

Reflection and Refraction

Theory:

Whenever a wave traveling in some medium encounters an interface or boundary with another medium either (or both) of the processes of (1) **reflection** and (2) **refraction** may occur if the speed of the wave is different in the two media.

If the wave being considered is light the speed of light in any medium is characterized by the **index of refraction** for the medium, n , where

$$n \equiv c/v \quad [1]$$

where c is the speed of light in a vacuum, and v is the speed of light in the medium. (Note that for a vacuum or air $n=1.00$.)

Reflection

In reflection, a ray of light traveling in a straight line in medium 1 encounters an interface with medium 2 and the incident ray is reflected (or bounced) backed into medium 1 at the interface of the two media as depicted in Figure 8 – 1.

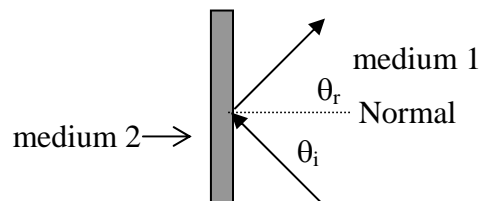


Figure 8 –1

The normal is a reference point which is always perpendicular to the surface at the “point of impact” where the light is incident onto the surface. If the ray incident on the interface makes an angle θ_i with the normal to the surface at the “point of impact” on the interface, the reflected ray will make an angle θ_r with the normal from the “point of impact” equal to the incident angle θ_i . The relationship between the angles θ_i and θ_r for all reflections is called the Law of reflection which can be stated in two parts:

1. $\theta_i = \theta_r$, and
 2. θ_i and θ_r are coplanar, (i.e. lie in the same plane.)
- [2]

For light parallel to the principal axis and incident on a spherical (or cylindrical) surface with a radius R , the reflected light will cross the principal axis at a focal point, f , from the vertex (see Figure 8-2) such that

$$f = R/2 \quad [3]$$

where R is the radius of curvature.

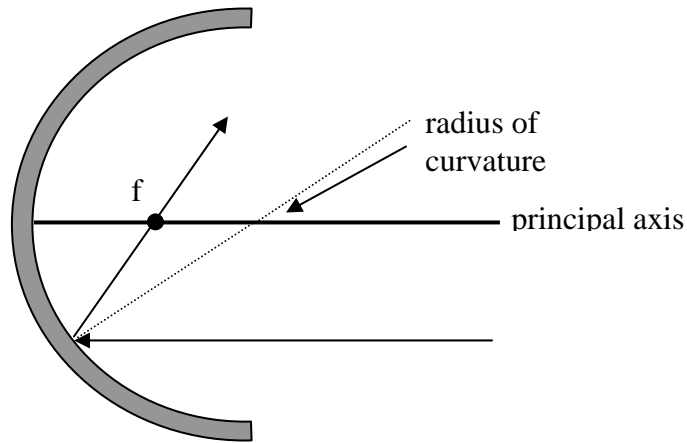


Figure 8 –2

Refraction

In refraction, a ray of light traveling in a straight line in medium 1 encounters an interface with medium 2, penetrates the interface and then moves in a straight line in medium 2 as depicted in Figure 8 – 3. If the incident ray originally in medium 1 makes an angle θ_1 with the normal to the surface in medium 1, the refracted ray will make an angle θ_2 with the same normal in medium 2. The relationship between θ_1 and θ_2 for every refraction is called the **law of refraction** which can be stated in two parts:

1. $n_1 \sin \theta_1 = n_2 \sin \theta_2$, and [4]
2. θ_1 and θ_2 are coplanar.

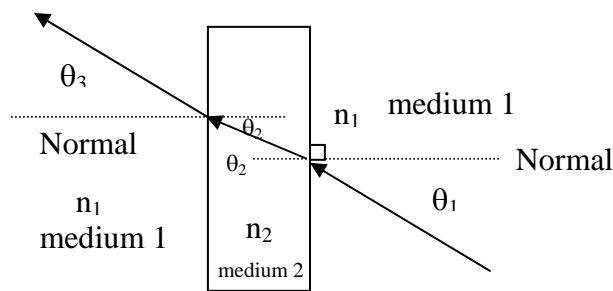


Figure 8 –3

Figure 8–3 represents two interfaces the first is from a lower to higher index of refraction (medium 1 (n_1) < medium 2 (n_2)), and the second is from a higher to low index of refraction (

medium 2 (n_2) > medium 1 (n_1)). At the interface of $n_1 < n_2$ the angle θ_2 will be less than θ_1 in relation to the normal which is in agreement with equation [4]. Likewise when $n_2 > n_1$ the angle θ_1 will be greater than θ_2 in relation to the normal. From this it can be stated that:

A light ray incident at an angle θ from the normal will bend towards the normal when traveling from a less dense medium to a denser medium, and bend away from the normal when traveling from a denser medium to a less dense medium.

