Chapter 2: Reflection and Refraction of Light

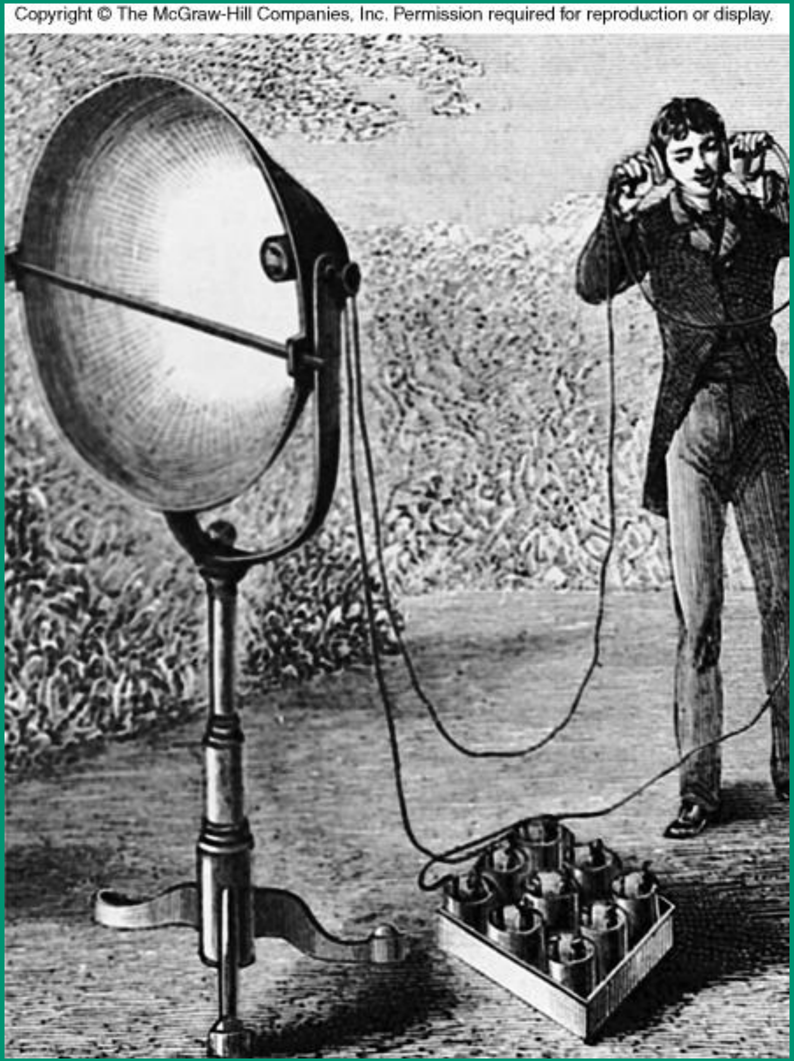


Figure 23.02

Nature of Light: Waves vs Particles

Early beliefs:

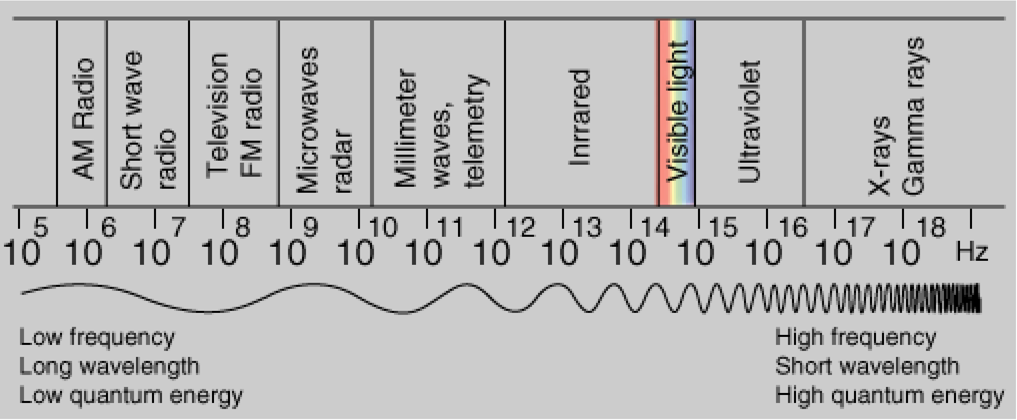
Light is a stream of particles emitted either by the object being viewed or emanating from the eyes of the viewer.

- ❑ **Newton** was the chief architect of the particle theory of light: He believed the particles left the object and stimulated the sense of sight upon entering the eyes.
- ❑ **Christian Huygens** argued that light might be some sort of a wave motion.
- ❑ **Thomas Young** (1801) provided the first clear demonstration of the wave nature of light: Because of their interference properties.
- ❑ **Einstein** (in 1905) proposed an explanation of the photoelectric effect that used the idea of quantization.

The quantization model assumes that the energy of a light wave is present in particles called *photons*.

Figure 23.02

Wavefronts and Rays, 1



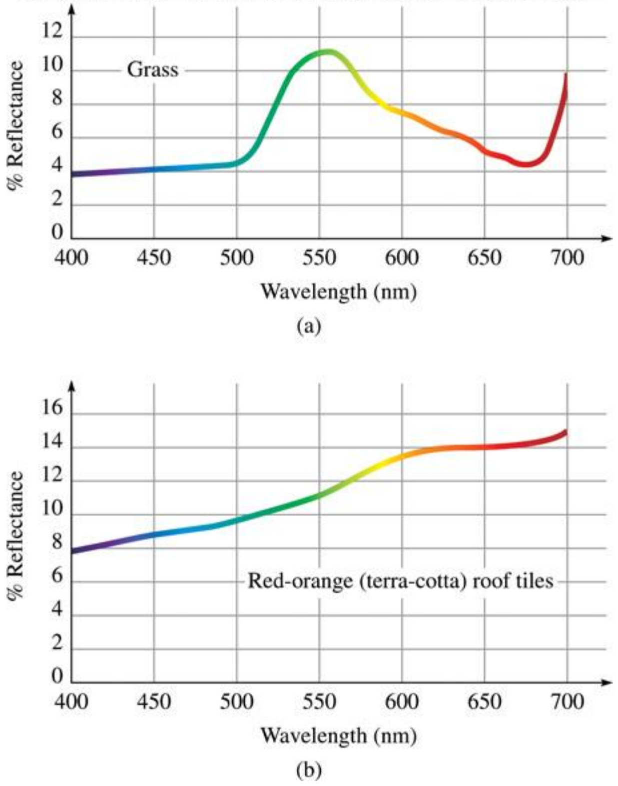


Figure 23.03

Wavefronts and Rays, 2

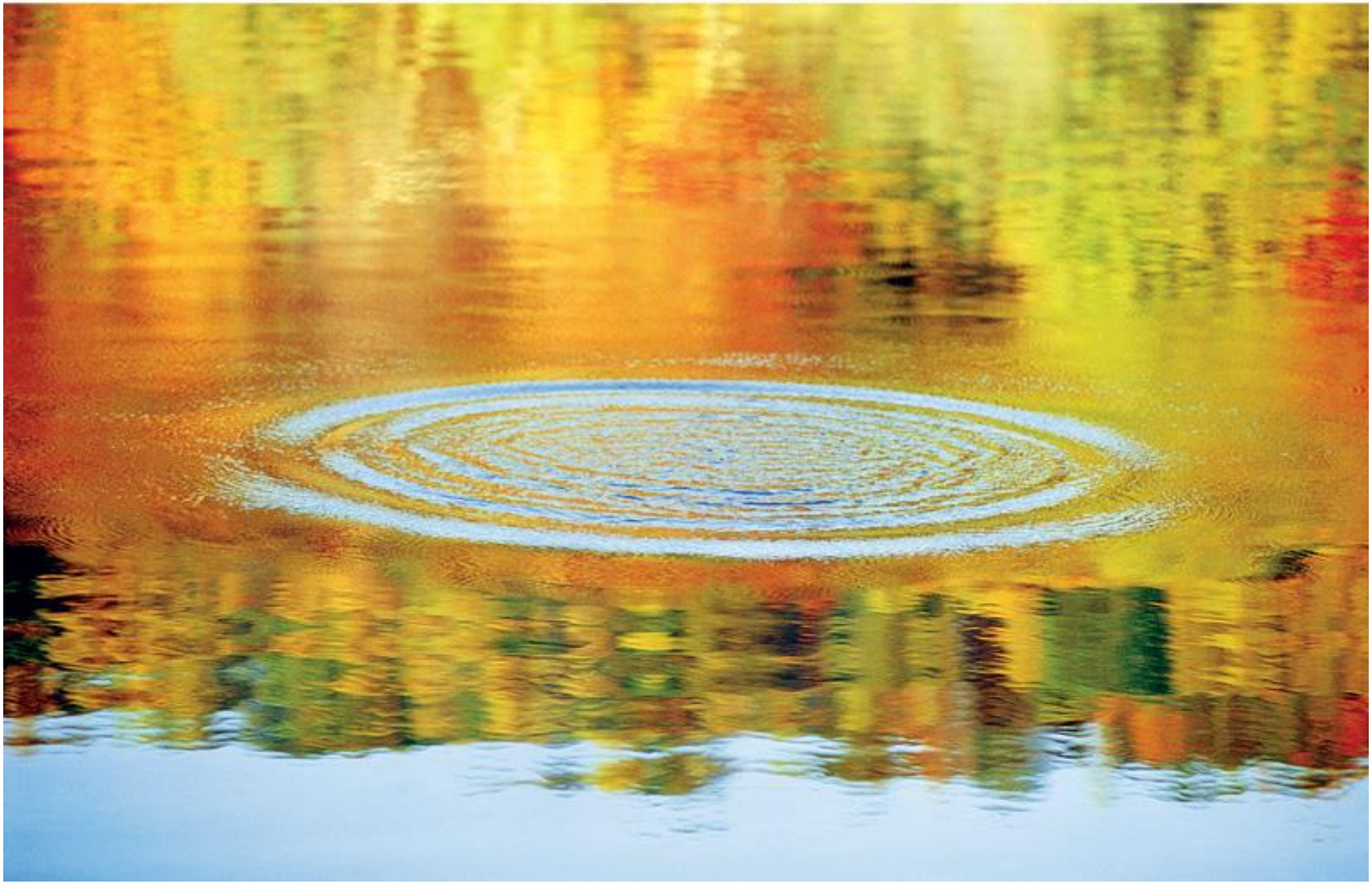
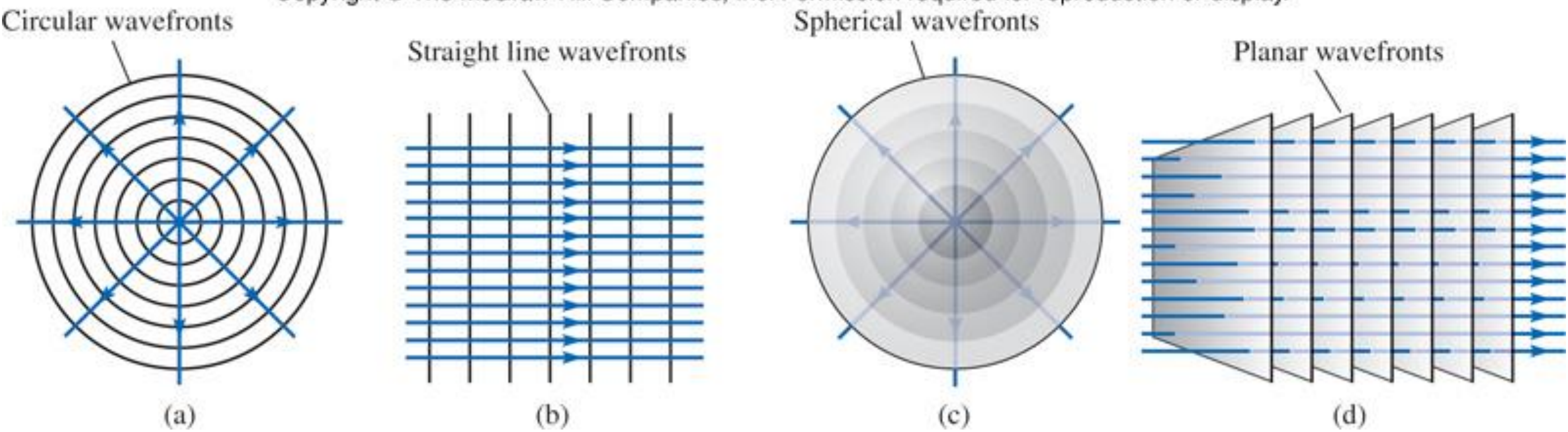


