PASCO ®

Beginning Optics System
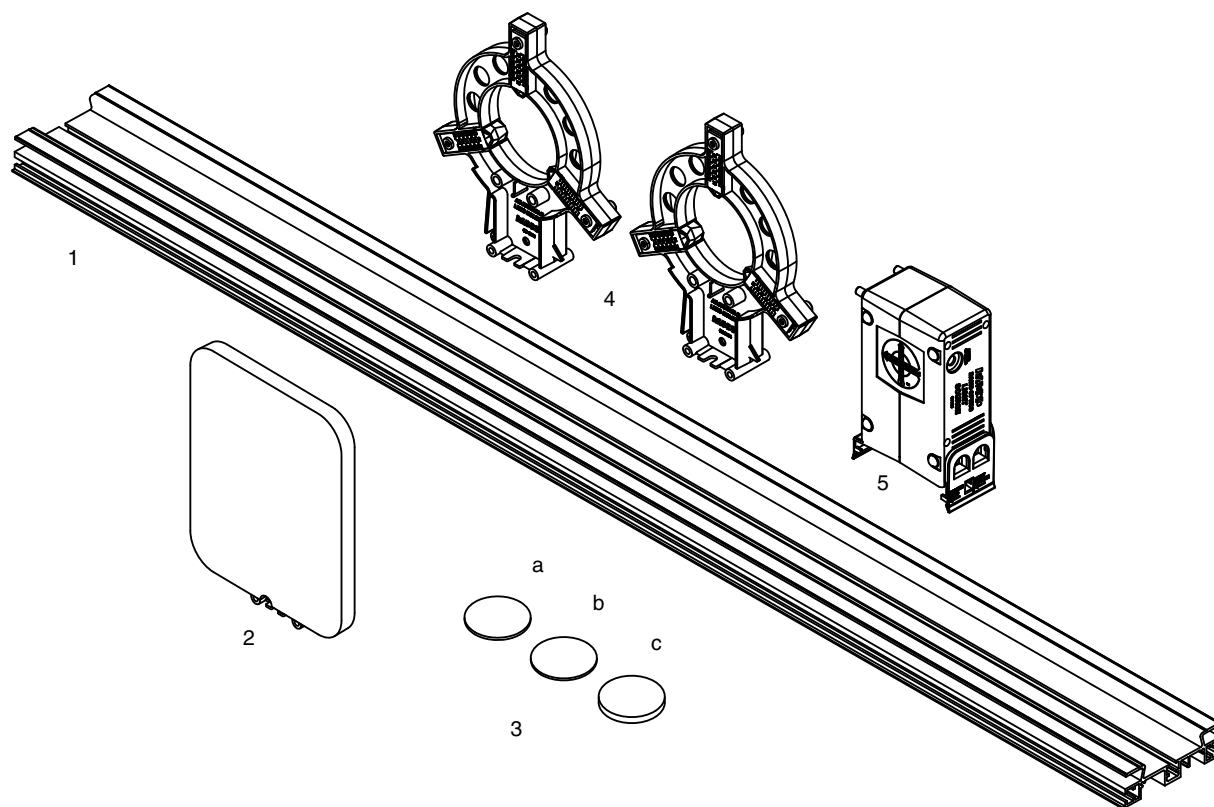## OS-8459

Contents

Beginning Optics System
OS-8459

Included Equipment		Part Number
1.	1.2 m Optics Bench	OS-8508
2.	Viewing Screen	OS-8460
3.	Geometric Lens Set	OS-8466A
	a. +100 mm Convex Lens	636-042
	b. +200 mm Convex Lens	636-043
	c. -150 mm Concave Lens	636-044
4.	Adjustable Lens Holder (2)	OS-8474
5.	Light Source*	OS-8470

*AC adapter not shown

Introduction

The PASCO Beginning Optics System contains the optics components you will need for a variety of experiments and demonstrations. This manual includes student instructions and teacher's notes for 5 typical experiments.

For an even greater variety, you can expand the system with any of the Beginning Optics kits and components available from PASCO, including lasers, polarizers, diffraction slits, and light sensors. See the PASCO Physics catalog or visit www.pasco.com for details.

About the Equipment

For detailed information on the Light Source and Adjustable Lens Holder, see the instruction sheets included with those components.

Optics Bench   Basic Optics components, such as the view screen and the adjustable lens holders, snap into the wide central channel of the optics bench. Place the base of the component on the bench and push down firmly to snap it in place. To move it, squeeze the tab on the base and slide the component along the bench.

Use the metric scale on the bench to measure the positions of components.

Light Source   The included light source can be used on a tabletop or mounted on the bench. It functions as a bright point source, an illuminated crossed-arrow object, a primary-color source, and a ray box with up to five parallel rays.

Adjustable Lens Holders   The Beginning Optics System includes two adjustable lens holders. The three 'fingers' of the lens holder hold a lens in place. The holder can hold lenses from 25 millimeters (mm) to 75 mm in diameter. Use them on the optics bench with the light source, viewing screen, and other Basic Optics components.

Viewing Screen   Mount the screen on the bench to view real images formed by lenses.

