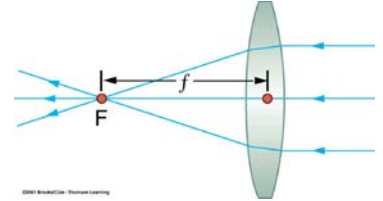


# Physics 41: Image Formation by Converging Lenses & Mirrors

**Objective:** Apply the **thin-lens equation** and the **mirror equation** to determine the focal length of a converging lens and mirror.

**Apparatus:** Biconvex glass lens, spherical concave mirror, meter ruler, optical bench, lens holder, self-illuminated object (generally a vertical arrow), screen.

**Converging Lenses** A convex lens is a converging lens which bends light rays into focus. The focal length,  $f$ , is the distance to the focal point where parallel rays converge as shown.

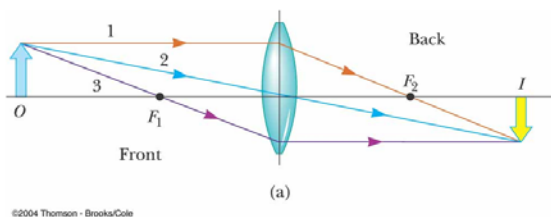


A Ray Diagram is a simple picture using only 2 or 3 light rays reflected off an object to visualize how images are formed. For a converging lens, the following three rays are drawn:

1. Ray 1 is drawn parallel to the principal axis and then passes through the focal point on the back side of the lens
2. Ray 2 is drawn through the center of the lens and continues in a straight line
3. Ray 3 is drawn through the focal point on the front of the lens (or as if coming from the focal point if  $p < f$ ) and emerges from the lens parallel to the principal axis

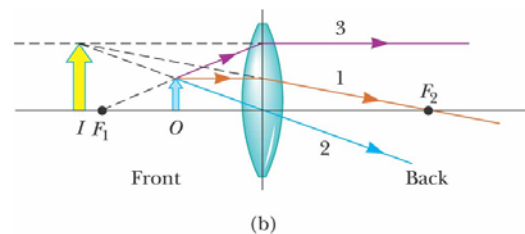
Using these rules to make a scale drawing we can accurately describe the location and size of an image formed by a lens. Ray Tracing is limited by the accuracy with which you can draw but it is highly useful conceptually and visually.

## Ray Diagram for Converging Lens, $p > f$



- The image is real ( $q > 0$ )
- The image is inverted ( $M < 0$ )
- The image is on the back side of the lens ( $q > 0$ )

## Ray Diagram for Converging Lens, $p < f$



- The image is virtual ( $q < 0$ )
- The image is upright ( $M > 0$ )
- The image is larger than the object ( $M > 1$ )
- The image is on the front side of the lens ( $q < 0$ )

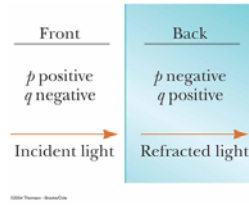
The thin lens equation also predicts image location. All distances are measured from the center of the lens. If the lens equation yields a negative image distance, then the image is a virtual image on the same side of the lens as the object. If it yields a negative focal length, then the lens is a diverging lens rather than the converging lens in the illustration. In this lab we will only be dealing with positive converging (convex) lenses. The lens equation can be used to calculate the image distance for either real or virtual images and for either positive or negative lenses. The linear magnification relationship allows you to predict the size of the image. If the magnification is negative, the image is inverted. Here are the rules for thin lenses as given in the book. The object and image distances are given by “ $p$ ” and “ $q$ ”, respectively.

$$\frac{1}{p} + \frac{1}{q} = \frac{2}{R} = \frac{1}{f}$$

$$M = \frac{h'}{h} = -\frac{q}{p}$$

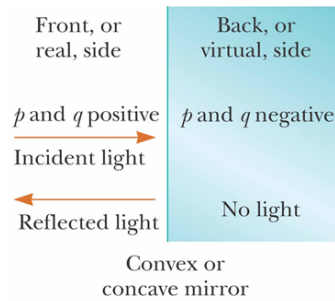
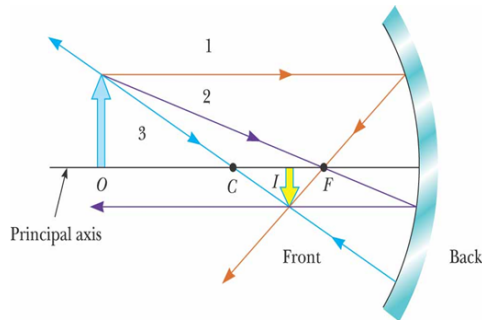
Table 36.3

Sign Conventions for Thin Lenses		
Quantity	Positive When	Negative When
Object location ( $p$ )	Object is in front of lens (real object)	Object is in back of lens (virtual object)
Image location ( $q$ )	Image is in back of lens (real image)	Image is in front of lens (virtual image)
Image height ( $h'$ )	Image is upright	Image is inverted
$R_1$ and $R_2$	Center of curvature is in back of lens	Center of curvature is in front of lens
Focal length ( $f$ )	Converging lens	Diverging lens



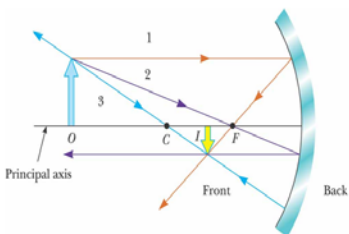
**Converging Mirrors:** As with lenses, the position of the object relative to the center of curvature determines if the image will be real, virtual, inverted, magnified, etc. We will explore the following situations and use ray diagrams to find image locations.

