Chap 23

Light

23-4 Index of Refraction (n)

Index of refraction of a certain material is defined as the ratio of the speed of light in vacuum to that in that material v.

$$n = \frac{c}{v} \qquad (23\text{-}4)$$

- $n \geq 1$ always , Table 23.1 in the book

23-5 Refraction : Snell's Law

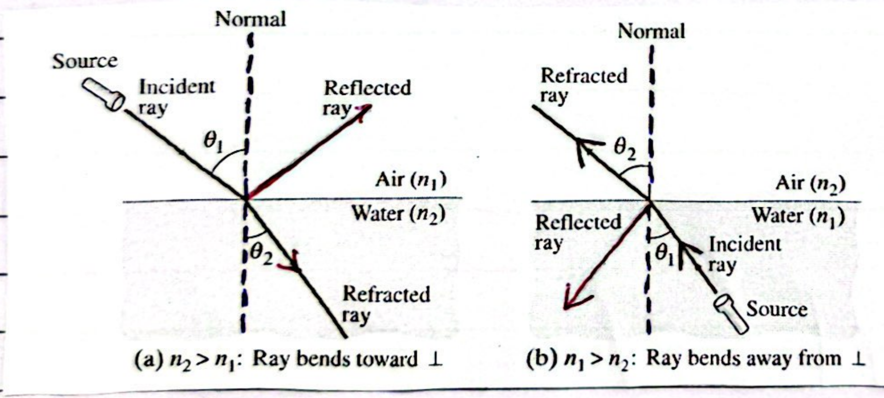


FIGURE 23–21 Refraction. (a) Light refracted when passing from air (n_1) into water (n_2): $n_2 > n_1$. (b) Light refracted when passing from water (n_1) into air (n_2): $n_1 > n_2$.

When light passes from one transparent medium into another with a different index of refraction, some of the incident rays is reflected at the boundary. The rest passes into the new medium. If a ray of light is incident at an angle ($\neq 90°$), the ray changes direction as it enters the new medium. This change in a direction of the light is called refraction.

Figure 23-21, shows a ray passing from air with $\boxed{(n_1)}$ to water with $\boxed{(n_2)}$ (where $\boxed{n_2 > n_1}$) at angle $\boxed{\theta_1}$ which is the angle the incident ray makes with the normal to the surface and is called $\boxed{\text{the angle of incidence}}$. Angle θ_2 is the angle of refraction which is the angle the refracted ray makes with the normal to the surface.

- If $n_2 > n_1$ the refracted ray will bend toward the normal to the surface that is $\theta_2 < \theta_1$
- If $n_1 > n_2$ the refracted ray bends away from the normal that is $\theta_2 > \theta_1$

examples (the legs in water, the straw in water)

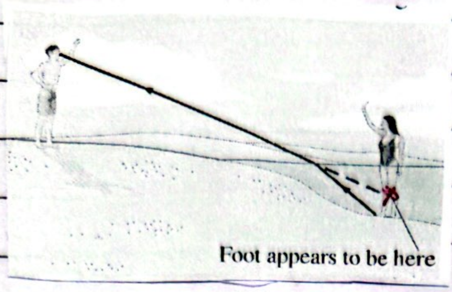
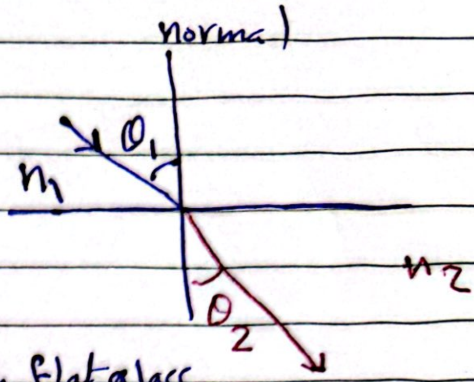


FIGURE 23–23 A straw in water looks bent even when it isn't.

Snell's Law



Snell's law is written as

$$\boxed{n_1 \sin\theta_1 = n_2 \sin\theta_2}$$

Example 23-8 Refraction through flat glass

Light traveling in air strikes a flat piece of uniformly thick glass at $\theta_1 = 60^\circ$. as shown in Figure (23-24). If n of glass is 1.5 (a) What is the angle of refraction θ_A in the glass; (b) What is the angle θ_B at which the ray emerges from glass.

