

Introduction to Lenses, & Telescopes

Equipment: Four lenses, an optical bench, a screen, lens holders, a bench-mountable light source (with two crossed arrows on its front), a set of high-intensity lamps.

Objectives: To relate image and object distances to focal lengths for various lenses. To be able to determine focal length, image size, brightness, and f-numbers for various lenses. To understand the differences between telescopic systems, and astronomical telescopes of various types. To construct a simple refracting telescope.

Discussion: A *telescopic system* is designed to produce parallel rays of light. An *astronomical telescope* amplifies light with a system of lenses and/or mirrors. For the purpose of this exercise, a *converging lens* is defined as a lens with two convex surfaces. A *diverging lens* is a lens with two concave surfaces. An *object* is any article that is being viewed through an optical system; e.g., when one looks at a tree through a camera lens, telescope, or the naked eye (all are examples of optical systems), the tree is referred to an optical object. *Object Distance* is the distance from an object to a lens, eyeball, or other optical element. An *image* is the likeness of an object produced at a point in space by a lens or system of lenses, again, a lens, a telescope, a pair of binoculars or your eye. *Image Distance* is the distance from a lens or other optical element to an image.

The *focal length* (f) of a lens is a unique characteristic of the lens. The focal length of a lens may be loosely defined as the distance from a lens at which a distant object will produce an image. Focal length is related to the *object distance* (p) and the *image distance* (q) by the following *thin lens equation*:

$$\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$$

Finally, the *f-number* of a lens is a measure of how bright an image a lens will produce.

In this exercise you will study the elements of simple optical systems. A set of converging lenses has been provided for you. You will begin by measure the focal lengths of these lenses. Diverging lenses, which are often used along with mirrors in telescopes, are more complicated and therefore more difficult to study and are not included here. In addition to focal length, you will measure several other lens parameters and use this information to construct a simple telescope. We will also explore some rudimentary mathematical relationships between elements in simple optical systems.

Procedure

You will begin by using objects at various distances from each of the four lenses that have been provided to form images on a screen. In each case you will record both the object and image distances and use the thin lens formula given above to find the focal length of each

lens. Notice if the object distance (p) is very large in this equation, $1/p$ becomes very small and the formula reduces to:

$$\frac{1}{q} = \frac{1}{f} \Rightarrow q = f$$

This means that at very large object distances, the image distance equals the focal length for a lens. This suggests an alternative method of measuring focal lengths. Can you think of what it might be? What is the relationship for image distance and focal length for a faraway object? Record the answer in your lab notebook.

Measuring focal length, magnification, and brightness of converging lenses

Step 1: You have been provided with a set of four converging lenses, an optical bench, several lens holders, a screen, a light for the optical bench and a set of small high-intensity lamps. The optical bench should be set up on a table at the opposite end of the room from a set of three high-intensity lamps. Take one of the converging lenses and place it in a lens holder. Position the lens holder at the 0 cm mark on the optical bench and point the end of the optical bench containing the lens holder at the high-intensity lamps.

Next place a screen on the optical bench. Move the screen back and forth along the bench until you have a sharp image of the lights on the screen. Record the object distance in your lab notebook as ∞ (this is the symbol for infinity but it is being used here to denote a large distance). Record the image distance from the scale on the optical bench. Each lab partner should try this a couple of times in order to determine the point of best focus. Record the average of all your image distance measurements. Also make note of the relative size of the image as compared to the size of the object. Repeat this process for each of your lenses.

Step 2: Place the small, bench mountable light source in a holder on the optical bench and position it at the 0 cm mark. Place one of the lenses in a lens holder and place it on the optical bench around the 50 cm mark. Put the screen in a holder, place it on the bench at the 100 cm mark. Move the lens back and forth along the bench until you obtain a sharp image of the light on the screen.

Note: *For one of the lenses you may be unable to obtain a clear image.* Identify this lens in your notes and continue with the next.

Record *both* the image and the object distances you obtain for each lens. The object distance is the distance from the light to the lens. The image distance is the distance from the lens to the screen. Again, each partner should try this a couple of times. Record the average values you obtain for each of your measurements in your lab notebook. Use these average values to compute, using the focal length equation, the focal length of each lens.

