

# 14

## Lenses, Diffraction, and Interference

### 14-1 Lenses, Telescopes, and Magnifying Glasses

When light shines through a lens, it is **refracted** or bent due to the shape and material of the lens. Parallel rays of light passed through some lenses will eventually converge at the **focal point**. The terminology used for lenses is much the same as that used for mirrors in Chapter 13.

*Vocabulary*

**Object distance:** The distance from the center of the lens to the object.

*Vocabulary*

**Image distance:** The distance from the center of the lens to the image. An image can be **real** (able to be projected on a screen), or **virtual** (not able to be projected on a screen).

*Vocabulary*

**Focal point:** The point where parallel rays meet (or appear to meet) after passing through a lens. The distance from this focal point to the center of the lens is called the **focal length**.

**Thin Lens Equation:** 
$$\frac{1}{\text{focal length}} = \frac{1}{\text{object distance}} + \frac{1}{\text{image distance}}$$

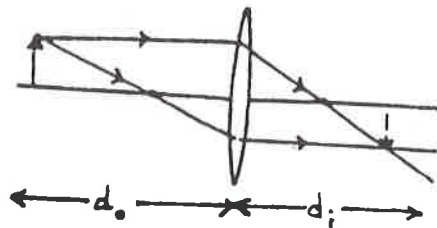
or 
$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

**NOTE:** Many situations involving lenses can also be solved using ray diagrams.

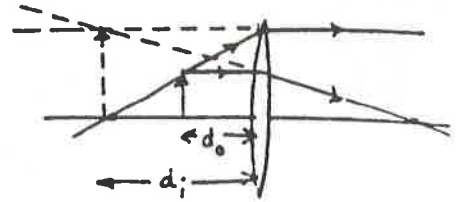
#### The Converging (Positive) Lens

The focal length of a converging lens is always a positive number.

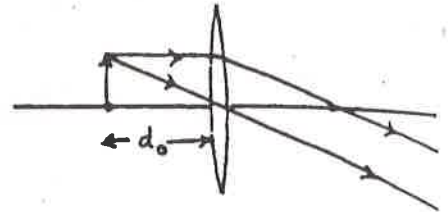
If an object is located outside the focal point of a converging lens, the image it forms is **real**, **inverted**, and on the opposite side of the lens. Both  $d_o$  and  $d_i$  are positive numbers.



If an object is located inside the focal point of a converging lens, the image it forms is virtual, upright, enlarged, and on the same side as the object. In this instance,  $d_o$  is positive and  $d_i$  is negative.



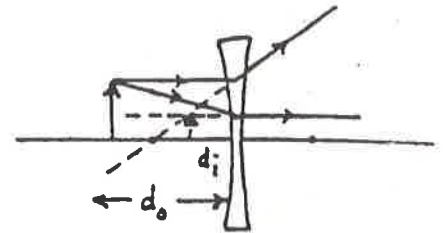
If the object is at the focal point, the rays do not converge and therefore no image is formed.



## The Diverging (Negative) Lens

The focal length of a diverging lens is always a negative number.

The image formed by a diverging lens is always virtual, upright, smaller, and on the same side of the lens as the object. In this instance,  $d_o$  is positive and  $d_i$  is negative.



If an object appears taller when seen through a lens, the object is magnified. The **linear magnification** of an object can be found by comparing the image distance to the object distance, or by comparing the image height,  $h_i$ , to the object height,  $h_o$ .

$$\text{linear magnification} = \frac{\text{image distance}}{\text{object distance}} = \frac{\text{image height}}{\text{object height}}$$

$$\text{or } m = \frac{d_i}{d_o} = \frac{h_i}{h_o}$$

Note that a negative magnification implies a virtual image.

Linear magnification has no units. It is simply a ratio of image to object distance or a ratio of image to object height.

