OBJECTIVES:
Recognize a meter, a centimeter, and a millimeter.
Correctly measure distances in mm, cm, and m.
Describe the appearance of both a converging lens and a diverging lens.
Define or describe the focal plane, focal length, object, and image of a lens.
Measure the focal length of a converging lens.
Describe and build a refracting telescope.
Describe the function of the objective lens of a refracting telescope.
Describe the function of the eyepiece of a refracting telescope.

BEFORE YOU COME TO LAB:
Review the Lab Notebook write-up so you know what to enter in your notebook and how to enter it.
Read this write-up.
At the top of a right hand page, enter the title “Lenses and Telescopes” (Table of Contents too).
Under the title, in your own words, define the following four terms: focal plane, focal length, object, and image. Use clearly labeled sketches to help. The information is in this write-up. You are free to use other resources like the web or a textbook but be sure to list the resources you used.

BRING TO LAB:
One paragraph in your notebook as described above.
This write-up.

INTRODUCTION TO LENSES:
Lenses can be classified as converging or diverging. A converging lens is thicker in the middle and thinner around the edges as shown in Figure 1. This lens focuses light that passes through it. Farsighted people use converging lenses to help them see nearby objects.

Fig 1: Converging Lens (Convex)
A diverging lens is thinner in the middle and thicker around the edge and spreads out light that passes through it. See Figure 2. Near sighted people use diverging lenses to help them see distant objects. Even though Galileo built his first telescope using one diverging and one converging lens, we will use converging lenses.

![Diverging Lens](image)

**Fig 2: Diverging Lens (Concave)**

A converging lens has two important properties that we can use to build a telescope. First, a converging lens can focus light. Second, a converging lens can magnify an object. You have already experienced both of these properties. Maybe as a kid you tried to burn a piece of paper by concentrating sunlight onto it with a magnifying glass, you were using a converging lens to focus the light rays from the sun onto the paper. When you examined a caterpillar with a lens, you were using a converging lens to magnify the caterpillar. A converging lens can focus light and a converging lens can magnify an object.

**INTRODUCTION - MEASURING FOCAL LENGTHS:**

One of the properties of a lens is its focal length. Since a converging lens focuses light, the focal plane of the lens is an imaginary plane located where the light focuses. If the light source is very distant, then the light always focuses the same distance away from the lens. Under this condition (source far away), the focal length is the distance from the lens to the focal plane. See Figure 3. For example, suppose you use a converging lens to focus the Sun onto a piece of paper. The Sun is the object. The small, bright spot of the focused Sun on the paper is the image. The focal plane coincides with the piece of paper. Since the Sun is distant, the distance from the lens to the paper is the focal length.

![Focal Length](image)

**Figure 3: Focal Length of Converging Lens**

**INTRODUCTION – REFRACTING TELESCOPE:**

Before we can make a telescope, consider a second property of a converging lens: magnification. When Sherlock Holmes examines a small fiber from a victim’s coat, he holds a converging lens close to the fiber. This magnifies the fiber.
However, to magnify a star, you cannot hold a lens close to the star to magnify it the same way you look at a fiber. You must use two lenses (at least) in a telescope: one lens forms an image of the distant star by focusing the star light, and the other lens magnifies the image that the first lens creates.

A refracting telescope or refractor basically uses two lenses, an objective lens and an eyepiece. The objective lens focuses light from a distant star, planet, galaxy, or moon onto its focal plane forming an image. The eyepiece magnifies that image.

A simple telescope can be built using two converging lenses as shown in Figure 4. Note how the objective lens focuses the light rays coming from the distant source. The eyepiece then magnifies this image.

![Fig 4: Simple Refracting Telescope](image)

**EQUIPMENT:**
1 optical bench
2 lens holders with clamps
1 screen with clamp (blank side & printed side) [DO NOT WRITE ON BLANK SIDE]
4 lenses (in a box)
1 ruler

**PROCEDURE:**
Work in groups of three if possible but no more than four. Obtain the equipment if it is not already set up. Notice that the optical bench has a distance scale on it that you can use to measure focal lengths. Set up the optical bench, lens holders, lens, and screen as shown in Figure 5. The instructor will show you how to use the optical bench and holders.

![Fig 5: Optical Bench, Lenses, and Holders](image)
RECORD KEEPING:
Keep your own record. Record the names of your partners, the date, and the location. Use your own record keeping techniques. Keep notes of what you are doing. Someone else should be able to reconstruct your experiment from your notes and diagrams.