You will notice that for each lens for which you are able to obtain an image, there are *two* positions of the lens that will produce the image, one closer to the light source (object), and

one closer to the screen (image). You might have noticed that in the thin lens equation the object distance (p) and the image distance (q) are interchangeable. This is what gives rise to these *points of conjunction*. It doesn't matter which of these positions that you use (both will yield the same value for f). Physically, this arises from a property of optical systems known as *reversibility*.

Example: Suppose that I compute an average object distance for a lens of 90 cm, and an average image distance of 10 cm. In this case, p (the object distance) is 90 and q (the image distance) is 10. I wish to solve:

$$\frac{1}{90} + \frac{1}{10} = \frac{1}{f}$$

To solve this equation I would add the terms on the left side of the equation in my calculator (or by finding a common denominator) and take the inverse of their sum (in other words, divide 1 by the sum). The answer is the focal length of the lens. In this case, $f = 9$ cm. Try this calculation for yourself.

Compare the values obtained for the image distance (q) of each lens from step 1 with the values obtained for the focal length (f) for each lens from step 2. What conclusion do you draw from this data? Is the thin lens formula that you were given valid? Does the focal length of a lens equal the image distance for large object distances? How does your data prove or disprove any of this.

Step 3: Examine the data from steps 1 and 2 above to determine any relationship between focal length and image size. State the relationship in your lab notebook.

Step 4: Lay out your lenses in front of you in order of increasing focal length. What physical property of each lens determines its focal length? Record the answer in your lab notebook.

Step 5: Measure and record the diameter of each lens. Does the diameter of a lens have any apparent effect on its focal length?

Step 6: The diameter of a lens determines its light gathering power, while the focal length determines how much area the gathered light is focused into (i.e., the magnification of the image). The ratio of these two quantities determines the brightness of the image. This ratio is called the *f-number* of the lens. Specifically:

$$f - number = \frac{f}{diameter}$$

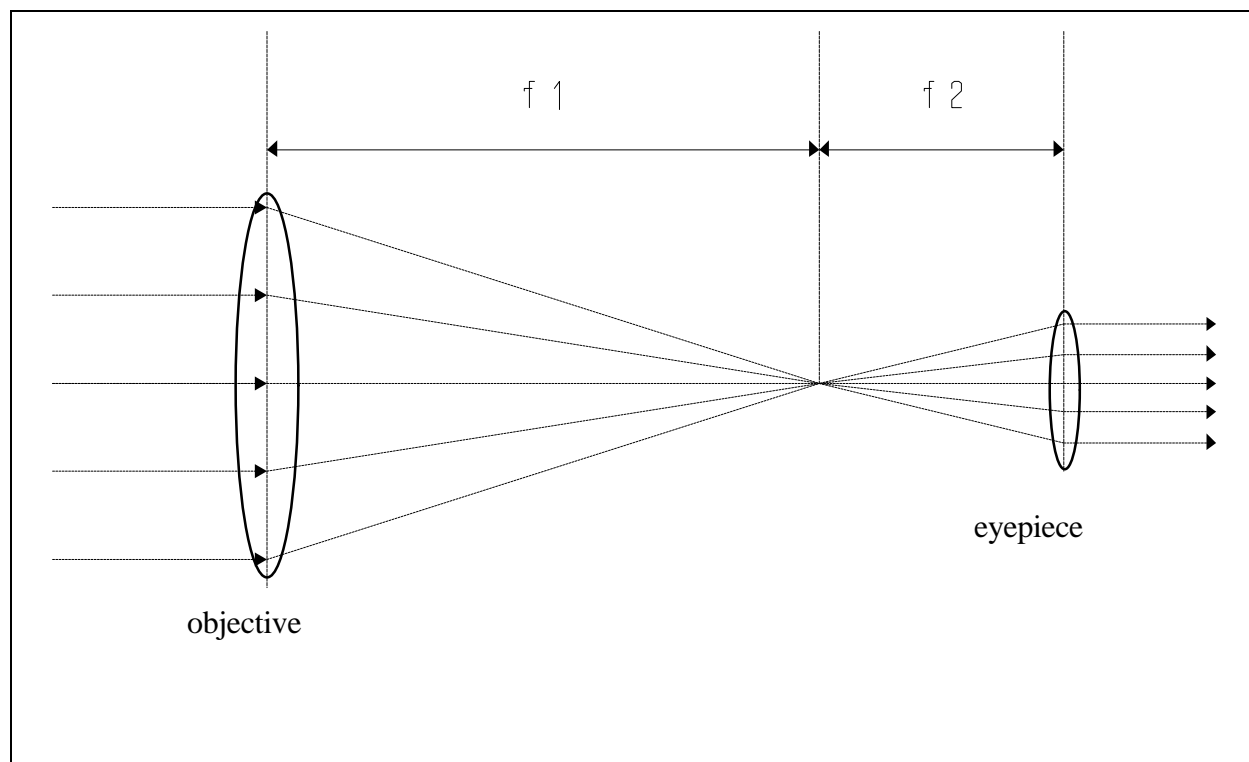
A large *f-number* means that the image is *not* very bright. Record the *f-number* for each of your lenses in your lab notebook. Which lens will produce the brightest image? Which lens will produce the dimmest? Rank your lenses in order of decreasing brightness.