Figure 23.04

Wavefronts and Rays, Huygen's Principle



- Huygens assumed that light is a form of wave motion rather than a stream of particles
- Huygens's Principle is a geometric construction for determining the position of a new wave at some point based on the knowledge of the wave front that preceded it

Figure 23.05

Constuction of Plane Waves: Example 23.1

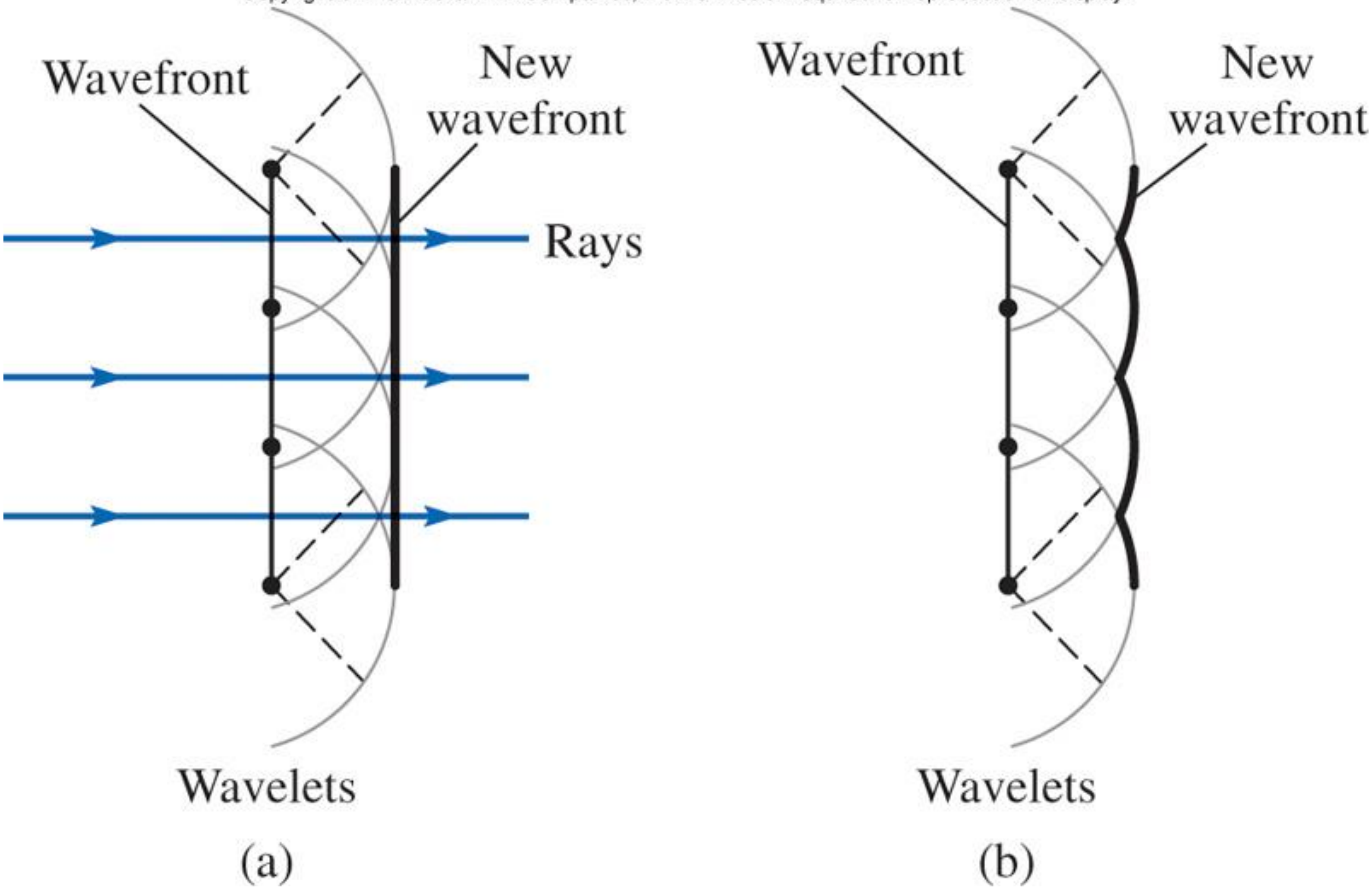
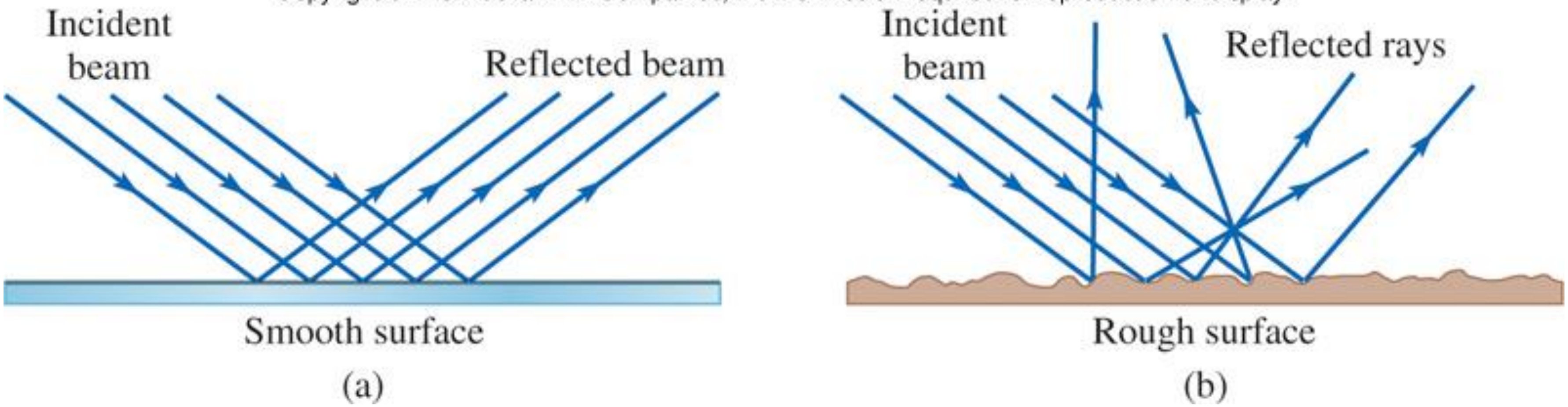
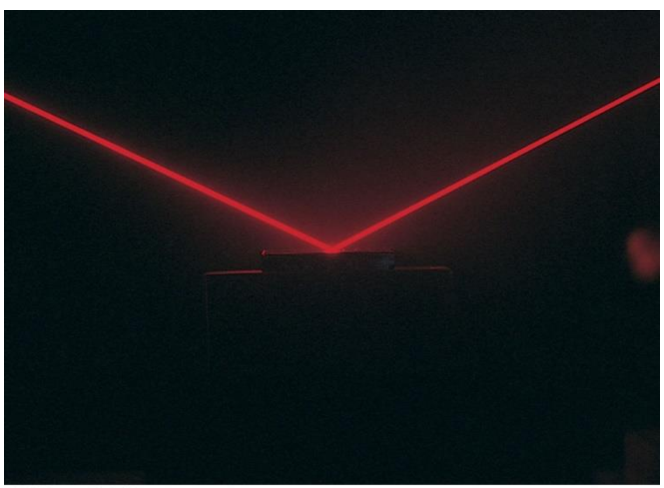


Figure 23.06

Reflection of Light: Specular and Diffuse Reflection





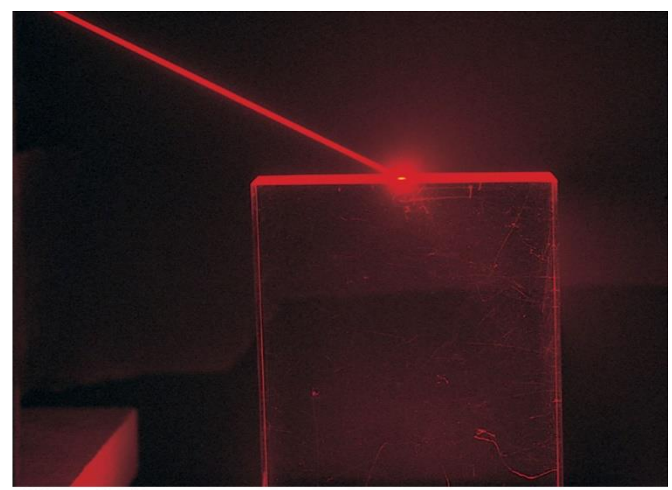
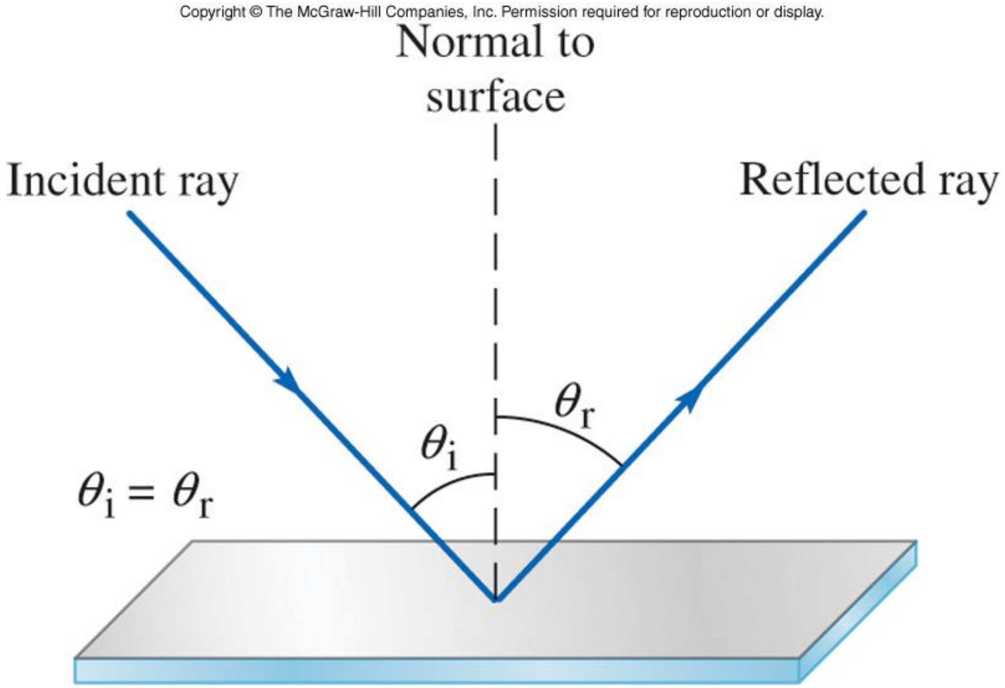


