Thin Lenses

Objective

The purpose of this experiment is to investigate the thin lens formula for both a single lens and combinations of lenses.

Materials

1. Component carrier (small)
2. Crossed arrow target
3. Diuser
4. Diverging lens of unknown focal length
5. Flashlight
6. Incandescent light source
7. Lenses (+100,-150)
8. Optical bench
9. Small viewing screen

Background

When a light wave goes from one medium into another the direction of propagation of the wave in the second medium changes according to Snell's law. (See any Introductory Physics text.) This phenomenon, known as refraction, happens because the velocity of the wave changes as it goes from one material into another. A light ray is a line drawn in the direction of propagation of the wave. Figure 1 shows a ray of light being refracted at the two surfaces of a lens.

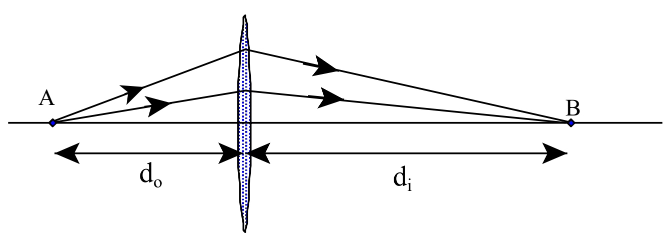

Figure 1

Snell's law may be applied to each ray at each surface of the lens. Provided that the angle between the rays and the principle axis is small, and if the lens thickness is small compared to other dimensions of interest, a remarkably simple formula results. It turns out that any ray leaving Point A arrives at Point B with the relationship between distances d_o and d_i given by

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

where f is a constant property of the lens known as "focal length". This equation is called the *thin lens equation*. An object a distance d_o from the lens will be imaged a distance d_i

from the lens. It should be obvious that if $d_o = \infty$, then $d_i = f$; this means that for a distant object the image is near the focal point, one focal length from the lens. Also, from an object a great distance away the rays are nearly parallel; thus parallel rays converge at the focal point. This is the origin of the name focal point. Now notice that if $d_o = f$, then $d_i = \infty$, which means that rays originating from a focal point will be parallel after going through the lens. Lens problems may also be solved graphically. Suppose an object of height h_o is a distance d_o from a lens of focal length f. To fnd the image location, size, and orientation make a scale drawing, and use three principle rays from a single point on the object as follows (refer to Figure 2).

1. A ray parallel to the principle axis goes through the focal point after passing through the lens.
2. A ray through the center of the lens is essentially undeviated.
3. A ray through the focal point travels parallel to the principle axis after passing through the lens.

(Actually only two of these are needed to locate the image.) Graphically the image is measured to be height h_i and located a distance d_i from the lens; within the limits of graphical accuracy this result will agree with the solution d_i from equation (1). From similar triangles in Figure 2 it is apparent that

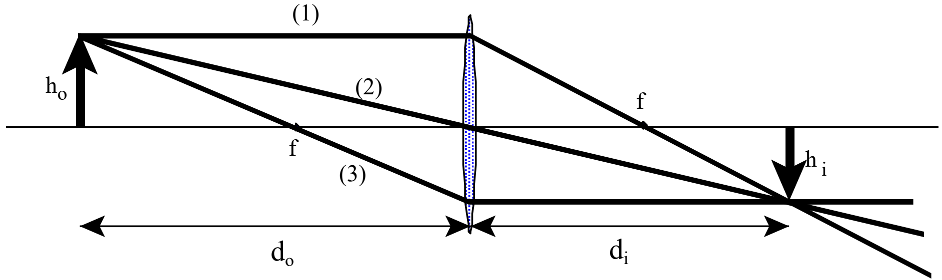

Figure2

$$\frac{h_i}{h_o} = -\frac{d_i}{d_o} \tag{2}$$

where the sign indicates orientation. $h_i$computed in this way should agree with the graphically determined image size. *Note*: h_i is positive if image is upright, and negative otherwise.