Geometric Lens Set   The lens set consists of three lenses, each 50 mm in diameter. Two of the lens are double convex with focal lengths of +100 mm and +200 mm. The third lens is a diverging double concave lens with a focal length of -150 mm.
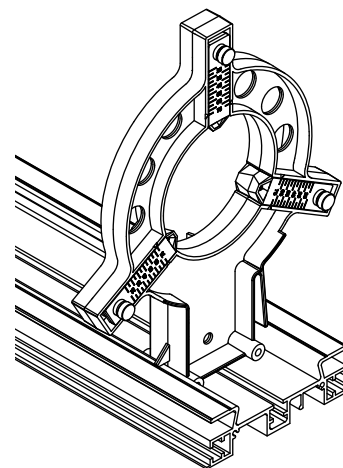
About the Experiments

The experiment instructions on the following pages are arranged and categorized according to which components of the Beginning Optics System they use. See the table at the top of each experiment for a detailed list of required equipment. Teachers' notes, including typical data and answers to questions, can be found in the section after the last experiment.

The experiments that call for the light source work best in a dimly lit room.

These experiments use the Optics Bench, Geometric Lens Set, Adjustable Lens Holders, and Viewing Screen. Experiments 1 and 3 also use the Light Source.

1. **Focal Length and Magnification of a Thin Lens** (page 5): Determine the focal length of a converging lens by forming an image on the viewing screen.

2. **Telescope** (page 9): Construct a telescope and determine its magnification.

3. **Microscope** (page 13): Construct a microscope and determine its magnification.

4. **Shadows** (page 17): Show the umbra and the penumbra of a shadow.

5. **Virtual Images** (page 19): Study the virtual images formed by a diverging lens.

Experiment 1: Focal Length and Magnification of a Thin Lens

Required Equipment from Beginning Optics System

Light Source	OS-8470
Bench	OS-8508
Converging lens of unknown focal length[1]	provided by the instructor
Screen	OS-8460

Other Equipment

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

[1]*Instructors: see note on page 25.*

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. 1.1)
$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

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. Mount the lens of unknown focal length in the adjustable lens holder. Place the view screen near one end of the optics bence and put the lens in front of the screen.

2. Aim the bench at a distant bright object, such as an open door, a lamp, or a window.

3. Move the lens away from and then closer to the screen to focus the image of object on the screen.

4. Have your partner measure the distance from the lens to the screen. This is the image distance, d_i. Record the distance: $d_i =$ _____

PASCO ®   5

Analysis

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

2. Use the Thin Lens Formula (Equation 1.1) 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 $1/d_i$:
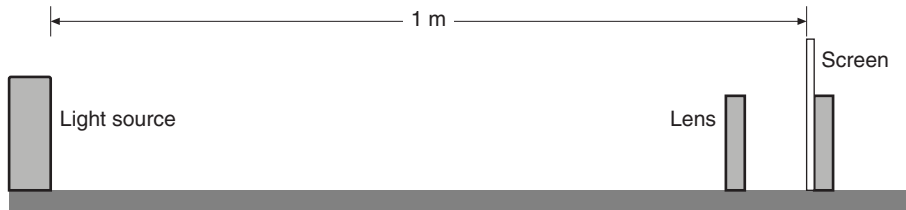

Figure 1.1

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 1.1).

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 1.1.

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 1.2 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.).
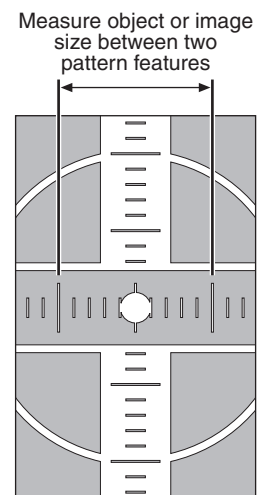
Analysis Part A: Focal Length

1. Calculate $1/d_o$ and $1/d_i$ for all the rows in Table 1.1.

Measure object or image size between two pattern features

Figure 1.2

PASCO ®

Table 1.1: 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						

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 = $1/f$ = _____

$$\frac{1}{d_o} = \frac{1}{f} - \frac{1}{d_i}$$
$$y = b + mx$$

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

3. For each intercept, calculate a value of f and record it in Table 1.2.

4. Find the percent difference between these two values of f and record them in Table 1.2.

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 1.2.

Table 1.2: 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 1.2), use image and object distances to calculate the magnification, M, at each position of the lens. Record the results in Table 1.3.

(eq. 1.2)
$$M = -\left(\frac{d_i}{d_o}\right)$$

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 1.3.

(eq. 1.3)
$$|M| = \frac{\text{image size}}{\text{object size}}$$

3. Calculate the percent differences between the absolute values of M found using the two methods. Record the results in Table 1.3.

Table 1.3: 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). Were these three values equal? If they were not, what might account for the variation?

