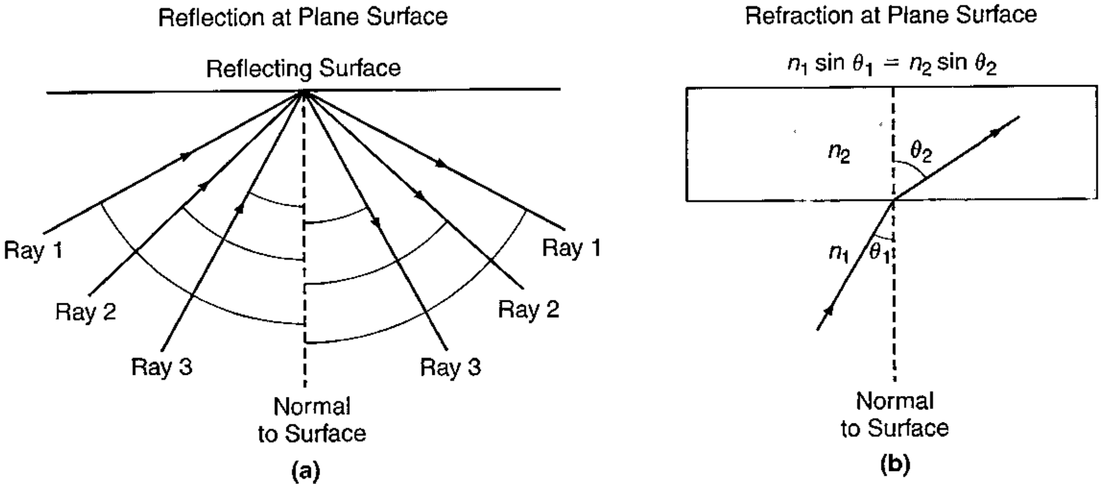


Figure 40-1 Illustration of reflection and refraction of light rays at a plane surface.

defined by $n = c/v$. Because $v \le c$, the only allowed values of n are $n \ge 1$. The relationship **(Snell's law)** between the angle of incidence θ_1 and the refracted angle θ_2 is

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 \qquad \text{(Eq. 1)}$$

When $n_1 > n_2$, Equation 1 implies that $\theta_1 < \theta_2$. This states that a ray going from a medium of a given index of refraction to one of a smaller index of refraction is bent away from the normal. If $n_1 < n_2$ then $\theta_1 > \theta_2$, and a ray going into a medium of larger index of refraction is bent toward the normal.

Focal Properties of Reflection and Refraction

Descriptions of the focal properties of reflection from spherical mirrors are shown in Figure 40-2. When reflection takes place from a concave spherical surface, incident parallel rays are converging and come to an approximate focus point. If R is the radius of curvature of the spherical surface, the focal point is a distance f (called the focal length) from the vertex of the spherical mirror where $f = R/2$. Incident parallel rays on a convex spherical mirror are diverging, but they appear to have come from a point. The distance from the vertex of the mirror to that point is called the focal length, and its magnitude is given by $f = R/2$. The focal length is positive for a concave converging mirror and negative for a convex diverging mirror.

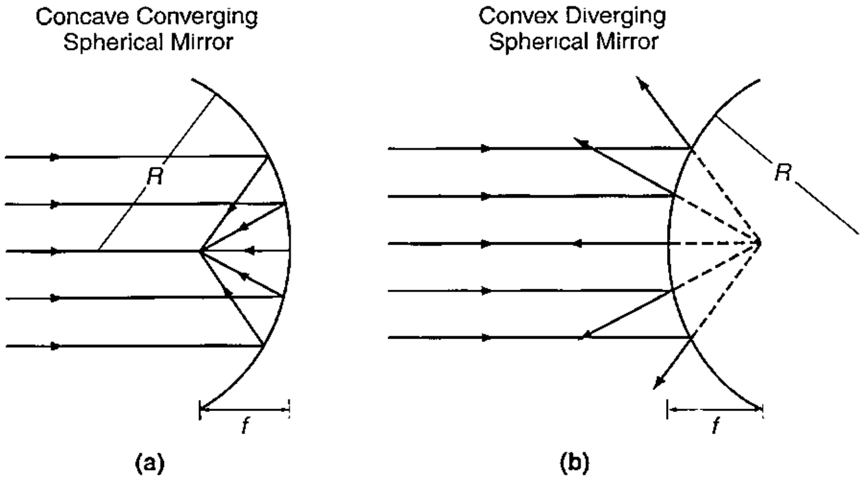


Figure 40-2 The focal properties of spherical mirrors for incident parallel rays.

