

Lab 7: The Basics of Optics and Telescopes

Objectives: This lab will give students a basic understanding of how lenses and telescopes work. Students will measure the properties of lenses, and make a telescope.

Introduction: The most important purpose of a telescope is to gather light. This makes it possible to observe objects that are too faint for the unaided eye. The Light Gathering Power of a telescope is proportional to the area of the telescope's objective mirror or lens. A mirror with a large diameter will give bright images, which makes faint objects visible.

The second most important purpose of a telescope is to resolve detail. For example, when viewed with the unaided eye, the images of two closely spaced stars may appear to merge into a single image. A telescope, on the other hand, might be capable of resolving the two stars into separate points of light. The problem is that the human eye does not have nearly the resolution, or ability to see fine detail, of a telescope. Resolution depends on the quality of the optics (which can be costly) and the wave nature of light.

The third purpose of a telescope is to produce a magnified image of the object we wish to observe. Surprisingly, the magnification is the least important property of a telescope. Magnification sets the size of the image, and can be changed by changing the eyepiece. We get high magnification by choosing an eyepiece with a short focal length, such as a 10mm eyepiece. Don't confuse resolving power with magnification. If we have a telescope with poor resolution, due to poor quality optics, we could try to produce extremely large (or magnified) images by choosing a short focal length eyepiece. However, these large images would still be blurry, because the telescope lacks resolution.

Telescopes can be built using lenses (refractors) or mirrors (reflectors). We will examine the properties of refractors to illustrate the general principles involved. Let us begin with the basic element in a refractor: the lens. Lenses are made from glass that is formed to have spherical surfaces. A lens can be used to change the direction that the light travels.

On your lab table, there should be two different types of lenses. One type is thicker in the middle than at the edges: this is the convex lens. The other type of lens is thicker at the edges than it is in the middle: this is the concave lens. The fundamental fact about light and lenses is that *light travels faster in air than in glass*. Let's see what this implies for a convex lens using the diagram below.

If you throw a stone into a pond, you will see that waves are formed, and that these waves travel outward forming concentric circles. These circles are called wave fronts and represent points having the same height above the average water level. A line perpendicular to the wave fronts at any point will give the direction of propagation of the waves. Light behaves very similarly to this, as shown in Figure 1.

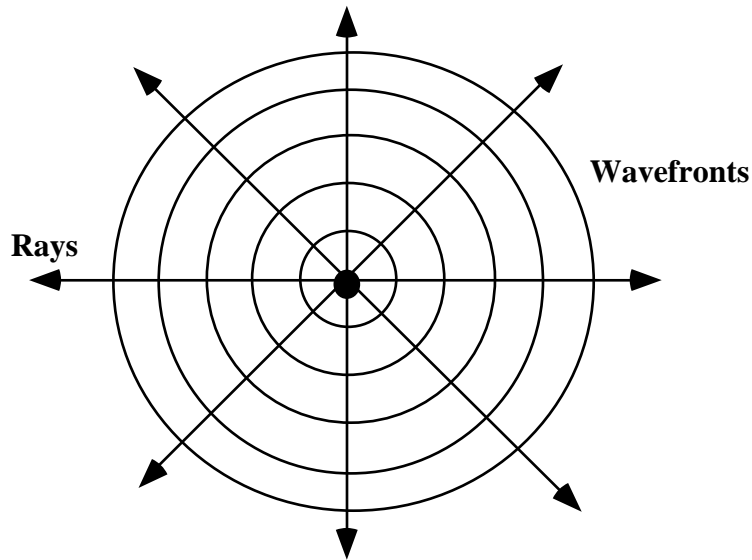


Figure 1. Spherical wave fronts leave a star at the speed of light, propagating outward in all directions. Notice that the rays are perpendicular to the wave fronts and point in the direction that the waves travel.

If we are very far from the star then the spherical wave fronts have such large radii that any small portion wave front appears as a plane. So, far from a star, the wave fronts are a set of parallel planes, with the rays perpendicular to the wave fronts. In this case we say that the rays are parallel (to each other), as shown in Figure 2.

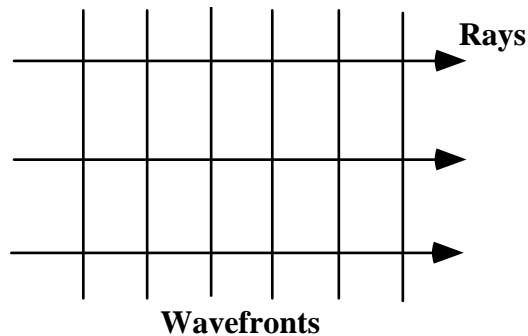


Figure 2. Plane waves and parallel rays

When light waves travel through air, all points on a particular wave front move with the same speed. But when the wave hits a glass surface, the lower part of the wave front (now inside the glass) moves slower than the upper part (still in the air). The ray is therefore bent, as shown in Figure 3.