A Simple Refracting Telescope

A refracting telescope is a simple optical system composed of elements that you have already studied. A refracting telescope consists of an *objective lens* and an *eyepiece*. The objective lens is a converging lens in the leading end of the telescope (the end you point at whatever you are looking at). The eyepiece is another converging lens that is used by the eye to examine the image produced by the objective. The *magnification* of a telescope is defined as the ratio of the focal length of the objective lens to the focal length of the eyepiece.

$$\text{Magnification} = \frac{f_{\text{objective}}}{f_{\text{eyepiece}}}$$

A diagram of a simple refracting telescope like the one that you are to construct is shown below. The object is to the left of the diagram. Notice that the distance between the two lenses is equal to the sum of their individual focal lengths.



To construct a refracting telescope, remove the screen and mountable light from the optical bench and in their place put a second lens holder. Examine the lens data you have accumulated. Using this data and the diagram above, construct a telescope with the lens of largest diameter for the objective and the lens of shortest focal length for the eyepiece.

The characteristics of your telescope:

Step 1: Record the focal length of the lenses used in your telescope.

Step 2: Point your telescope at the lamps at the other end of the room. Align your two lenses so that a straight line runs between the object (lamps) and the two lenses.

Step 3: Look through the eyepiece of your telescope and adjust the length between the two lenses to produce the sharpest image. Is the image upright or inverted? Is the image larger or smaller than the object?

Step 4: Compute the magnification of your telescope. Does the result of this calculation correlate with your observation? Record the results of your computations and observations in your lab notebook.

Step 5: Draw a sketch, similar to the one on the previous page, of your telescope.

Step 6: Replace the lenses in the foam container and remove all holders from the optical bench.

Exercises

1. What is the magnification of a telescope with an objective of 4000 mm and an eyepiece of 26 mm?
2. What is the primary purpose of a telescopic system?
3. A converging lens produces an image at 20 cm for an object 50 cm away from the lens. What is the focal length of this lens?
4. The radius of curvature of a lens affects its _____ while its diameter affects its _____.
5. A refracting telescope consists of two lenses, the _____ and the _____, located the sum of their _____ apart.
6. Examine the common telescope focusing arrangements shown on the following pages. Which figure best represents the telescope you constructed in this lab? Which represent the types of telescopes used in our night observation sessions?
7. The lenses in your eyes are converging lenses. Since converging lenses produce inverted images, why do you see everything right side up?

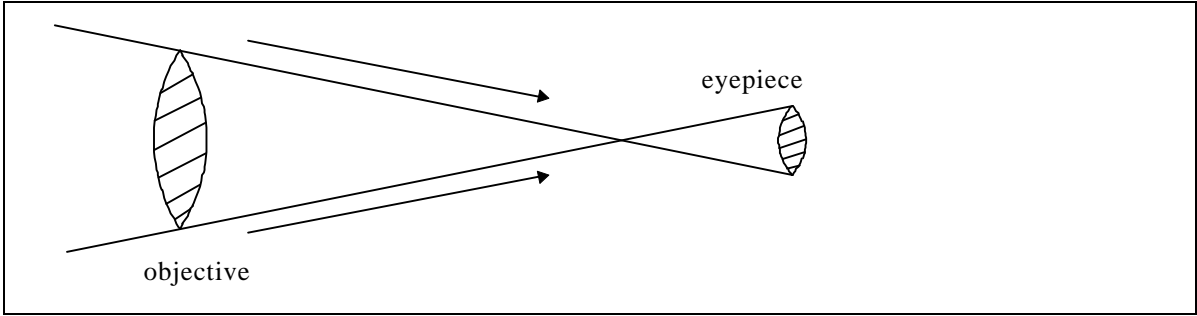


Figure 1. Refracting Telescope.

