Experiment 12: Focal Length and Magnification of a Thin Lens

Required Equipment from Basic Optics System

Light Source

Bench

Converging lens of unknown focal length[1]

Screen

Other Equipment

Metric ruler

Optics Caliper (optional, for measuring image sizes), PASCO part OS-8468

[1] *Instructors: see note on page 63.*

Purpose

The purpose of this experiment is to determine the focal length of a thin lens and to measure the magnification for a certain combination of object and image distances.

Theory

For a thin lens:

(eq. 12.1)

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

where f is focal length, d_o is the distance between the object and the lens, and d_i is the distance between the image and the lens. By measuring d_o and d_i the focal length can be determined.

Magnification, M, is the ratio of image size to object size. If the image is inverted, M is negative.

Part I: Object at Infinity

In this part, you will determine the focal length of the lens by making a single measurement of d_i with $d_o \cong \infty$.

Procedure

1. Hold the lens in one hand and the screen in the other hand. Focus the image of a *distant* bright object (such as a window or lamp across the room) on the screen.

2. Have your partner measure the distance from the lens to the screen. This is the image distance, d_i.

   d_i = _______________

Analysis

1. As d_o approaches infinity, what does $1/d_o$ approach?

2. Use the Thin Lens Formula (Equation 12.1) to calculate the focal length.

f = _______________

Part II: Object Closer Than Infinity

In this part, you will determine the focal length by measuring several pairs of object and image distances and plotting $1/d_o$ versus $1/d_i$.

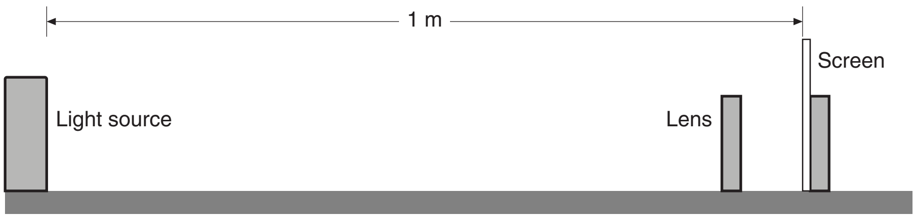

Figure 12.1

Procedure

1. Place the light source and the screen on the optics bench 1 m apart with the light source's crossed-arrow object toward the screen. Place the lens between them (see Figure 12.1).
2. Starting with the lens close to the screen, slide the lens away from the screen to a position where a clear image of the crossed-arrow object is formed on the screen. Measure the image distance and the object distance. Record these measurements (and all measurements from the following steps) in Table 12.1.
3. Measure the object size and the image size for this position of the lens.
4. Without moving the screen or the light source, move the lens to a second position where the image is in focus. Measure the image distance and the object distance.
5. Measure the object size and image size for this position also. Note that you will not see the entire crossed-arrow pattern. Instead, measure the image and object sizes as the distance between two index marks on the pattern (see Figure 12.2 for example).
6. Repeat steps 2 and 4 with light source-to-screen distances of 90 cm, 80 cm, 70 cm, 60 cm, and 50 cm. For each light source-to-screen distance, find *two* lens positions where clear images are formed. (You don't need to measure image and object sizes.).

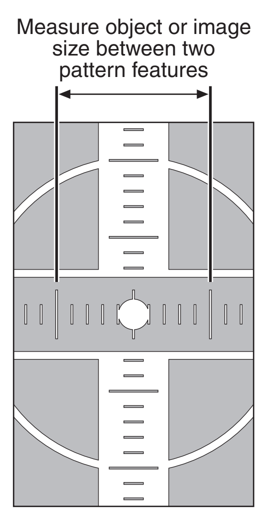

Figure 12.2

Analysis Part A: Focal Length

1. Calculate $1/d_o$ and $1/d_i$ for all 12 rows in Table 12.1.
2. Plot $1/d_o$ versus $1/d_i$ and find the best-fit line (linear fit). This will give a straight line with the x- and y-intercepts equal to $1/f$. Record the intercepts (including units) here:

   y-intercept = $1/f$ = _______________

   x-intercept = $1/f$ = _______________

Note: You can plot the data and find the best-fit line on paper or on a computer.