Experiment 2: Telescope

Required Equipment from Beginning Optics System

Bench	OS-8508
2 Convex Lenses (+100 mm and +200 mm)	From OS-8466A
Screen	OS-8460

Paper grid pattern (see page 23), or a 14 × 16 grid of 1 cm squares

Purpose

In this experiment, you will construct a telescope and determine its magnification.
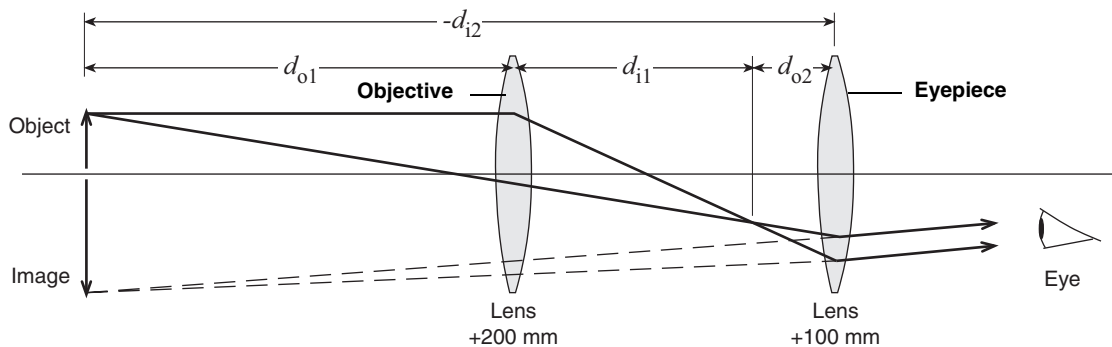
Theory

Figure 2.1

An astronomical telescope consists of two convex lenses. The astronomical telescope in this experiment will form an image in the same place as the object (see Figure 2.1).

The lenses are thin compared to the other distances involved, which allows the Thin Lens Formula to be used:

(eq. 2.1)
$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

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.

The magnification, M, of a two-lens system is equal to the product of the magnifications of the individual lenses:

(eq. 2.2)
$$M = M_1 M_2 = \left(\frac{-d_{i1}}{d_{o1}}\right)\left(\frac{-d_{i2}}{d_{o2}}\right)$$

Set Up

1. Tape the paper grid pattern to the screen to serve as the object.

2. The +200 mm lens is the objective lens (the one closer to the object). The +100 mm lens is the eyepiece lens (the one closer to the eye). Place the lenses near one end of the optics bench and place the screen on the other end (see Figure 2.2). Their exact positions do not matter yet.
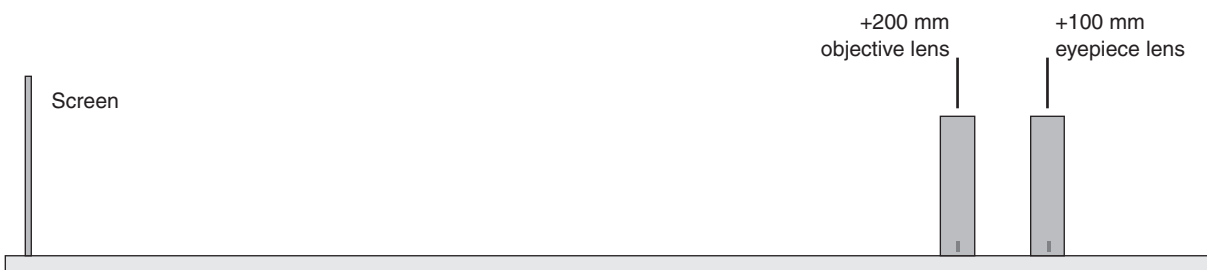
Figure 2.2

Procedure

1. Put your eye close to the eyepiece lens and look through both lenses at the grid pattern on the screen. Move the objective lens to bring the image into focus.
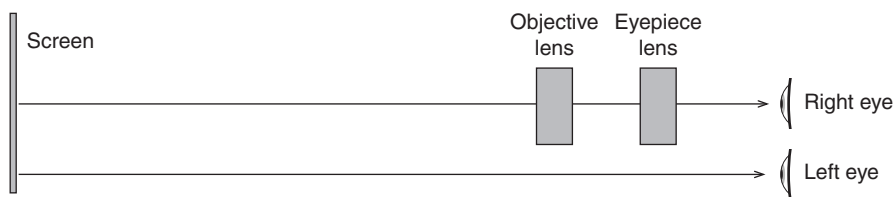

Figure 2.3

2. In this step, you will adjust your telescope to make the image occur in the same place as the object. To do this, you will look at both image and object at the same time and judge their relative positions by moving your head side to side. If the image and object are not in the same place, then they will appear to move relative to each other. This effect is known as parallax.

   Open both eyes. Look with one eye through the lenses at the image and with the other eye past the lenses at the object (see Figure 2.3). The lines of the image (solid lines shown in Figure 2.4) will be superimposed on the lines of the object (shown as dotted lines in Figure 2.4). Move your head left and right or up and down by about a centimeter. As you move your head, the lines of the image may move relative to the lines of the object due to the parallax. Adjust the eyepiece lens to eliminate parallax. Do not move the objective lens. When there is no parallax, the lines in the center of the lens appear to be stuck to the object lines.
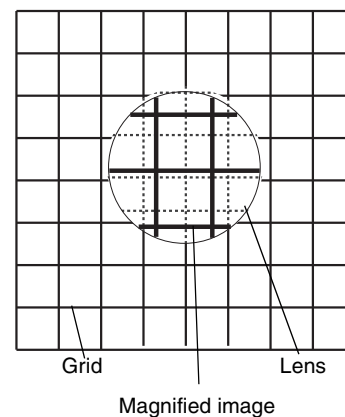

Figure 2.4

Note: You will probably have to adjust the eyepiece lens by no more than a few centimeters.