MEASURE THE FOCAL LENGTHS AND IMAGE SIZE: (columns 2 & 3 below)
PLEASE BE CAREFUL WHEN HANDLING THE LENSES. The instructor will demonstrate. PLEASE DO NOT DROP THE LENSES.
Set up the optical bench if it is not already. As in Fig, 5, place the screen (metal plate with white paper on at least one side) in a lens holder and put it in one of the clamps on the optical bench. Place one lens in a lens holder “aiming” at one of the distant light bulbs around the room. Turn the white side of the screen to face the lens.
Move the lens or screen along the bench until the image of the bulb appears on the screen. As long as the bulb is “far away”, the distance between the lens and the screen is the focal length of that lens.
Sketch and label your set up. (Use a camera if you have one or you may copy the pictures from this write-up and staple or tape them in your notebook.)
DO NOT WRITE ON SCREEN.

Construct the following table in your lab notebook or cut this out to use it.

<table>
<thead>
<tr>
<th>Lens color</th>
<th>Focal length (cm)</th>
<th>Image size (vertical height) (mm)</th>
<th>Magnification Rank</th>
<th>Magnification Distance (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Black</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Red</td>
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</tr>
<tr>
<td>Green</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Accurately measure the focal length of each of the four lenses and the vertical height (“image size”) of each image. Summarize your results in the table in your notebook (not on this sheet but you can cut this out and use this table). Leave columns 4 and 5 (right side) blank for now.

MEASURE THE MAGNIFICATION RANK: (column 4 in table)
Place the lenses on some printing on the lab write-up. Observe which lens makes the text the largest. Repeat for all four lenses and rank the lenses from largest magnification to smallest (which magnifies the most etc). The lens with the greatest magnification (1) gives you the largest text. Record your rankings in the fourth column of your table.
MEASURE THE MAGNIFICATION DISTANCE: (column 5 in table)
Place the printed side of the screen in the lens holder on the optical bench. (PLEASE DO NOT write or draw on the white screen.)
Place the shortest focal length lens in a lens holder on the optical bench.
Make sure the printed side of the screen faces the lens.
Put your eye right about a cm away from the lens and look through the lens at the printing.
Move the screen and the lens so that you can read the printing (for the black lens, the lens and screen will be close).
While looking through the lens (eye close to lens), slowly separate the lens and the printing. The print will gradually grow. Stop when the print JUST BEGINS to blur. Give your eye time to focus on the printed screen and the letters may become clear again. Measure the distance between the lens and screen at this point. Record this distance in the fifth column of your table. Include units.
Repeat for all lenses. (This is very difficult for the long focal length lenses.)
Think about this: Is it reasonable to conclude that this magnification distance is about the same as the focal length? (This should help you know about what answers you will be recording in the Magnification Distance column.)

NOW BUILD A REFRACTING TELESCOPE:
Set up two lenses on the optical bench.
Put your eye up to one lens and look through both lenses at a distant scene as shown in Figure 6.

Adjust the separation between lenses so you have a clear view of the distant wall. Try to focus on an outlet on the opposite wall from your light bulb. Any wall will work. You may end up seeing a focused image on the edge of your lens not in the center. Try different combinations of lenses to get the “best” telescope. To help you figure out which lenses to use, check out Fig. 4 and think about the introduction to this write-up where it discussed the Refracting Telescope. Think about what each of the two lenses in the telescope does and what you observed in this exercise about lenses. When you have the best telescope, show it to the instructor.

PUT THIS INFORMATION IN YOUR LAB NOTEBOOK:
1. Sketch and label the setup of your telescope.
2. Indicate which lenses you used by labeling their colors.
3. Label the objective lens and the eyepiece.
4. Show the location of the focal plane of the objective lens. (You measured where it is in your table. It is labeled in Figure 4. Look at Figure 4.)
5. Measure and record the distance between the lenses.
6. Draw each individual focal length. Your two focal lengths should add up to the total distance between the lenses but may be off a little.
QUESTIONS ABOUT THE REFRACTING TELESCOPE:

In your notes, answer the following questions:

1. Did you use converging or diverging lenses to make your telescope?
2. Why do different lenses produce different image sizes?
3. What does the objective lens do?
4. What does the eyepiece do?
5. Where is the focal plane of the objective lens? Between what? How far from that focal plane is the eyepiece and objective lens?
6. Why is the length of your telescope about equal to the sum of the focal lengths of the lenses you used? (Answer this by discussing what each lens does and where that happens?)

Image above from Horizons textbook, pg.80. Image (a) is a refracting telescope with 2 lenses. The primary lens is the objective lens and the eyepiece is also labeled. The focal length is the distance between the two lenses. Image (b) is a reflecting telescope has a mirror. This example has 2 mirrors and an eyepiece lens.