Table 12.1: Image and Object Distances

Distance from light source to screen	d_o	d_i	$1/d_o$	$1/d_i$	Image Size	Object Size
100 cm						
90 cm						
80 cm						
70 cm						
60 cm						
50 cm						

3. For each intercept, calculate a value of *f* and record it in Table 12.2.

4. Find the percent difference between these two values of *f* and record them in Table 12.2.

5. Average these two values of *f*. Find the percent difference between this average and the focal length that you found in Part I. Record these data in Table 12.2.

Table 12.2: Focal Length

	f
Result from x-intercept	
Result from y-intercept	
% difference between results from intercepts	
Average of results from intercepts	
Result from Part I	
% difference between Average of results from intercepts and result from Part I	

Analysis Part B: Magnification

1. For the first two data points only (the first two lines of Table 12.2), use the image and object distances to calculate the magnification, *M*, at each position of the lens. Record the results in Table 12.3.

(eq. 12.2)

$$M = -\left(\frac{d_i}{d_o}\right)$$

2. Calculate the absolute value of M (for each of the two lens positions) using your measurements of the image size and object size. Record the results in Table 12.3.

(eq. 12.3)
$$|M| = \frac{\text{image size}}{\text{object size}}$$

3. Calculate the percent differences between the absolute values of M found using the two methods. Record the results in Table 12.3.

Table 12.3: Magnification

	Point 1	Point 2
M **calculated from image and object distances**		
$\|M\|$ **calculated from image and object sizes**		
% difference		

Questions

1. Is the image formed by the lens upright or inverted?
2. Is the image real or virtual? How do you know?
3. Explain why, for a given screen-to-object distance, there are two lens positions where a clear image forms.
4. By looking at the image, how can you tell that the magnification is negative?
5. You made three separate determinations of f (by measuring it directly with a distant object, from the x-intercept of your graph, and from the y-intercept). Where these three values equal? If they were not, what might account for the variation?

Experiment 13: Focal Length and Magnification of a Concave Mirror

Required Equipment from Basic Optics System

Light Source

Bench

Concave/convex Mirror

Half-screen

Other Equipment

Metric ruler

Optics Caliper (optional, for measuring image sizes), PASCO part OS-8468

Purpose

The purpose of this experiment is to determine the focal length of a concave mirror and to measure the magnification for a certain combination of object and image distances.

Theory

For a spherically curved mirror:

(eq. 13.1)

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

where f is focal length, d_o is the distance between the object and the mirror, and d_i is the distance between the image and the mirror. By measuring d_o and d_i the focal length can be determined.

Magnification, M, is the ratio of image size to object size. If the image is inverted, M is negative.

Part I: Object at Infinity

In this part, you will determine the focal length of the mirror by making a single measurement of d_i with $d_o \cong \infty$.

Procedure

1. Hold the mirror in one hand and the half-screen in the other hand. Use the concave side of the mirror to focus the image of a *distant* bright object (such as a window or lamp across the room) on the half-screen. (See Figure 13.1.)

2. Have your partner measure the distance from the mirror to the screen. This is the image distance, d_i.

   d_i = _______________

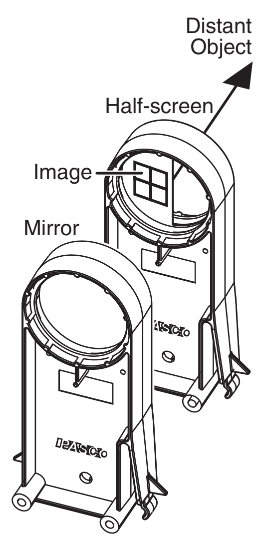

Figure 13.1

Analysis

1. As d_o approaches infinity, what does $1/d_o$ approach?

2. Use the Equation 13.1 to calculate the focal length.

$f =$ _______________

Part II: Object Closer Than Infinity

In this part, you will determine the focal length of the mirror by measuring several pairs of object and image distances and plotting $1/d_o$ versus $1/d_i$.

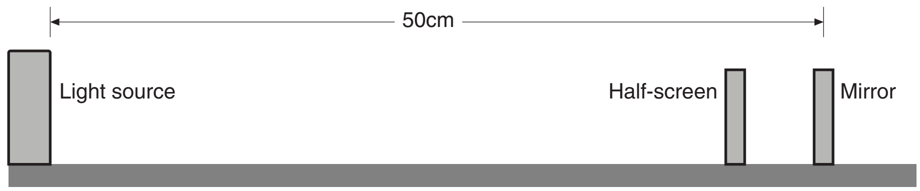

Figure 13.2

Procedure

1. Place the light source and the mirror on the optics bench 50 cm apart with the light source's crossed-arrow object toward the mirror and the concave side of the mirror toward the light source. Place the half-screen between them (see Figure 13.2).

