What You Need to Know:
In this lab you will be exploring the first part of optics, the reflection and refraction of light at a plane (flat) surface and a curved surface.

*Reflection* occurs when an incident ray of light bounces off of a smooth surface like a mirror. See Figure 1. *Refraction* occurs when a ray of light that is traveling in one medium, let’s say air, enters a different medium, let’s say glass, and changes the direction of its path. See Figure 2.

In order to describe reflection or refraction at a plane surface you need to measure angles with respect to a common reference line. The reference line that is used is called a *normal*. A normal is a line that is perpendicular to a surface. In Figure 1 you see a ray of light that is incident on a plane surface. The *angle of incidence*, $\theta_1$, of a ray of light is defined as the angle between the incident ray and the normal. If the surface is a mirror, then the *angle of reflection*, $\theta_2$, of a ray of light is defined as the angle between the reflected ray and the normal.

If the light is refracted as in Figure 2, then $\theta_2$ is defined as the *angle of refraction*. ($\theta_1$ is still the angle of incidence). The amount that the ray of light will refract is related to the *index of refraction* of the medium. The index of refraction, $n$, (no units) is defined as the ratio of the speed of light in a vacuum to the speed of light in the medium. In this lab however, we will use a different equation, called Snell’s Law, to calculate the index of refraction. Snell’s Law is ...

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

Now let’s examine reflection and refraction at a curved surface. There are
two different kinds of curved surfaces that you will be dealing with for reflection; a concave mirror and a convex mirror. Both of these are considered to be spherical mirrors, which means that the mirror is part of the arc of a large circle. This implies that the mirror has an associated radius of curvature, $R$. See Figure 3. The center of the mirror is called the vertex. A line drawn through the vertex and the center of curvature, $C$, is called the principal axis. Halfway between the vertex and the center of curvature is the focal point, $F$. The distance from the focal point to the vertex of the mirror is the focal length, $f$. The relationship between the radius of curvature and the focal length is, $R = 2f$.

For a concave mirror, all of the light rays that run parallel to the principal axis will reflect off of the mirror and converge at the focal point. See Figure 4. For a convex mirror, parallel lights rays will reflect off of the mirror and diverge from the focal point. See Figure 5. You can use dashed lines that trace back along the reflected rays to show that the light rays diverge from the focal point.
Both $R$ and $f$ have sign conventions that are given in the chart below. In general though, concave mirrors have a positive focal length and convex mirrors have a negative focal length.

![Figure 4 - Concave mirror](image1.png)

**FIGURE 4 - Concave mirror with parallel incoming rays**

![Figure 5 - Convex mirror](image2.png)

**FIGURE 5 - Convex mirror with parallel incoming rays**

Curved surface refraction occurs when light travels through a lens. There are two different types of lenses: a converging lens and a diverging lens. A converging lens has a center that is thicker than its edges while a diverging lens has a center that is thinner than its edges. See Figures 6 & 7. Also notice that there are focal points on both sides of the lens. This does not imply that one focal length is positive and the other negative. The sign conventions are given in the chart on the next page.
Sign Conventions for Lenses

- The focal length, $f$, is $+$ for a converging lens
- The focal length, $f$, is $-$ for a diverging lens

The equipment You will be using a Ray Box throughout this lab. The Ray Box will be used as a source of parallel light rays. You can set it for white light rays or for colored light rays. There is a mask on the side of the box that slides back and forth that will allow you to control the number of light rays that emerge from the box. For white light you can have between 1 and 5 light rays. For colored light you can have 1 to 3 light rays, each a different color.

Sharing Duty For much of this lab you will share, with your lab partner, the duty of drawing Light Ray Diagrams (LRDs). This will save time and paper. For example, one person will draw the LRD for the concave mirror and the other person will draw the LRD for the convex mirror. You will SWITCH for the lenses so that each of you will make an LRD for a diverging light-ray case.

NOTE: When tracing a light ray, just put a dot at the beginning of the ray and a dot at the end of the ray. Draw in all of your lines by connecting the dots AFTER you’ve passed the light box to your partner. ALSO, all data, calculations, and answers to questions should go on paper OTHER than your light ray diagram sheet.

What You Need To Do:
Reflection - Plane Surface Plug in your Ray Box. Set the Ray Box up so that a single white light ray is emerging from it. Take out the three-sided mirror from the Ray Optics container. Place the plane side of the mirror in
the path of the light ray. Each lab partner should do the following on his/her own paper. Each should use a different angle of incidence.