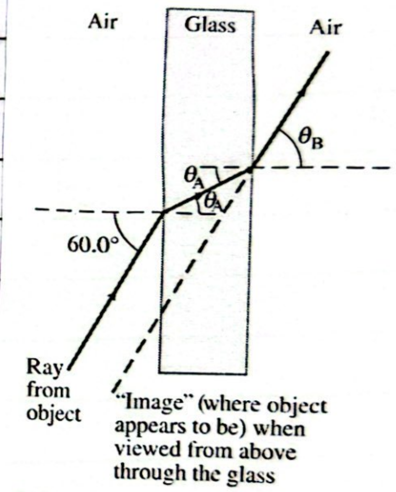


FIGURE 23–24 Light passing through a piece of glass (Example 23–8).

Solution

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

$$(1) \sin 60^\circ = (1.5) \sin\theta_A$$

$$\Rightarrow \sin\theta_A = \frac{1}{1.5}\sin(60) = 0.667(0.867) = 0.5774$$

$$\theta_A = \sin^{-1}(0.5774) = 35.3^\circ$$

(b) $\sin\theta_A(1.5) = (1)\sin\theta_B$

$\Rightarrow$

$$\sin\theta_B = \frac{1.5}{1}\sin(35.3^\circ) = 1.5(0.5774) = 0.866$$

$\Rightarrow$

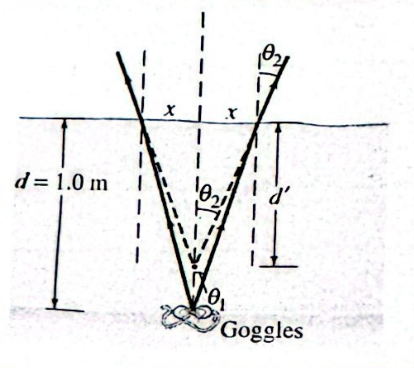
$$\theta_B = \sin^{-1}(0.866) = 60^\circ.$$

- The direction of light ray is unchanged by passing through a flat piece of aglass of uniform thickness but the ray is displaced slightly through to one side.

Example 23-9 Apparent depth of a pool.

A swimmer has dropped her goggles to the bottom of a pool of depth 1 m. But the goggles do not look that deep

FIGURE 23–25 Example 23–9.



Why? (because of refraction).

How deep do the goggles appear to be when you look straight down the water?

Solution

Suppose $d = 1$ the real depth, d' is the apparent depth.

$n_{water} = n_1 = 1.33$, then using Snell's Law

$n_1 \sin\theta_1 = n_2 \sin\theta_2 = \sin\theta_2$

but for small angles $\sin\theta \approx \tan\theta \approx \theta$, then

$\theta_2 = n_1 \theta_1$ but

$\theta_2 \approx \tan\theta_2 = \frac{x}{d'}$ and $\theta_1 = \tan\theta_1 = \frac{x}{d}$ $\Rightarrow$

$\frac{x}{d'} = n_1 \frac{x}{d} \Rightarrow d' = \frac{d}{n_1} = \frac{1}{1.33} = 0.75\,m$

23-6 Total Internal Reflection; Fiber Optics

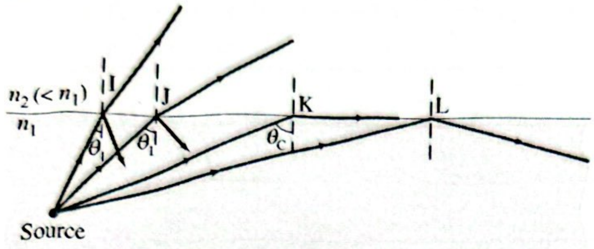


FIGURE 23–26 Since $n_2 < n_1$, light rays are totally internally reflected if the incident angle $\theta_1 > \theta_C$, as for ray L. If $\theta_1 < \theta_C$, as for rays I and J, only a part of the light is reflected, and the rest is refracted.

When light passes from a material with index of refraction n_1 into another one of n_2 (when $(n_1 > n_2)$, the refracted ray bends away from the normal as for $\boxed{\text{rays I and J}}$ in Figure 23-26.

At a particular incident angle, the angle of refraction will be $90°$. and the refracted ray will move with the surface $\boxed{\text{(ray K)}}$.

The incident angle in this case is called the $\boxed{\text{critical angle } \theta_c}$. From Snell's Law

$$\sin\theta_c = \frac{n_2}{n_1}\sin\theta_2 = \frac{n_2}{n_1}\sin 90° = \frac{n_2}{n_1}$$

For incident angle $\theta_1 > \theta_c$ there is no refracted ray (ray L). This effect is called $\boxed{\text{total internal reflection}}$

Example 23-10 View up from under water.

