INSIDE LAB 6: The Properties of Lenses and Telescopes

OBJECTIVE: *To construct a simple refracting telescope and to measure some of its properties.*

DISCUSSION:

In tonight's lab we will build a simple telescope from the ground up and use it to look at things in the lab. A telescope consists of two lenses to focus light. But before we can put two lenses together, we must explore the properties of a single lens.

There are many kinds of lenses we can use. Their overall shape differentiates the two principle types of lenses. One bows out from the center, and the other bows in:

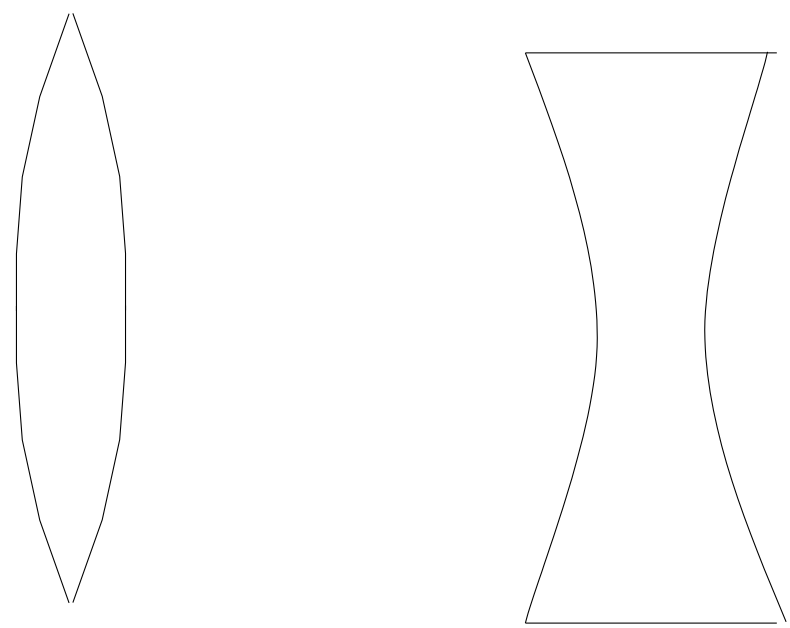

Figure 1. Convex lens on the left; concave lens on the right.

The lens on the left is called a **convex lens**, and the one the right is called a **concave lens.** Convex lenses are easier to understand than concave ones, so we'll work with those first.

How does a convex lens form an image? When parallel light rays enter a convex lens, the curved surfaces of the lens cause the rays to bend so that they converge to a point, as shown in the figure below.

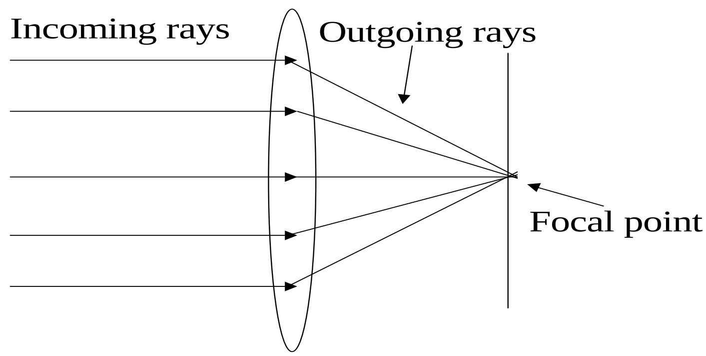

Figure 2. Parallel rays enter a convex lens and converge at the Focal point.

Rays striking the lens near its edge are bent or **refracted** the most, while rays passing through the center are not bent at all. The point where the rays meet is called the **focal point** of the lens.

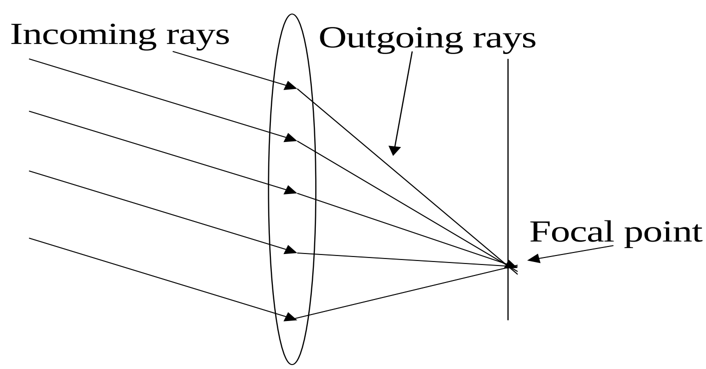

Figure 3. A second set of parallel rays enters a convex lens and converges at the Focal point; compare to Figure 2 above.

In the first figure, only rays that are parallel to the bottom edge of the paper are shown. But parallel rays can enter the lens from any direction. The second figure illustrates what happens to parallel rays entering the lens from some other direction. Notice that again the center ray is not bent; but the other rays are refracted, and they intersect the center ray on the right side of the lens. Notice also that this intersection takes place on the same line as in Figure 1. In fact, all sets of parallel rays entering the lens, regardless of the direction from which they originate, converge to points that lie in a common plane.