2. Slide the half-screen to a position where a clear image of the crossed-arrow object is formed. Measure the image distance and the object distance. Record these measurements (and all measurements from the following steps) in Table 13.1.

3. Repeat step 2 with object distances of 45 cm, 40 cm, 35 cm, 30 cm, 25 cm.

4. With the mirror at 25 cm from the light source and a clear image formed on the half-screen, measure the object size and image size. To measure the image size, hold a small scrap of paper against the half-screen and mark two opposite points on the crossed-arrow pattern (see Figure 13.3). If at least half of the pattern is not visible on the screen, have your partner slightly twist the mirror to bring more of the image into view. Remove the paper and measure between the points. Measure the object size between the corresponding points directly on the light source.

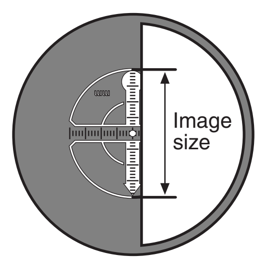

Figure 13.3

Table 13.1: Image and Object Distances

d_o	d_i	$1/d_o$	$1/d_i$	**Image Size**	**Object Size**
50.0 cm					
45.0 cm					
40.0 cm					
35.0 cm					
30.0 cm					
25.0 cm					

Analysis Part A: Focal Length

1. Calculate $1/d_o$ and $1/d_i$ for all six rows in Table 13.1.

2. Plot $1/d_o$ versus $1/d_i$ and find the best-fit line (linear fit). This will give a straight line with the x- and y-intercepts equal to $1/f$. Record the intercepts (including units) here:

y-intercept = $1/f$ = _______________

x-intercept = $1/f$ = _______________

Note: You can plot the data and find the best-fit line on paper or on a computer.

3. For each intercept, calculate a value of f and record it in Table 13.2.

4. Find the percent difference between these two values of f and record them in Table 13.2.

5. Average these two values of f. Find the percent difference between this average and the focal length that you found in Part I. Record these data in Table 13.2.

Table 13.2: Focal Length

	f
Result from x-intercept	
Result from y-intercept	
% difference between results from intercepts	
Average of results from intercepts	
Result from Part I	
% difference between Average of results from intercepts and result from Part I	

Analysis Part B: Magnification

1. For the last data point only (d_o = 25 cm), use the image and object distances to calculate the magnification, M. Record the results in Table 13.3.

(eq. 13.2)
$$M = -\left(\frac{d_i}{d_o}\right)$$

2. Calculate the absolute value of M using your measurements of the image size and object size. Record the results in Table 13.3.

(eq. 13.3)
$$|M| = \frac{\text{image size}}{\text{object size}}$$

3. Calculate the percent differences between the absolute values of M found using the two methods. Record the results in Table 13.3.

Table 13.3: Magnification

M **calculated from image and object distances**	
$\|M\|$ **calculated from image and object sizes**	
% difference	

Questions

1. Is the image formed by the mirror upright or inverted?

2. Is the image real or virtual? How do you know?

3. By looking at the image, how can you tell that the magnification is negative?

4. You made three separate determinations of f (by measuring it directly with a distant object, from the x-intercept of your graph, and from the y-intercept). Where these three values equal? If they were not, what might account for the variation?

Experiment 14: Virtual Images

Required Equipment from Basic Optics System

Light Source

Bench

-150 mm lens

+200 mm lens

Viewing screen

Concave/convex Mirror

Half-screen

Other Equipment

Tape

Purpose

In this experiment, you will study virtual images formed by a diverging lens and a convex mirror.

Theory

A virtual image cannot be viewed on a screen. It forms where the backwards extensions of diverging rays cross. You can see a virtual image by looking at it through a lens or mirror. Like all images, a virtual image formed by a lens or mirror can serve as the object of another lens or mirror.

Part I: Virtual Image Formed by a Diverging Lens

In this part, you will set up a diverging lens to form a virtual image. You will then use another lens to form a real image of the virtual image. In this way you can identify the location of the virtual image.

Procedure

1. Place the -150 mm lens on the bench at the 30 cm mark.
2. Place the light source at the 10 cm mark with the crossed-arrow object toward the lens.
3. Record the object distance d_{o1} (the distance between the light source and the lens) in Table 14.1.