Describe what a person would see who looked up at the world from beneath the perfectly smooth surface of a lake or swimming pool.

Response: using Snell's Law to find θ_c

$$\sin\theta_c = \frac{1}{1.33} = 0.75 \Rightarrow \theta_c = \sin^{-1}(0.75) = 49^\circ.$$

Thus, the person would see the outside world compressed into a circle whose edge makes a 49° angle with the vertical (Figure 23-27)

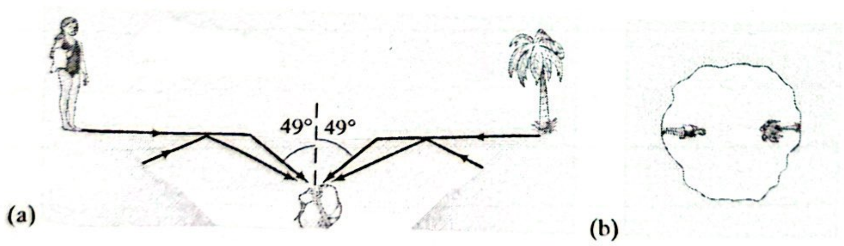


FIGURE 23–27 (a) Light rays entering submerged person's eye, and (b) view looking upward from beneath the water (the surface of the water must be very smooth). Example 23–10.

23-9

Fiber Optics; Medical Instruments

Total internal reflection is the principle behind fiber optics. The main two types of fiber optics used are the glass fiber and the plastic fiber. These fibers are as thin as a few micrometers in diameter. A bundle of such slim (thin) transparent fibers is called a light pipe or fiber-optic cable.

Light, infrared, ultraviolet and microwave rays can be transmitted along the fiber with almost no loss because of total internal reflection.

Figure (23-29) shows how light traveling down a thin fiber makes only glancing collisions with the walls so that total internal reflection occurs.

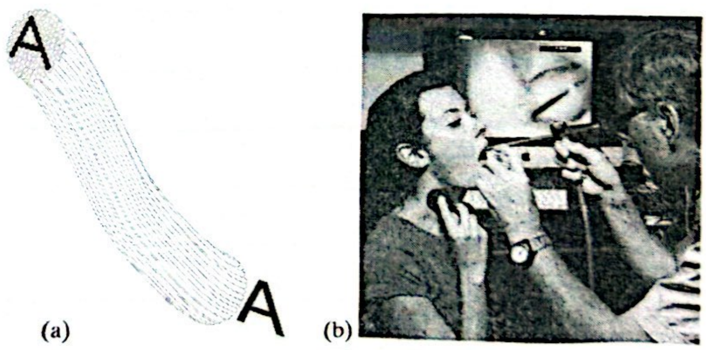
FIGURE 23–29 Light reflected totally at the interior surface of a glass or transparent plastic fiber.

Important applications of fiber-optic cable are in communications and medicine

23-10

The use of fiber optics to transmit a clear picture is useful in medicine, Figure (23-30). Such instruments, including bronchoscopes, Colonoscopes, and endoscopes for viewing the lungs, Colon and Stomach or other organs respectively, These instruments are extremely useful for examining hard to reach places.

FIGURE 23–30 (a) How a fiber-optic image is made. (b) Example of a fiber-optic device inserted through the mouth to view the vocal cords, with the image on screen.



23.7 Thin Lenses; Ray Tracing

The development of optical devices using lenses dates to the sixteenth century. Today we find lenses in eyeglasses, cameras, magnifying glasses, telescopes, binoculars, microscopes and medical instruments. A thin lens is usually circular and its two faces are portions of a sphere. The two faces can be concave, convex or plane. Several types are shown in Figure 23-31