Figure 23.08

The Laws of Reflection



- The *normal* is a line perpendicular to the surface
  - It is at the point where the incident ray strikes the surface
- The incident ray makes an angle of θ_i with the normal
- The reflected ray makes an angle of θ_r with the normal

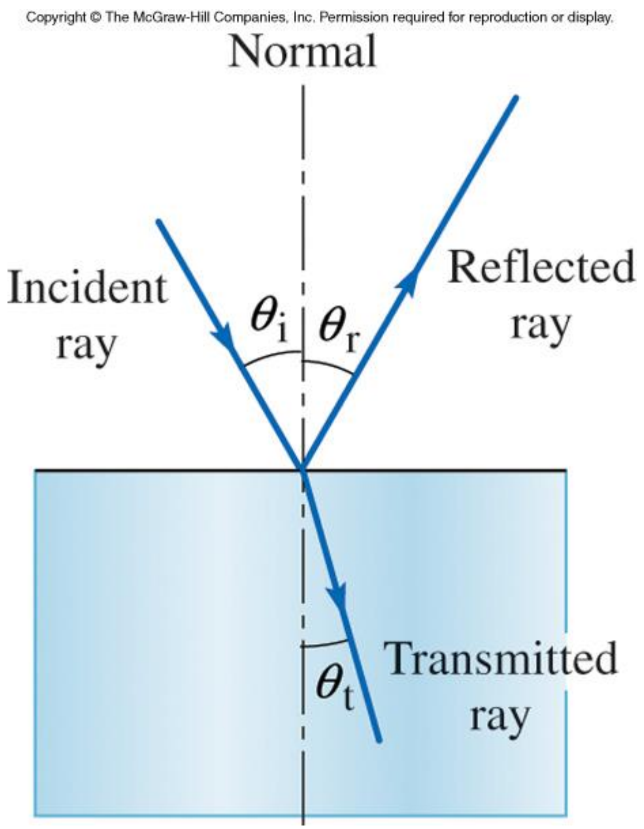
Laws of Reflection

- The angle of reflection is equal to the angle of incidence $\theta_i = \theta_r$
- The incident ray, the reflected ray and the normal are all in the same plane

Figure 23.09

The Refraction of Light: Snell's Law

- Light may refract into a material where its speed is lower
- The angle of refraction is less than the angle of incidence
  - The ray bends *toward* the normal



$$\frac{\sin \theta_i}{\sin \theta_t} = \frac{\lambda_i}{\lambda_t}$$

$$\frac{\lambda_i}{\lambda_t} = \frac{v_i/f}{v_t/f} = \frac{v_i}{v_t} = \frac{c/n_i}{c/n_t} = \frac{n_t}{n_i}$$

Snell's Law

$$n_i \sin \theta_i = n_t \sin \theta_t \qquad (23\text{-}4)$$

Snell's Law – Example

- Light is refracted into a crown glass slab
- $\theta_1 = 30.0^o$, $\theta_2 = ?$
- $n_1 = 1.00$ and $n_2 = 1.52$
  - From Table 23.1 (page 844)
- $\theta_2 = \sin^{-1}(n_1 / n_2) \sin \theta_1 =$ 19.2^o
- The ray bends toward the normal, as expected

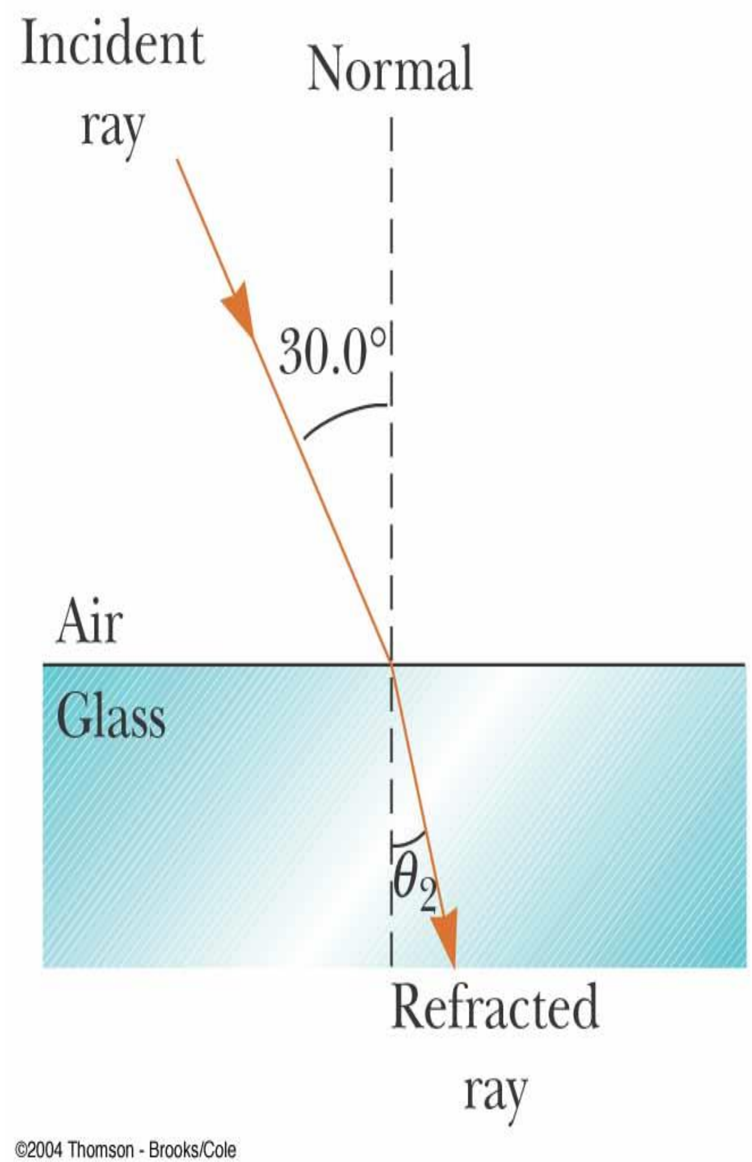
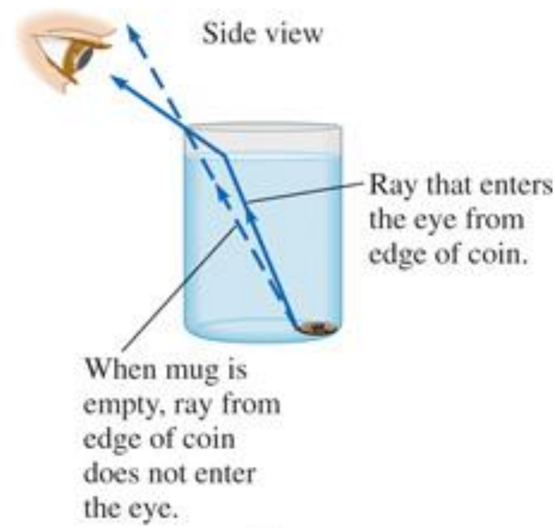


Figure 23.12

Physics at Home

(a)

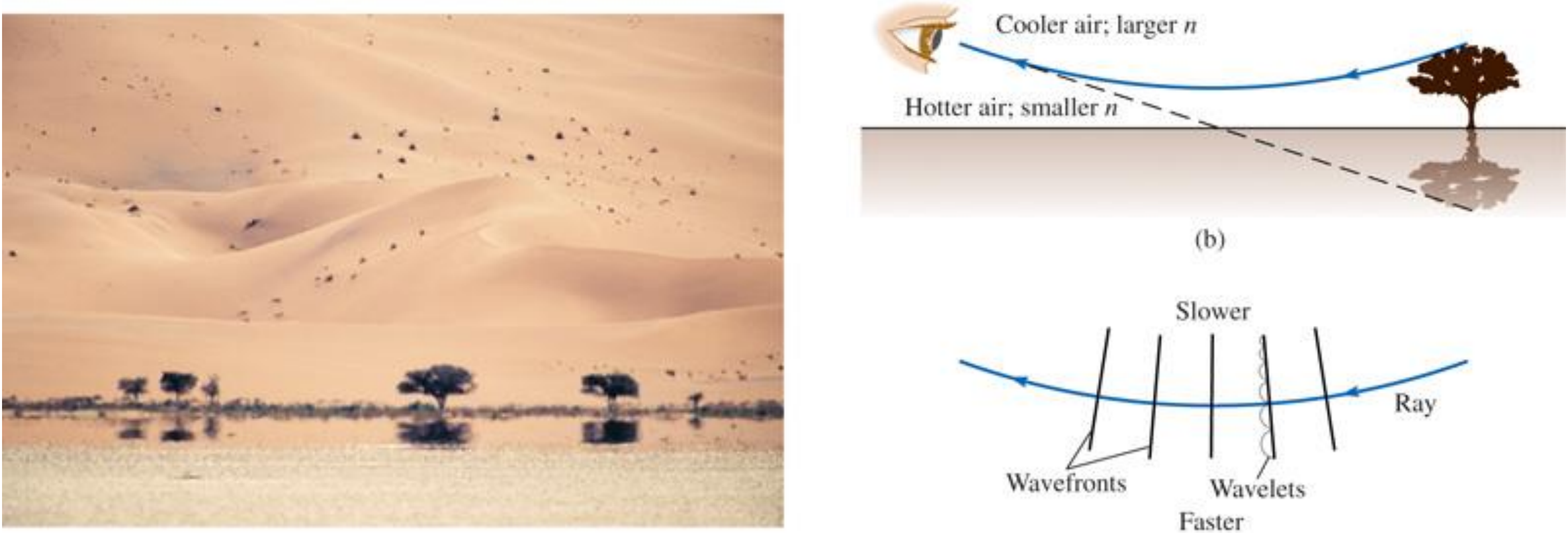
(b)



(c)

