PHY 112L Activity 9

Geometrical Optics: Reflection and Refraction

Name: _____ ID #:_____

Section: _____ Date: _____

Lab Partners: _____ TA initials: _____

Objectives

1. Introduce the law of reflection for mirrors and Snell's law of refraction for lenses
2. Verify the law of reflection and investigate the properties of spherical mirrors
3. Experimentally determine the index of refraction of an acrylic trapezoid using Snell's Law and compare (lab report)
4. Verify Snell's law of refraction and investigate the properties of spherical lenses

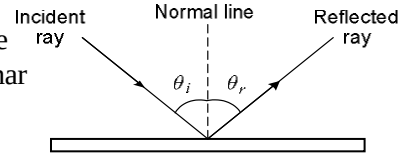
Materials & Resources

1. Light box, protractor, 3-sided mirror unit, acrylic rhombus, concave and convex lenses, and printer paper.

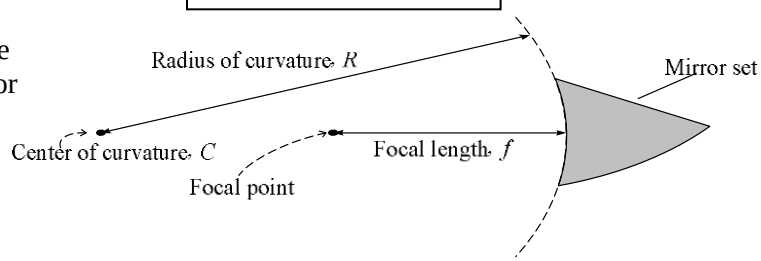
Introduction

Optical phenomena occur so frequently in our day to day lives that at least a basic understanding of them is nearly imperative. In this lab, we will be examining some fundamental properties of light and some basic behaviors of the most common optical components, mirrors and lenses. The two main properties of light examined here are the laws of reflection and refraction.

The law of reflection ($\theta_i = \theta_r$) says that the angle of incidence and the angle of reflection are equal when both are measured from the normal line of a planar surface; it governs the basic behavior of mirrors and is illustrated to the right.

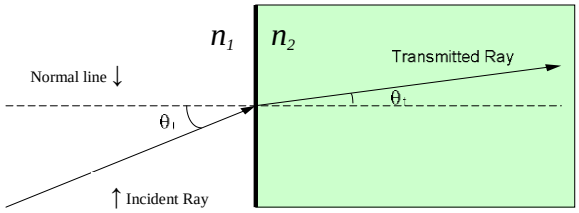


Flat or plane, as well as spherical mirrors, are the simplest to describe mathematically and the easiest to manufacture because of their symmetry. The law of reflection is easiest to explain for a flat mirror, where $\theta_i = \theta_r$ when measured from the normal line. Mirrors of other shapes can easily be thought of as composed of a "large number" of "very small, flat mirrors" arranged to make a larger mirror of a certain shape.

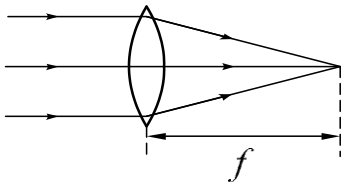


Concave (and convex) mirrors are said to be spherical because every point on the mirror is the same distance R from the center of curvature C, as shown above. The reflective surface of a concave mirror faces the center of the sphere and causes reflected light rays to converge toward the mirror's focal point, but that of a convex mirror points away from the center and causes reflected light rays to diverge away from the focal point. But in both cases, the focal length f of the mirror is located halfway between the reflective surface and C as shown above, so that $R = 2f$. Note that the focal point is in front of the mirror for concave, and behind it for convex, mirrors.

Snell's law ($n_1 \sin\theta_i = n_2 \sin\theta_t$) governs the behavior of lenses and relates the incident angle θ_i of a light ray passing through a substance with refractive index n_1 to its angle of transmission θ_t through a new substance with a different index of refraction n_2 and is illustrated to the right.



