Converging Lens

Goal: To measure the focal length of a converging lens using various methods and to study how a converging lens forms a real image.

Lab Preparation

The picture on the screen in a movie theater is called a "real image." It is made by light from an object passing through a converging lens as shown in Figure 1.

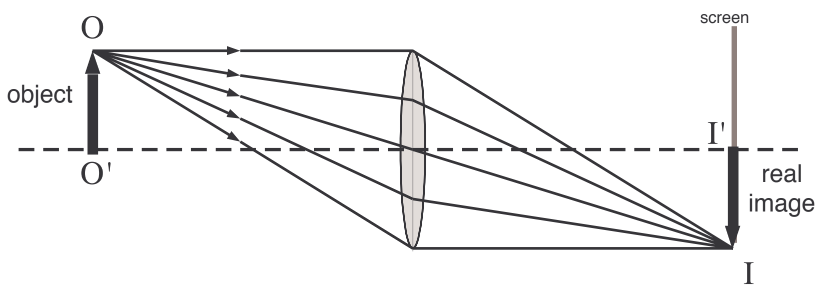

Figure 1

Light rays starting from point *O* on the object are bent by the lens so they all converge to meet at point *I*, which is the real image of point *O*. Similarly, light from point O′ converges to point I′ on the image. The lens bends the rays by refraction as the light enters and leaves the lens. To produce this image, a converging lens is thicker at its center than at its edge.

Note that the ray from *O*, which happens to fall on the center of the lens, passes through it in essentially a straight line with no bending. Thus a straight line drawn from *O* to *I* passes through point *C* (Figure 2). This fact is useful for determining the height h_i of the image in terms of the object height h_o and the distances d_o and d_i of object and image from the lens. Since both $\overline{OCI}$ and $\overline{O'CI'}$ are straight lines, the triangles $\overline{OO'C}$ and $\overline{II'C}$ are similar triangles.

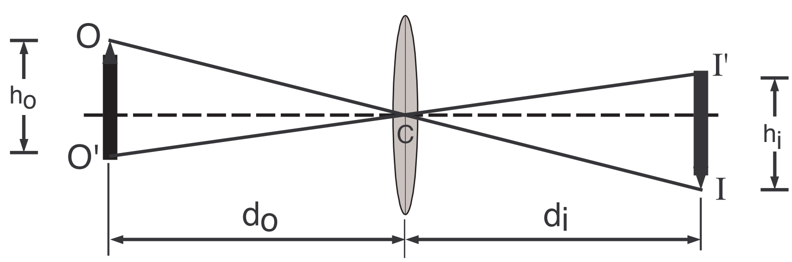

Figure 2

The ratio of h_i to h_o is the same as the ratio of $-d_i$ to d_o (since h_i is negative). The ratio of image height to object height is called the magnification *M*:

$$M = \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

In Figures 1 and 2, the dotted horizontal line is the axis of symmetry of the lens, known as the optical axis or principal axis. If we point this axis at a very distant object, such as the sun, the rays from the sun that fall on the lens are all parallel to each other and the optical axis. These rays come together at the focal point of the lens as shown in Figure 3.

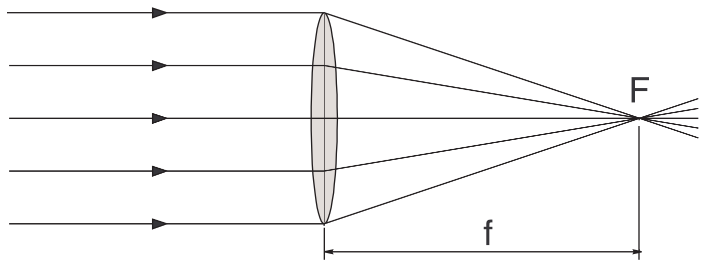

Figure 3

The distance from the center of the lens to the focal point is called the focal length, f of the lens.

The thin-lens equation relates the focal length to the object and image distance. This relationship is

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

Here, f is the focal length, d_o is the object distance and d_i is the image distance. Note that if the object is very far away ($d_o \rightarrow \infty$) the image distance reduces to f.

To graphically locate an image as in Figure 4, we can do the following:
1) Draw a straight line parallel to the optical axis from the object to the lens (so from O to P). This ray must be refracted so that is passes through the focal point.
2) Draw a straight line from point O through the center of the lens. This ray will pass straight through the lens.
3) Where the lines leaving the lens cross is the location of the image (shown as point I).

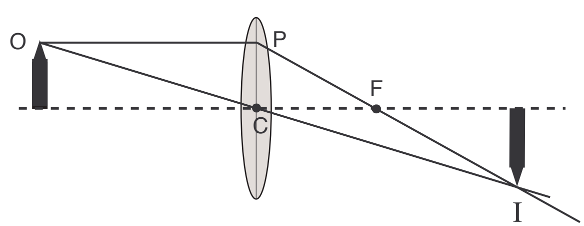

Figure 4

Procedure

I. Determining the focal length of a lens by various methods

Construct the following table to record your results for the following methods.

Method	d_o	d_i	f
I-a			
I-b			
II-a			
II-b			
III-a			
III-b			

A. **Method I-a.** Have only the screen and lens mounted on the optical bench. Place the screen at the very end of the optical bench at the 0.0 cm mark. Put a clear light bulb - with the filament easily visible - at the other end of the optical bench. Place the lens between them and adjust the position of the lens to obtain a focused image of the filament on the screen. Measure and record the image distance (lens center to screen) and object distance (lens center to filament). Calculate the focal length f of the lens.