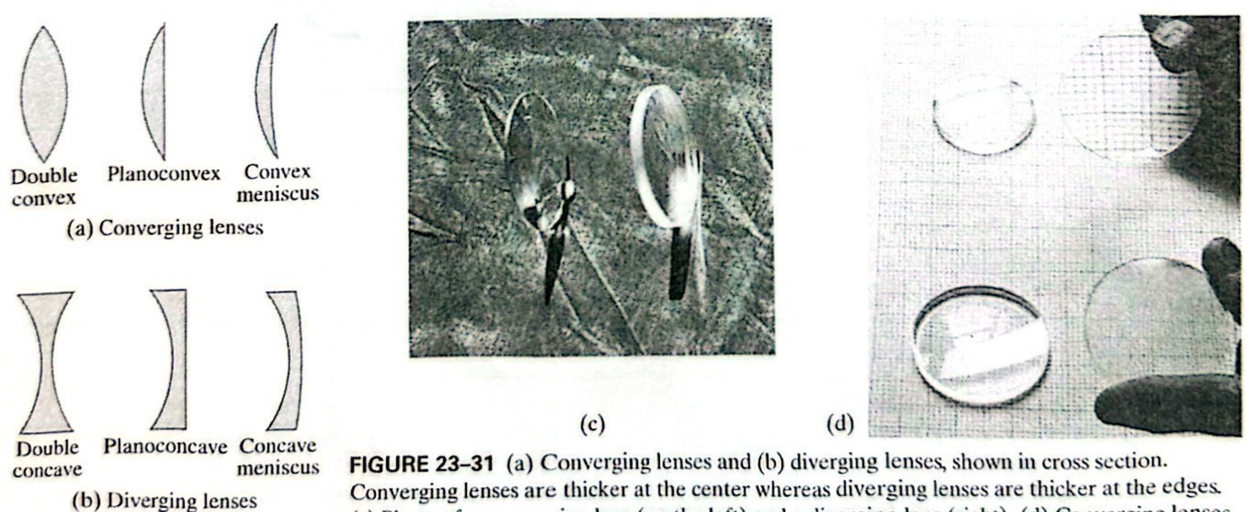


FIGURE 23–31 (a) Converging lenses and (b) diverging lenses, shown in cross section. Converging lenses are thicker at the center whereas diverging lenses are thicker at the edges. (c) Photo of a converging lens (on the left) and a diverging lens (right). (d) Converging lenses (above), and diverging lenses (below), lying flat, and raised off the paper to form images.

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FIGURE 23–33 Parallel rays are brought to a focus by a converging thin lens.

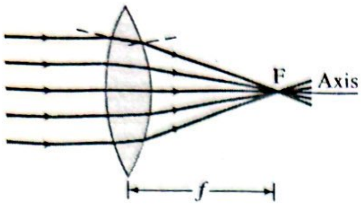
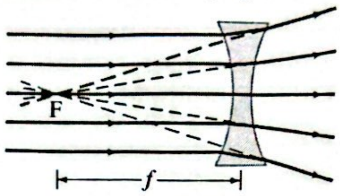


FIGURE 23–34 Image of the Sun burning wood.

FIGURE 23–36 Diverging lens.



- Optometrists and ophthalmologists, instead of using the focal length, use the reciprocal of the focal length to specify the strength of eyeglass (or contact) lenses. This is called the $\boxed{\text{power}}$, $\boxed{P}$, of a lens

$$P = \frac{1}{f} \qquad (23\text{-}7).$$

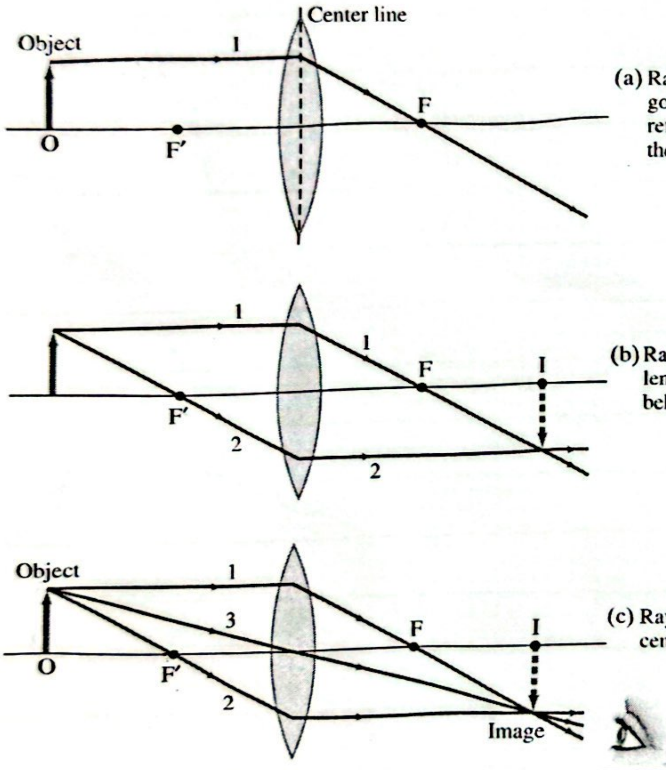
- The unit for lens power is the $\boxed{\text{diopter (D)}}$ which is the inverse of meter: $1\,D = 1\,m^{-1}$.