Similar to the way non-flat mirrors can be composed of a bunch of tiny "flat" ones, lenses can be composed of a bunch of small flat boundaries between n_1 and n_2 arranged to make larger shapes, such as convex (illustrated to the right) or concave lenses whose parameters (R and f) are similar to those for spherical mirrors.



1. *Law of Reflection (Plane Mirrors)*

1) Place the light source, label side up, on a white sheet of paper on the table as shown in Figure 1. Adjust the slit so that only one light ray is coming out. Align the light ray with the center of the flat side of the mirror. Imagine the normal line of the surface and orient the mirror to create an angle of incident (about 30°).
2) Mark the position of the surface of the mirror on the page and trace the incident and reflected rays with arrows as shown.
Note: the rays may be wider than the tip of your pencil. In this case, trace the center of the ray as closely as possible. Also, take care not to bump the light source or mirror unit. If necessary, place both the light source and mirror completely on the sheet of paper to help avoid either object being knocked out of alignment.

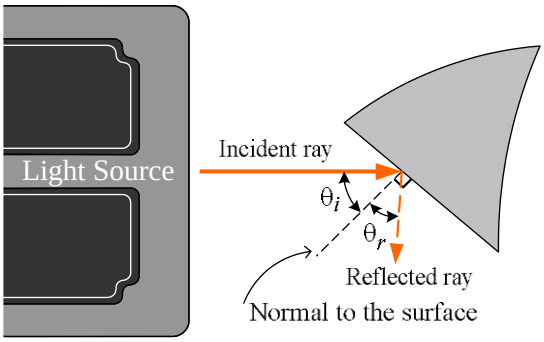


Figure 1

3) Mark the reflection point on the line representing the mirror surface, or the place where the ray is reflected by the mirror. As before, mark the center of the reflection as closely as possible.
4) At the point of reflection, use a protractor to draw a perpendicular (normal) line from the surface of the mirror. Use a ruler to extend the rays traced in step 3 far enough that θ_i and θ_r can be effectively measured with the protractor and record the values below. *Note that the rays may need to be extended 4-5 inches to be measured.*
5) Repeat this for each of the angles listed in the table below, and calculate the difference between θ_i and θ_r for each measurement. If possible, have different group members draw a sketch and make a measurement.
Note that the angles do not need to be exact; just be sure to make three measurements of angles of increasing size.
6) Clearly label each sketch with the target angle and let each group member, as well as the TA, initial the sketches.
Note*: Photo copies of this sketch will be accepted for each group member's lab report* <u>*if*</u> *they are properly initialed.*

Angle	Incidence angle, θ_i	Reflection angle, θ_r	Difference (θ_i - θ_r)
About 30°			
About 45°			
About 60°			

<u>Questions</u>:

1) For each case above, are the measured angles of incidence and reflection similar, i.e. are the differences nearly zero?

2) Are your experimental ray traces *consistent* with the stated law of reflection? Why or why not?

3) Since the rays coming from the light source do have some thickness, both the incident and reflected rays have a right and a left side from the viewpoint *behind* the mirror. Does the right side of the reflected ray from this perspective come from the right or left (circle one) side of the incident ray? Briefly justify your answer below.

4) Does the difference between θ_i and θ_r increase or decrease (circle one) as the angle of incidence increases? Briefly justify your answer in terms of the thickness of the rays below.