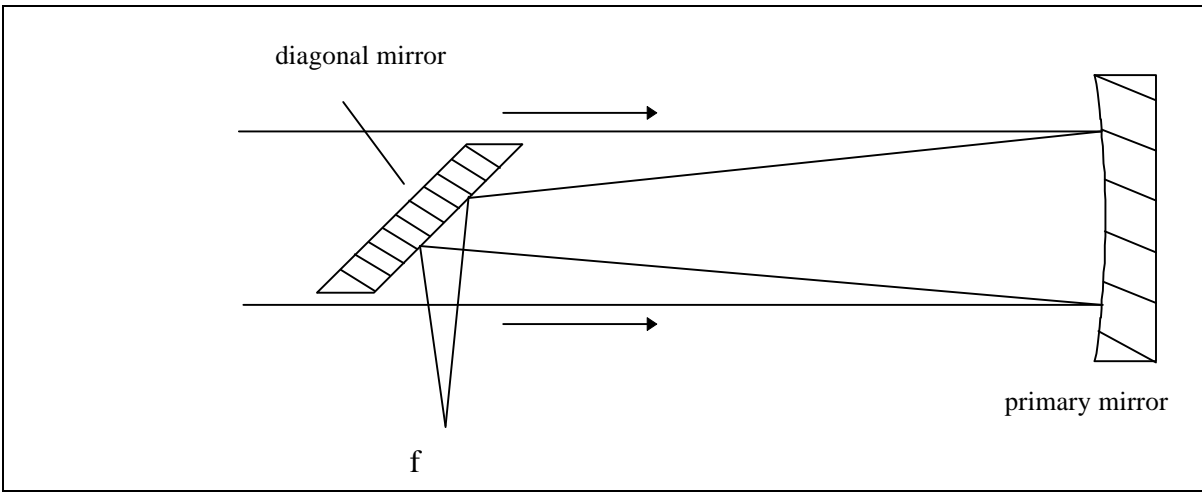


Figure 2. Newtonian Telescope.

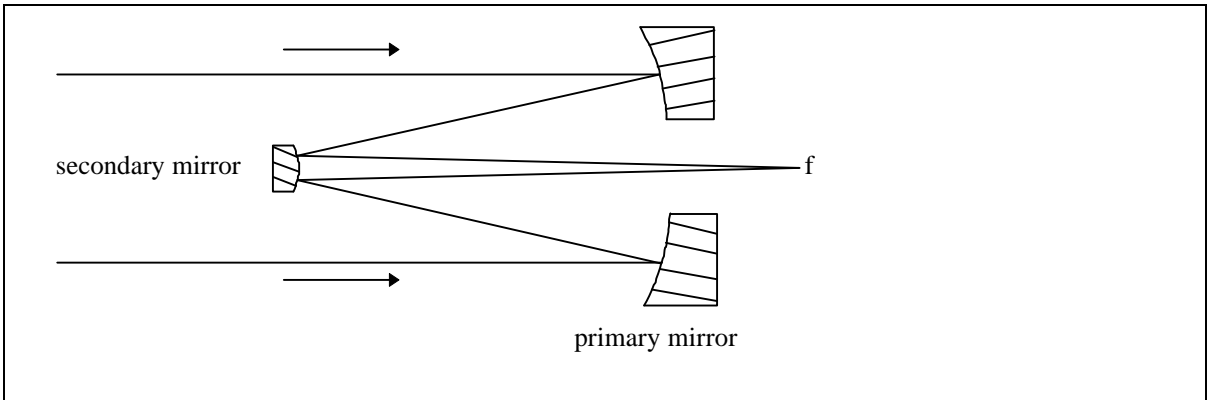


Figure 3. Cassegrain Telescope.