Figure 23.13

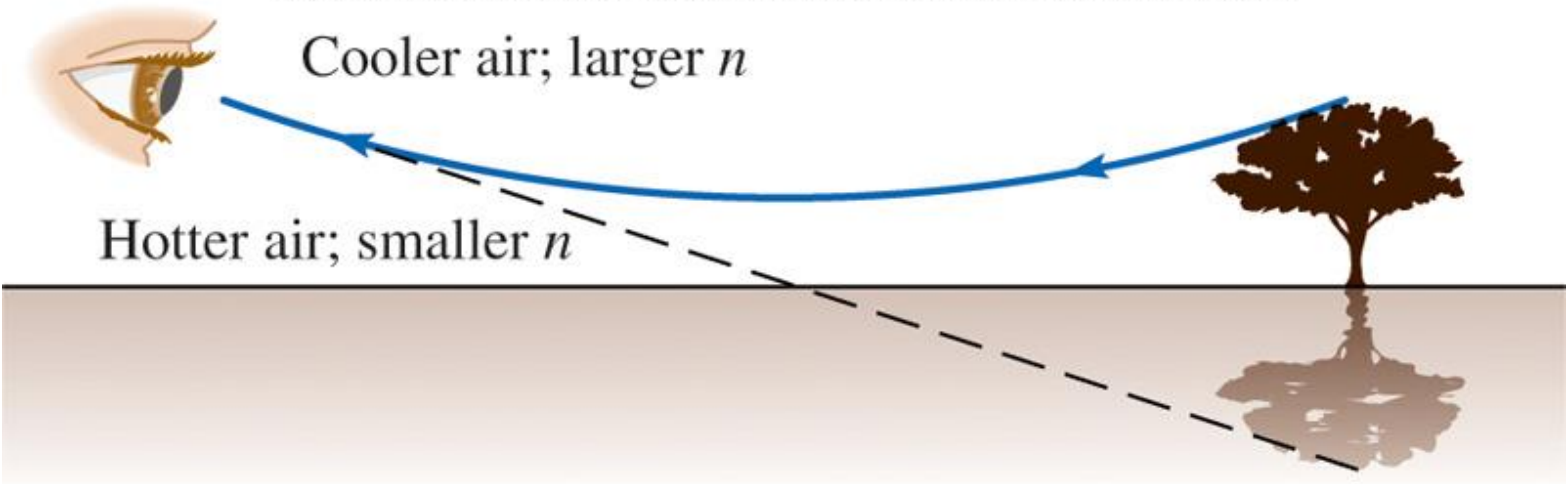
Mirages



(a) (b) (c)

Figure 23.13b

Mirages

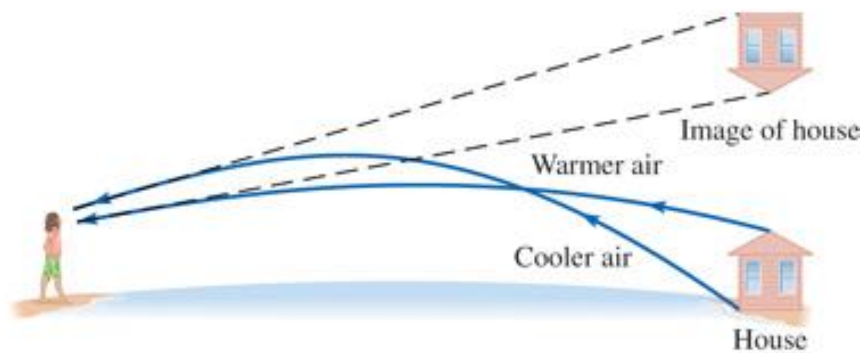


(b)

Figure 23.14

Mirages

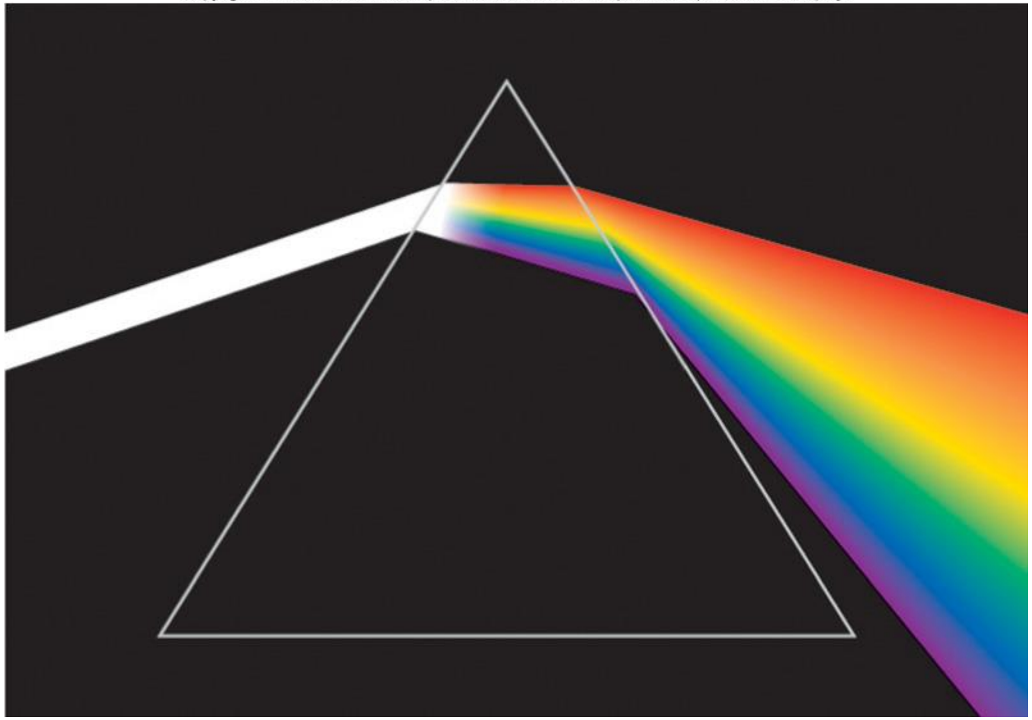
(a)



(b)

Figure 23.15

Dispersion in a Prism



- For a given material, the index of refraction varies with the wavelength of the light passing through the material
- **This dependence of *n* on *λ* is called *dispersion***
- Snell's law indicates light of different wavelengths is bent at different angles when incident on a refracting material

Figure 23.16ab

Total Internal Reflection

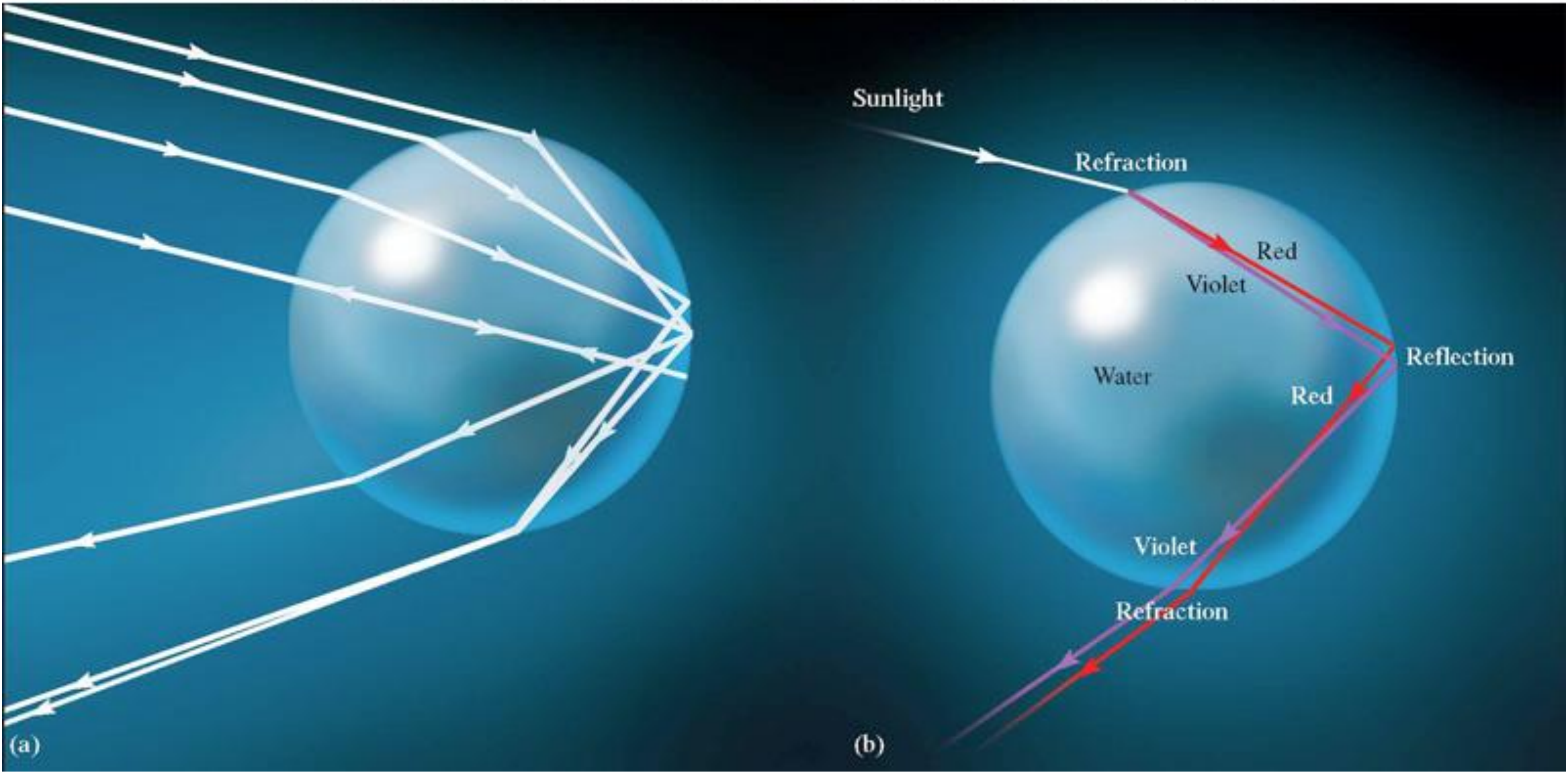
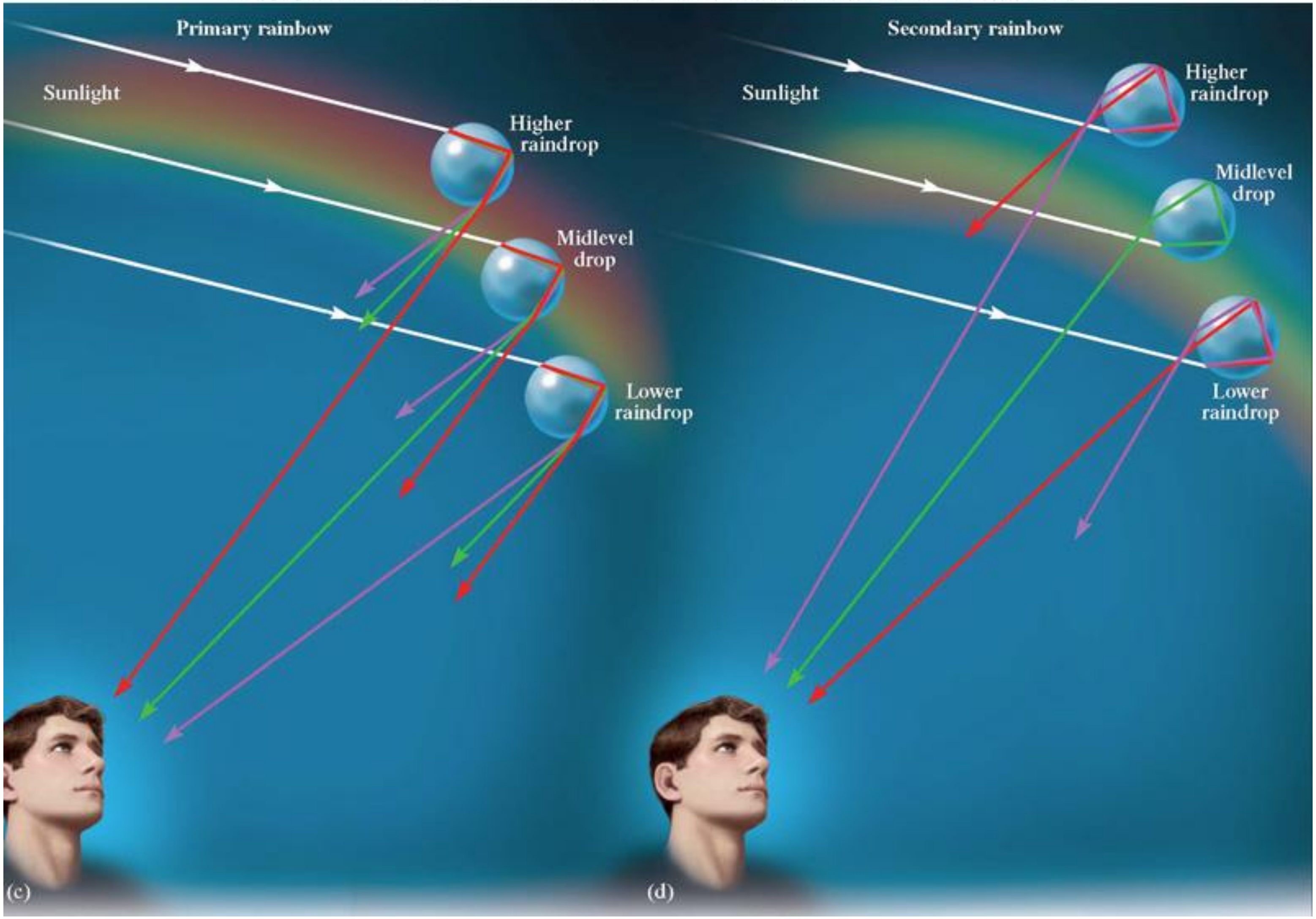