3. Record the positions of the lenses and screen in Table 2.1.

4. Estimate the magnification of your telescope by counting the number of object squares that lie along one side of one image square. To do this, you must view the image through the telescope with one eye while looking directly at the object with the other eye. Remember that magnification is negative for an inverted image. Record the observed magnification in Table 2.1.

Analysis

To calculate the magnification, complete the following steps and record the results in Table 2.1:

1. Measure d_{o1}, the distance from the object (paper pattern on screen) to the objective lens.

2. Determine d_{i2}, the distance from the eyepiece lens to the image. Since the image is in the plane of the object, this is equal to the distance between the eyepiece lens and the object (screen). Remember that the image distance for a virtual image is negative.

3. Calculate d_{i1} using d_{o1} and the focal length of the objective lens in the Thin Lens Formula (Equation 2.1).

4. Calculate d_{o2} by subtracting d_{i1} from the distance between the lenses.

5. Calculate the magnification using Equation 2.2.

6. Calculate the percent difference between the calculated magnification and the observed value.

Table 2.1: Results

Position of Objective Lens	
Position of Eyepiece Lens	
Position of Screen	
Observed magnification	
d_{o1}	
d_{i2}	
d_{i1}	
d_{o2}	
Calculated Magnification	
Percent Difference	

Questions

1. Is the image inverted or upright?

2. Is the image that you see through the telescope real or virtual?

Further Study

Image Formed by the Objective Lens

Where is the image formed by the objective lens? Is it real or virtual? Use a desk lamp to brightly illuminate the paper grid (or replace the screen with the light source's crossed-arrow object). Hold a sheet of paper vertically where you think the image is. Do you see the image? Is it inverted or upright? Remove the sheet of paper and hold a pencil in the same place. Look through eyepiece lens; you will see two images, one of the pencil and one of the grid pattern. Are both images inverted? Use parallax to determine the location of the pencil image.

Object at Infinity

Remove the screen and look through the lenses at a distant object. Adjust the distance between the lenses to focus the telescope. Estimate the observed magnification.

Now calculated the magnification by taking the ratio of the focal lengths of the lenses. Compare the calculated magnification to the observed magnification.

How is the distance between the lenses related to their focal lengths?

PASCO ®

Experiment 3: Microscope

Required Equipment from Beginning Optics System

Bench	OS-8508
2 Convex Lenses (+100 mm and +200 mm)	From OS-8466A
Screen	OS-8460

Paper grid pattern (see page 23), or a 14 × 16 grid of 1 cm squares

Purpose

In this experiment, you will construct a microscope and determine its magnification.
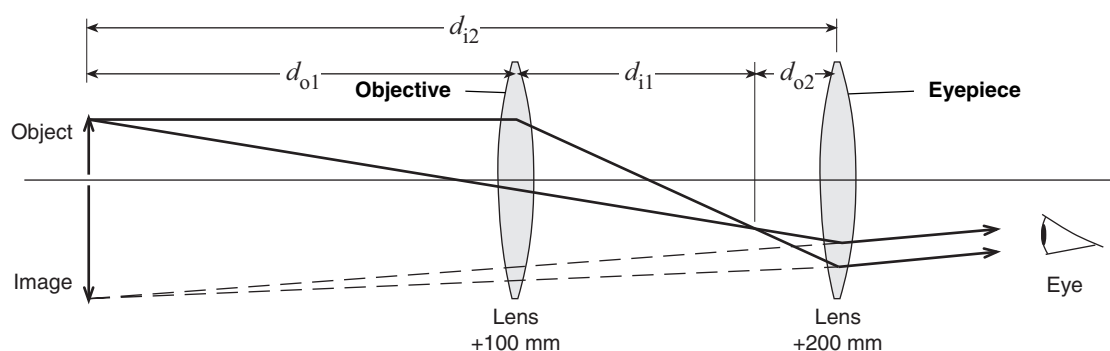
Theory

Figure 3.1

A microscope magnifies an object that is close to the objective lens. The microscope in this experiment will form an image in the same place as the object (see Figure 3.1).

The lenses are thin compared to the other distances involved, which allows the Thin Lens Formula to be used:

(eq. 3.1)
$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

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.

The magnification, M, of a two-lens system is equal to the product of the magnifications of the individual lenses:

(eq. 3.2)
$$M = M_1 M_2 = \left(\frac{-d_{i1}}{d_{o1}}\right)\left(\frac{-d_{i2}}{d_{o2}}\right)$$

Set Up

1. Tape the paper grid pattern to the screen to serve as the object.

2. The +100 mm lens is the objective lens (the one closer to the object). The +200 mm lens is the eyepiece lens (the one closer to the eye). Place the lenses near the middle of the optics bench and place the screen near the end of the bench (see Figure 3.2).
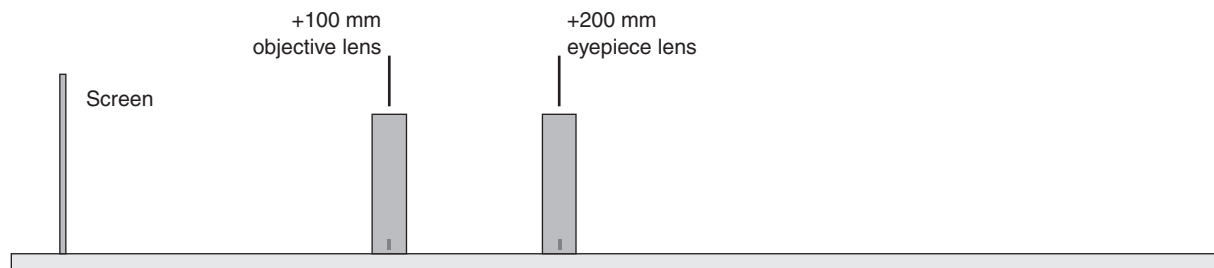
Figure 3.2