2. *Spherical Mirrors (Concave and Convex)*

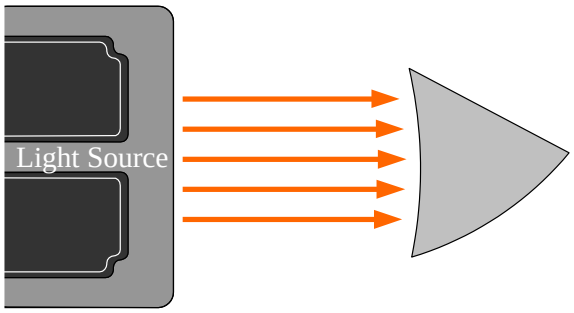


Figure 2

1) Set the light source on a new sheet of paper and adjust the output of the light source so that 5 rays come out. Shine the rays straight into the concave mirror as shown in Figure 2.
Note that the concave mirror is adjusted properly only when the center ray is reflected back on itself.
2) Trace the surface of the mirror and the incident and reflected rays. Take care to trace the center of the rays as was done in the last section. Use arrows to represent ray directions, as shown.
3) Notice that the rays appear to all be converging on a single point. This point is the *focal point* of the mirror, and the distance from the surface of the mirror to the focal point is the *focal length.* Verify that all of the rays are traced to the focal point, then measure the focal length and record it below.
4) Since the focal length f is related to the radius of curvature of the mirror R by $R = 2f$, extend the line traced for the center ray to twice the focal length and mark this spot. Place the point of a compass on this point and the pencil end on the mirror trace where the center ray crossed, and then draw an arc along the traced mirror curvature. Clearly label and initial this sketch for making copies for the lab report.

Concave Focal Length, f = _____ ( ) *Radius of Curvature, R = 2f =* _____ ( )

5) Repeat steps 1 – 4 above using the convex side of the mirror unit. Record the convex values below.
To find the focal point of the convex mirror, the reflected rays must be extended backward, as if through the mirror, to the focal point where they all cross behind the mirror. This is the *virtual image* of the *diverging* mirror.

Convex Focal Length, f = _____ ( ) *Radius of Curvature, R = 2f =* _____ ( )

6) Since the accepted value for the radius of curvature of both mirrors is 12.5 cm, calculate the percent error in the measurement of each mirror's focal length and record your results below.

Concave % Error = _____ % *Convex % Error =* _____ %

Questions:

1) The thickness of the light rays reduces the precision with which the focal point, and therefore the focal length, of the mirrors can be determined. Explain below how the ray thickness reduces the precision in finding f for each mirror.

   Concave mirror–

   Convex mirror–

2) Why is the image of the diverging or convex mirror called a *virtual* image?

3) How is this virtual image physically different from the real image created by the concave mirror?

4) Is the compass-drawn radius smaller than, equal to, or larger than (circle one) the traced radius of the concave mirror? Briefly explain why below.

5) Is the compass-drawn radius smaller than, equal to, or larger than (circle one) the traced radius of the convex mirror? Briefly explain why below.

3. *Snell's Law - Refraction at a Flat Boundary (Lab Report)*

Note: In this part, each member of the lab group will need to follow steps 1 – 6 below to draw their own sketch, gather their own data, and make their own calculations for the lab report. Photo copies will NOT be accepted here.

1) Place the trapezoid and light source with a single ray output on a new sheet of paper. Position the trapezoid so that the light ray passes through *both* parallel sides as shown in Figure 3. Be sure to orient it so that the incident and transmission angles are large enough to be accurately measured (at least 30° for θ_i).

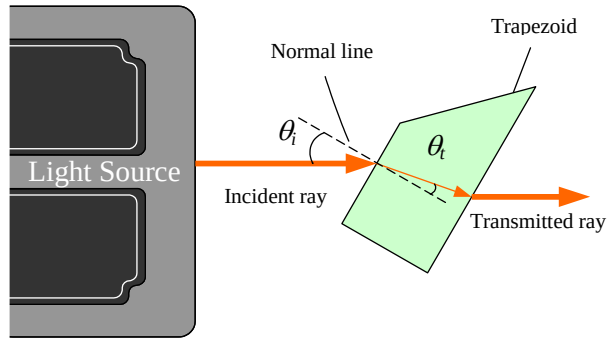


Figure 3

2) As before, carefully trace the incident and transmission rays with direction arrows and trace the edge of the parallel sides of the trapezoid. With a ruler, draw a line to connect the incident point and the transmission point, with an arrow showing the direction of the ray. Use the protractor to draw a normal line *through* the rhombus at the *point of incidence* on the mirror; verify that the lines are long enough to make an accurate angle measurement.

3) Measure the angles θ_i and θ_t shown in Figure 3, and then use Snell's Law and the accepted refractive index of air, $n_{air} = 1$, to calculate the refractive index through acrylic. Record your results below. *Show your work* in the space provided to the right.