Figure 23.16cd

Total Internal Reflection

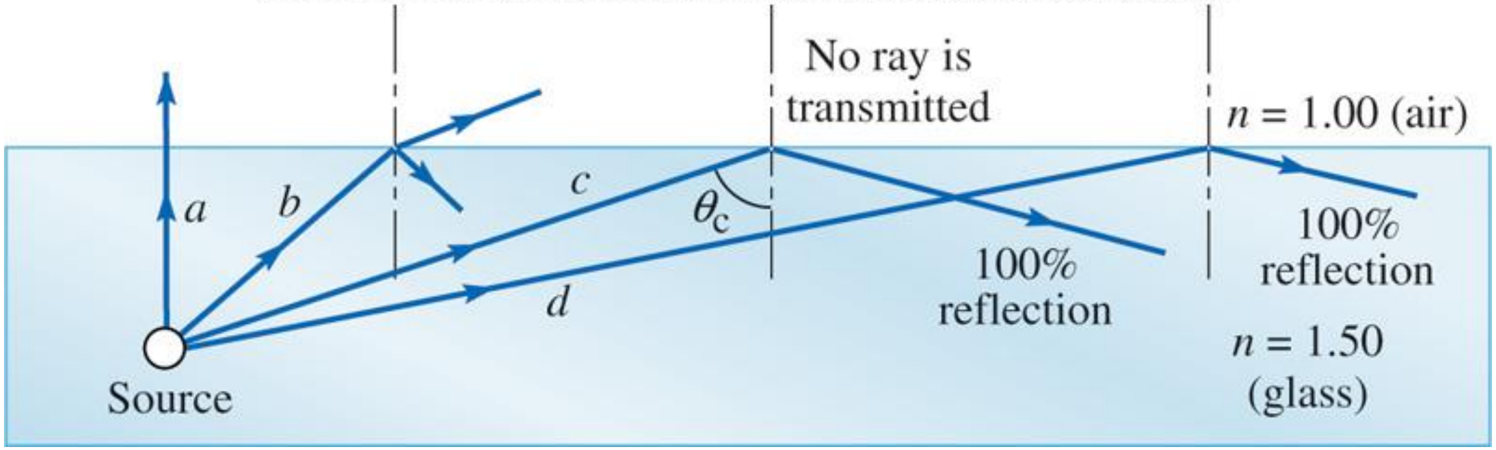


Double Rainbow

- The secondary rainbow is fainter than the primary
- The secondary rainbow arises from light that makes two reflections from the interior surface before exiting the raindrop
- Higher-order rainbows are possible, but their intensity is low

Figure 23.17

Partial and Total Internal Reflection



- There is a particular angle of incidence that will result in an angle of refraction of 90°
  - This angle of incidence is called the *critical angle*, θ_C

Critical angle:

$$\theta_c = \sin^{-1} \frac{n_t}{n_i}$$

no transmitted ray for $\theta_i \geq \theta_c$

Fiber Optics

- An application of internal reflection
- Plastic or glass rods are used to "pipe" light from one place to another
- Applications include:
  - medical use of fiber optic cables for diagnosis and correction of medical problems
  - Telecommunications

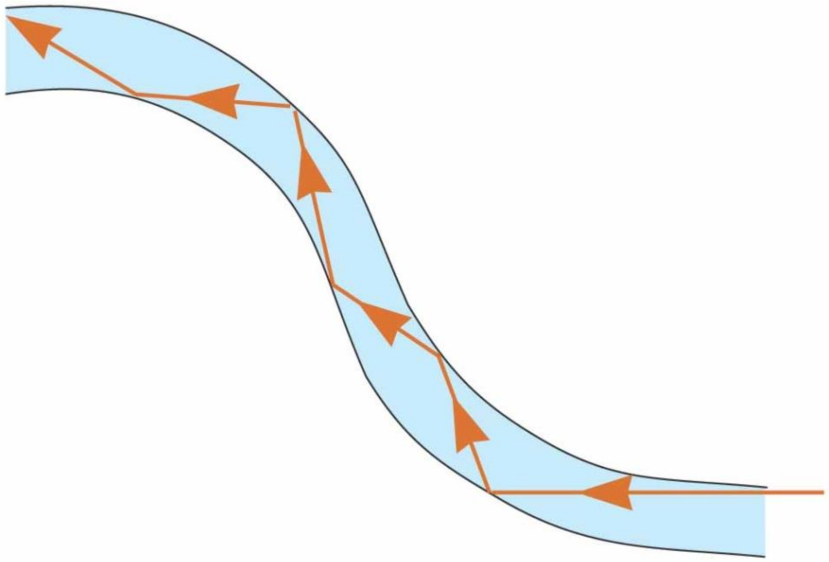
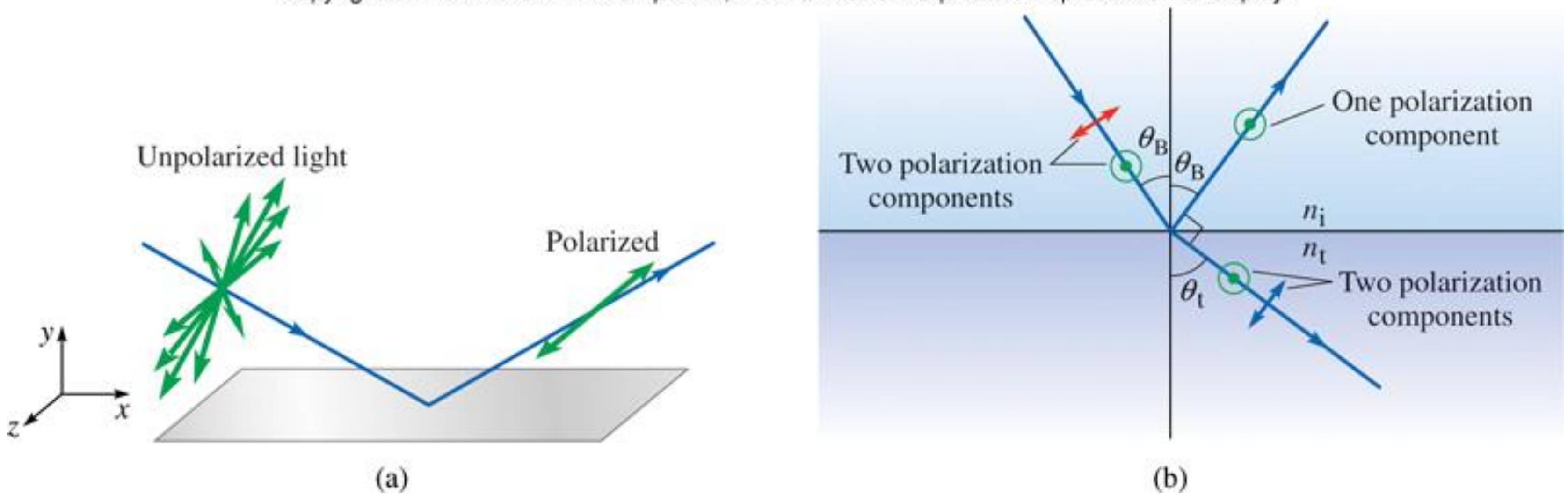


Figure 23.24

Polarization by Reflection: Brewster's Angle



A 2-component unpolarized Light:

At some angle, the reflected and refracted rays would be perpendicular to each other => $\theta_B + \theta_t = 90^o$