Procedure

1. Put your eye close to the eyepiece lens and look through both lenses at the grid pattern on the screen. Move the objective lens to bring the image into focus.
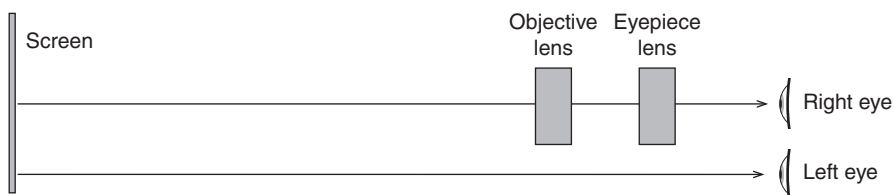

Figure 3.3

2. In this step, you will adjust your microscope to make the image occur in the same place as the object. To do this, you will look at both image and object at the same time and judge their relative positions by moving your head side to side. If the image and object are not in the same place, then they will appear to move relative to each other. This effect is known as parallax.

   Open both eyes. Look with one eye through the lenses at the image and with the other eye past the lenses at the object (see Figure 3.3). The lines of the image (solid lines shown in Figure 3.4) will be superimposed on the lines of the object (shown as dotted lines in Figure 3.4). Move your head left and right or up and down by about a centimeter. As you move your head, the lines of the image may move relative to the lines of the object due to the parallax. Adjust the eyepiece lens to eliminate parallax. Do not move the objective lens. When there is no parallax, the lines in the center of the lens appear to be stuck to the object lines.
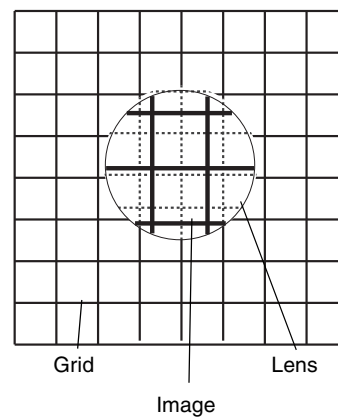

Figure 3.4

Note: Even when there is no parallax, the lines may appear to move near the edges of the lens because of lens aberrations. Concentrate on the part of the image seen through the centers of the lenses. Be sure that the eye looking at the object (the left eye in Figure 3.3) is looking directly at the object and not through the objective lens.

3. Record the positions of the lenses and the object in Table 3.1.

4. Estimate the magnification of your microscope by counting the number of object squares that lie along one side of one image square. To do this, you must view the image through the microscope with one eye while looking directly at the object with the other eye. Remember that magnification is negative for an inverted image. Record the observed magnification in Table 3.1.

Analysis

To calculate the magnification complete the following steps and record the answers in Table 3.1:

1. Measure d_{o1}, the distance from the object (paper pattern on screen) to the objective lens.

2. Determine d_{i2}, the distance from the eyepiece lens to the image. Since the image is in the plane of the object, this is equal to the distance between the eyepiece lens and the object (screen). Remember that the image distance for a virtual image is negative.

3. Calculate d_{i1} using d_{o1} and the focal length of the objective lens in the Thin Lens Formula (Equation 3.1).

4. Calculate d_{o2} by subtracting d_{i1} from the distance between the lenses.

5. Calculate the magnification using Equation 3.2.

6. Calculate the percent difference between the calculated magnification and the observed value.

Table 3.1: Results

Position of Objective Lens	
Position of Eyepiece Lens	
Position of Screen	
Observed magnification	
d_{o1}	
d_{i2}	
d_{i1}	
d_{o2}	
Calculated Magnification	
Percent Difference	

Questions

1. Is the image inverted or upright?

2. Is the image that you see through the microscope real or virtual?

Further Study

Image Formed by the Objective Lens

Where is the image formed by the objective lens? Is it real or virtual? Us a desk lamp to brightly illuminate the paper grid (or replace the screen with the light source's crossed-arrow object). Hold a sheet of paper vertically where you think the image is. Do you see the image? Is it inverted or upright? Remove the sheet of paper and hold a pencil in the same place. Look through eyepiece lens; you will see two images, one of the pencil and one of the grid pattern. Are both images inverted? Use parallax to determine the location of the pencil image.

Increasing Magnification

While looking through your microscope, move the objective lens a few centimeters closer to the object. Which way do you have to move the eyepiece lens to keep the image in focus. How close can you move the objective lens and still see a clear image? (Make a pencil mark on the paper grid so you have something very small to focus on.) What is the theoretical limit to how close you can move the objective lens?

