Spherical Mirrors & Index of Refraction
Spring 2024

Introduction

In this lab, you will be using ray tracing to locate the image created by an object near a spherical mirror, and to calculate the index of refraction for a glass prism. *You **must** use a very sharp pencil or pen in order to pass this lab!* Where appropriate, label the object and the image, and indicate their direction (before and after they reflect or refract). Draw a solid line for real rays, and a dashed line for virtual rays. *Each person will turn in their own journal, but you only need one set of ray tracings per group.*

Spherical Mirrors:

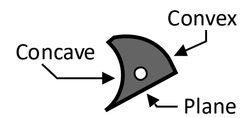

Figure 1a

Figure 1a shows the small three-faced mirror that you will use. The mirror has magnets that will hold the mirror and paper to the metal board so that they don't move during while you are tracing the rays. Each side represents a different type of mirror surface: *concave* (the inner curved portion); *convex* (outer-curved portion); and a flat plane mirror (not used in today's experiment). Note that the cross-section of each curved face is that of a sphere (or a circle, in the plane of the paper)

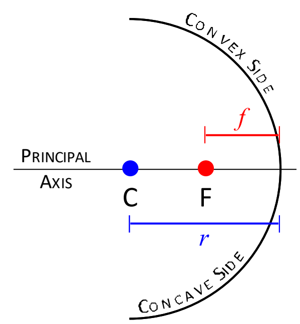

Figure 1b

Figure 1b shows the spherical mirror reference points. The principal axis is the line that intersects the mirror at the center. Point *C* marks the center of curvature, and its distance from the mirror is the radius of curvature, *r*. The focal point, *F* is located midway between the mirror and the center of curvature, and its distance from the mirror is the focal length, *f*. If a mirror is spherical, then $r = 2f$.

Ray Tracing:

Figure 2 shows that the center of curvature, *C* is located by noting the intersection of at least two axial rays (a ray that reflects back upon itself). The focal point, *F* is located by noting where a ray that was parallel to the principal axis reflects and crosses the principal axis.

Three additional rays can be drawn to locate images created by spherical mirrors (see the color-coded rays in **Figures 3** and **4**):

a) The incident ray is parallel to the axis, and reflects through the focal point, *F* (Red).

b) The incident ray goes through *F*, and reflects parallel to the axis (Green).

c) The incident ray goes through the center of curvature, *C*, and reflects back upon itself (Blue).

You need only draw *two* of the above rays to minimize clutter in your ray diagrams. If you find one ray to be difficult (or impossible) to use, draw the other two rays.

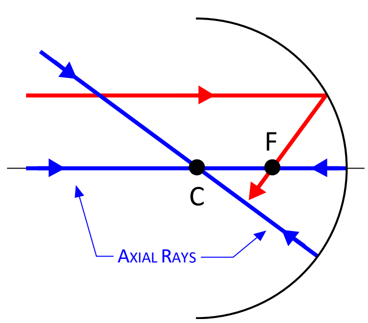

Figure 2: Locating *C* and *F*

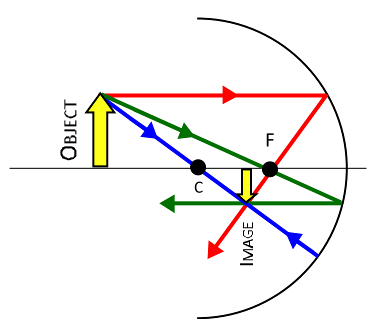

Figure 3: Concave mirror image

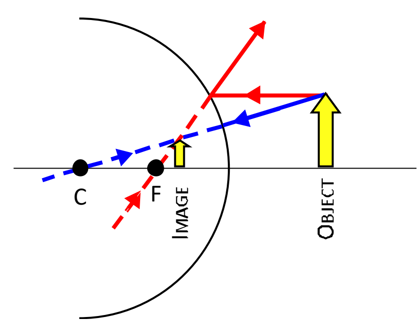

Figure 4: Convex mirror image

Experiment

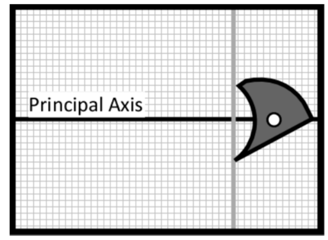

Figure 5: Location of concave mirror on page

1. ***Concave Mirror I** (Is the focal length ½ the radius?):*

   a. Draw two perpendicular lines on the grid side of a piece of graph paper: a dark line along the long axis of the page, and a lighter line along the short axis, about 5 centimeters from the right edge (**Figure 5**).