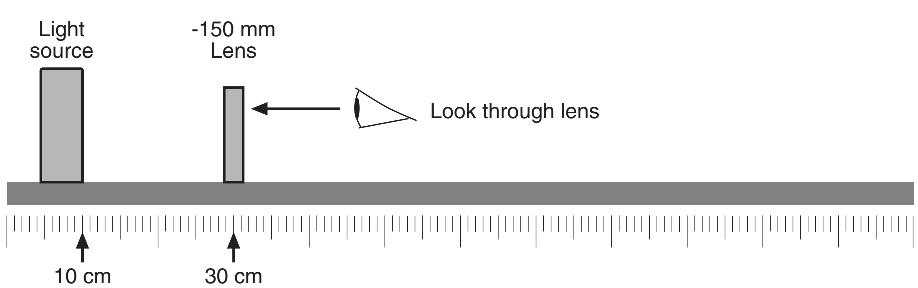

Figure 14.1

4. Look through the lens toward the light source (see Figure 14.1). Describe the image. Is it upright or inverted? Does it appear to be larger or smaller than the object?

____
____
____

5. Which do you think is closer to the lens: the image or the object? Why do you think so?

____
____
____

6. Place the +200 mm lens on the bench anywhere between the 50 cm and 80 cm marks. Record the position here. _____________

7. Place the viewing screen behind the positive lens (see Figure 14.2). Slide the screen to a position where a clear image is formed on it. Record the position here. _____________

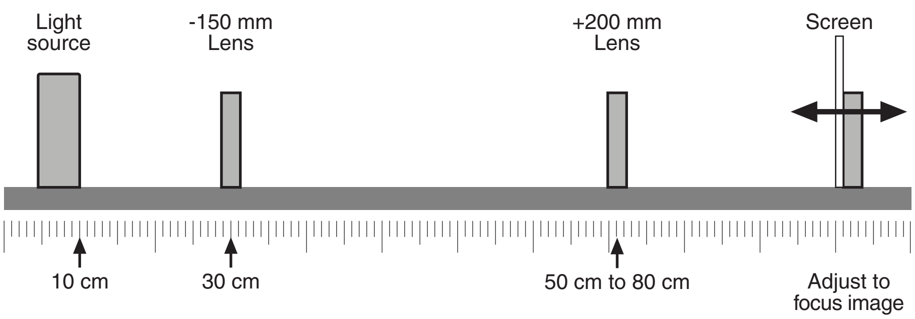

Figure 14.2

The real image that you see on the screen is formed by the positive lens with the virtual image (formed by the negative lens) acting as the object. In the following steps, you will discover the location of the virtual image by replacing it with the light source.

8. Remove the negative lens from the bench. What happens to the image on the screen?____

9. Slide the light source to a new position so that a clear image is formed on the screen. (Do not move the positive lens or the screen.) Write the bench position of the light source here. _____________

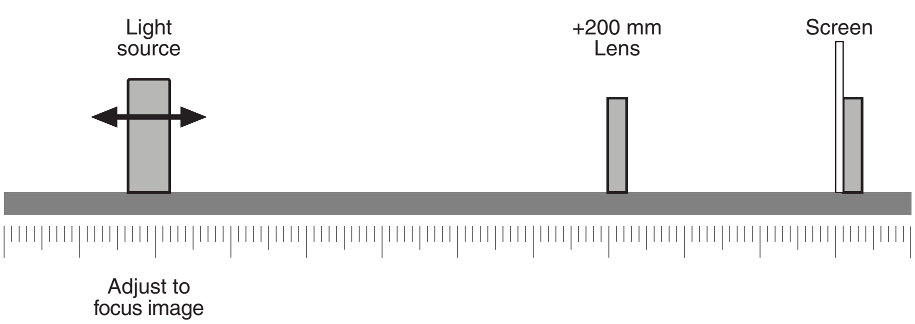

Figure 14.3

Analysis

The current position of the light source is identical to the previous position of the virtual image.

1. Calculate the virtual image distance d_{i1} (the distance between the negative lens and the virtual image). Remember that it is a negative. Record it in Table 14.1.

2. Calculate the magnification and record it in Table 14.1.

(eq. 14.1)

$$M_1 = -\left(\frac{d_{i1}}{d_{o1}}\right)$$

Table 14.1: Negative Lens

d_{o1}	
d_{i1}	
M_1	

Questions

1. How do you know that the current position of the light source is identical to the position of the virtual image when the negative lens was on the bench?

