

THIN LENSES

Objectives: • To investigate the image-forming properties of thin lenses.

To Do Before Lab: • Read this lab

Apparatus: several lenses in holders, ray optics kit, optical bench with a screen and a light source

Introduction:

A thin lens is a lens whose thickness is small compared to the distance between the lens and the object and the distance between the lens and the image. As a first approximation, the lenses used in cameras, binoculars, microscopes, the eye, eyeglasses, and contacts, and many other optical instruments, can be treated as thin lenses.

Light travels through a uniform medium in a straight path. However as you saw in the Snell's Law lab, when light crosses a boundary between two different media its path is bent (unless it is travelling at right angles to the boundary). This phenomenon is called **refraction**, and it is due to the fact that the speed of light is different in the two media. When light travelling in air enters a piece of glass its speed decreases and it bends toward the normal. When it leaves the glass and reenters the air, its speed increases and it bends away from the normal. By carefully designing the shape of a piece of glass we can get light to bend in just the right way and we can make useful optical components such as lenses and prisms. Today we will explore two classes of lenses - converging and diverging lenses. We will not concentrate on analysis of the refraction at the air/glass boundaries; rather we will learn about the most basic property of a lens, its **focal length**, and will develop an understanding of some applications of lenses.

Part I: Omitted

Part II: Converging Lenses

Rays of light travelling parallel to the axis of a converging lens are bent by the lens (by refraction at the air - glass and glass - air interfaces) and pass through a single point on the axis. This point is called the **focus** or **focal point** and is commonly labeled F, as in Fig. 1. Rays of light travelling parallel to the axis, but coming from the right in Fig. 1 will also be focussed to a point. For a thin lens, the distance from the center of the lens to either focal point is the same, and is called the focal length, f .

The two **planes** that are perpendicular to the axis and which contain the focal point are called the **focal planes**. For ideal lenses, parallel rays entering the lens at a given angle to the axis will come to a focus at a point in the focal plane, as shown in Figure 2.

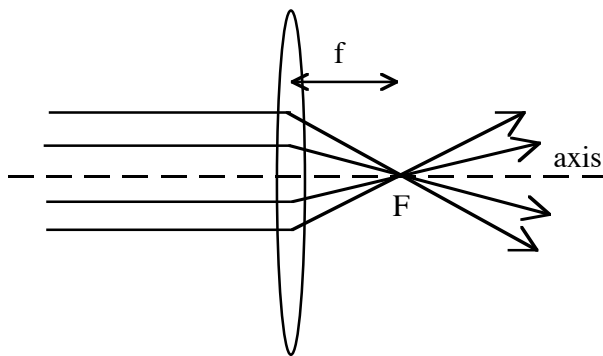


Figure 1

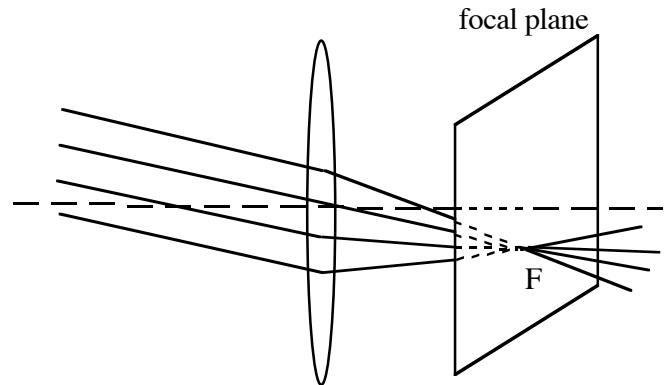


Figure 2

(1) 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. Include a diagram that describes your procedure.

(2) When an object is not very far from the lens, but is still further than the focal length, light from the object that passes through the lens is focussed and forms an image beyond the focal plane. When analyzing such a situation, it is useful to consider the principal rays that come from a single point on the object. The reason these rays are useful is because their paths are simple to follow. (Actually, only two rays are needed to determine the image point; the third ray is useful as a check.) The three rays are:

- a) a ray that travels parallel to the axis of the lens and therefore passes through the far focal point,
- b) a ray that passes through the near focal point and emerges parallel to the axis, and
- c) a ray that passes through the center of the lens and continues travelling along the original path.

See Fig. 3.

Employing these rays, a geometrical argument shows that:

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \quad (1)$$

where d_o is the distance between the object and the lens, d_i is the distance between the image and the lens, and f is the focal length of the lens. This is called the **thin lens formula**.