## The Refracting Telescope

A refracting telescope is a device that uses one lens to produce a real image, and a second lens to produce the virtual image that is seen by your eye. The amount of linear magnification you see when you look at an object through a telescope depends upon the focal length of each of the lenses. The lens that points toward the object is the objective lens and the lens you look through is the eyepiece. The focal lengths of each of these lenses are labeled  $f_o$  and  $f_e$ , respectively.

$$\text{linear magnification} = \frac{\text{focal length of objective lens}}{\text{focal length of eyepiece}} \quad \text{or} \quad m = \frac{f_o}{f_e}$$

## The Magnifying Glass

When using a magnifying glass, the amount of **angular magnification** of an object depends upon how close you hold the magnifying glass to the object. It also depends upon the near point of your own eye, which is the closest point at which an unaided eye can focus on an object. A person's near point increases with age and the eyes lose some of their adaptable, elastic properties. However, for the ease of calculations, assume the near point of the eye is 25 cm unless otherwise noted.

$$\text{angular magnification} = \frac{\text{near point}}{\text{focal length}} \quad \text{or} \quad M = \frac{\text{near point}}{f}$$

## Solved Examples

**Example 1:** Mukluk, an Inuit, makes a converging lens out of ice that will enable him to concentrate light from the sun to start a fire. When he holds the ice lens 1.00 m from a snow-covered wall, an image of his 5.00-m-distant igloo is projected onto the snow. a) What is the focal length of the ice lens? b) Draw a ray diagram of the situation.

a. *Given:*  $d_o = 5.00 \text{ m}$   
 $d_i = 1.00 \text{ m}$

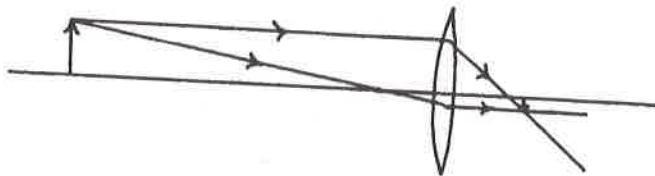
*Unknown:*  $f = ?$   
*Original equation:*  $\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$

*Solve:*  $\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{5.00 \text{ m}} + \frac{1}{1.00 \text{ m}} = 1.20 \text{ m}^{-1}$

Taking the reciprocal gives  $f = \frac{1}{1.20 \text{ m}^{-1}} = 0.833 \text{ m}$

The focal length of 0.833 m is close to the image distance of 1.00 m.

b.



**Example 2:** A diverging lens is placed 5.0 cm in front of a laser beam to spread the light for the production of a hologram. a) What is the focal length of the lens if the beam of laser light seems to come from a point 2.0 cm behind the lens? b) Draw a ray diagram of the situation.

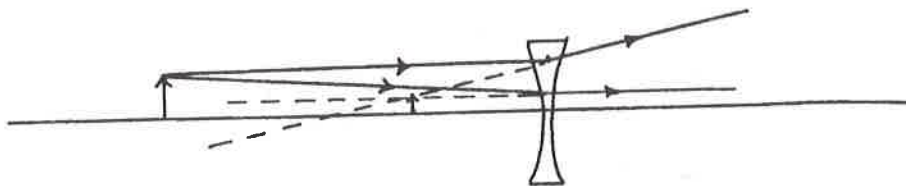
a. *Given:*  $d_o = 5.0 \text{ cm}$   
 $d_i = -2.0 \text{ cm}$

*Unknown:*  $f = ?$   
*Original equation:*  $\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$

$$\text{Solve: } \frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{5.0 \text{ cm}} + \frac{1}{-2.0 \text{ cm}} = \frac{2}{10. \text{ cm}} - \frac{5}{10.0 \text{ cm}} = -\frac{3}{10.} \text{ cm}^{-1}$$

$$f = -\frac{10.}{3} \text{ cm} = -3.3 \text{ cm}$$

b.



