## LABORATORY 11 GEOMETRICAL OPTICS II: LENSES AND IMAGES <br> Objectives

- To be able to explain the concepts of focal point and focal length
- To be able to explain image formation by a thin lens
- To be able to explain image formation by a pinhole
- To be able to determine the focal length by measurement and by calculation
- To be able to explain the concept of parallel rays
- To be able to explain the concepts of real image and virtual image
- To be able to explain the concept of magnification
- To be able to calculate the magnification
- To be able to explain the differences between different types of lenses
- To be able to draw and use ray diagrams
- To be able to discuss how the object distance, image distance and focal length are related
- To be able to use the thin lens equation to solve problems

Overview: In this lab we will explore image formation by lenses. We will examine real and virtual images, upright and inverted images, the concepts of focal point and focal length for both converging and diverging lenses, discuss ray diagrams and verify the thin lens equation.

## Equipment:

1 optical bench
120 cm lens
1 Pasco Light source
1 screen

## Exploration 1: Image Formation

Exploraton 1.1 Take the pre-test for this lab.

## Exploration 1.2

a. On the optical bench, start with the light source approximately 90 cm away from the screen. Place the lens in between the light source and the screen, so that a clear image of the source appears on the screen. Remove the lens. Can you create a clear image of the source on the screen without a lens? Write down ideas that might explain your observations.
b. Place the lens in between the light source and the screen, so that a clear image of the source appears on the screen. Move the screen toward and away from the lens. What happens to the image of the source on the screen? Write down ideas that might explain your observations.
c. With the lens in between the light source and the screen, so that a clear image of the light source appears on the screen, compare the image to the object. Is the image upside down? Right side up? Write down ideas that might explain your observations.

## Equipment:

1 optical bench
120 cm lens
1 Pasco Light source
1 screen
1 pinhole

## Exploration 1.3

a. With the light source approximately 1.2 m away from the screen. Place a pinhole between the light source and the screen. Is there anywhere that you can place the pinhole so that a clear image of the light source appears on the screen? Is there more than one place that you can place the pinhole so that a clear image of the light source appears on the screen? Write down ideas that might explain your observations.
b. With the pinhole in between the light source and the screen, so that a clear image of the light source appears on the screen, compare the image to the object. Is the image upside down? Right side up? Write down ideas that might explain your observations.

## Equipment:

1 optical bench
120 cm lens
1 Pasco Light source
1 screen
1 index card

## Exploration 1.4

a. With the lens back in place and a clear image of the light source on the screen, what would happen if you covered half the lens with an index card? What would happen if you covered the right half? The left half? The top? The Bottom? Predict first, before you try it. Explain your prediction.

## Discuss your prediction with the TA.

b. Test your prediction in part $\mathbf{a}$. Write down ideas that might explain your observations.

What if you cover more than half of the lens? What if you cover all but a small hole? Try it. Write down ideas that might explain your observations.

## Equipment:

1 optical bench
120 cm lens
1 Pasco Llight source
1 screen

## Exploration 1.5

a. If the lens is placed so that a clear image appears on the screen, and the screen is removed, is there any position from which you can still see the image? Explain.
b. Try standing a few feet behind where the screen was. Look back at where the screen was, toward the lens (and the light source). You will have to have your eye at the level of the lens. Ask your TA for help. Do you see the image where the screen was? Is it right side up or upside down? How do you know where it is located?

## Equipment:

1 optical bench
1 Pasco ray box
1 large converging lens
1 large diverging lens

## Exploration 2 Focal Point and Focal Length

## Exploration 2.1

a. Use the ray box to direct five approximately parallel rays through a lens as in each of the pictures A and B below.


A


B

Lenses shaped as in diagram A are called convex or converging lenses and those shaped as in diagram $B$ are called concave or diverging lenses.

When parallel rays enter a convex lens, the place where the rays cross is called the focal point of the lens. The distance from the center of the lens to the focal point is called the focal length of the lens.


Parallel rays passing through a concave lens all appear to emanate from the same point. The point from which they appear to emanate is called focal point of the lens. The distance from the center of the lens to the focal point is called the focal length of the lens.

b. The focal point is defined for rays that are parallel to the optic axis, a straight line through the center of the lens, as in the picture below.


You used slits in front of the ray box to create parallel rays. An object an infinite distance away, also provides parallel rays. In reality, an object a very long distance from the lens is a source of approximately parallel rays. The sun's rays hitting the earth, for example, are approximately parallel rays.

Choose a converging lens from your table and determine approximately the focal length of the lens, using a source of approximately parallel rays.

Describe your process in the space below and record the approximate focal length of the lens.
c. If the source of light is significantly closer than infinity, but outside the focal point, the rays will still cross after passing through the lens but at a location different than the focal point. Consider an object in the shape of an arrow placed 45 cm from a 20 cm focal length lens, as in the picture below.


There are many rays of light from the top of the arrow that pass through the lens. It is sufficient to draw only two of those rays to find the location of the top of the image of the arrow. We could determine the path of the rays from the law of refraction, but we know that a ray coming in parallel to the axis of the lens must go through the focal point and,
by symmetry, a ray through the focal point, would leave parallel. These two rays can determine the top of the image of the arrow. If the bottom of the arrow is on the axis of the lens, the bottom of the image of the arrow, must lie on that axis. The image of the arrow, must be as in the diagram below.


From the diagram, we could measure the distance of the image from the lens (called the image distance). The image distance is 90 cm .

The magnification is the ratio of the image height $\left(h_{i}\right)$ to the object height $\left(h_{o}\right)$. It is common to define the magnification to be positive when the image is upright and negative when the image is inverted. If the image is inverted then $h_{i}$ is considered to be negative.

$$
m=\frac{h_{i}}{h_{o}}
$$

A line drawn from the tip of the arrow to the tip of the image would pass through the center of the lens.