For any interface from a dense to less dense medium there can be found an angle of incidence from the normal which will cause the light ray not to penetrate the interface but to travel along the interface as shown in Figure 8-4. Using Figure 8-3, it can be shown that if θ_2 was increased from the normal, θ_3 would eventually become 90° to the normal therefore travelling along the surface of the interface. The angle θ_2 at this point is called the critical angle. From this it can be found that:

$$\begin{aligned}
 n_1 \sin \theta_c &= n_2 \sin 90, \text{ or} \\
 \sin \theta_c &= \frac{n_2}{n_1}, \text{ or} \\
 \theta_c &= \sin^{-1}\left(\frac{n_2}{n_1}\right)
 \end{aligned}
 \tag{5}$$

In equation [5], (n_2/n_1) is called “the index of refraction of medium 2 relative to medium 1”. Note that if medium 2 is air then $n_2 = 1$ and that n_1 can be found by

$$n_1 = 1/ \sin \theta_c \tag{6}$$

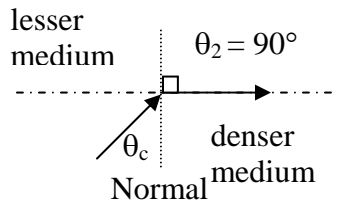


Figure 8 –4

A phenomenon called **total internal reflection** occurs when the angle of incidence of the light ray from the normal at the dense to less dense interface exceeds the critical angle. At all angles where $\theta > \theta_c$ all of the light is reflected back into the denser medium. Fiber optics is based upon this principal.

Equipment:

- 1 Pasco Scientific circular ray table
- 1 Pasco Scientific light source
- 1 Optics kit and a half moon piece of optics
- 1 wooden board

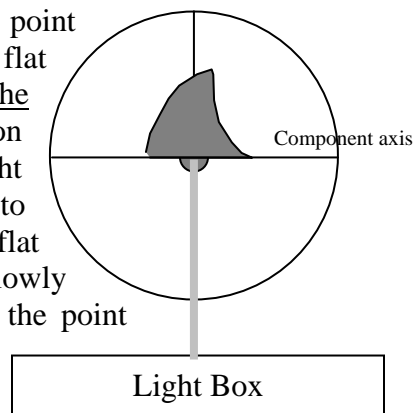
Procedure:

Reflection:

1. Familiarize yourself with the above equipment. Note that the light source has no switch , therefore to turn it on or off you must unplug the DC power source from the light source. Please do this when the light source is not in use to prolong the life of the bulb. Also note that on one end of the light source is a sliding plate this will selected the number of light rays which is emitted from the light source.
2. Notice on the wooden board a dowel pin raised above the surface. Place the board so that this surface faces up and then put the circular ray table with the degree scale side face up onto the dowel pin. The table should be able to rotate easily. Plug in the light source and adjust the sliding plate completely to the left, then slide it to the right until a single light ray is emitted. Place the light source on one end of the board with the slits on the bottom and facing towards the ray table. Adjust the optics table so that the Normal on the plate lies on a line perpendicular to the front surface of the light source. Align the light source so that the ray of light travels along the normal from one side of the table to the other.

In making measurements the better the light ray is aligned down the normal the more accurate the measurements will be. Even more critical is the alignment of the optical piece which is discussed in the next procedure step.

3. To make accurate angular measurements the point where the light is incidental to the surface (be it flat or curved) of the optical piece needs to be at the intersection of the component and normal lines on the ray table. To do this first turn on the light source. Then place the triangular mirrored piece to the far side of the component line with the flat surface towards the component line. Move it slowly towards the component line until you feel that the point where the ray is incident on the surface is at the intersection of the normal and component lines. There may be a dimmer reflected ray coming off the surface at some arbitrary angle. Rotate the mirrored surface, while trying to maintain the beam incident at the center, so that the reflected beam is reflected straight back along the normal line. Once you are satisfied that the beam is reflected back along the normal proceed to the next step.