B. **Method I-b.** Repeat part A with a mask over the lens, allowing light through only the center half of the lens. Re-adjust the lens position to achieve a more sharply focused image. By using only the central part of the lens spherical aberration effects are reduced, but the image is dimmer since less light is used to form it. This will give a better estimate of the focal length. Determine the focal length f from the new image and object distance.

C. **Method II-a.** Remove the light bulb from the bench and replace it with the gold/black colored pointed object. Replace the screen with the silver pointer and remove the mask from the lens. Look over the silver pointer, through the lens, at the object as in Figure 5. Keep your eye at least 30 cm from the silver pointer.

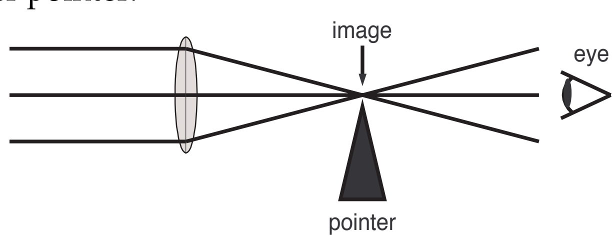

Figure 5

You are looking at the back of the real image, which previously appeared on the screen. You now want to put the silver pointer at the same position as the real image using the method of parallax. Moving your head from side to side, adjust the silver pointer's position until you see no relative motion between the silver pointer and the image of the object. When there is no relative motion, the image forms at the silver pointer's location. Have your lab instructor check this when you are done (or if you need help).

Measure the image distance from the lens center to the pointer and measure the object distance from the lens center to the object. From these determine the focal length of the lens. This method gives a better estimate of the focal length.

D. **Method II-b.** We could improve on Method II-a if we could only get closer to the silver pointer and see more clearly if any parallax is there. To do this, hold a magnifying glass close to your eye; move closer to the silver pointer until you can see the silver pointer (Figure 6). You will also see the image because it is at the same place as the pointer (or very nearly so).

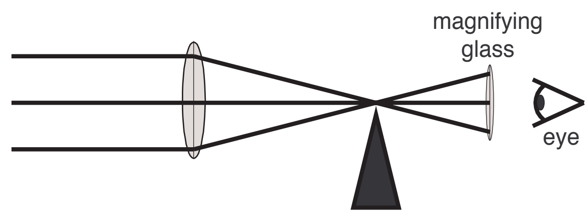

Figure 6

Now move your head and magnifying glass from side to side and make fine adjustments to the silver pointer's position again until there is no parallax between the image and pointer. Once again measure the object distance and image distance and use them to find the focal length *f*. Use this value as your best determination of focal length later in the experiment.

E. **Method III-a.** When an object is very far away from a lens, it will produce an image at the focal point of the lens. Put the optical bench, lens, mask, and screen on a cart so it can be wheeled to the hallway to be aimed at objects outside. Have only the screen and lens (without mask) on the optical bench. Place the lens at a convenient cm mark. Point the optical bench at some object more than 50 meters away. Put the screen on behind the lens and adjust the screen to obtain a focused image of the object on the screen. For practical purposes this makes $d_o \gg d_i$ and practically speaking $1/d_o = 0$ in the lens equation so $f = d_i$.

Measure the distance from lens center to screen. This is a rough estimate of the focal length.

F. **Method III-b.** Repeat Method III-a with the mask over the lens, only allowing light though the center of the lens. You will again find the focus is sharper but dimmer. Measure the distance from lens center to screen. This will give a better estimate of the focal length than the unmasked lens, provided the image is bright enough to still see.

II. Magnification - study of a real image

A. Place the illuminated object box near one end of the optical bench. Set the lens (with mask) a distance between one and two times the focal length away from the object (remember - use method II-b for your focal length). Adjust the screen position so a focused image of the object appears on it (Figure 7).

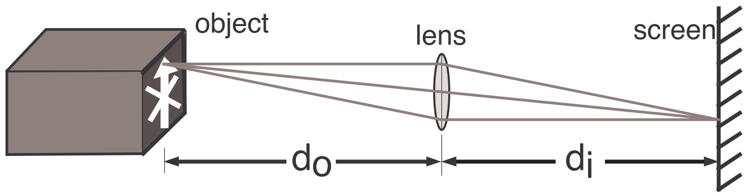

Figure 7

Measure the object distance d_o and the image distance d_i. Measure also the object height h_o and the image height h_i. Enter these dimensions in a table like the one below.

d_o	d_i	h_o	h_i	$M=h_i/h_o$	$M=-d_i/d_o$	Expected $d_{i,exp}$	% Difference

B. Repeat part A with the lens set at exactly twice the focal length. As before, adjust the screen to get a sharp focus. Measure d_o, d_i, h_o, and h_i.

C. Repeat part A with the object distance set at greater than twice the focal length. Adjust the screen to get a sharp focus. Measure d_o, d_i, h_o, and h_i.

For each trial above calculate the observed magnification $M = h_i/h_o$ and the magnification expected by theory $M = -d_i/d_o$. Also for each trial find the expected image distance $d_{i,exp}$ by using the thin-lens equation and compare this value to the measured image distance d_i by calculating the percentage difference.

***When finished with your lab clean up your lab station.**

Homework

(Do this in lab if there is time) For part II C ($d_o > 2f$), graphically find the image distance. Make a scaled drawing that will fill most of a sheet of paper. Rather than use the object height from your measurements, use an object that is actually 5.0 cm tall on your drawing. Choose a suitable scale for the object and image distances along the optical axis and write this scale on your drawing. Locate the image using ray construction, measure the value of the image distance, and compare it to the measured image distance d_i from your lab.