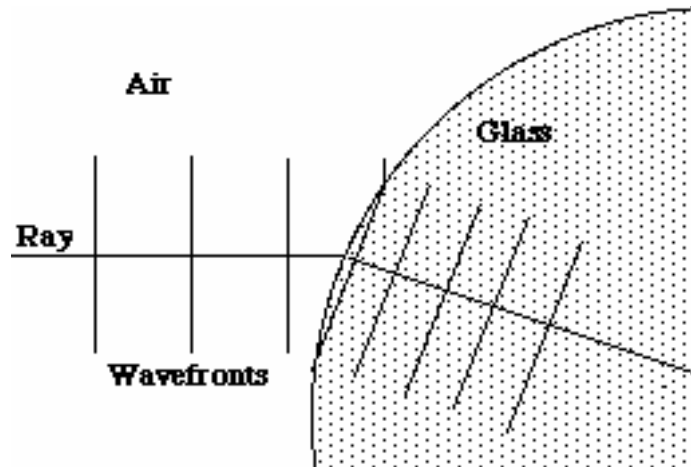


Figure 3. Plane waves that travel into a spherical glass surface are refracted. The waves slow down and change direction upon entering the glass.

Rays from distant objects, such as stars, are essentially parallel to each other. When parallel rays of light pass through a converging lens, they intersect at the focal point. The distance from the center of the lens to the focal point is called the focal length and is denoted by f , as shown in Figure 4.

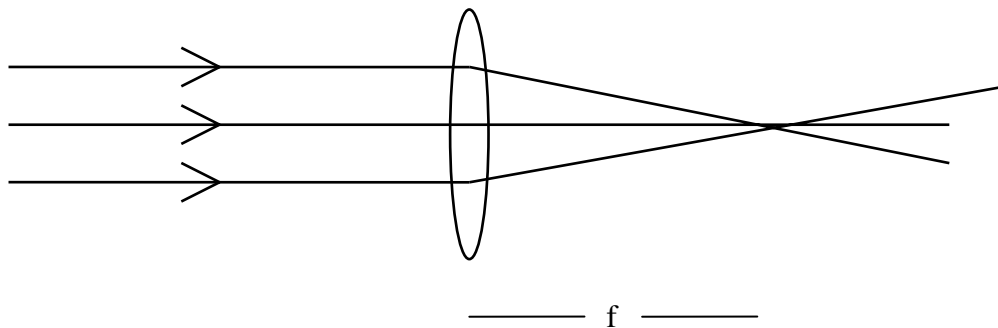


Figure 4. The light from a star consists of parallel rays which are brought to a focus by the converging lens. The distance from the lens to the focus is called the focal length.

Procedure:

The Properties of Lenses: On the optical bench on your lab table, place a convex lens in a holder and a screen in a second holder (or improvise, with a piece of white paper). To measure the focal length of the lens, we need an object at infinity. A tree or building outside the room will do. With the lens and the screen on the optical bench, bring a tree or building to a focus on the screen, by moving the screen back and forth until you see a sharp image of the tree or building.

The focal length of the lens is the distance from the lens to where the sharp image appears. Record the focal length in Table 1 (below), in the column marked "Focal length (cm)." Also measure the diameter of the lens, and record it in Table 1, in the column "Diameter (cm)."

Repeat the procedure with each of the other converging lenses, and record their focal lengths and diameters in Table 1, too. Then, for each lens, calculate $f\text{-ratio} = f/D = \text{Focal Length} / \text{Diameter}$, and record these in Table 1.

Now try the same thing with the concave lens. Can you find the focal point using the above method? Answer the questions about this, below Table 1.

Go back to one of the convex lenses. Instead of using images of objects outside the window, mount a light source on your optical bench. Place the lens between the light source and the screen, and move the screen until a sharp image appears on the screen. If you are unable to obtain a sharp image on the screen, try increasing the distance between the bulb and the lens. The object distance is the distance from the lens to the light source. The image distance is the distance between the lens and the screen. You will obtain a new value for the image distance every time you change the object distance. **Try five different object distances, recording both the object and image distance each time.** Record the values in Table 2. Do you see a pattern emerging (that is, does a larger value of o require a smaller value of i ? A larger value of i ?)