Trace the incident and reflected light ray. (Again, just use dots for the light rays and then pass the ray box to your partner). Make sure to draw a line for the mirror surface. Also make sure that your light rays are at least 9 cm long. Using the protractor, make a normal at the point where the ray reflects. The diagram should look similar to Figure 1. Measure the angle of incidence and the angle of reflection.

**Question #1** Based on both of your observations on reflection, what can you say about the relationship between the angle of incidence and the angle of reflection?

Turn over the Ray Box and slide the mask so that red light is emerging. (You can use the diverging lens on its side to prop up the edge of the Ray Box to lengthen the light ray). Overlay the red light ray on top of the incident ray that you already drew. YOU DON’T HAVE TO TRACE IT. Observe how the ray reflects. Try blue. Try green.

**Question #2** Does the color of the light affect the relationship that you determined in **Question #1**?

**Reflection - Curved Surface** Set up the Ray Box so that 5 white light rays are emerging from it. Place the concave side of the mirror in the path of the light rays. Make sure that the center ray is reflecting directly back on itself.

- Trace the five incident and reflected rays. Draw a line for the mirror surface. Pass the Ray Box to your lab partner who will do the convex mirror.

- Notice for the convex lens that the reflected rays do not converge. You will have to draw in dashed lines behind the mirror as in Figure 5.

- Measure the focal length of the mirror. (For the convex mirror, all of the light rays might not converge at exactly the same point. Just
use the central location of where they all cross as a reference point in measuring the focal length).

- Calculate the radius of curvature for each mirror.

**Question #3** Does the color of the light affect your focal length?

**Refraction - Plane Surface** Shine a single ray of white light into the rhombus as shown in Figure 9. Make sure the frosted side of the rhombus is face down so that you can see the light ray inside of the rhombus. Each lab partner should do the following procedure but with a different angle of incidence.

- Trace a line around the rhombus.

- Trace the incident light ray and the outgoing light ray.

- Make sure each line is at least 9cm long.

- Draw a line inside of the rhombus connecting the incident ray and the outgoing ray.

- Using the protractor, draw two normal lines as shown in Figure 9.

- Measure the angle of incidence and the angle of refraction at the first surface. You will have to extend the light ray inside of the rhombus to measure the angle.

- Use Snell’s Law to calculate the index of refraction of the rhombus. The index of refraction of air is 1.0.

- Average your index of refraction with your lab partner’s.

- Compare the average value to the actual value of 1.5 by calculating a percent error.
**Question #4** Notice that the *angle of incidence* at the *first surface* is equal to the *angle of refraction* at the *second surface*. Explain or prove algebraically (using Snell’s Law) why this is true.

**Question #5** Do different colors refract at different angles?

**Refraction - Curved Surface** Set up the Ray Box so that 5 light rays are emerging. Place the converging lens in the path of the light rays. Whichever lab partner drew the diagram for the convex mirror will do the converging lens and vice-versa.

**NOTE:** For the diverging lens do not use the reflected rays off of the first surface.

Do the following ...

- Trace a line around the lens.
- Trace the 5 incident rays as well as the 5 refracted rays.
- Measure the focal length. Get the focal length from your partner as well.

**Question #6** Do you still get the same focal lengths if you turn the lenses around to face the other way? Did you expect this result? Explain why?
Color - Prism White light is actually a mixture of all colors. To demonstrate this, put the rhombus in the path of a single white light ray. See Figure 10. Make sure that the ray exiting the rhombus is very close to the surface of the rhombus. What do you see?

![Figure 10 - Rhombus with refracting light ray](image)

**Question #7** Which color refracts the most? The least?

**Question #8** Re-examine your answer to **Question #5**. Re-answer the question now. What is different about this situation?

Color - Mixing You just saw how light can be separated into colors. Now you will do the reverse. Slide the mask on the Ray Box so that the three primary colors appear. Use the diverging lens on its side to prop up the end of the Ray Box. Place the converging lens in the path of the colored light. Stand up a white sheet of paper outside of the focal point. Slowly move the paper towards the focal point.

**Question #9** What do you see when the paper reaches the focal point?

**Question #10** Try combining different pairs of colors together. (The mirror, placed on its side, blocks one of the light rays nicely). What do you see? Did your results turn out how you expected?

What You Need To Turn In:
Turn in all of your drawings. Make sure all of your data, like focal lengths, is recorded on your lab paper, not on the light ray diagram sheet. Answer all of the questions in the sections where they are asked.