EXERCISES :

EXERCISE 1:

First make sure you have all the equipment you need: an optical bench (a metal bar you can clamp things to), a working light source, a box of several color-coded lens (look for the colored tab), and a screen. Your first task is to form a clear image of the light source on the screen with each lens in the box. Make a careful record your set-up. You can record any data you wish, but a person not in the lab should be able read your data and from it completely reproduce your configuration to get the same image that you did. Use the rest of this page for your work. Make sure you include a few sentences describing the images you see.

NOTE: You cannot form an image on a screen with just a concave lens. Place the thickest convex lens against the concave lens and measure the image distance for the combination.

EXERCISE 2:

Using the data you gathered in Exercise 1, fill out the following table.

Lens	Source to lens distance	Lens to image distance	Focal length

Table 4.1 Optical distances when a clear image is formed on the screen.

It turns out that for each lens, there is an important relationship between these distances:

$$\frac{1}{\text{source to lens distance}} + \frac{1}{\text{lens to image distance}} = \frac{1}{\text{focal length}}$$

The constant is called the **focal length** of the lens. If the light source were located an *infinite* distance behind the lens, the distance from the lens to the image would be the focal length. (See the discussion above on how the lenses form an image. Optional exercise: prove that this is true using the equation above.)

NOTE: The pair of concave and convex lenses obeys a slightly different relationship

$$\frac{1}{\text{source to lens distance}} + \frac{1}{\text{lens to image distance}} = \frac{1}{f_{convex}} - \frac{1}{f_{concave}}$$

EXERCISE 3:

Use the focal-length equation to argue for or against the following assertion.

There is more than one combination of distances that will produce a clear image on the screen.

(Hint: Think about what happens as the source moves further and further away from the lens.)

EXERCISE 4:

Using the focal-length equation along with your data from Exercise 1, calculate the focal length for <u>each lens</u>, including the concave lens. *Remember, to do the concave lens last since you need the focal length of the lens you paired with it to find the concave lens's focal length.* Hint: It is easiest to use the orange convex lens to find the focal length of the concave lens.

Focal Lengths:

EXERCISE 5

Select the lens with the longest focal length. Hold it just in front of your eye and use it as a magnifying glass to view your fingerprint. Repeat this for the rest of your lenses. How does the magnification you observe vary with the focal length of each lens?

Now, using the lens with the longest focal length, project an image of the ceiling light onto the table. Repeat this for the rest of your lenses. How does the size of the image you observe vary with the focal length of each lens?

EXERCISE 6:

Now that you have successfully created images using a single lens, try focusing the image using two intermediate lenses. Start by putting the source at one end of the optical bench and the screen at least half way down the bench and maneuver the two lenses in between to form a clear image. This will prove to be difficult but remember that we are working up to a telescope which will have two lenses (an eyepiece and an objective). For a realistic telescope, one lens should be as close to your eye as possible and the object (a screen here) should be very far away.

Next remove the screen and place your two lenses at the opposite end of the bench from the source. Looking through the closest lens and keeping its position constant, maneuver the second lens until the source looks focused through the furthest lens.

Finally, remove the source. You have created a telescope!

The distance between the lenses will have a simple relation to the focal lengths of the lenses you use. **See if you can figure out what this simple relation is.** If you use this relationship you should find that it is much easier to form an image. **What is different now and why do you think it is easier to form an image?**

EXERCISE 7:

Remove the light source and screen from the optical bench and hold your telescope up so you can look through one of the lenses. Describe what you see, including the apparent sizes of things and how they are oriented.

To determine quantitatively how much larger objects appear to be when seen through the telescope view a set of distant calibrating lines placed on the wall of the laboratory. With both eyes open, one viewing the lines through the lenses and the other viewing the lines naturally, attempt to merge the two images of the lines so that their separations can be compared, as shown in Figure 4. From your observations determine how many times larger does an object appears through the telescope than it does to your naked eye? This is the magnification of the telescope.

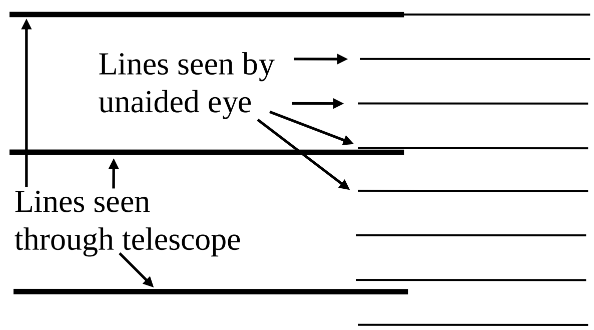

Figure 4. Lines for Measuring Magnification
3x magnification seen here

Repeat these observations for each combination of lenses for which you have data. Do things look like you expected?

Observations:

When two lenses are used to make a telescope, we give each a special name. The lens you look through is called the **eyepiece** and the other lens is called the **objective.** The magnifying power of a telescope can be mathematically expressed by a simple relationship between the focal lengths of these two lenses.

EXERCISE 8:

Write an equation expressing the magnification of your telescope in terms of the focal lengths of the objective and eyepiece. *(Hint: magnification does not have units; it's just a number.)* Use this equation to calculate the theoretical magnification of your telescope, and compare the result with the magnification you observed.

EXERCISE 9:

What would be the magnification of a telescope with eyepiece and objective reversed? Show a sample calculation using your data and check that it agrees with what you see when you try this.