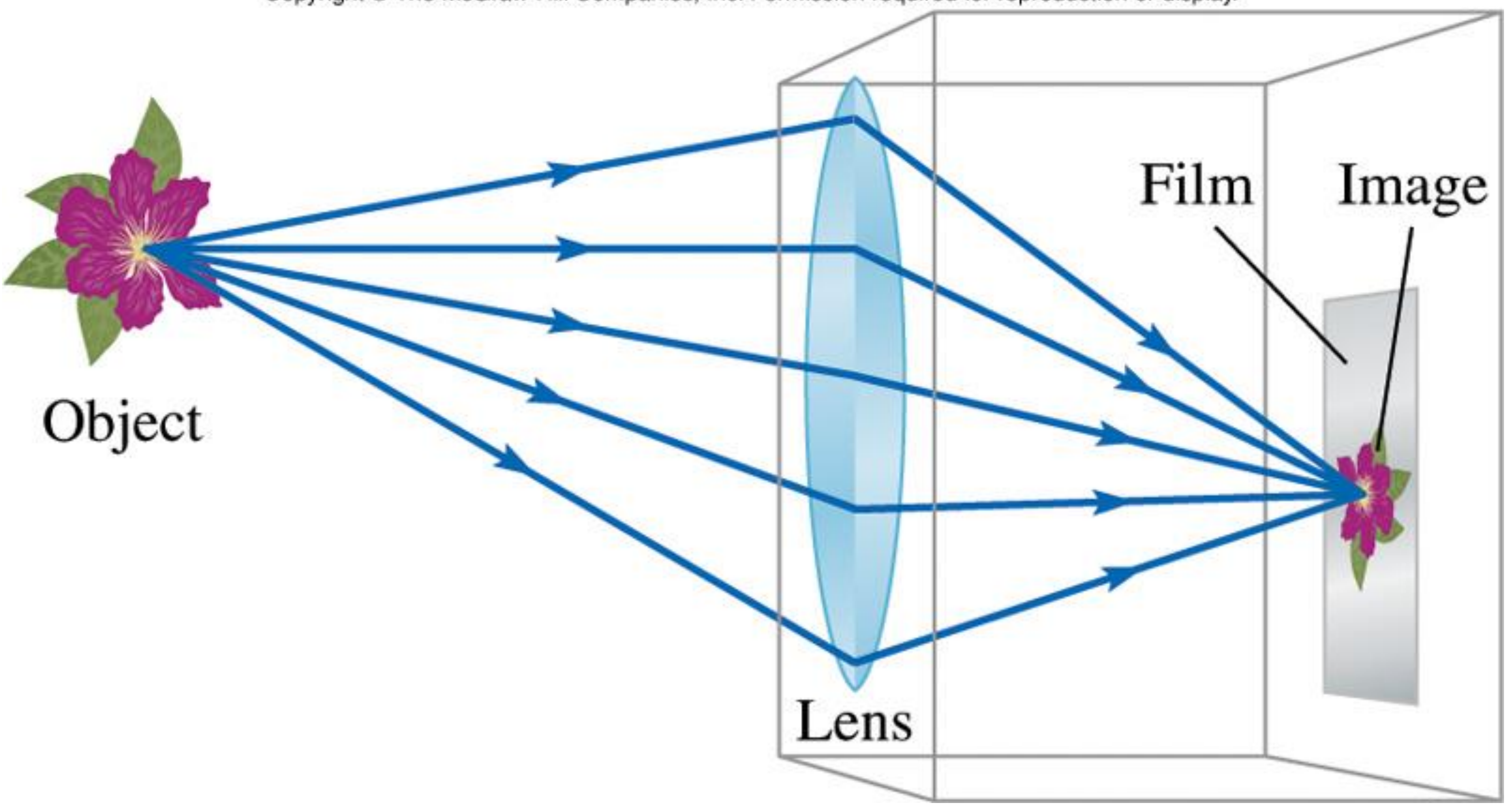
The reflected beam is fully polarized: one component only.

Brewster's angle:

$$\theta_B = \tan^{-1}\frac{n_t}{n_i} \qquad (23\text{-}6)$$

Figure 23.25

Formation of Images Through Reflection or Refraction



Notation for Mirrors and Lenses

- The ***object distance*** is the distance from the object to the mirror or lens:
  - Denoted by ***p***
- The ***image distance*** is the distance from the image to the mirror or lens:
  - Denoted by ***q***
  - Images are formed at the point where rays actually intersect or appear to originate
- The ***lateral magnification*** of the mirror or lens is the ratio of the image height to the object height:
  - Denoted by ***M***

- A ***real image*** is one in which light actually passes through the image point: Real images can be displayed on screens
- A ***virtual image*** is one in which the light does not pass through the image point
  - Virtual images cannot be displayed on screens
  - The light appears to diverge from that point

- To find where an image is formed, it is always necessary to follow at least two rays of light as they reflect from the mirror