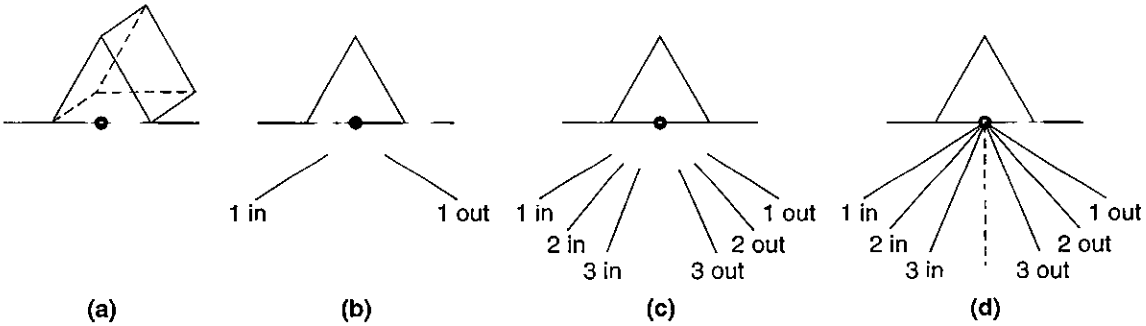
EXPERIMENTAL PROCEDURE

Reflection

1. Use black tape to cover all of the slits from the ray box—except the central slit—to produce a single ray to examine reflection and refraction from a plane surface.
2. Place the 60.0° prism on a piece of white paper in the position shown in Figure 40-3(a). Draw a straight line along the face of the prism and place a small dot in the center of the line as shown.
3. Place the ray box about 0.15 m away from the prism and adjust the single ray to strike the plane surface at the position of the dot at an angle of incidence estimated to be about 60°. With a straightedge, draw a straight line in the direction of the incident ray and one in the direction of the reflected ray. This will produce the lines shown in Figure 40-3(b). Repeat this process two more times, once for an incident ray of about 45° and once for an incident ray of about 30° to produce the lines shown in Figure 40-3(c).
4. At the point of the dot construct a perpendicular to the face of the prism. Extend all six of the lines showing the ray directions until they intersect at the point of the dot to produce the lines shown in Figure 40-3(d). Use a protractor to measure the incident angles and reflected angles for each of the rays. Record all these angles (to the nearest 0.1°) in the Data Table.

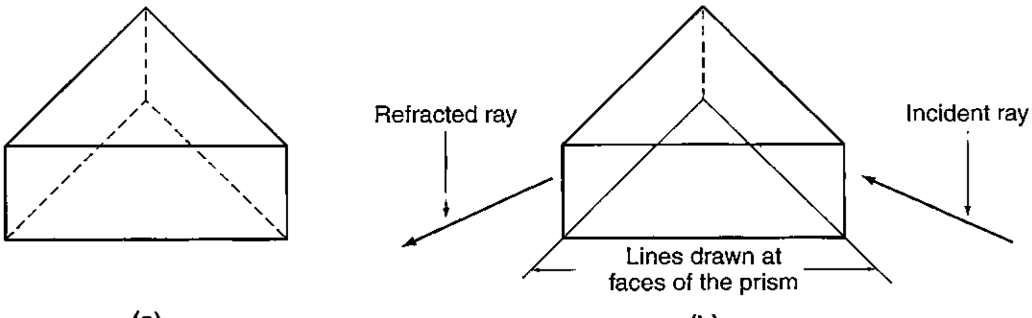
Refraction

1. Place the prism on the paper as shown in Figure 40-4(a). Draw straight lines on the paper along two adjacent faces of the prism as shown in part (b) of the figure.
2. Place the ray box about 0.15 m away from the prism. Adjust the direction of the ray box so that the incident ray strikes one face of the prism at an angle of about 50° to a line drawn normally (90 degrees) to the prism face. Use a straightedge to draw a line in the direction of the incident ray and one in the direction of the refracted ray as shown in Figure 40-4(b) and Figure 40-5.