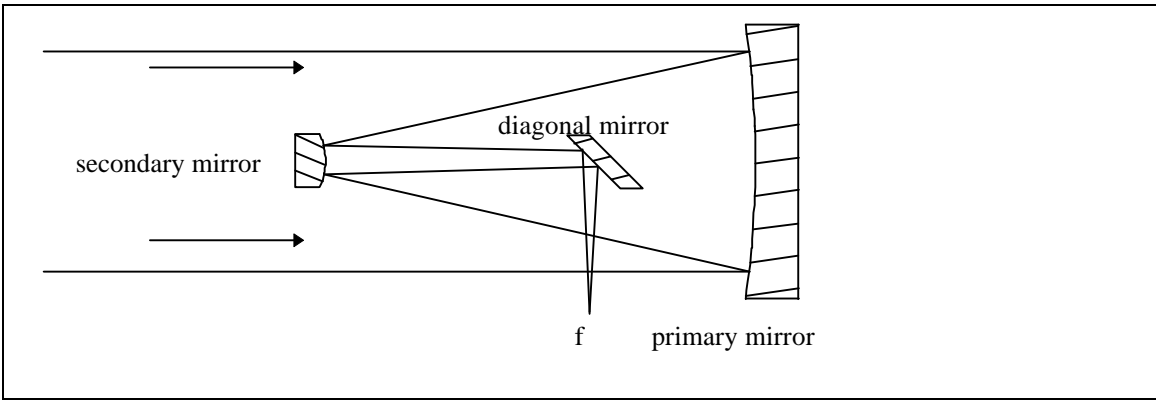


Figure 4. Cassegrain-coud'e Telescope.

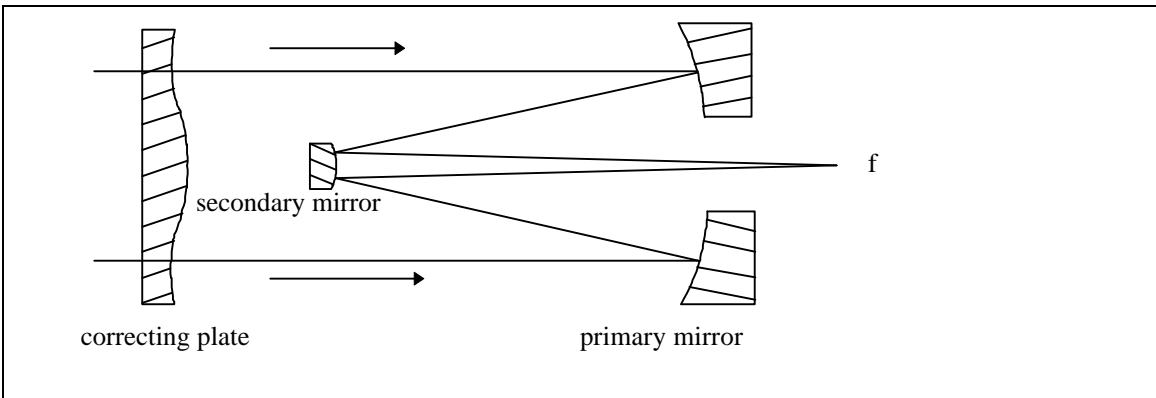


Figure 5. Schmidt-Cassegrain Telescope.

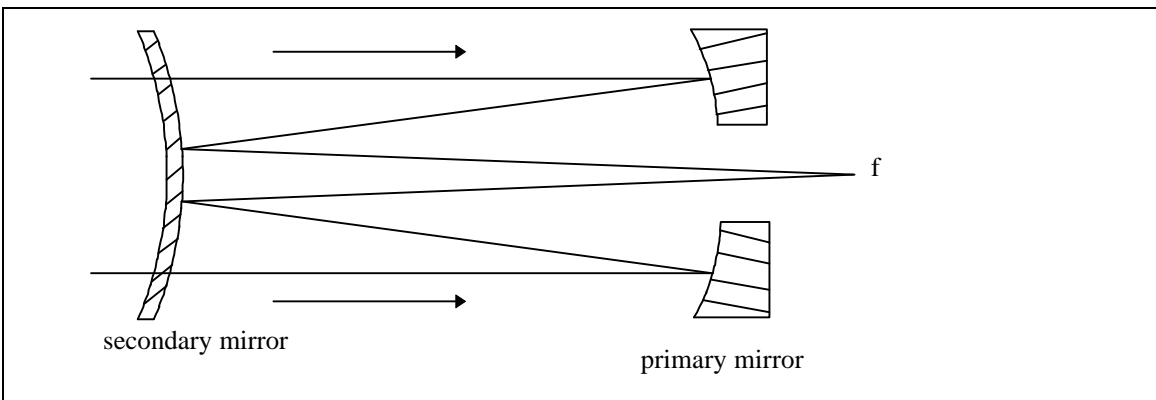


Figure 6. Maksutov-Cassegrain Telescope.