Figure 23.26

Example 23.4

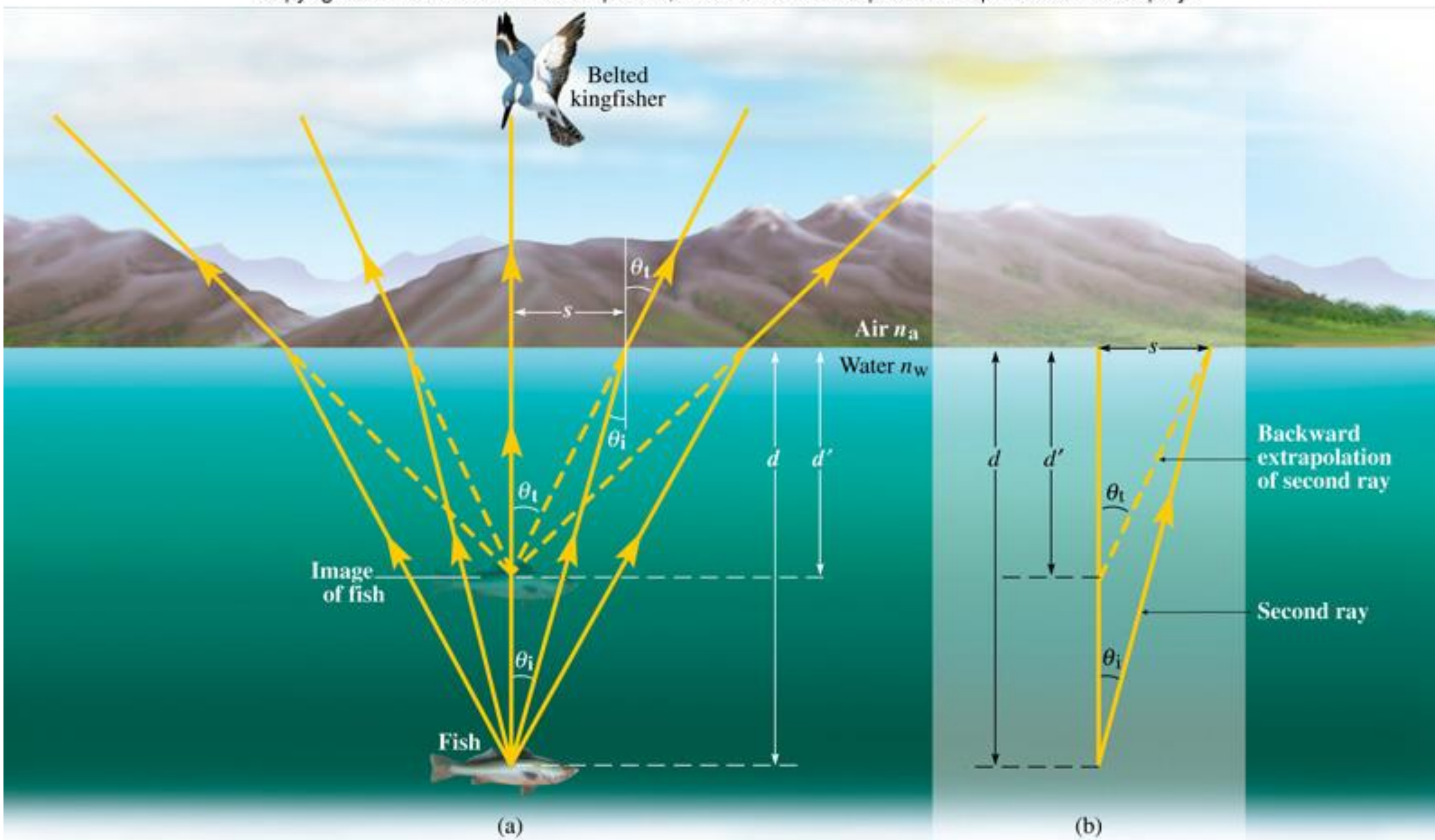


Figure 23.27

Plane Mirrors

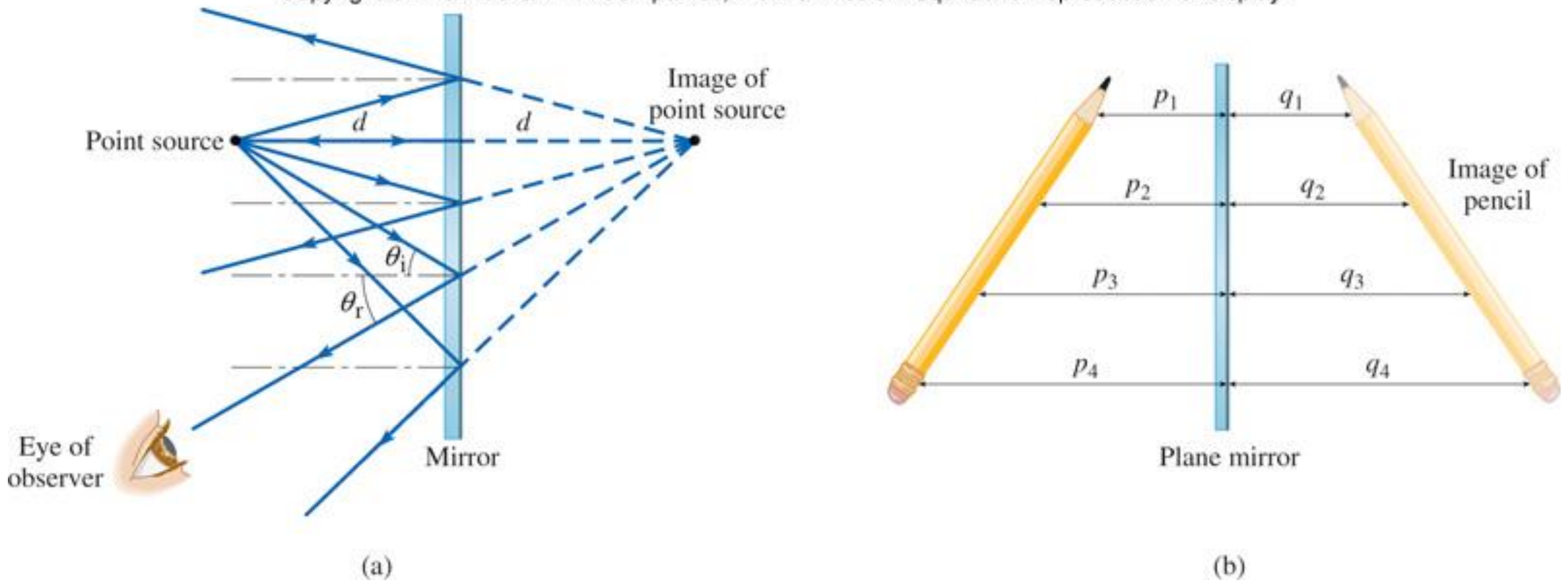
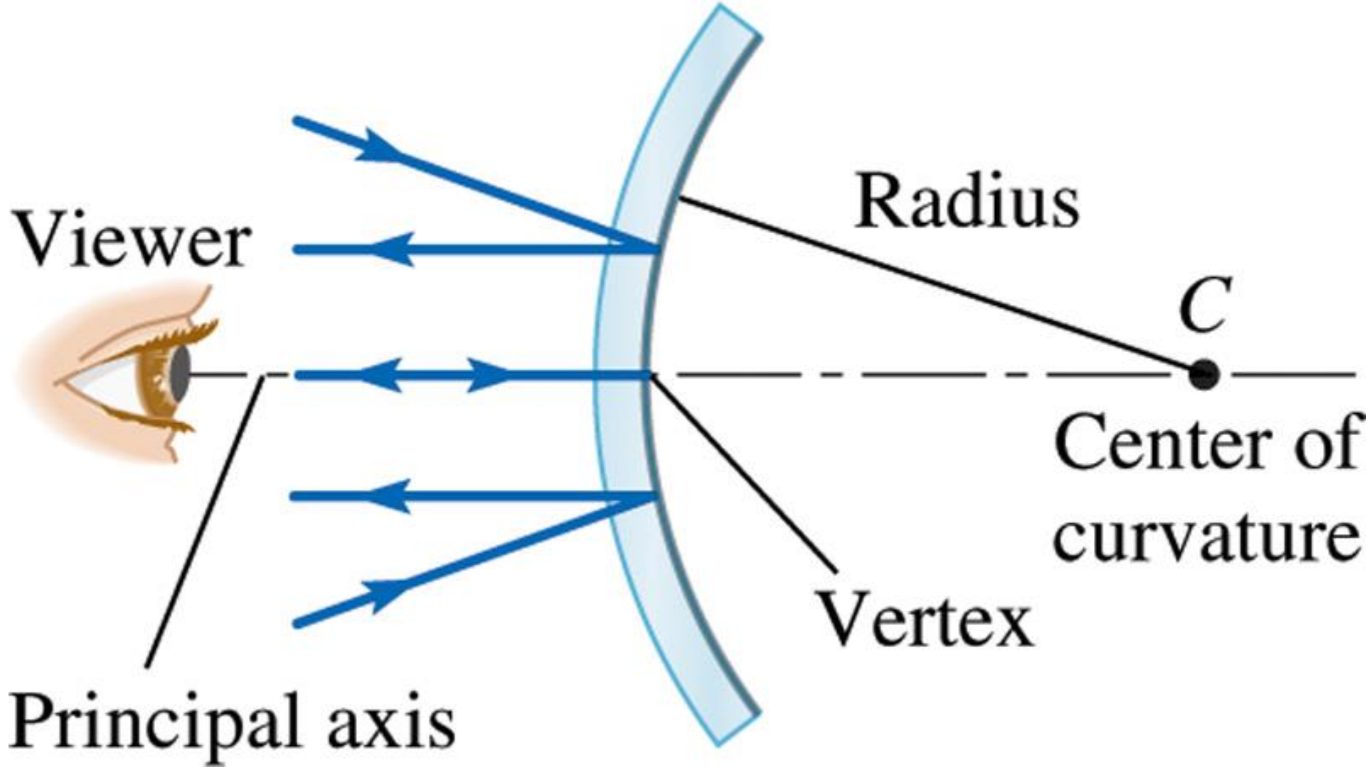


Figure 23.30

Convex Spherical Mirrors



The focal point of a convex mirror is on the principal axis a distance R/2 behind the mirror

Figure 23.31

Convex Spherical Mirrors: How do they work?

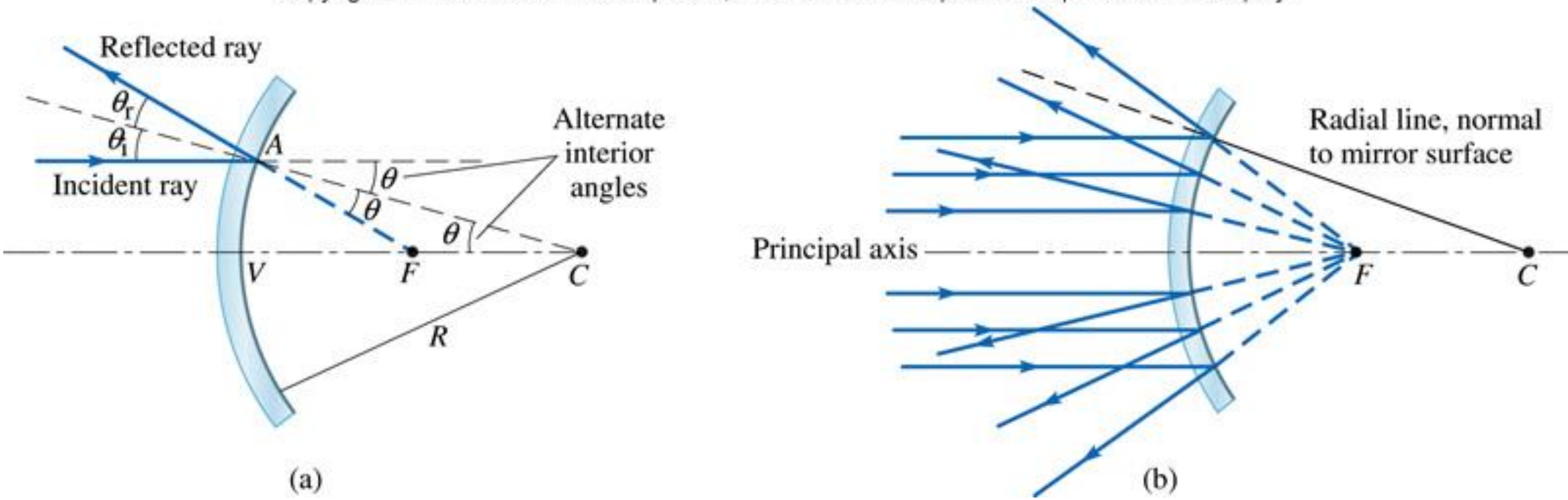
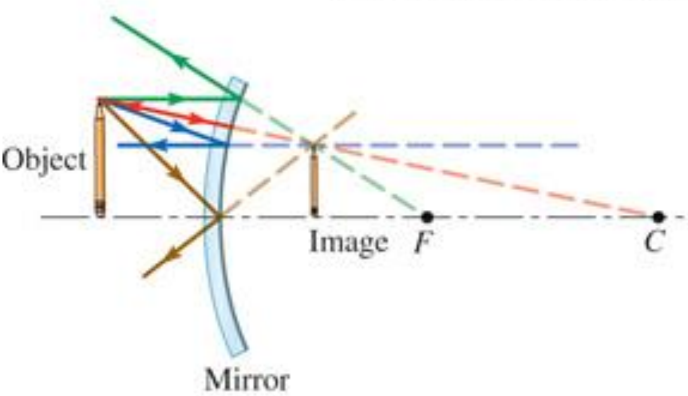


Figure 23.32

Convex Spherical Mirrors: How do they work?

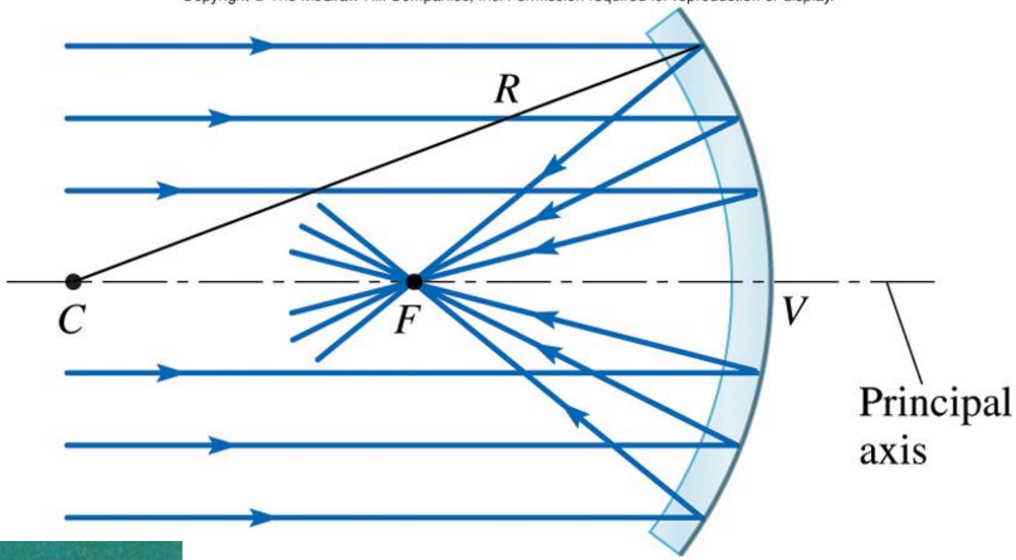


Principal rays for convex mirrors

1. A ray parallel to the principal axis is reflected as if it came from a focal point.
2. A ray along a radius is reflected back upon itself.
3. A ray directed toward the focal point is reflected parallel to the principal axis.
4. A ray incident on the vertex of the mirror reflects at an equal angle to the axis.

Figure 23.34

Concave Spherical Mirrors



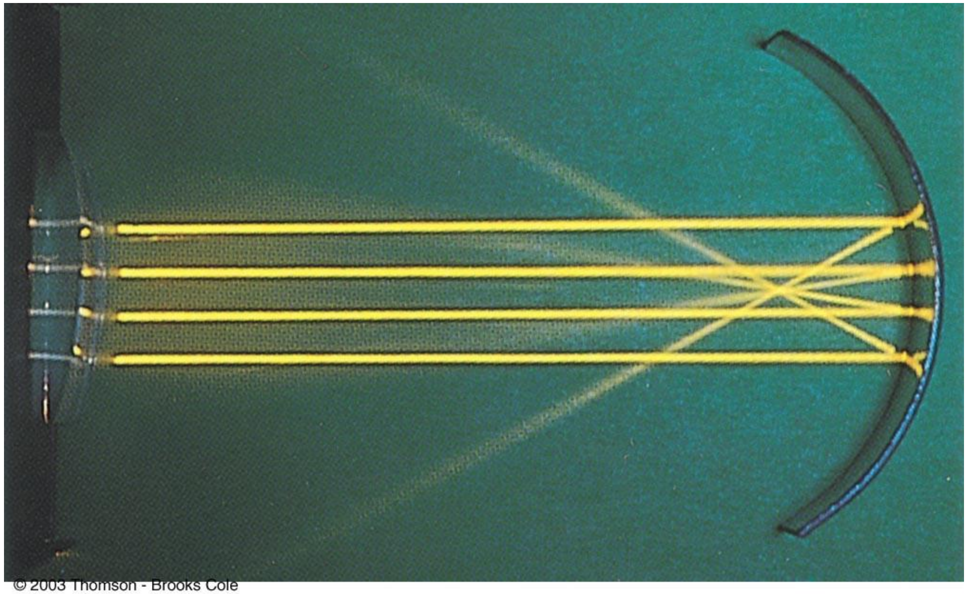
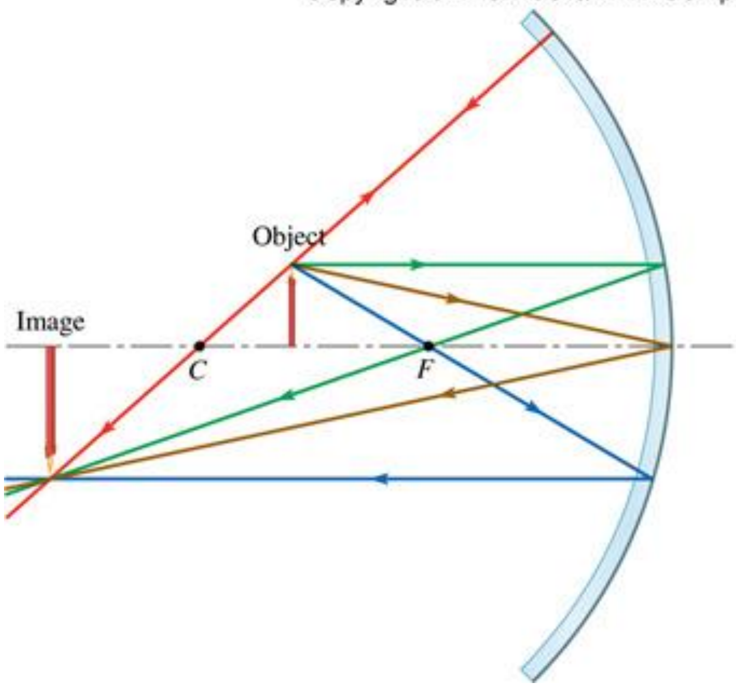