From geometry, the ratio of the object height to the image height is

$$
\frac{h_{i}}{h_{o}}=-\frac{d_{i}}{d_{o}}
$$

For a thin lens the focal length, $f$, object distance, $d_{0}$, and image distance, $d_{i}$, are related by the following equation

$$
\frac{1}{f}=\frac{1}{d_{i}}+\frac{1}{d_{o}}
$$

with the following set of rules:

1. $d_{o}$ is positive if the object is on the side of the lens from which the light is coming, otherwise, it is negative.
2. $d_{i}$ is positive if the image is on the opposite side of the lens from where the light is coming. Otherwise, it is negative.
3. The focal length, $f$, is positive for a convex (converging) lens and negative for a concave (diverging) lens.

The magnification is then defined as

$$
m=\frac{h_{i}}{h_{o}}=-\frac{d_{i}}{d_{o}}
$$

The formula $\frac{1}{f}=\frac{1}{d_{i}}+\frac{1}{d_{o}}$ is called the thin lens equation.

## Equipment:

1 optical bench
1 Pasco Light source
2 convex lens
1 screen

## Investigation 1: Determining the focal length of a convex lens

## Investigation 1.1

Now we will use the thin lens formula to determine the focal length of a convex lens.
a. Mount the light source on an optical bench. The arrow within a circle will be your object. Next take a convex lens and place it 30 cm in front of the light source. By moving the screen, determine where the image forms. Record the image distance and object distance in the table below. Calculate the focal length of the lens and record it in
the table as well. Repeat for four other object distances of your choosing. Calculate an average focal length for the lens.

| Trial | Object distance | Image distance | Focal Length |
| :---: | :---: | :---: | :---: |
| 1 |  |  |  |
| 2 |  |  |  |
| 3 |  |  |  |
| 4 |  |  |  |
| 5 | X | X |  |
| Average |  |  |  |

b. Take a second convex lens with a different radius of curvature and repeat the above procedure to fill the table below.

| Trial | Object distance | Image distance | Focal Length |
| :---: | :---: | :---: | :---: |
| 1 |  |  |  |
| 2 |  |  |  |
| 3 |  |  |  |
| 4 |  |  |  |
| 5 | X | X |  |
| Average |  |  |  |

c. Which lens had a greater radius of curvature? How do the focal lengths of the two lenses compare? Does this make sense? Explain
d. Discuss the image of the object. Is it real or virtual? Upright or inverted?
e. Determine the focal length of one of the lenses by a different method. Explain your method and record your results in the space below.

## Equipment:

1 optical bench
1 Pasco Light source
2 convex lens
1 screen

## Exploration 3 Virtual images

## Exploration 3.1

a. In determining the focal length of one of the lenses, you may have placed the object at a distance from the lens that was closer than the focal point. If you did, what did you see? Where was the image? If you didn't, try it now. Where is the image? You may want to look back through the lens toward the light source. (Remove the screen.) What do you see?
b. Is the image real or virtual? Is it upright or inverted?
c. Use a ray diagram or an equation(s) to verify the location of the image and if it is real or virtual, upright or inverted. Draw the diagram or show your work in the space below.

## Equipment:

1 optical bench
1 Pasco Light source
1 diverging lens
1 screen

## Exploration 3.2 Diverging lens

a. Mount a diverging lens in front of the light source. Choose an object distance and locate the image. Is the image in front of or behind the lens? Is it real or virtual? Is it larger or smaller than the object? Upright or inverted?
b. Use a ray diagram or an equation(s) to verify the location of the image and if it is real or virtual, upright or inverted. Draw the diagram or show your work in the space below.
c. Try a different object distance. Observe the image again. How does the image change, as you change the object distance?
d. Is it possible for a diverging lens to form an image on a screen? Explain.
e. Is it possible for a diverging lens to form a real image? Explain.
f. Is it possible for a diverging lens to form an inverted image? Explain.

## Equipment:

1 optical bench
1 Pasco Light source
1 concave lens
1 screen

## Investigation 2: Determining the focal length of a concave lens

## Investigation 2.1

a. Design an experiment to determine the focal length of a concave lens. Describe your experiment in the space below.
b. Carry out the experiment you designed in part a. Record your results here.

## Equipment:

1 optical bench
1 Pasco Light source
1 convex lens
1 screen

## Application 1 Magnifying Glass

## Application 1.1

a. Mount the convex lens on the optical bench. In the movies, Sherlock Holmes is frequently seen moving a magnifying glass over a clue to get a better look at it. We're going to reverse that process, and move the "clue" while the observer and lens hold still. Have one of your lab partners hold a small object up to the lens so that you can see an enlarged image of the object. Then ask the person to slowly move the object further from the lens. During this process your distance from the lens needs to be constant. They should move the object through the focal point and about $10-15 \mathrm{~cm}$ beyond. Repeat this process until everyone in your group has watched the image. Describe what you see in the space below.
b. Could you use this as a method to determine the focal point? If so, determine the focal point of one of the lenses you used in Investigation 1.1 and compare to the value you calculated in the Investigation.

Summary. Discuss what you have learned about image formation by lenses or pinholes.

## Laboratory 11 Homework <br> Lenses and Images

1) An object is located 15 cm from the center of a lens, as shown in the diagram below. The focal length of the lens is 30 cm .

a) Find the location of the image. Show your work and explain your reasoning.
b) Calculate the magnification and determine if the image is inverted or upright. Show your work and explain your reasoning.
c) Is the image real or virtual? Show your work and explain your reasoning.