   b. Place a piece of blank paper on the metal board, and then the graph paper (grid side down) on top. Place the mirror centered along the long dark line (the *principal axis*) with the two edges of the mirror on the shorter light line (**Figure 5**). Plug in the light-ray box.

   c. Slide the aperture on the light-ray box so that it emits three light rays. Align the center ray along the principal axis with the two other rays parallel to and on either side of the principal axis. Rotate the mirror as needed so that the three reflected rays intersect on the principal axis, and then trace along the front edge of the mirror to mark its location.

   d. Draw the two incident rays parallel to the axis and trace their reflections. Mark and label the *focal point,* **F** with a small dot (**Figure 2**).
      - *Drawing rays*: Mark the path of incident and reflected rays using small dots. Remove the mirror and light box, then use a ruler to connect the dots. Draw an arrow to indicate the direction of *each ray*.

   e. Remove the mirror, and then measure and record the focal length, f.

   f. Replace the mirror, and check that it is aligned correctly. Set the light-ray box so that it emits a single ray and then aim it at the mirror at an angle so that it reflects upon itself (**Figure 2**). Draw this *axial ray* and the label the radius of curvature, **C**. Remove the mirror and then measure the radius of curvature, r.

   g. If a mirror is spherical, then $r = 2f$. Do your measurements show this for your mirror?

2. ***Concave Mirror II***: Finding an Image

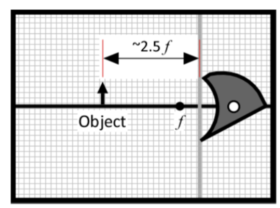

Figure 6: Image of distant object

   a. Create a new picture with the axes marked the same as before. With the light-ray box emitting three rays, locate the focal point and mark it with a small dot (don't bother drawing rays here).

   b. Draw an arrow that is **4 grid-boxes tall**, starting on the axis about **2.5** focal lengths from the mirror; this arrow will represent the object (**Figure 6**, *not to scale*). With the light box emitting a single ray, find the *image* of this *object* using two rays that originate at the arrowhead. The image is located where the reflected rays intersect; draw another arrow to represent the image of the object arrow (**Figure 3**).

   c. Is the image in this case real or virtual? Upright or upside down? Bigger or smaller than the object? Be sure to label the object and image arrows.

3. ***Concave Mirror III** ("The makeup mirror"):*

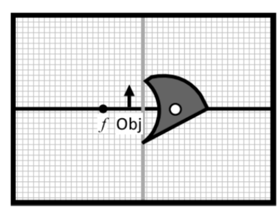

Figure 7: Image of close object

   a. Create a new picture using the same mirror placed **in the center** of your paper (**Figure 7**) and mark the focal point like you did in step *2a*. Draw an arrow **3 grid-boxes** tall, starting on the axis ½ the focal length from the mirror to represent an object.

   b. Find the image of this object using two rays that originate at the object arrowhead. The image is located where the reflected rays intersect. If the reflected rays diverge, you need to trace them backwards until they meet.

   c. Is this image real or virtual? Upright or Upside down? Bigger or smaller than the object? Again, be sure to label the object and image.
      - *Thought question: If the object is placed on the focal point, where will the image be located?*

4. ***Convex Mirror*** *("The security mirror"):*

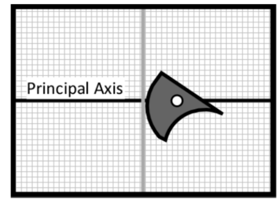

Figure 8: Convex mirror placement

a. It is difficult to determine the location of the focal point and center of curvature on a convex mirror since you need to aim the ray behind the mirror (**Figure 4**). So, you will again use the focal length and radius measured for the concave mirror in step 1 (assuming both have the same radius).