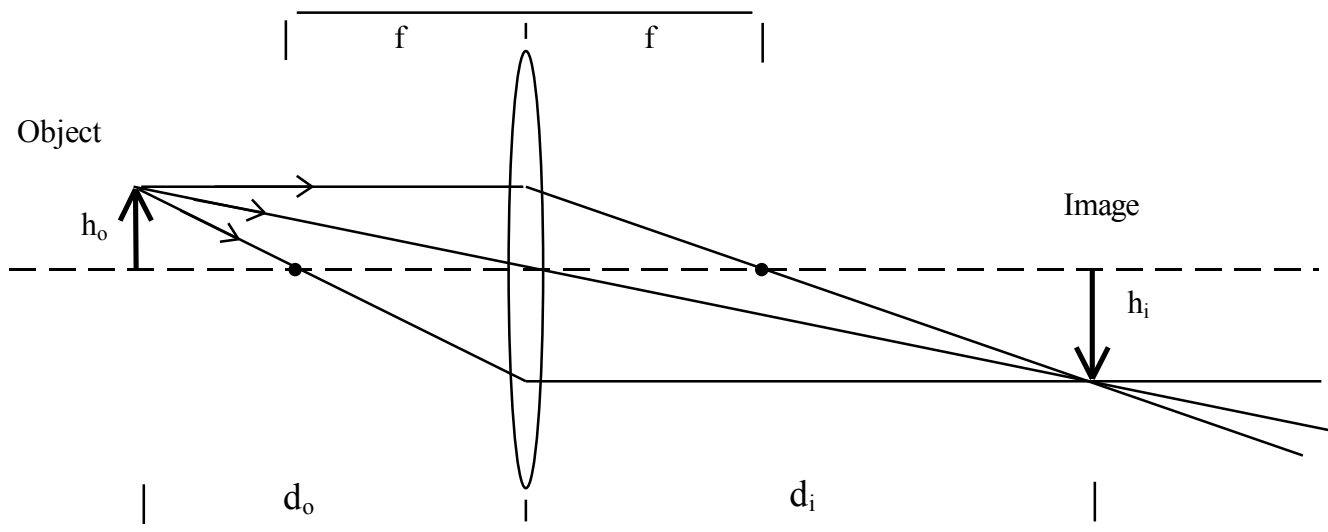


Fig. 3

(3) To test the above formula, choose the lens of shortest focal length and measure d_o and d_i for various positions of the lens relative to the illuminated object. Also determine how large the image is relative to the object in each case. Include an estimate of the error for each measurement. Using d_o , d_i , and h_o for one of your object positions, draw a *scaled* ray diagram to determine h_i . Does the image size in your drawing agree with experiment? Graph d_i vs. d_o and then $\frac{1}{d_i}$ vs. $\frac{1}{d_o}$. Determine the focal length f of the lens.

(4) Refer to the above diagram and derive an expression for the **lateral magnification**

$$M \equiv \frac{\text{image size}}{\text{object size}} = \frac{h_i}{h_o} \quad (2)$$

in terms of d_o and d_i . Go back to your data table and consider the measurements for the largest d_o . For the data with the largest d_o , find the uncertainty in the measured lateral magnification (h_i/h_o).

Part III: Magnification

You have probably used a magnifying glass before, perhaps even to bring Saharan temperatures to small bugs. This short section explores the simple principle behind these tools. There is one confusing point, however. In the interest of reducing suspense in our busy, jet-setting lives we will announce right away that this involves a new, distinct definition of magnification.

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 can not focus on it, This is called the **near point**. Find your own near point. Call this distance n .

(1) We can aid our eye and “get a lot closer” with a convex lens. Use the #1 or 2 lens as an eyepiece and magnify the print on a page. Neat! Estimate how much bigger is the print as observed through the lens as compared to using your naked eye?

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

$$m = \frac{\theta'}{\theta} \quad (3)$$

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.: $m \neq M$!

By the way, why does the image look “smeary” around the edges? This effect can occur in mirrors as well (as it did during the manufacture of the primary mirror in the Hubble Space - Oops.)

(2) Using diagrams of an object at your near point and of an object as viewed with the magnifying glass show that

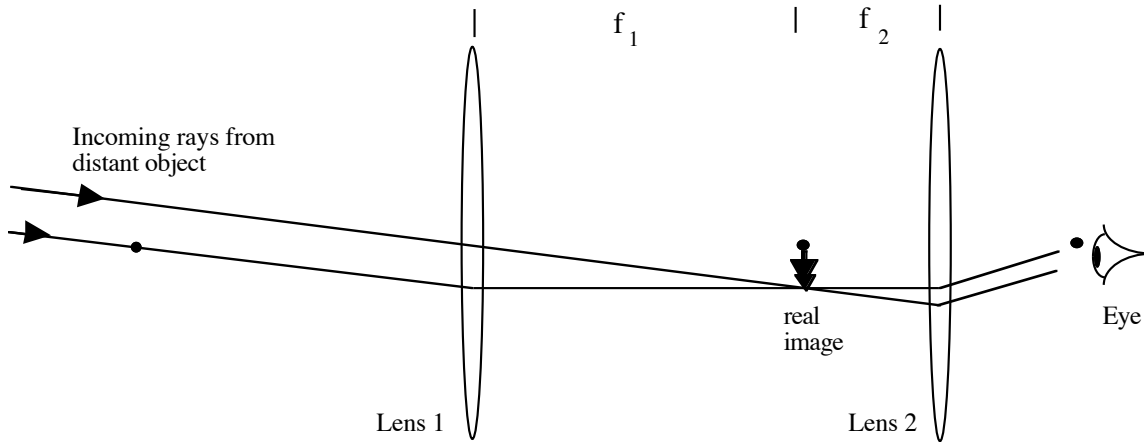
$$m = \frac{n}{f} + 1 \quad (4)$$

Compute this number for your lens and check to see whether it agrees with your estimate in (1). Is this image real or virtual? How does the glass bring the object “a lot closer”?

IV. The Telescope

A converging lens produces a small image on the screen of distant objects. If the screen is removed, the real image is still there in space. You can look from behind the lens and see this image directly. Alternatively, you can use a second converging lens as a magnifying glass to enlarge this image. Based on your observations in Part III what is the point of bringing a small image up close?

This configuration of two convex lenses is called an astronomical refractor. Below is a diagram for the refractor.



The angular magnification of a telescope is given by $m = \frac{f_1}{f_2}$, so it makes sense to have a large f_1 and a small f_2 . Derive this formula for m .

Construct a telescope using two of your lenses and use it to view an object outside the window. Convince yourself that the second lens must be placed behind the real image. You can focus the image in a telescope by changing the distance between the two lenses. If you want to focus on an object closer than outside the window, should you increase or decrease the distance between the lenses? Explain. Test your prediction by using your telescope to look at the light source at the opposite end of the optics bench.