## Ray Diagrams: Concave Mirrors

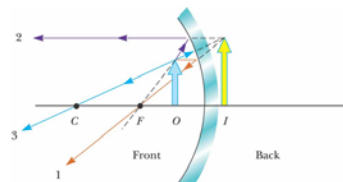


- Ray 1 is drawn from the top of the object parallel to the principal axis and is reflected through the focal point,  $F$
- Ray 2 is drawn from the top of the object through the focal point and is reflected parallel to the principal axis
- Ray 3 is drawn through the center of curvature,  $C$ , and is reflected back on itself
- The intersection of any two of the rays at a point locates the image. The third ray serves as a check of the construction

### Concave Mirror, $p > R$



### Concave Mirror, $p < f$



- The center of curvature is between the object and the concave mirror surface ( $f > 0$ )
- The image is real ( $q > 0$ )
- The image is inverted ( $M < 0$ )
- The image is smaller than the object ( $absM < 1$ )

$$\frac{1}{p} + \frac{1}{q} = \frac{2}{R} = \frac{1}{f}$$

- The object is between the mirror surface and the focal point ( $p > 0$ )
- The image is virtual ( $q < 0$ )
- The image is upright ( $M > 0$ )
- The image is larger than the object ( $M > 1$ )

## **Experimental Procedure**

### Part 1: The Converging Lens: The Bench

- A. Set up the lens apparatus as shown by your instructor. Using focal length of your lens using an object that is very far away – across the street.
- B. Place the object light at a distance further than the focal length and move the screen until you bring the image into focus. Record the image and object distance and the object and image height in data sheet.
- C. Use the lens equation to calculate the focal length. Compare this value to what you obtained in part A.
- D. Repeat parts B and C for 4 more object distances for a total of 5.
- E. What value of the focal length do you feel most confident in? You can average your values and get an uncertainty too. Express your focal length in standard form.

### Part 2: The Converging Lens: Ray Diagrams

On a separate piece of paper, draw a careful ray diagram for you final focal length and one of your object distances. You are to locate the image distance using the ray diagram. Pick carefully and use a conversion factor so you can fit the entire diagram on your sheet of paper. Locate the image and measure the image distance and height. Compare and contrast your results with what you got on the bench. Enter you results in the data sheet. You will attach your ray diagram to your data sheet. It must be labeled very carefully. NEATNESS COUNTS.

### Part 3: The Converging Lens: Virtual & Real Images

Move the object inside the focal point and find the virtual image. Can you project onto your screen? Move the object around to answer these questions and answer them in the data sheet.

- a) For what range of object distances will the image be smaller than the object?
- b) For what range of object distances will the image be larger than the object?
- c) For what range of object distances will the image be upright?
- d) For what range of object distances with the image be inverted?
- e) For what range of object distances will the image be real?
- f) For what range of object distances will the image be virtual?

### Part 4: The Converging Mirror

Repeat the above procedure for the mirror! Have fun!

# Physics 41: Image Formation Lab Data Sheet

Lab Section: \_\_\_\_\_

Name: \_\_\_\_\_

Date: \_\_\_\_\_

## Part 1: The Converging Lens

Focal length (cm) : \_\_\_\_\_ Object height (cm) : \_\_\_\_\_

	p(cm)	q (cm)	f (cm)	% Diff	H'(cm)	M
1						
2						
3						
4						
5						

Average focal length: \_\_\_\_\_ Average deviation: \_\_\_\_\_

Best guess of focal length in standard form with +/- uncertainty:

## Part 2: The Converging Lens: Ray Diagrams

Which data set from above are you testing? \_\_\_\_\_

Ray Diagram Image Distance q(cm): \_\_\_\_\_ % diff: \_\_\_\_\_

Ray Diagram h' (cm): \_\_\_\_\_ Magnification: \_\_\_\_\_ % diff: \_\_\_\_\_

## Part 3: The Converging Lens: Virtual & Real Images

a) For what range of object distances will the image be smaller than the object?

b) For what range of object distances will the image be larger than the object?

c) For what range of object distances will the image be upright?

d) For what range of object distances with the image be inverted?

e) For what range of object distances will the image be real?

f) For what range of object distances will the image be virtual?

Part 4: The Converging Mirror

Focal length (cm) : \_\_\_\_\_ Object height (cm) : \_\_\_\_\_

	p(cm)	q (cm)	f (cm)	% Diff	H'(cm)	M
1						
2						
3						
4						
5						

Average focal length: \_\_\_\_\_ Average deviation: \_\_\_\_\_

Best guess of focal length in standard form with +/- uncertainty:

The Converging Mirror: Ray Diagrams

Which data set from above are you testing? \_\_\_\_\_

Ray Diagram Image Distance q(cm): \_\_\_\_\_ % diff: \_\_\_\_\_

Ray Diagram h'(cm): \_\_\_\_\_ Magnification: \_\_\_\_\_ % diff: \_\_\_\_\_

The Converging Mirror: Virtual & Real Images

- a) For what range of object distances will the image be smaller than the object?
  
- b) For what range of object distances will the image be larger than the object?
  
- c) For what range of object distances will the image be upright?
  
- d) For what range of object distances with the image be inverted?
  
- e) For what range of object distances will the image be real?
  
- f) For what range of object distances will the image be virtual?