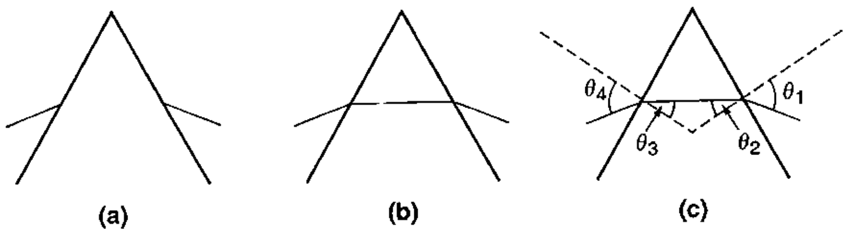
(a) (b) (c) (d)

Figure 40-3 Tracing incident and reflected rays from a plane surface.



(a) (b)

Figure 40-4 Refraction of a ray incident on one face of a 60° prism.



These lines may have to be extended some distance in either direction in order to measure the angles with a protractor.

Figure 40-5 Step-by-step process to trace the rays and determine the four angles.

3. Using a separate sheet of paper for each ray, repeat Steps 1 and 2 for two other rays, one incident at an angle of about 60° with respect to the normal and the other incident at about 70° with respect to the normal.
4. Construct the lines tracing the path of each of the incident rays through the prism in the order of the steps shown in Figure 40-5. This will produce a figure from which the angles θ_1, θ_2, θ_3, and θ_4 can be determined with a protractor. Measure these angles for each of the three cases and record the values of all four angles (to the nearest 0.1°) in the Data Table.

Focal Properties of Reflection and Refraction

1. Remove the black tape from the ray box slits. Place the plastic plano-convex lens next to the slits to produce five parallel rays from the ray box. The lens may have to be rotated just slightly to produce the best set of parallel rays.
2. Place the circular metal reflector on a piece of white paper and trace its outline on the paper. Place the ray box about 0.15 m away on the concave side of the reflector. Align the five parallel rays with the center of the reflector to produce a pattern like the one in Figure 40-2(a). Make a tracing of this pattern, and from it, measure the focal length of the concave reflector. Record it in the Data Table as f_{con}.
3. Turn the reflector around and repeat Step 2 on another piece of paper with the reflector now acting as a convex mirror. Trace the pattern, which should look like that of Figure 40-2(b). Extend the reflected rays back to the point from which they appear to come. Measure the focal length and record it in the Data Table as f_{div}.
4. Using a compass, construct a circular arc that is the same radius of curvature as the reflector. Record in the Data Table the radius of that constructed circle as R, the radius of curvature of the reflector.
5. Place the plastic converging and diverging lenses on separate pieces of paper and trace the ray pattern produced by the parallel beam of rays from the ray box. Patterns like those of Figure 40-3 should be observed. Measure the focal length of the converging lens and record it in the Data Table as f_{con}. Measure the diverging lens focal length and record it in the Data Table as f_{div}.

CALCULATIONS

Reflection

1. Calculate the difference $|\theta_i - \theta_r|$ between the measured values of the incident and reflected angles for each of the three rays and record them in the Calculations Table.

Refraction

1. According to Snell's law, at the first surface $(1)\sin\theta_1 = n\sin\theta_2$. The value of $n = 1$ has been used for air, and n is the index of refraction of the prism. At the second surface, the equation is $n\sin\theta_3 = (1)\sin\theta_4$. Solving these two equations for n gives

$$n = \frac{\sin\theta_1}{\sin\theta_2} \quad \text{and} \quad n = \frac{\sin\theta_4}{\sin\theta_3} \qquad \text{(Eq. 2)}$$

2. Use these two equations to calculate two values of n for each of the incident rays. These are not independent measurements because the errors made in drawing the rays to determine the angle tend to produce two values of n with compensating errors. Take the average of the two values calculated by Equation 2 as a single measurement and record in the Calculations Table the average value of n for each ray.
3. Calculate the mean $\bar{n}$ and standard error α_n for the three measurements of n and record them in the Calculations Table.

Focal Properties of Reflection and Refraction

1. Calculate the percentage difference between the value of f_{con} and the value of f_{div} for the reflector.
2. According to theory, the value of the focal length for the reflector should be equal to $R/2$. Calculate the percentage difference between the measured value of $R/2$ and the focal lengths f_{con} and f_{div} for the reflector.

