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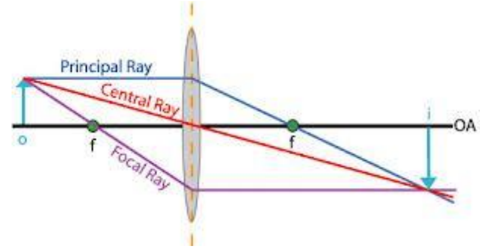


Optics

Purpose

- Discover the basics of geometric optics
- Understand the principles behind a refractor and a reflector telescope

Equipment

- Various lenses and mirrors
- Cardboard tube telescope kit
- Newtonian / reflecting telescope
- Metre stick
- Lens holders
- Cardboard screen

Introduction and Theory: A lens or a mirror can form two types of images. A *real image* can be seen on a screen placed at the image position, whereas a *virtual image* cannot. Whether or not the image is real or virtual, the following relationship exists:

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

Here f is the focal length of the lens or mirror, d_o is the object distance (distance from lens or mirror to the object) and d_i is the image distance (distance from lens or mirror to the image).

This equation is known as the mirror equation or the thin lens equation. In this experiment, the following sign convention for the above equation will be used:

- f is positive for converging lenses and concave mirrors and negative for diverging lenses and convex mirrors
- d_o is positive for real objects and d_o is negative for virtual objects
- d_i is positive for real images and d_i is negative for virtual images

Note: All objects in this experiment are real but images may be real or virtual.

Question 1: Differences between lenses and mirrors.
Look at the assortment of lenses and mirrors on your desk. Sketch at least one of each of the following.

Converging Lenses	Concave Mirrors
Diverging Lenses	Convex Mirrors

Question 2: Determining the Focal Length of a Converging Lens.

In a refracting telescope, the focal lengths of the lenses play an important role. You will determine the focal lengths of two converging lenses before constructing a telescope.

If the object distance in the lens equation is infinite, the focal length is equal to the image distance. This suggests a method of measuring the focal length. Since the classroom is not infinitely large, an infinite distance will be approximated as the distance from the east wall of the classroom to trees in the park outside the windows.

- Place the lens in its holder on the metre-stick.
- Place the cardboard screen behind the lens.
- Go to the east wall of the classroom and obtain an image on the screen of the trees outside.
- Focus a clear image of the trees by adjusting the position of the screen.

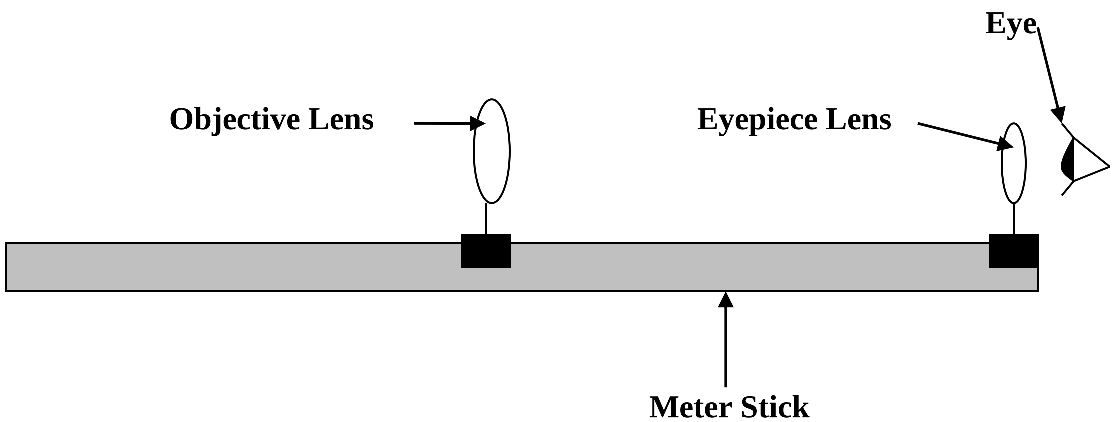
a) Record the positions of the lens and the screen for two different lenses.

b) Calculate the image distances and complete the table below. In this situation, the image distance is equal to the focal length.

Lens #	**Focal Length, *f* (cm)**	**Image Inverted or Upright?**	**Image smaller or larger?**
Converging Lens 1			
Converging Lens 2			

Question 3: Constructing a simple refracting telescope.

We are now going to use the two lenses from Question 2 to construct a simple refracting telescope. Mount the lens with the shorter focal length at one end of the optical bench (aka meter stick). This lens is going to be our *eyepiece lens*. Place the other lens (called our *objective lens*) somewhere else along the optical bench.



Stand at the east side of the room and point the telescope toward the trees outside, and move the objective lens along the bench until you see a focused image of the trees through the eyepiece.

a) Measure the distance between the two lenses and record it in the space below.

$d =$	cm

b) Add the focal lengths of the lenses (from Question 2) together and record it in the space below.

$f_1 + f_2 =$	cm

c) Write a sentence stating the relationship you observed between the distance you measured on your simple telescope and the sum of the focal lengths.

d) Is the image you see in your telescope inverted or upright? Is the image larger or smaller than the object? To verify your observations, calculate the magnification of the image with the following formula. Inverted images have negative magnifications.

$$M = -\frac{f_o}{f_e}$$

Question 4: Paper tube telescope.

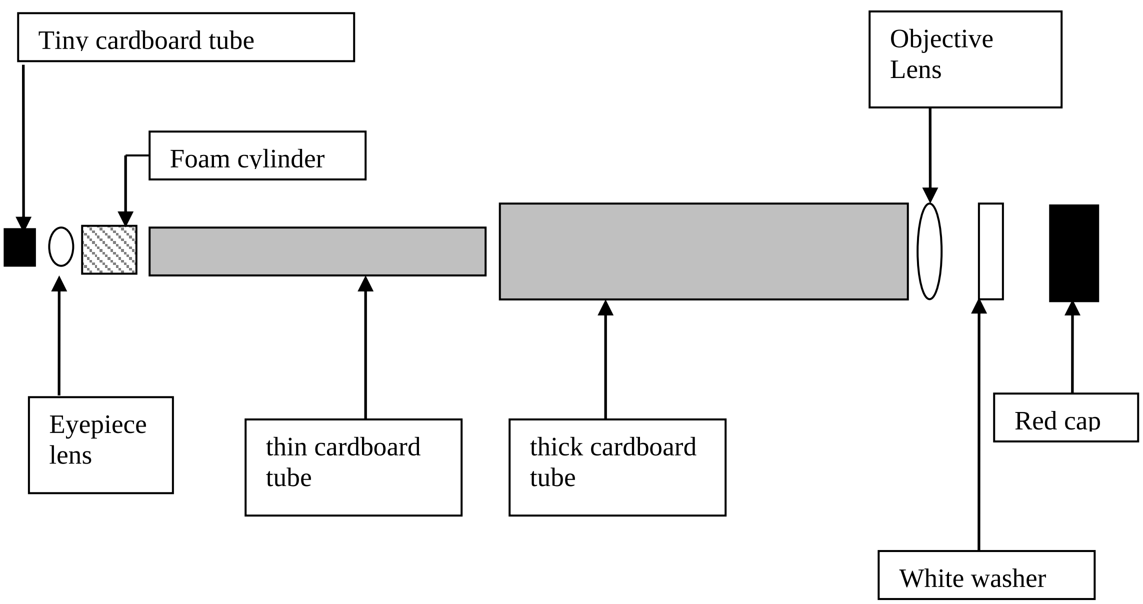
Using the knowledge you have gained so far, you are now going to construct a "homemade" telescope from the parts in the telescope kit. **Before** constructing the telescope, let's get the lenses' focal lengths.

a) First, using the techniques from Question 2, estimate the focal length of the objective lens and the eyepiece lens.

Estimated f_o = cm
Estimated f_e = cm

b) Calculate the theoretical distance you would want between the two lenses in order to focus the telescope on an image a far distance away. Remember your conclusion from Question 3.

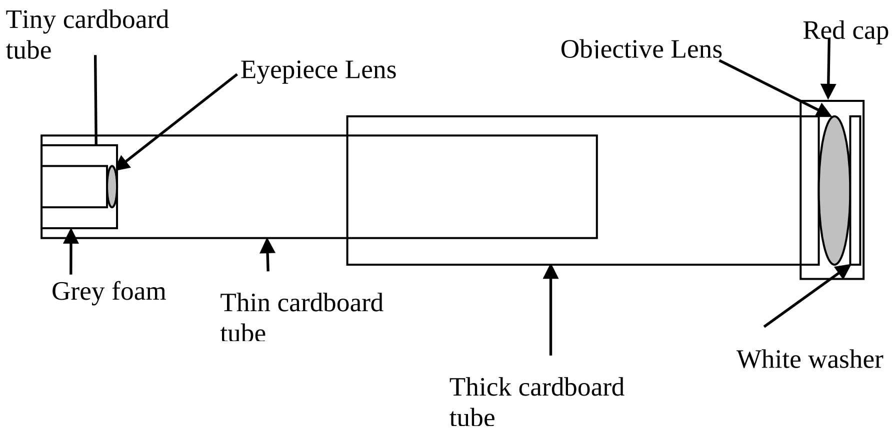
$d_{theoretical}$ = cm



Take the red cap and place the white washer inside it. Place the large lens in next. Then place the red cap snugly over one end of the thick cardboard tube.

Put the small lens in one end of the grey foam cylinder so that the rounded side will face outwards. Push the tiny cardboard tube over the small lens, so that both are inside the foam cylinder. Place the grey foam/lens piece into one end of the thin cardboard tube so that the end of the foam is flush with the end of the tube.

Slide the open end of the thin cardboard tube into the open end of the thick tube. Voila! You now have your telescope!



Now, standing at the east end of the lab, focus the telescope by sliding the thinner tube into/out of the thicker tube, on the trees outside. Alternatively, you can go out into the hallway and focus on the far end of the hallway.

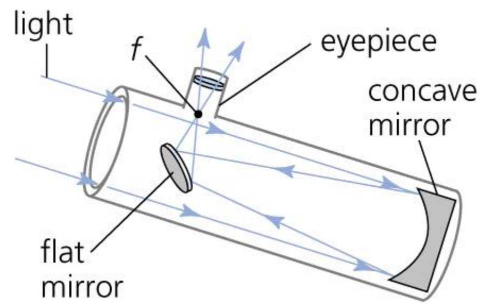
c) Once you have a focussed image, measure the distance between the two lenses and write it in the space below.

d_{measured} = cm

d) How do $d_{\text{theoretical}}$ and d_{measured} compare? What factors could account for any differences in the value (beyond measurement uncertainty)? What are the pros and cons of this type of telescope (list at least two pros and two cons)?

Question 5: Mirror focal length.

Some telescopes don't use lenses. Instead they use mirrors to focus the light rays. These are generally called "reflector telescopes". The origin of this type of telescope dates back to the work of Isaac Newton. A schematic of a generic reflector telescope is shown on the right.



In this section we will experiment with some of the optical properties of a concave mirror.

a) Draw a concave mirror, specifying the side that light reflects from.

b) Look at your image in the mirror. Try different distances to the mirror. Describe what you see.

c) Form an image of the trees outside on the cardboard screen using the concave mirror. (This is a very similar process to Question 2.) Estimate the focal length of the concave mirror.

Question 6: Newtonian telescope.
Look inside the tube of the Newtonian telescope, but do not touch anything inside the tube. The primary mirror is a concave mirror. The secondary mirror is a small flat mirror that reflects the image of the object (star, galaxy, nebula) into the eyepiece. The focal length of the primary is *f*.

a) Estimate and record the distance between the centre of the primary mirror and the centre of the flat mirror, then between the flat mirror and the lens of the eyepiece.

b) Add the two values from (a). This is the focal length of the telescope.

c) Compare the focal length of the telescope to the length of the tube of the telescope. Conclude.

Say you observe the Andromeda galaxy in the countryside with the above telescope. You just estimated f_o. Read the focal length of the eyepiece (usually given in mm) on the eyepiece itself. The sky is clear and there is no light pollution. The visual angular diameter of the galaxy is 0.5°. The magnification of the telescope can be calculated using

$$M = -\frac{f_o}{f_e}$$

d) Calculate the magnification of the telescope with that eyepiece.

e) Calculate the apparent size of Andromeda in the telescope.

f) To increase the apparent size of the galaxy, should you use an eyepiece with a larger or a smaller focal length? Explain.

Instructor's initial: __________