Procedure

1. In a darkened room, with one shade raised a few inches, let light from a distant landscape pass through a converging lens onto a white screen a few centimeters away. Vary the position of the lens or screen until a clear image is seen on the screen. The distance from the lens to the screen is the focal length of the lens. Why? (On a dark, cloudy day it may be necessary to use a lighted object on the far side of the room.)

2. Set up the optical bench using the crossed arrow target on the front of the light source as the object; project the image on the screen using a converging lens. Experiment with using the frosted glass between the source and the crossed arrow target to make

illumination more uniform. (If your lens is closer to the object than the focal length you won't get an image on the screen.) Determine the focal length by use of equation (1). Observe that equation (2) is also valid. Using object distance and focal length, graphically solve for image distance.

3. Using the set up in the previous part, move the lens toward or away from the screen until another image is seen. How are the new values of $d_o$and $d_i$related to their previous values? Hint: Equation (1) must still be satisfied.

4. Next consider what happens when light passes through a diverging lens. Figure 3 shows parallel rays of light approaching the lens, and Figure 4 shows the use of a ray diagram to locate an image.

Notice that in Figure 4 the three principle rays are again drawn but now the rays are diverging after passing through the lens; thus no real image is formed—i.e., the image cannot be seen on a screen. However, the rays diverge as if they had passed through an image; this is called a virtual image. Application of Snell's law here yields an equation identical to equation (1) and similar triangles yield equation (2). The sign convention in Table 1 may be used with equation (1). Inspection of equation (1) shows that for a negative f and positive d_o, it is impossible for d_i to be positive; thus no real image can be formed by a diverging lens alone. However, a diverging lens may be used with a converging lens to form a real image.

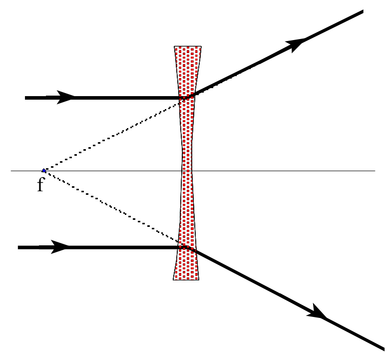

Figure 3

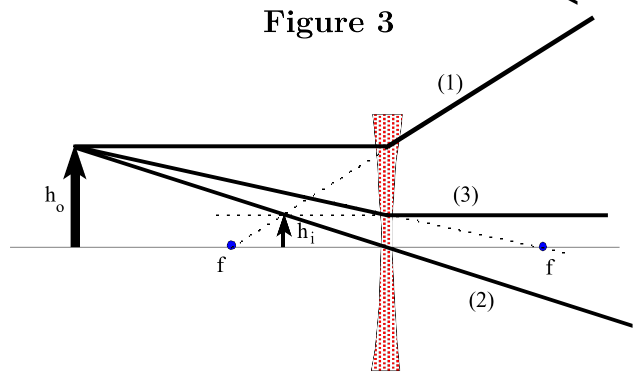

Figure 4

5. Place the converging lens at a distance a few centimeters greater than its focal length from the object. Use the screen to locate the real image formed. Record this image position.

6. Then move the screen farther away so that the light hitting it is an unclear blur. Put the diverging lens between the converging lens and the screen, and vary its position until an image is formed on the screen. If you don't succeed at first, try starting again with the object farther from the converging lens.

7. You may use the thin lens equation to compute the focal length of the diverging lens as follows:

   (a) The image formed by the first lens alone is the object for the second lens.

(b) This object is beyond the second lens, therefore the object is virtual.

(c) The object distance for the second lens has just been found and the image distance is the distance from the lens to the screen; so the thin lens equation may be used to compute the focal length. (Follow the sign convention carefully.)

d_o	$+$	object (real) on the incoming ray side	$-$	object (virtual) on the outgoing ray side
d_i	$+$	image (real) on the outgoing ray side	$-$	image (virtal) on the incoming ray side
f	$+$	if converging lens	$-$	if diverging lens

Table 1: *Sign convention. An image is real if light rays are converging towards it, and Virtual if light rays seem to be diverging from it. An object is real if light rays are diverging From it, and virtual if light rays seem to be converging towards it.*