# CONSTRUCTION OF A REFRACTING TELESCOPE

# 5

## OBJECTIVES

The objectives of this activity are intended to meet the following course goals:

G4. Students will understand how astronomical instruments operate and their limitations.

G8. Students will develop critical and/or analytical thinking skills.

After completing this activity the student will be able to:

1. Use an optical bench to find the focal length of a lens
2. Find the focal length of a lens when an object is placed at infinity
3. Construct a simple Galilean telescope
4. Calculate a telescope's resolving power, light gathering, and magnification
5. Understand the meaning of resolving power, light gathering, and magnification
6. Draw the design and light path for a simple refracting telescope

## STUDENT MATERIALS

Students schould bring the following items with them to the observatory:

pencil
metric ruler
calculator

## LABORATORY MATERIALS NEEDED

Project Star telescope kits (or other similar materials)
Telescope construction sheets from Project Star package
Optical benches with lens holders and image screens
Goose neck lamps or some other suitable light sources

## INTRODUCTION

In 1610 Galileo used a simple optical device called a telescope to make historic observations of the universe. He did not invent the telescope, but he was the first person to point one toward the night sky. With his telescope he was able to observe features on the moon, sunspots, the moon's of Jupiter, and countless faint stars in the Milky Way. In this activity you will construct a simple telescope similar to the one used by Galileo.

The optical design of a simple telescope is basically two lenses held in place by a tube, as shown in Figure 1. This is a basic refracting telescope compose of two lenses. The main lens is called the objective lens and is a large diameter lens with a long focal length. It is this lens that produces all the image quality such as resolution and images brightness. The second lens is the eyepiece and is a small diameter lens with a short focal length. The eyepiece is nothing more than a magnifying lens used to inspect and magnify the details already created in the image produced by the objective. It can be compared to Sherlock Holmes magnifying glass that he used to inspect small details already present at a crime scene. The remainder of the telescope is a tube to hold the two lenses and focusing mechanism.

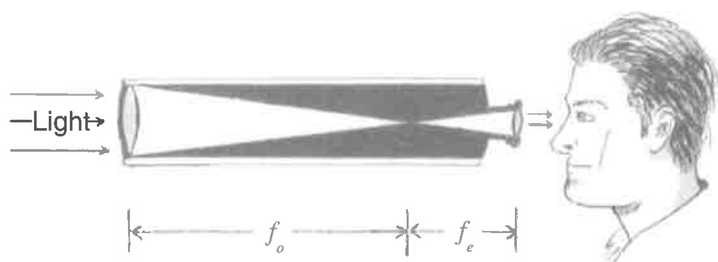


**Figure 1:** Optical design of a simple telescope.

Parallel light means that the light source is a point an infinite distance away from us. We can assume this is the case for stars. We cannot assume this for sources of light that are close to us (such as light bulbs). A finite-sized light source (like a light bulb) a finite distance away (like centimeters) will emit light in all directions, not just parallel to the axis of the lens. In this case, Fig. 1 does not show the correct situation. To find the focal length we must use the simple lens equation:

**f = (SI)/(I + S) where**

**f** = focal length of the lens

**I** = image distance = distance from the lens to the image

**S** = object distance = distance from the source to the lens.

This equation says that:

focal length = image distance times object distance all divided by the sum of the image distance and object distance.

## PROCEDURE

### A. Measuring the focal length of lenses.

1. Set up your optical bench as shown in Figure 2. The gooseneck lamp will be your light source. The light from the bulb in the lamp will pass through the lens and produce an image on the screen. Place the end of the light bulb as close to the zero mark on the optical bench as you can.
2. Place the objective lens (large diameter) in the lens holder. Move either the lens or the screen or both until you see a large focused image of the light bulb on the screen. When the image is in focus record the object distance, S, and the image distance, I, in Table I.
3. Move the lens on the optical bench to a new location and refocus. Repeat the procedure in step 2 two more times for a total of three measurements.
4. Calculate the focal length using the simple lens equation for each position of the lens. Record your answers to a tenth of a centimeter. Calculate the average focal length and record the result.

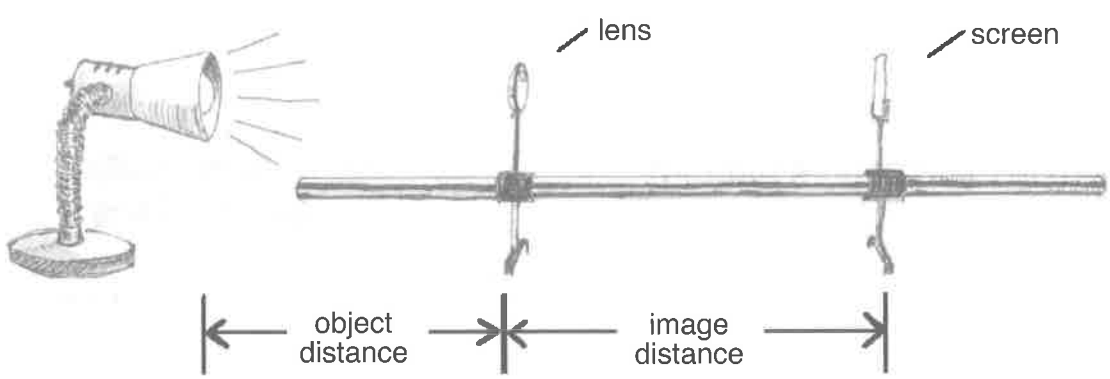


**Figure 2:** Optical bench setup used for measuring lens focal length.

5. Repeat the procedures in steps 1-4 using the eyepiece lens (small diameter). The tiny eyepiece lens may not fit into the lens holder. Therefore, you may need to hold it between your fingers and estimate its position on the optical bench. Again measure three object and image distances, calculate three focal lengths, and the average focal length. Record your results in Table I.