**Example 3:** Irwin, a coin collector, is looking at a rare coin held behind a magnifying glass whose focal length is 5.0 cm. a) If the eyes' near point is 25 cm, what is the angular magnification? b) If the coin is 2.0 cm in diameter, how large will its diameter appear to be when it is held in this position under the magnifying glass?

a. *Given:* near point = 25 cm  
 $f = 5.0 \text{ cm}$

*Unknown:*  $M = ?$   
*Original equation:*  $M = \frac{\text{near point}}{f}$

*Solve:*  $M = \frac{\text{near point}}{f} = \frac{25 \text{ cm}}{5.0 \text{ cm}} = 5.0$  The coin is magnified 5.0 times.

b. *Given:*  $m = 5.0$   
 $h_o = 2.0 \text{ cm}$

*Unknown:*  $h_i = ?$   
*Original equation:*  $m = \frac{h_i}{h_o}$

*Solve:*  $h_i = mh_o = (5.0)(2.0 \text{ cm}) = 10. \text{ cm}$

**Example 4:** The ship *Speedwell* brought many early settlers to this country in the 1600s. Oceanus sits high above the ship's deck in the crow's nest watching through a telescope for the first sign of land. How much does the telescope magnify if the eyepiece has a 2.0-cm focal length and the objective lens has a 80.-cm focal length?

*Given:*  $f_o = 80. \text{ cm}$   
 $f_e = 2.0 \text{ cm}$

*Unknown:*  $m = ?$   
*Original equation:*  $m = \frac{f_o}{f_e}$

*Solve:*  $m = \frac{f_o}{f_e} = \frac{80. \text{ cm}}{2.0 \text{ cm}} = 40.$  The telescope magnifies 40. times.

## Practice Exercises

**Exercise 1:** Harold and Roland find a discarded plastic lens lying on the beach. The boys discuss what they learned in physics last semester and argue whether the lens is a converging or a diverging one. When they look through the lens, they notice that objects are inverted. a) If an object sitting 25.0 cm in front of the lens forms an image 20.0 cm behind the lens, what is the focal length of the lens? b) Is it a converging or a diverging lens?

Answer: a. \_\_\_\_\_

Answer: b. \_\_\_\_\_

**Exercise 2:** Sadie looks at her friend's face through a diverging lens. a) Is the image real or virtual? b) If her friend's face is 50.0 cm from the lens that forms an image at a distance of 20.0 cm, what is the focal length of the lens? c) Draw a ray diagram of the situation.

Answer: a. \_\_\_\_\_

Answer: b. \_\_\_\_\_

**Exercise 3:** Giorgio is clicking shots of the fashion model Nadine as she walks toward him across the studio. Giorgio's camera contains a lens with a focal length of 0.0500 m. a) How far back must the film be located when Nadine is 3.00 m from the camera? b) Should the lens be moved in or out as Nadine approaches closer to the photographer? c) Draw a ray diagram of the situation with Nadine at 3.00 m and 1.00 m from the camera.



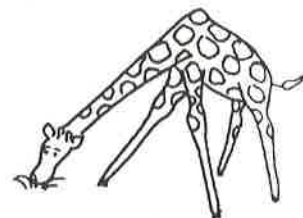
Answer: a. \_\_\_\_\_

Answer: b. \_\_\_\_\_

**Exercise 4:** Dr. Wasserman is showing slides to his biology class. a) If the slides are positioned 15.5 cm from the projector lens that has a focal length of 15.0 cm, where should the screen be placed to produce the clearest image of the slide? b) Draw a ray diagram of the situation.

Answer: a. \_\_\_\_\_

- Exercise 5:** Marlin is out on a safari. Looking through his telescope, he spots a giraffe in the distance. The telescope has an objective lens of 40-cm focal length and an eyepiece of 2-cm focal length. a) What is the magnification of the giraffe?  
b) How large is the image formed by the telescope if the giraffe appears to be 1.5 cm high to the naked eye?



Answer: a. \_\_\_\_\_

Answer: b. \_\_\_\_\_

- Exercise 6:** Emilio, an entomologist, studies a millepede that he holds behind a magnifying glass whose focal length is 2.00 cm. a) Assuming Emilio's near point is 25.0 cm, what is the angular magnification? b) Does Emilio have to bring the magnifying glass closer to, or farther from, the millepede in order to make it appear larger?



Answer: a. \_\_\_\_\_

Answer: b. \_\_\_\_\_

- Exercise 7:** Mr. Crabtree, a jeweler, looks through his jeweler's loupe (a small magnifying glass attached to his glasses) in order to read the engraving on a pewter bowl. The loupe has a focal length of 3 cm. If Mr. Crabtree's near point is 24 cm, what is the angular magnification of the engraving?

Answer: \_\_\_\_\_