For example, a 20-cm focal length lens has a power $P = \frac{1}{0.2\,m} = 5\,D$.

Consider parallel rays (come from a distant object) refracted from a double convex lens (Figure 23-33). Then the focal point (F) is the image point for an object at infinity on the lens axis. The distance of the the focal point from the center of the lens is called the focal length (f) for both convex and concave lenses

- The focal point can be found by locating the point where the sun's rays (far object) are brought to a sharp image, Figure (23-34), for a converging lens.
- The focal point (F) of a diverging lens can be found by locating the point from which refracted rays, originating from parallel incident rays, seem to emerge as shown in Figure (23-36)

- To determine an image point, we can consider three rays indicated in Figure 23-37. The point where these three rays cross is the image point (I) for the object point



(a) Ray 1 leaves one point on object going parallel to the axis, then refracts through focal point behind the lens.

(b) Ray 2 passes through F′ in front of the lens; therefore it is parallel to the axis behind the lens.

(c) Ray 3 passes straight through the center of the lens (assumed very thin).

FIGURE 23–37 Finding the image by ray tracing for a converging lens. Rays are shown leaving one point on the object (an arrow). Shown are the three most useful rays, leaving the tip of the object, for determining where the image of that point is formed. (Note that the focal points F and F′ on either side of the lens are the same distance *f* from the center of the lens.)

Because the rays actually pass through the image (Figure 23-37), it is a real image, which can be detected by film, electronic sensor or white surface.

Diverging lens

By drawing the same three rays emerging from a single object point, we can determine the image position formed by a diverging lens as shown in Figure 23-39. Note that ray 1 is drawn parallel to the axis and refracted as it seems to come (dashed line) from the focal point F in front of the lens. Ray 2 is directed to F′ and is refracted parallel to the lens axis. Ray 3 passes directly through the center of the lens. The three rays seem to emerge from a point on the left of the lens. This is the image point (I)

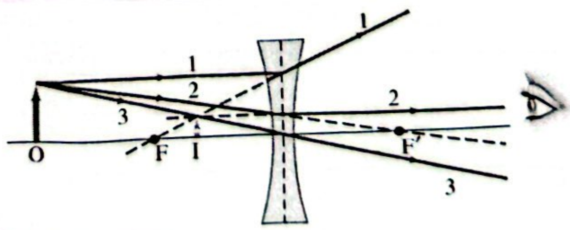


FIGURE 23–39 Finding the image by ray tracing for a diverging lens.

23-8 The Thin Lens Equation

This equation will make the determination of the image position : quicker and more accurate than doing by tracing.

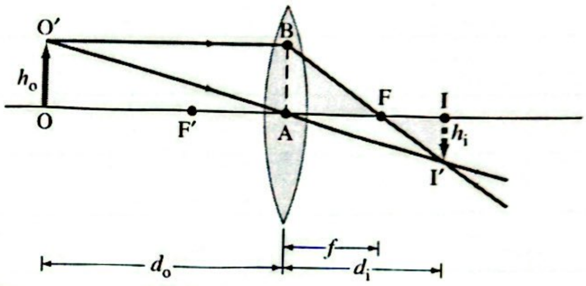


FIGURE 23–40 Deriving the lens equation for a converging lens.

This equation is given by

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

Thin Lens equation 23-8

where (see figure 23-40) and Figure (23-41)

- d_o is the object distance, which is the distance of the object from the center of the lens.
- d_i is the image distance, which is the distance of the image from the center of the lens
- f is the focal length

F is the focal point behind the lens.

F' is the focal point in front of the lens.

O is the object position

I is the image position

h_o is the height of the object

h_i is the height of the image

. The thin lens equation (23-8) is valid for converging lenses and diverging lenses both and for all situations, if we use the following sign conventions:

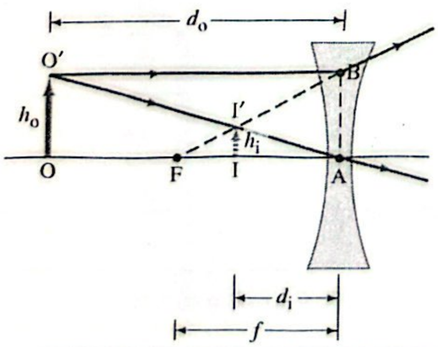


FIGURE 23–41 Deriving the lens equation for a diverging lens.