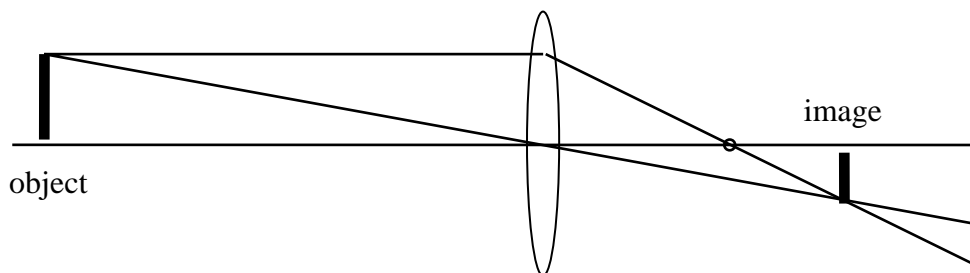


Figure 5. A ray tracing showing the image formed by a converging lens. Notice that the image is upside down (inverted) compared to the object.

Calculate $1/i$ and $1/o$ for each one of your measurements and enter each of these numbers in Table 2. Many calculators have a key that calculates reciprocals, usually marked $1/x$. Ask for help if you don't know about this key.

Next, calculate $(1/i) + (1/o)$ for each one of your measurements and enter these numbers in Table 2. Do you see a pattern now? Is there anything special about the numbers in the last column? Calculate the reciprocals of the numbers in the last column. Did this number come up anywhere else during this lab?

You should now be on the verge of discovering an important equation from optics! Use the information that you have compiled so far to write down this famous equation.

Name: _____ Your lab day: Mon Tues (Circle one)

Lab Instructor: _____ Time: 5:30 p.m. 7:30 p.m. (Circle one)

Be sure the read the worksheet carefully, and answer all the questions.
 Each student must turn in her or his own worksheet.

Table 1: Use *different* lenses for each of these measurements.

Measure the focal lengths of all your lenses and record the measurements below
 (See the Procedure in “The Properties of Lenses,” above.)

Measure and record the diameters of the lenses too, and calculate the f-ratios for each.

QUESTION: For the convex lenses: Are the images you see upright or inverted? _____

Lens	Focal length (cm) = f (measure this)	Diameter (cm) = D (measure this)	f-ratio=f/D (calculate this)
1			
2			
3			
concave			

QUESTION: For the concave lens: Are the images you see upright or inverted? _____

QUESTION: Can you find the focal point of a concave lens using the above method? Why or why not?

Table 2: Use *one* lens for all the measurements for this table.

Use five different object distances, recording both the object distance (o) and image distance (i) each time.
 Then calculate the numbers for the other columns. See the Procedure in “The Properties of Lenses” above.

o = Object distance (cm)	i = Image distance (cm)	1/o = 1/(object distance) (cm ⁻¹)	1/i = 1/(image distance) (cm ⁻¹)	(1/o) + (1/i)	1/(previous column) = 1 / ((1/o)+(1/i)) = f

For the five different object distances, notice that a pattern emerges:
 a larger value of o (the object distance) requires a smaller value of i (the image distance).

QUESTION: The last column is the reciprocal of the numbers in the previous column.
 This number came up elsewhere during this lab: What is it? _____

This relation, $1/f = (1/o) + (1/I)$, is called *the Lensmaker’s equation*. It’s the fundamental law that governs the science of optics, from eyeglasses to binoculars to telescopes.

Building a telescope: With a converging lens, bring the image of a far-away object into focus. This lens is the objective of the telescope we will build.

QUESTION: What is the most important purpose of a telescope? _____

QUESTION: In the context of the previous question, which will be more effective for gathering light, a lens with a larger diameter, or a lens with a smaller diameter?

QUESTION: If two lenses have the same focal length, f , but different diameters D_1 and D_2 (with D_1 larger than D_2), which f -ratio (shorter or longer) would you choose if you want the image to be brighter?
[Hint: notice that photographers use long lenses for higher magnification, but these require more light.]

Now look at the image on the screen and try to resolve as much detail as you can with your eyes. Notice that the closer your eye is to the image, the more detail you can see. This can become difficult if you really want to see fine detail, but you know a simple solution to this problem! You can use another converging lens to magnify the image, so you can see fine detail more easily.

Take the screen off the holder and replace it with a second converging lens. Use this combination to look at objects in the lab, or at trees or buildings outside the lab. The lens closer to your eyes plays the role of the eyepiece in a telescope. You now have in your hands a simple refracting telescope, called a Keplerian refractor.

QUESTION: Does a Keplerian refractor give an upright image, or an inverted image? Try it yourself and see!

QUESTION: Draw a simple diagram of a Keplerian refractor, and label which lens is convex, and which is concave:

Next, change the eyepiece to a concave lens. What you get is a Galilean refractor.

QUESTION: Does a Galilean refractor give an upright image, or an inverted image? Try it yourself and see!

QUESTION: Draw a simple diagram of a Galilean refractor, and label which lens is convex, and which is concave: