Image Formation with Lenses

When light from an object passes through a lens, the light is refracted in such a way that an *image*, or reproduction, of the object is formed. The image may be larger or smaller than the object and upright or inverted relative to the object. It may appear on the same side of the lens as the object, or on the opposite side, and it may be closer to the lens than the object or further from the lens. The nature and location of the image are determined by the shape and composition of the lens and by the distance between the lens and the object.

In this lab you will examine image formation using mainly thin *bi-convex* (converging) lenses. This type of lens serves as a good model for understanding the lenses found in cameras, microscopes, binoculars, and many other optical devices, including our own eyes.

Equipment: Optics bench, light source, lenses #1, #4, and #5, viewing screen, ruler.

Procedure:

Part I – Seeing the light

1. Check that the illuminated screen (the object) is at 0.0 cm on the optics bench. Place lens #1 (a bi-convex lens) so that its center is 30.0 cm from the object. In order to see the image, position yourself at the far end of the bench, and look back towards the lens and the object. After you have found the image, move your head closer to it to get a better view. Record your observations of the image, noting its size and orientation relative to the object. Using both eyes to give you better depth perception, determine the approximate location of the image. Note: The image is not “in the lens”; it is between you and the lens. Ask your instructor for help if necessary. You have just observed a *real* image.

2. Slide the viewing screen along the optics bench until it is at the position of the focused image. Adjust the screen position to get the sharpest image possible. Measure the distance from the center of the lens to the screen. Estimate your uncertainty.

3. The focal length of a converging thin lens can most easily be found by forming an image of a very distant object (such as something seen through a window). Because the object is far away from the lens, light rays from any point on the object that reach the lens will be travelling essentially parallel to each other. Therefore the image will be formed in the focal plane. Use this information to find the focal length of all three converging lenses that you have, and record your results.

4. Make a schematic diagram of your set-up in Part I step 2 showing the object, the lens and the image. Label the object distance and the image distance. Include the principal rays.

Part II – How does the image change as the object distance is changed?

1. Using lens #1 investigate quantitatively how the image distance d_i is related to the object distance d_o. Both distances are measured relative to the center of the lens. Include an estimate of the uncertainty for each image distance.

2. The “thin lens equation” gives a simple algebraic relation between d_o, d_i, and the focal length of the lens f.

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

Devise a method for checking this quantitatively. Find the focal length using this method. Do your focal lengths agree? Comment on the relative merits of the two methods of finding focal length. Include a discussion of uncertainties.

3. The lateral magnification, *M*, produced by a lens is defined by the equation $M=\frac{h_i}{h_0}$, where h_i is the image size and h_o is the object size. By convention, if the image is inverted, h_i is negative, as is the magnification. Put the lens 30 cm from the lens and measure the diameter of the larger circle on the object and on the image. What is the magnification? Find a formula that relates the magnification to the object distance and the image distance.

Part III - The Magnifying Glass

(1) Place lens #1 5.0 cm from the illuminated screen. From a distance of about 30 cm, look through the lens, toward the screen. Qualitatively describe the size and orientation of the image relative to the object. The image you are seeing is an example of a *virtual* image. This image cannot be seen on a screen, and no light actually comes from the image location. Rather, the lens bends the light in such a way that the light *appears* to come from the image location. Note that to our eye a virtual image is indistinguishable from a real image.

(2) Determining the location of a virtual image is a little tricky because it cannot be seen on a screen. To find the image, one person should hold a pencil above and behind the lens while the other person simultaneously looks *through* the lens at the image and *over* the lens at the pencil. The person holding the pencil moves it backward and forward and the person looking through the lens determines when the pencil and the image are at the same distance. See Fig. 1. Determine the image distance and estimate your uncertainty.

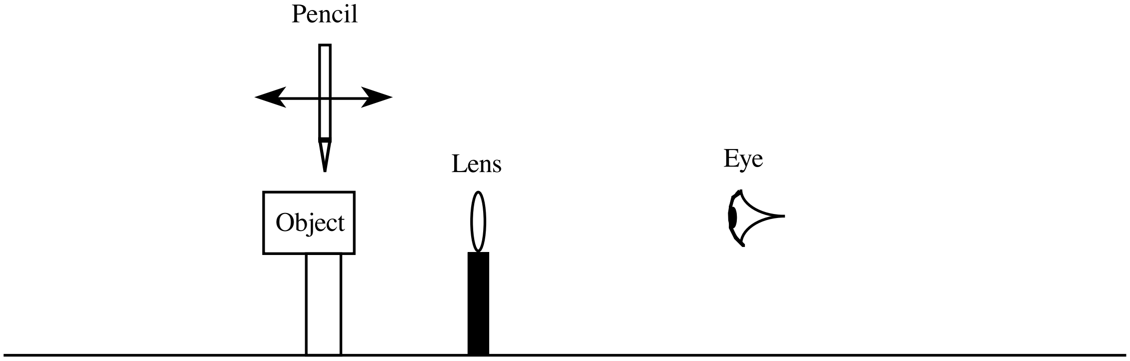

Figure 1. Setup for measuring the position of a virtual image.

The apparent size of an object is determined by the size of the image on the retina. This in turn depends on the angular size of the object. To look closely at an object we increase its angular size by bringing closer to our eye. However, at some point it “goes fuzzy” and we cannot focus on it. This is called the near point. Find your own near point. Call this distance n.

(3) We can aid our eye and "get a lot closer" with a convex lens. Use the #1 lens as an eyepiece and magnify the print on a page. Estimate how much bigger the print is as observed through the lens as compared to using your naked eye when the page is at your near point.

The magnification is due to a larger angular size. This angular magnification is defined by

$$m = \frac{\theta'}{\theta}$$

in which θ is the angular size of the object without the lens and θ' is the angular size of the object as it appears to you through the lens. N. B.: $m \neq M$!

Part IV - Compound Systems

Microscopes and telescopes are examples of *compound* optical instruments; each uses 2 lenses. Two lenses are used in a microscope to provide a greater magnification than is possible with just a magnifying glass. In a telescope, two lenses allow the viewing and magnification of distant, and in many cases, very dim objects. In both cases, the lens closer to the object is (ingeniously) called the objective. The lens that one looks through is called the *eyepiece*, and it functions just like a magnifying glass.

The Telescope

The objective lens in a telescope is used to form a real, smaller, but nearby, image of a distant object. The eyepiece then magnifies the image formed by the objective. The experiment is set up for you near a window. Place lens #5 (the objective) at the 10 cm position. The opaque light shield attached to the objective helps to block extraneous light. Locate the image of a distant object and place lens #1, the eyepiece, 5 cm behind the image position. Look through the telescope at the distant object suggested by your instructor. If necessary, adjust the position of the eyepiece slightly until you have a sharp image.

Make a diagram of the telescope showing both eyepiece and objective, their foci, rays, and the orientation of the image.