1. The focal length is positive for converging lenses and negative for diverging lenses.

2. The object distance is positive if the object is on the side of the lens from which light is coming other wise it's negative

3. The image distance is positive if the image on the opposite side of the lens from which light is coming; if it is on the other side it is negative.

4. The height of the image h_i is positive if the image is upright (erect) and negative if the image is inverted.

Notes

1. The height of the object h_o is always upright and positive

2. The image distance is positive for a real image and negative for virtual image

$\boxed{\text{Magnification}}$ (m)

Magnification of a lens is defined as the ratio of the image height to the object height

$$m = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

For an upright image the magnification is positive and for an inverted image the magnification is negative.

- The power of a converging lens, in diopters; is positive, whereas the power of a diverging lens is negative.
- A $\boxed{\text{Converging Lens}}$ is referred to as $\boxed{\text{a positive lens}}$ and $\boxed{\text{A diverging lens}}$ as a $\boxed{\text{negative lens}}$

Example 23-12 Image formed by converging lens.

(a) What is the position and (b) the size of the image of a 7.6 cm high leaf placed 1 m from a +50 mm-focal-length Camera lens?

Solution

1. Ray diagram

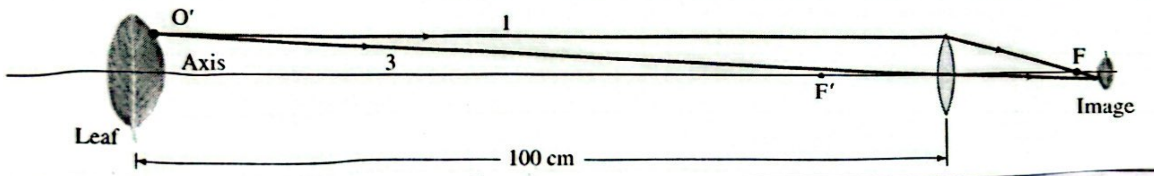


FIGURE 23–42 Example 23–12. (Not to scale.)

2. Thin lens and magnification equations must be used

(a) $\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \Rightarrow \frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o}$

$= \frac{1}{5\,cm} - \frac{1}{100\,cm} = \frac{20-1}{100} = \frac{19}{100\,cm} \Rightarrow$

$d_i = \frac{100\,cm}{19} = 5.26\,cm$ behind the lens since it's positive

(b) $m = -\frac{d_i}{d_o} = \frac{-5.26}{100} = -0.0526$

but $m = \frac{h_i}{h_o} \Rightarrow h_i = m h_o = -(0.0526)(7.6\,cm)$

$= -0.4\,cm$, the image is 4 mm high.

the minus means the image is inverted.

Example 23-13 Object close to a converging lens

An object is placed 10 cm from a 15 cm-focal-length converging lens. Determine the image position and size (a) analytically and (b) using ray diagram?

Solution

(a) $\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \Rightarrow \frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o} = \frac{1}{15} - \frac{1}{10} = \frac{2-3}{30} = \frac{-1}{30\,cm}$

$\Rightarrow d_i = -30\,cm$ which means the image is virtual because d_i is negative and it is in the same side of the object.

(b) $m = \frac{-d_i}{d_o} = -\frac{-30\,cm}{10\,cm} = 3$, the image is upright since m is positive

(b) the ray diagram agrees with the above results Figure 23-43

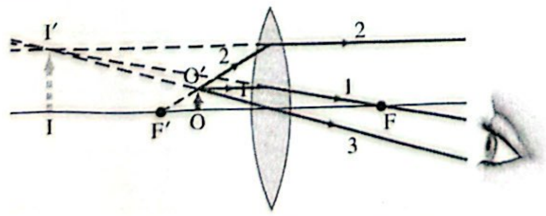


FIGURE 23–43 An object placed within the focal point of a converging lens produces a virtual image. Example 23–13.

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Example 23-14 Diverging Lens

Where must a small insect be placed if a 25-cm-focal-length diverging lens is to form a virtual image 20 cm from the lens, on the same side as the object?

Solution

f is negative since the lens is diverging $\Rightarrow f = -25$ cm

also, d_i is negative, because the image is virtual and the image is in front of the lens $\Rightarrow d_i = -20$ cm, then

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \Rightarrow \frac{1}{d_o} = \frac{1}{f} - \frac{1}{d_i} = -\frac{1}{25\text{cm}} + \frac{1}{20\text{cm}}$$

$$= \frac{-4+5}{100} = \frac{1}{100} \rightarrow d_o = 100\text{cm in front of the lens}$$