- Without touching the triangular mirror or the light source adjust the ray table so that the incident ray is directed 5° (below or above) the normal. Note the reflected beam. It should be 5° (above or below) the normal if not, carefully move the triangular mirror so that the reflected ray is also 5 degrees.
- Rotate the ray table for an angle of incidence $\theta_i = 10^\circ$ from the normal. Record the angle of reflection θ_r in Data Table 8 – 1. Repeat this step until the data table for the flat surface is completed.
- Repeat steps 2 through 5 for the concave and convex surfaces of the mirrored piece. When measuring the convex surface the reflected ray diverges. Make the best measurements possible. Turn off the light source. Answer the questions relating to the laws of reflection.
- Remove the ray table and place a piece of graph paper on either the lower portion of the wooden board or on the lab table itself. Place the triangular mirrored surface on the paper with the concave side facing the light source. Turn on the light source, align the light ray to the center of the concave surface. Adjust the mirror so that the reflected ray is reflected back down the incident ray.
- Without disturbing the position of the mirror trace the concave surface onto the paper with a pencil. On the light source adjust the sliding plate to allow 3 light rays. Observe the reflected rays. Adjust the sliding plate for 5 light rays, and observe the reflected rays. Determine as best as possible where the 5 light rays converge, and mark this point. Measure on the paper the distance from the mirrored surface to the point where the rays converge (focal point, f). Record on Data Sheet 1. Determine the radius of curvature using equation [3]. Sketch a representation of what you observed on the data sheet.
- Rotate the mirrored surface to the convex surface. Make observations of what you see and sketch on the data sheet. On your drawing show where the focal point and radius of curvature are in respect to the mirrored surface. See Note below.

<p>Note: the focal point and radius of curvature of the convex surface has the same values as the concave surface.</p>

Index of Refraction:

- Place the ray table back onto the wooden board. Adjust the light source for one ray, and align it down the normal. Locate the half-moon piece of optics and place it on the ray table with the flat side facing the light source and align it along the component axis. Turn on the light source and adjust it or the optics piece so that the light ray travels through the optics undeviated.
- Rotate the ray table so that the angle of incidence θ_i is 10° from the normal. Record the angle of refraction θ_r of the departing ray into Data Table 8 – 2. Repeat this for each angle of incidence in Data Table 8 – 2.

3. Calculate $\sin \theta$ for each angle and then plot $\sin \theta_i$ vs. $\sin \theta_r$. Draw the best straight line through the data points and determine the slope of the line. Record the slope as the index of refraction, n .
4. Rotate the table so that the flat side of the half moon piece faces away from the light source, see figure 8 - 6. Adjust the light source and/or the piece of optic as you did in step 1.
5. Observe the light ray leaving the half-moon piece of optic, rotate the ray table until the point where the light ray no longer leaves the piece of optics from the flat surface. This is the critical angle, record this value on your data sheet. From equation [6] determine the index of refraction, n . And record it on your data sheet.

Data Sheet 1

Reflection

Data Table 8 – 1

angle of incidence θ_i	Angle of reflection θ_r		
	flat surface	concave surface	convex surface
10°			
20°			
30°			
40°			
50°			
60°			
70°			

What is the Law of Reflection?

Does the above data agree with the law of reflection? If not why?

Reflections from a concave surface.

Focus point _____ cm Radius of curvature from equation [3] _____ cm

Sketch below 3 to 5 incident and reflected rays from a concave spherical mirrored surface. Indicate the direction the ray travels, the focal point and location of the radius of curvature.

Reflections from a convex surface.

Focus point _____ cm Radius of curvature _____ cm

Where would be the focal point for a convex reflective surface?

Sketch below 3 to 5 incident and reflected rays from a convex spherical mirrored surface. Indicate the direction the ray travels , the focal point and location of the radius of curvature.

Index of Refraction

Data Table 8 –2

angle of incidence θ_i	angle of refraction θ_r	$\sin \theta_i$	$\sin \theta_r$
10°			
20°			
30°			
40°			
50°			
60°			
70°			

Plot $\sin \theta_i$ vs. $\sin \theta_r$. Determine the slope and record the value below.

Index of refraction for acrylic is $n =$ _____

Critical angle:

θ_c for acrylic = _____

Using equation [6] $n =$ _____

What is the law of refraction?