PASCO ®

Experiment 4: Shadows

Required Equipment from Beginning Optics System (2 systems needed)

2 Benches	OS-8508
2 Light Sources	OS-8470
1 Screen	OS-8460

Purpose

The purpose of this experiment is to show the umbra (darker part) and the penumbra (lighter part) of the shadow.

Set Up

1. Place the two optics benches beside each other.

2. Put one light source on each bench with the point source (circular hole) facing the other end of the bench.

3. Place the screen on one of the benches at the opposite end to the light sources.

Procedure

1. Plug in only one of the light sources.

2. Hold a pencil about 5 cm away from the screen so its shadow is cast on the screen. Now turn the light source around so the crossed-arrow illuminates the pencil and screen. How does the shadow change?

3. Rotate the light source back to the point-source position. Plug in the second light source. Make a sketch of the shadow of the pencil. Label the umbra and the penumbra.

4. Move the pencil away and toward the screen. How does the shadow change?

5. Block the light from each point source in succession to determine which part of the shadow is caused by each light source. Indicate your observation on your sketch.

PASCO ®

Experiment 5: Virtual Images

Required Equipment from Beginning Optics System

Light Source	OS-8470
Bench	OS-8508
-150 mm lens and +200 mm lens	From OS-8466A
Viewing screen	OS-8460

Other Equipment

Tape

Purpose

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

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.

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 5.1.
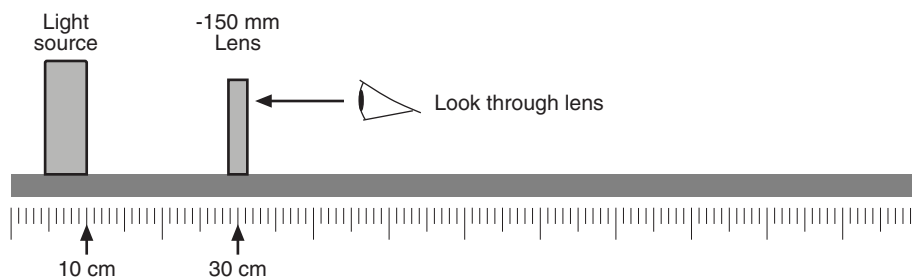

Figure 5.1

4. Look through the lens toward the light source (see Figure 5.1). 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 5.2). Slide the screen to a position where a clear image is formed on it. Record the position here. _____
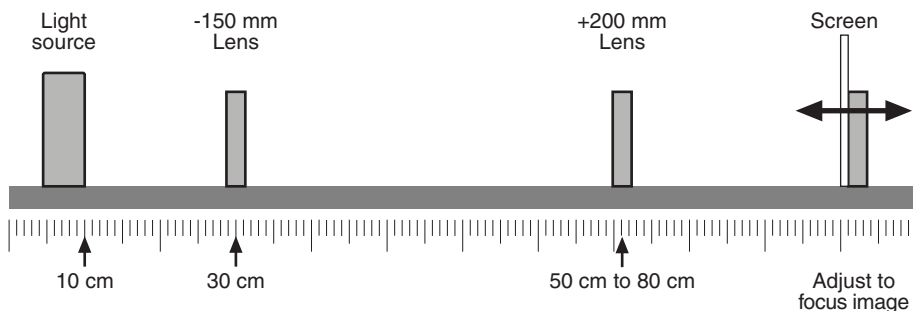
| Light source | -150 mm Lens | | +200 mm Lens | Screen |

| 10 cm | 30 cm | | 50 cm to 80 cm | Adjust to focus image |

Figure 5.2

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. _____
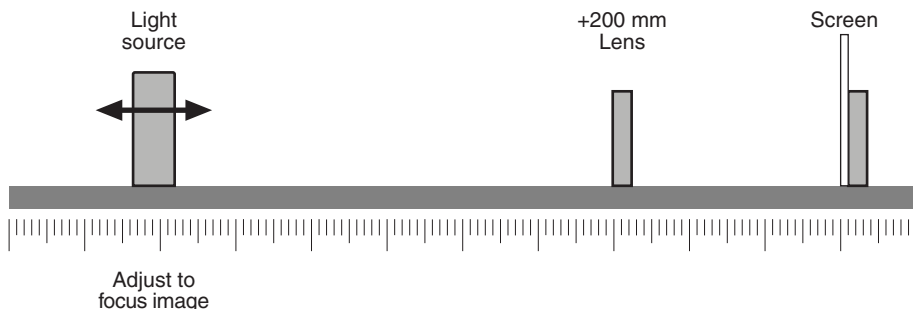
| Light source | | +200 mm Lens | Screen |

| Adjust to focus image | | | |

Figure 5.3

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 5.1.

2. Calculate the magnification and record it in Table 5.1.

(eq. 5.1)
$$M_1 = -\left(\frac{d_{i1}}{d_{o1}}\right)$$

Table 5.1: 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.