Incidence Angle, θ_i = _____ *Transmission Angle,* θ_t = _____ *Refractive Index,* n_{acr} = _____

4) Calculate the percent error in your determination of the refractive index of the acrylic rhombus using $n_{acr} = 1.49$ as the accepted value. Record your result below and show your percent error calculation in the space to the right.

Refractive Index % Error = _____ %

5) Draw a second normal line *through* the rhombus at the *point of transmission* on the opposite side of the rhombus, verify that the lines are long enough to make an accurate angle measurement, measure the angle θ_T that the transmitted ray makes with this second normal line, and then calculate the percent difference between θ_t and θ_T. Record your results below and show your percent difference calculation in the space provided here.

Transmitted Ray Angle, θ_T = _____

% difference between θ_t and θ_T = _____ %

6) Carefully draw an extension of the incident ray forward, as if the rhombus were not there; similarly, extend the transmitted ray backward through the rhombus surface.

Questions:

1) Is the normal line on the incident side parallel to the normal line on the transmission side? Should it be? Why?

2) Are the extensions of the incident and transmitted rays parallel to each other? Should they be? Why or why not?

3) Is your measured value for the index of refraction of acrylic higher or lower (circle one) than the accepted value?

4) List all sources of error that are *physically consistent* with your refractive index measurement results below.

4. *Spherical Lenses (Concave and Convex)*

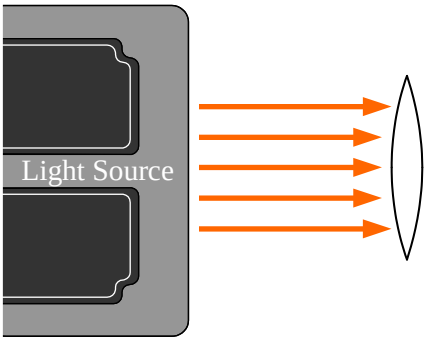


Figure 4

1) Place the light source on a new sheet of paper and adjust the slit so that 5 light rays come out. Adjust the convex lens so that the light rays strike the lens as shown in Figure 4. Be sure that the incident center ray passes through the center of the lens and that the center transmitted ray forms a straight line with the center incident ray. Carefully verify that the center ray passes through the center of the lens without any of the deflection illustrated in part 3 above.
2) Trace around the surface of the lens, as well as the incident and transmitted rays, as done in the previous sections. Carefully trace all 5 transmitted rays to the focal point. The width of the light rays may make the exact focal point difficult to precisely determine. Use the center of the rays when tracing, then the center of the focal spot should give the best results. Remove the lens and mark where the center of the lens was.
3) Measure the distance between the lens center and the focal point, the focal length *f*, and record below. Since the refractive index of acrylic is $n_{acr} = 1.49$ and the lens has the same radius of curvature on both sides, the focal length *f* of the lens is related to its radius of curvature *R* by $R = f$. Place the point of a compass on the focal point and the pencil end on the spot for the center of the lens, and then draw an arc of a circle with radius *f*.
Clearly label and initial this sketch for making copies for the lab report.

Convex Focal Length, f = _____ ( ) *Concave Focal Length, f* = _____ ( )

4) Repeat steps 1 – 3 above using the concave lens. Record the concave values to the right above. To find the focal point of the concave lens, the refracted rays must be extended backward, as if through the lens, to the focal point where they all cross behind the lens, near the light source. This is the *virtual image* of the *diverging* lens.
5) Since the focal length of both lenses is 12.7 cm, calculate the percent error in the measurement of each lens's focal length and record your results below.

Convex % Error = _____ % *Concave % Error* = _____ %

Questions:

1) The thickness of the light rays reduces the precision with which the focal point, and therefore the focal length, of the lenses can be determined. Explain below how the ray thickness reduces the precision in finding *f* for each lens.

   Concave lens–

   Convex lens–

2) Why is the image of the diverging or concave lens called a *virtual* image?
3) How is this virtual image physically different from the real image created by the convex lens?
4) Is the compass-drawn radius smaller than, equal to, or larger than (circle one) the traced radius of the convex lens? Briefly explain why below.
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