## B. Telescope Construction

Project Star produced the telescope you will build. Use the directions supplied by Project Star to construct your telescope.

## C. Telescope Properties

The three most important properties of a telescope include its angular resolution, light gathering ability, and its magnification.

### Angular Resolution

A telescopes angular resolution is its ability to see tiny angles. The smaller the angle that a telescope can clearly resolve the smaller the details it can show the observer. Before Galileo used a telescope on the moon the human eye could not resolve craters on the moon because the eye' diameter does not give it enough resolving power. The larger diameter objective of a telescope improves the angular resolution visible. Therefore when Galileo first pointed a telescope at the moon he became the first person to resolve lunar craters. Usually, the resolution is expressed as an angle in arc seconds. For most optical telescopes the angular resolution can be calculated using

**angular resolution** = 11.6/D, where D is the telescope's aperture in **centimeters**.

Measure the diameter of your telescopes objective lens and then calculate its angular resolution. Show your work.

D = __________ cm
angular resolution = __________ arc seconds.

### Light Gathering

One reason astronomers build large-aperture telescopes is to gather more light. You can catch more rainwater with a large bucket than with a small one. It can be seen in Figure 1 that the telescope's large objective lens take a large number of light rays and compresses them down so that the entire bundle fits through the human eye. This allows feeble light coming from faint objects to be seen through the telescope. One of the most important functions of a telescope is to make the image brighter. It was the telescopes improved light gathering ability that allowed Galileo to see that the faint band of light in the night sky called the Milky Way was actually composed of countless numbers of stars fainter then the unaided human eye could detect. It should be obvious that the larger the objective lens the fainter a telescope can see. Therefore, a telescope's light gathering ability is directly proportional to the primary lens or mirror's surface area. Because most telescope optics has a circular lens or mirror the surface area is simply the area of a circle, which can be written as

**telescope surface area** = $\pi(D/2)^2$ where $\pi = 3.14$ and D = telescope's aperture.

Calculate the surface area of your telescopes objective lens using your previous value for D. Show your work.

Surface area of telescope = ______________ $cm^2$.

When fully dilated the human eye has an average diameter of 8 mm. Calculate the surface area of a dilated human eye. Show your work.

Surface area of a human eye = ____________ $cm^2$.

Your telescope's larger diameter objective allows it to see fainter stars than your smaller diameter eye. By comparing the surface area of your telescope to that of the average human eye the light gather power of your telescope can be estimated. Calculate the ratio of the telescopes surface area to that of the average eye. Show your work.

How many times fainter can the telescope see than can be seen by the unaided eye?

## Magnification

Magnification is simply the ratio of the telescope's focal length, $f_o$, to the eyepiece's focal length, $f_e$ and can be written as

**magnification** = $f_o / f_e$ , where $f_o$ and $f_e$ must be expressed in the same units.

Notice that magnification is a ratio and therefore has no units. However, the symbol X is sometimes used to indicate how many **times** the object is enlarged. An example would be 10X for a magnification of 10 times.

Using your previously measured values (Table I) of $f_o$ and $f_e$ for your telescope and calculate your telescope's magnification. Show your work.

Mag. = ___________X

## TABLE I

Measurement of the objective and eyepiece focal lengths.

**Objective Lens**

| Trial # | S (cm) | I (cm) | $f_o$ (cm) |
|---|---|---|---|
| 1 | | | |
| 2 | | | |
| 3 | | | |

$f_o$ (avg) = _______ cm

**Eyepiece Lens**

| Trial # | S (cm) | I (cm) | $f_e$ (cm) |
|---|---|---|---|
| 1 | | | |
| 2 | | | |
| 3 | | | |

$f_e$ (avg) = _______ cm

# CONSTRUCTION OF A REFRACTING TELESCOPE

NAME: ______________________________

LAB SECTION: ______________________________

1. What are the two main differences between a telescopes objective lens and its eyepiece lens?

2. Look through your telescope and determine if the image is right side up or upside down?

3. In the space below make a sketch of the optical path of your telescope that shows why the image is right side up or upside down as stated in your answer to question 2.

4. Your astronomy class has caused you to want to buy a telescope to look at the moon and planets. You have narrowed your list of telescopes down to two different models. One of them is a 3-inch refractor with magnifications of 50x, 300x, and 1000x. The other telescope is an 7-inch refractor with magnifications of 50x, 100x, and 150x. Which of these two telescopes should you purchase if you want to see the smallest possible details on the moon and planets? Why?

5. When you purchase your telescope it will usually come with a selection of several eyepieces with different focal lengths. Why does the manufacturer send multiple eyepieces?