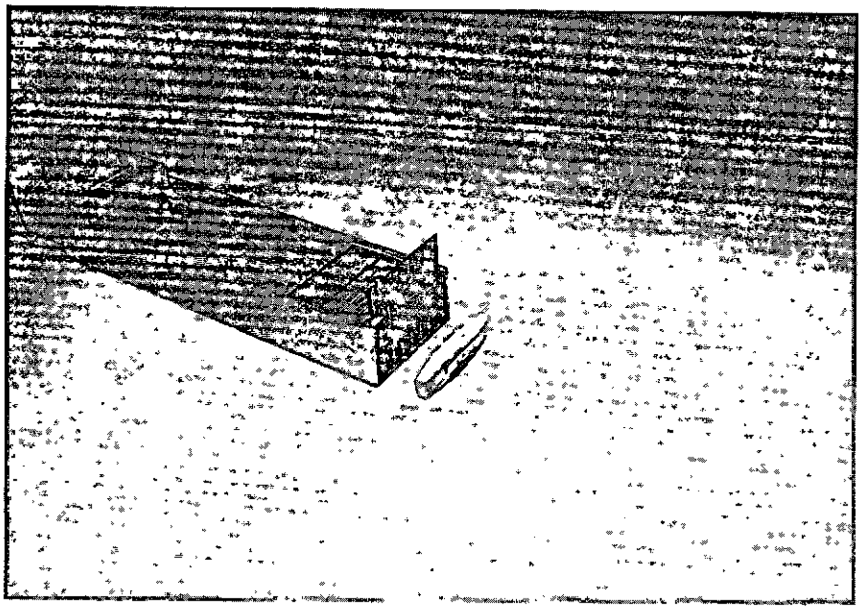


Figure 40-6 Ray box showing focus of incident parallel rays.

Name Section Date

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PRE-LABORATORY ASSIGNMENT

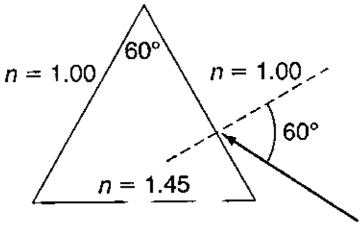
1. Define the index of refraction.

2. State the law of reflection. Use a diagram to define the angles involved.

3. State Snell's law. Define terms and angles using a diagram.

4. A light ray is incident on a plane interface between two media. The ray makes an incident angle with the normal of 25.0° in a medium of $n - 1.25$. What is the angle that the refracted ray makes with the normal if the second medium has $n = 1.55$? Show your work.

5. A 60.0° prism has an index of refraction of 1.45 as shown below. A ray is incident as shown at an angle of 60.0° to the normal of one of the prism faces. Trace the ray on through the prism and find the angles θ_2, θ_3, and θ_4 as defined in the laboratory instructions. Show your work.



Name

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Date

Lab Partners

40 LABORATORY 40 Reflection and Refraction with the Ray Box

LABORATORY REPORT

Data Table

	Ray	θ_i	θ_r
Reflection			

Calculations Table

Angle Difference

	Ray	θ_1	θ_2	θ_3	θ_4
Refraction					

n	$\bar{n}$	α_n

		f (cm)	R (cm)
Mirrors	Concave f_{con}		
	Convex f_{div}		

% Diff of f	*% Diff of R/2*

		f (cm)
Lenses	Converging Lens	
	Diverging Lens	

SAMPLE CALCULATIONS

1. Angle Difference = $|\theta_i - \theta_r'| =$
2. $n = \frac{1}{2}\left(\frac{\sin\theta_1}{\sin\theta_2} + \frac{\sin\theta_4}{\sin\theta_3}\right) =$
3. % Diff between f_{con} and $f_{\text{div}} =$
4. % Diff between f and $R/2 =$

QUESTIONS

1. Are your data consistent with the law of reflection? State your answer as quantitatively as possible.

2. State as quantitatively as possible the precision of your value for n, the index of refraction of the prism.

3. State how your data for the prism are evidence for the validity of Snell's law.

4. How well do your data for the focal lengths of the concave and convex mirror agree with the expectation that $f = R/2$? State your answer as quantitatively as possible.

5. Using the value of n determined for the prism, find the speed of light in the prism.

6. Inside the prism the wavelength of the light must change as well as the speed. Is a given wavelength longer or shorter inside the prism? Consider specifically light with a wavelength of 500 nm in air. What is the wavelength of this light inside the prism?