2. In step 5 of the procedure, you predicted the position of the virtual image relative to the light source. Was your prediction correct?

3. Is M_1 positive or negative? How does this relate to the appearance of the image?

4. Draw a scale diagram showing the light source in its original position, both lenses, the screen, and both images. Label every part.

5. Draw another diagram at the same scale showing the light source in its final position, the positive lens, the screen, and the image.

Part II: Virtual Image Formed by a Convex Mirror

In this part, you will find the location of a virtual image formed by convex mirror.

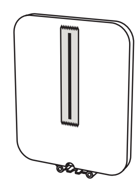

Figure 14.4

Procedure

1. Stick a piece of tape to the viewing screen and draw a vertical line on it as shown in Figure 14.4.

2. Place the half-screen on the bench near one end. Turn the screen so its edge is vertical (see Figure 14.5).

3. Place the concave/convex mirror on the bench, about 20 cm from the half-screen, with the convex side facing the half-screen.

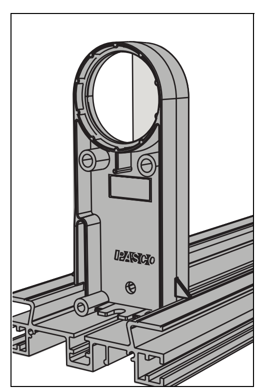

Figure 14.5

4. Look through the half-screen into the mirror. Describe the image of the half-screen. Is it upright or inverted? Does it appear to be larger or smaller than the object?

___

___

___

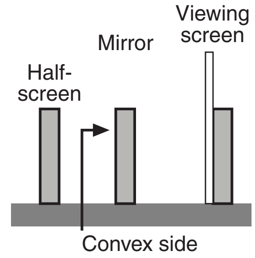

Figure 14.6

5. Guess where the image is. Place the viewing screen on the bench at this location (see Figure 14.6).

In the following steps, you will adjust the position of the viewing screen so that it is in the same place as the virtual image.

6. Look over the top of the half-screen (Figure 14.7a) so that you can see the virtual image of the half-screen and the line drawn on the viewing screen at the same time (Figure 14.7b).

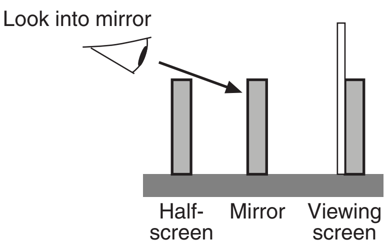

Figure 14.7a

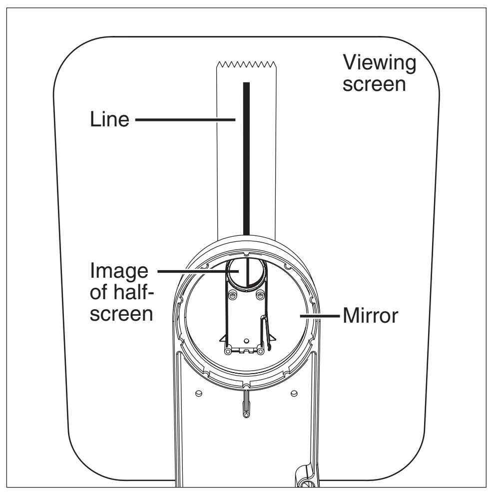

Figure 14.7b

7. Move your head left and right by a few centimeters. If the line on the viewing screen and the image of the half-screen are not at the same distance from your eye, they will appear to move relative to each other. This effect is known as parallax.

8. Adjust the position of the screen and check for parallax again. Repeat this step until there is no parallax between the line and the image. When you move your head, they should appear to be "stuck" together.

Analysis

The viewing screen is now in the same location as the virtual image.

1. Record the object distance d_o in Table 14.2.

2. Calculate the image distance d_i (the distance between the mirror and the virtual image). Remember that it is a negative. Record it in Table 14.2.

3. Use d_o and d_i to calculate the magnification and record it in Table 14.1.

Table 14.2: Convex Mirror

d_o	
d_i	
M	

Questions

1. Is the magnitude of d_i less than or greater than d_o? If you replace the convex mirror with a plane mirror, what would be the relationship between d_i and d_o?

2. Is M positive or negative? How does this relate to the appearance of the image?

3. Draw a scale diagram showing the half-screen, mirror, viewing screen, and virtual image. Label every part.