PASCO ®

Telescope and Microscope Test Pattern

Attach a copy of this pattern to the viewing screen for experiments 2 and 3.
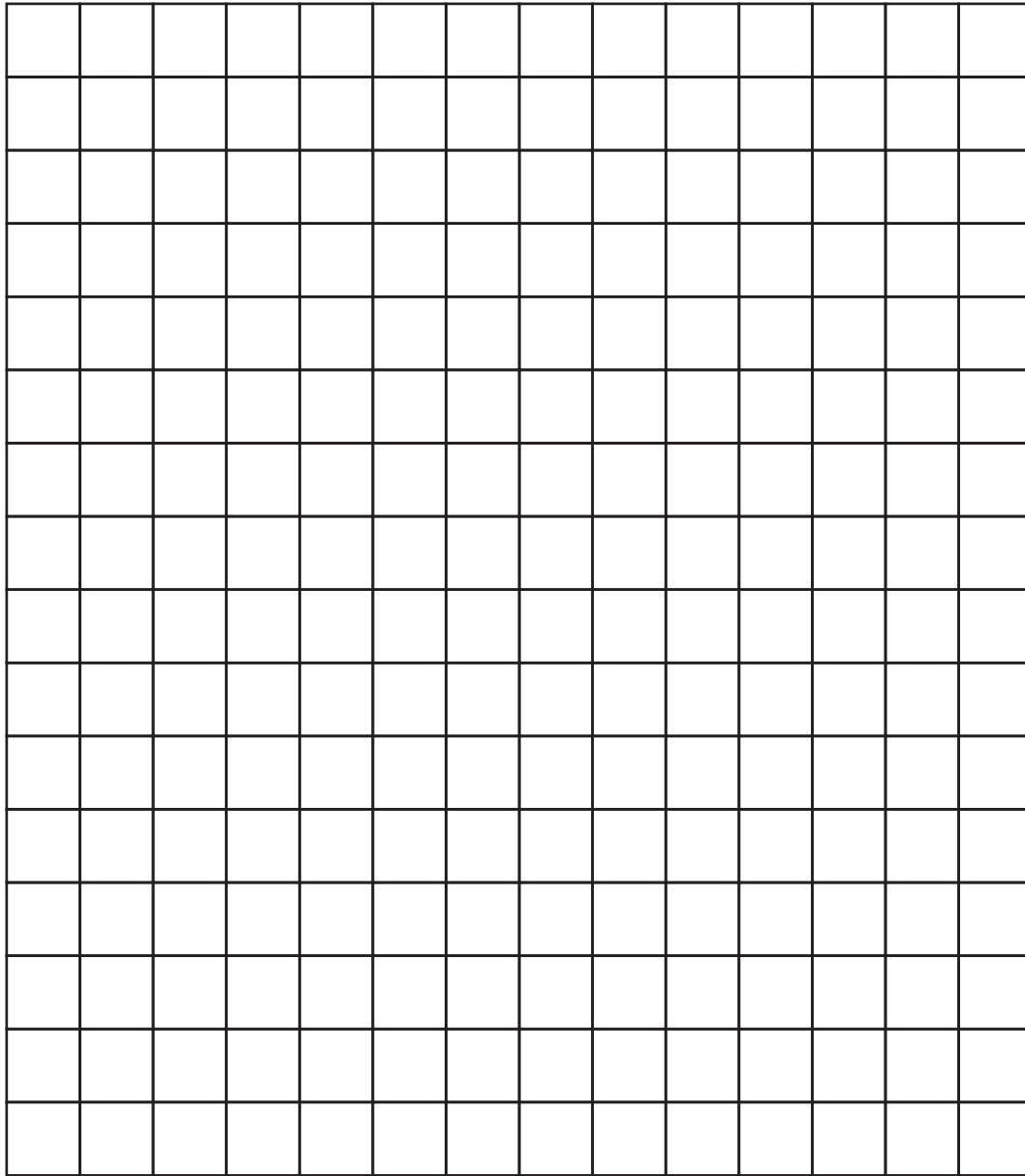
1 cm grid

Teacher's Guide

Experiment 1: Focal Length and Magnification of a Thin Lens

Note on equipment: Provide students with the +100 mm lens. Don't mention the focal length. Other converging lenses will also work, but you may have to modify the light source-to-screen values given in Table 1.1.

Part 1:   For a distant object, $1/d_o$ approaches zero, therefore the image will form clearly with a lens-to-screen distance of $d_i = f \cong 10$ cm.

Part 2:   Typical results.

Table 1.1: Image and Object Distances

Distance from light source to screen	d_o (cm)	d_i (cm)	$1/d_o$ (cm⁻¹)	$1/d_i$ (cm⁻¹)	Image Size	Object Size
100 cm	88.5	11.5	0.0113	0.0870	5.5 mm	42 mm
	11.0	89.0	0.0909	0.0112	81 mm	10 mm
90 cm	78.3	11.7	0.0128	0.0855		
	11.3	78.7	0.0885	0.0127		
80 cm	68.0	12.0	0.0147	0.0833		
	11.5	68.5	0.0870	0.0146		
70 cm	57.7	12.3	0.0173	0.0813		
	11.9	58.1	0.0840	0.0172		
60 cm	47.1	12.9	0.0212	0.0775		
	12.3	47.7	0.0813	0.0210		
50 cm	36.0	14.0	0.0278	0.0714		
	13.4	36.6	0.0746	0.0273		

y-intercept = $1/f$ = 0.0977 cm⁻¹

x-intercept = $1/f$ = 0.103 cm⁻¹

Table 1.2: Focal Length

	f
Result from x-intercept	9.75 cm
Result from y-intercept	10.2 cm
% difference between results from intercepts	4.4%
Average of results from intercepts	9.98 cm
Result from Part I	10.0 cm
% difference between Average of results from intercepts and result from Part I	0.2%