Create a new picture using the convex side of the mirror placed **in the center** of your paper (**Figure 8**). Mark the positions of **C** and **F** using your previous measurements.

b. Draw an arrow that is **4 grid-boxes** tall, starting on the axis **1.5** focal lengths from the convex mirror to represent an object. Find the *image* of this *object* using two rays that originate at the arrowhead. The image is located where the reflected rays intersect (**Figure 4**).

c. Is the image real or virtual? Upright or upside down? Bigger or smaller? Be sure to label the object and image.

5. ***Index of Refraction*** *(What is the value of **n** for glass?):*

In this section you will use *Snell's Law* to calculate the index of refraction, **n** for a glass prism. Snell's law is stated as:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

Note that $n = \frac{c}{v} = \frac{\text{speed of light in vacuum}}{\text{speed of light in material}}$, and the subscripts represent the angles and indices of refraction for the two materials the light ray passes through. Note that angles are measured **from** a normal to the surface **to** the ray.

a. Place the glass prism near the center of the page and trace around its edges. *Use the magnetic mirror to hold the paper in place!*

b. With the light box emitting a single ray, trace a ray entering the triangle approximately 30° from the normal (**Figure 9**). Aim the ray at the lower third of the prism to give you enough room to measure the angles!

c. Use several dots to mark the direction of the ray as it enters and exits the glass; be sure to mark the points at the air-glass boundary. Remove the prism, and use a ruler to draw the rays, including the one that passes inside of the glass (**Figure 9**).

- *Note: you may see a ray that travels straight through the prism, denoted by the red segment in **Figure 10**. This ray is caused by light that travels over the top of the prism, and should be ignored.*

d. Measure the angles with a protractor; be sure to position the protractor correctly (Figure 11). Calculate the index of refraction for the glass triangle by applying Snell's law to θ_1 and θ_2, then applying again to θ_3 and θ_4 (use $n_{air} = 1.00$). Calculate the *%Difference* between your average measured value and the actual index of refraction for glass: $n_{glass} = 1.50$.

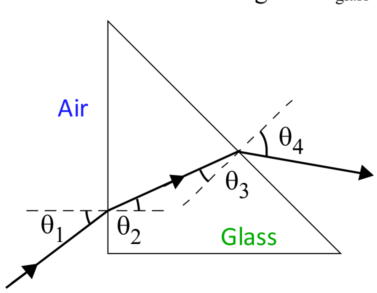

Figure 9:
Tracing a ray through the prism

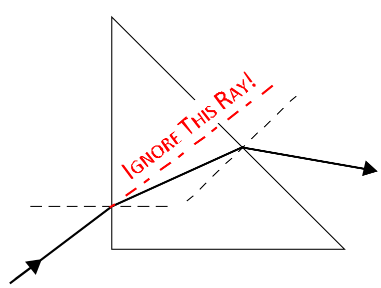

Figure 10:
Ignore the ray passing over the prism

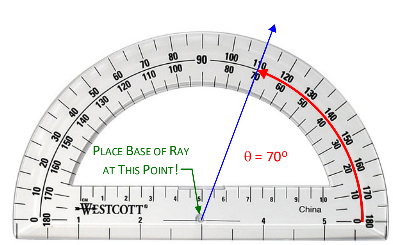

Figure 11:
Correct placement of protractor

6. ***Critical Angle***:

a. Draw a *new* picture and aim a ray (again, toward the bottom third of the prism) so it leaves the opposite side of the glass triangle at 90° (**Figure 12**). Measure and record the angle **in** the glass: this is the *critical angle*, θ_c, beyond which all the light will be reflected internally.

b. Calculate the expected value for θ_c for a ray traveling *from* glass *to* air (use the actual value for the index of refraction of glass). Calculate the *%Difference* between your measured and expected values of the critical angle.

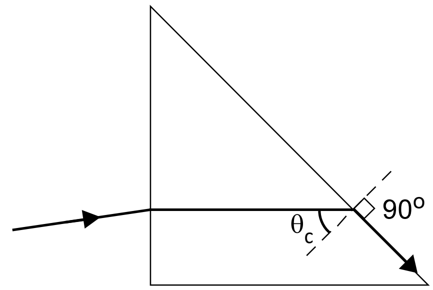

Figure 12