Table 1.3: Magnification

	Point 1	Point 2
M **calculated from image and object distances**	-0.130	-8.09
$|M|$ **calculated from image and object sizes**	0.13	8.1
% difference	0%	0.1%

Answers to questions: **1.** The image if inverted. **2.** The image is real because it can be viewed on a screen. **3.** For a given object-to-image distance, the two object distance-image distance pairs are the inverse of each other, which demonstrates the reversibility of light through a lens. **4.** The magnification is negative because the image is inverted. **5.** The three determined values of *f* are unlikely to be exactly equal, primarily due to measurement error.

Experiment 2: Telescope

Typical results:

Table 2.1: Results

Position of Objective Lens	63.4 cm
Position of Eyepiece Lens	102.2 cm
Position of Screen	0.0 cm
Observed magnification	-5
d_{o1}	63.4 cm
d_{i2}	-102.2 cm
d_{i1}	29.2 cm
d_{o2}	9.6 cm
Calculated Magnification	-4.9
Percent Difference	2%

Answers to questions: **1.** The image is inverted. **2.** It is a virtual image.

Further study, Image Formed by the Objective Lens: The objective lens forms a real, upright image; to see it, hold a sheet of paper at distance d_{i1} from the objective. When a pencil is placed at this location, it's virtual image, viewed through the eyepiece lens, coincides with the virtual image of the grid pattern viewed through both lenses.

Further study, Object at Infinity: When adjusted for a distant object, the distance between the lenses is equal to the sum of the focal lengths.

Experiment 3: Microscope

Typical results:

Table 3.1: Results

Position of Objective Lens	20.9 cm
Position of Eyepiece Lens	54.9 cm
Position of Screen	0.0 cm
Observed magnification	-3
d_{o1}	20.9 cm
d_{i2}	-54.9 cm
d_{i1}	19.2 cm
d_{o2}	14.8 cm
Calculated Magnification	-3.41
Percent Difference	12%

Answers to questions: **1.** The image is inverted. **2.** It is a virtual image.

Further study, Image Formed by the Objective Lens: The objective lens forms a real, upright image; to see it, hold a sheet of paper at distance d_{i1} from the objective. When a pencil is placed at this location, it's virtual image, viewed through the eyepiece lens, coincides with the virtual image of the grid pattern viewed through both lenses.

Further study, Increasing Magnification: As the objective lens is moved closer to the object, the eyepiece must be moved further away. In practice, the objective can be moved to within about 13 cm before distortion from lens aberrations becomes significant. The theoretical limit is 10 cm, or the focal length of the objective lens.

Experiment 4: Shadows

When the pencil is illuminated by the point source, the shadow appears sharper than when illuminated by a distributed light source (the crossed-arrow object). When illuminated by both point sources, the pencil casts two shadows. The area where the shadows overlap is the umbra. The areas of partial shadow are the penumbra. By moving the pencil toward the screen, the relative size of the umbra is increased. By moving the pencil away from the screen, the umbra is decreased until the two shadow separate entirely.

Experiment 5: Virtual Images

Notes on procedure: **(Step 4)** The image is upright and appears smaller than the object. **(Step 5)** Answers will vary. By observing parallax between the image and the light source, you can determine that the image is in front of the object. **(Step 8)** When the negative lens is removed, the image on the screen goes "out of focus."

Typical results:

Table 5.1: Negative Lens

d_{o1}	20.0 cm
d_{i1}	-8.3 cm
M_1	0.42

Answers to questions: **1.** You know that the final position of the light source and the original position of the virtual image are the same because both caused the +200 mm lens to form an image in the same place. **2.** Answers will vary. **3.** M_1 is positive, meaning that the image is upright.

4.

5.
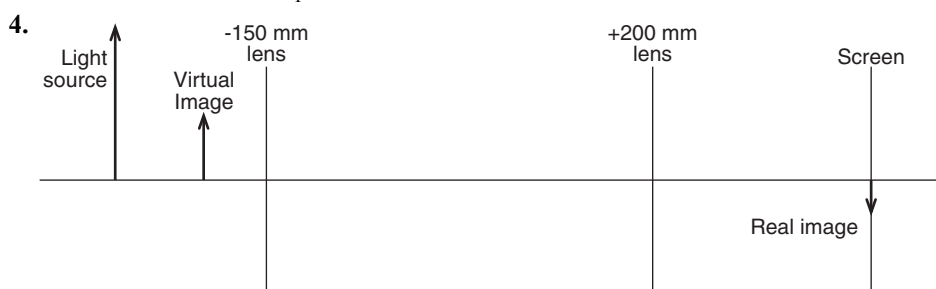
Technical Support

For assistance with any PASCO product, contact PASCO at:

Address: PASCO scientific
           10101 Foothills Blvd.
           Roseville, CA 95747-7100

Phone: 916-786-3800 (worldwide)
           800-772-8700 (U.S.)

Fax: (916) 786-3292

Web: www.pasco.com

Email: support@pasco.com

Authors: Ann Hanks
           Dave Griffith
           Alec Ogston