Figure 23.35

Concave Spherical Mirrors: How do they work?

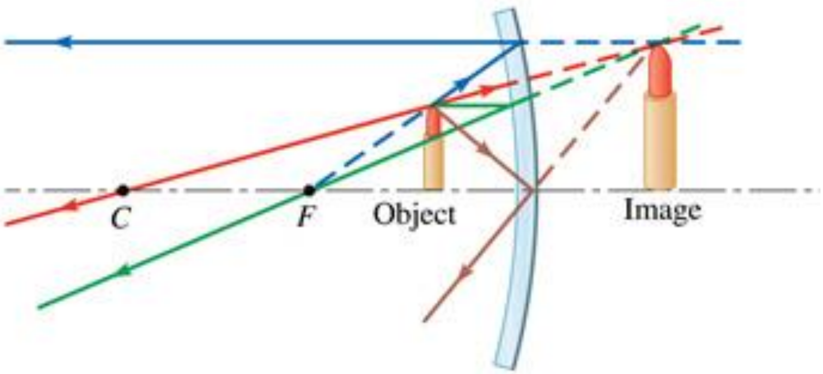


Principal rays for concave mirrors

1. A ray parallel to the principal axis is reflected through the focal point.
2. A ray along a radius is reflected back upon itself.
3. A ray along the direction from the focal point to the mirror is reflected parallel to the principal axis.
4. A ray incident on the vertex of the mirror reflects at an equal angle to the axis.

Figure 23.36

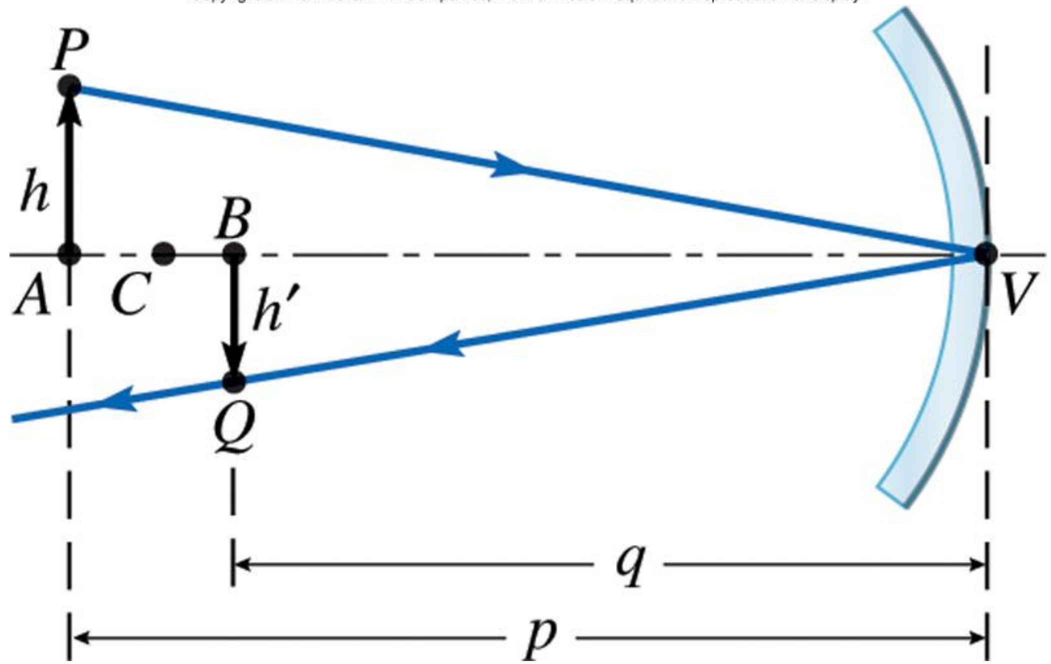
(a)



(b)

Figure 23.38

Transverse Magnification



$$|m| = \frac{\text{image size}}{\text{object size}}$$

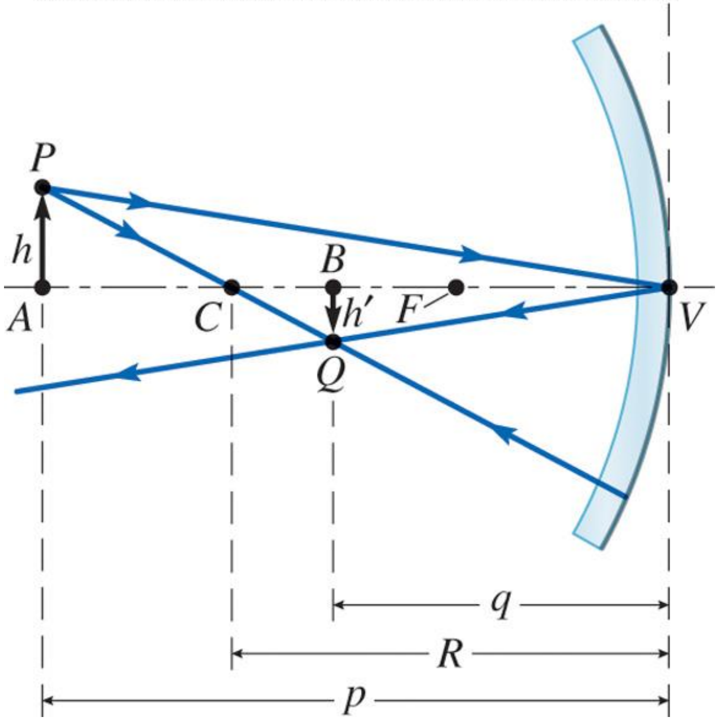
$$m = \frac{h'}{h}$$

Magnification equation:

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

Figure 23.39

The Mirror Equation



Mirror equation:

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

Figure 23.40

Objects Located at Infinity or at Large Distances

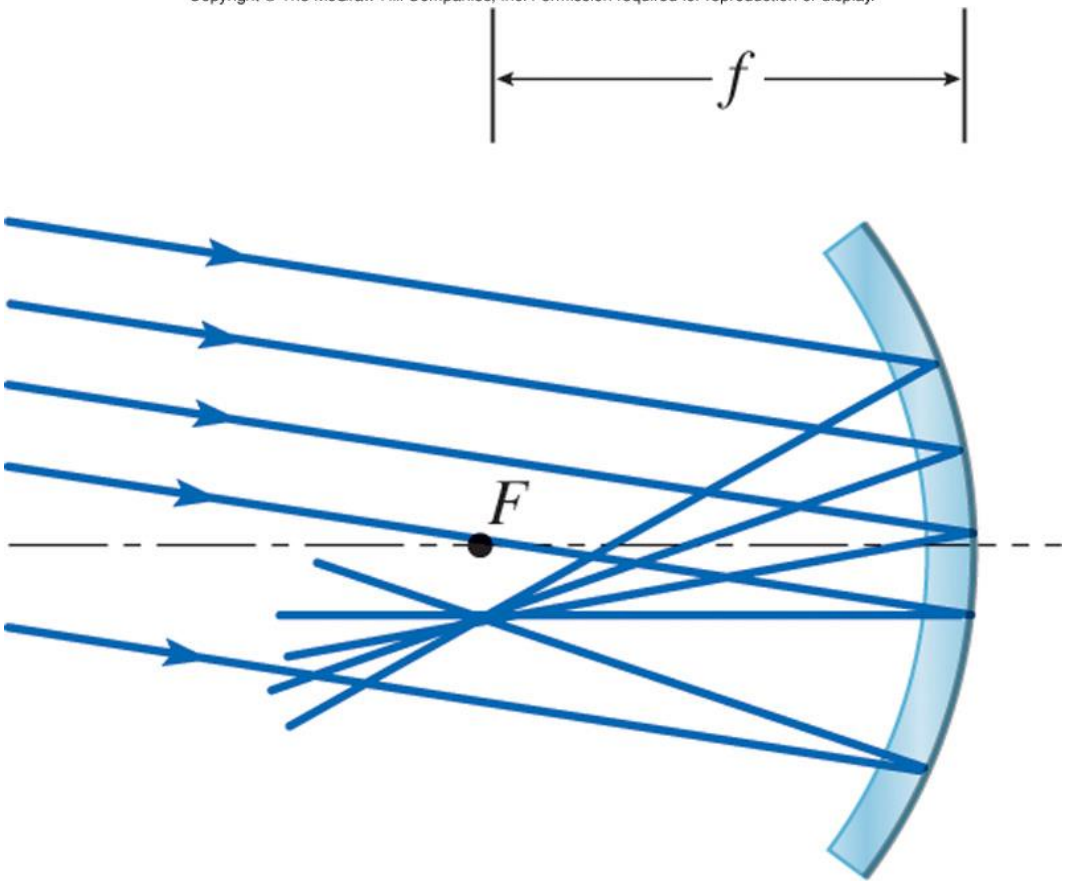


Table 23.02

Sign Conventions

Table 23.2

Sign Conventions for Mirrors

Quantity	When Positive (+)	When Negative (–)
Object distance p	Always*	Never*
Image distance q	Real image	Virtual image
Focal length f	Converging mirror (concave): $f = \frac{1}{2}R$	Diverging mirror (convex): $f = -\frac{1}{2}R$
Magnification m	Upright image	Inverted image

*In Chapter 23, we consider only real objects. Chapter 24 discusses multiple-lens systems, in which *virtual* objects are possible.

Figure 23.42

Thin Lenses

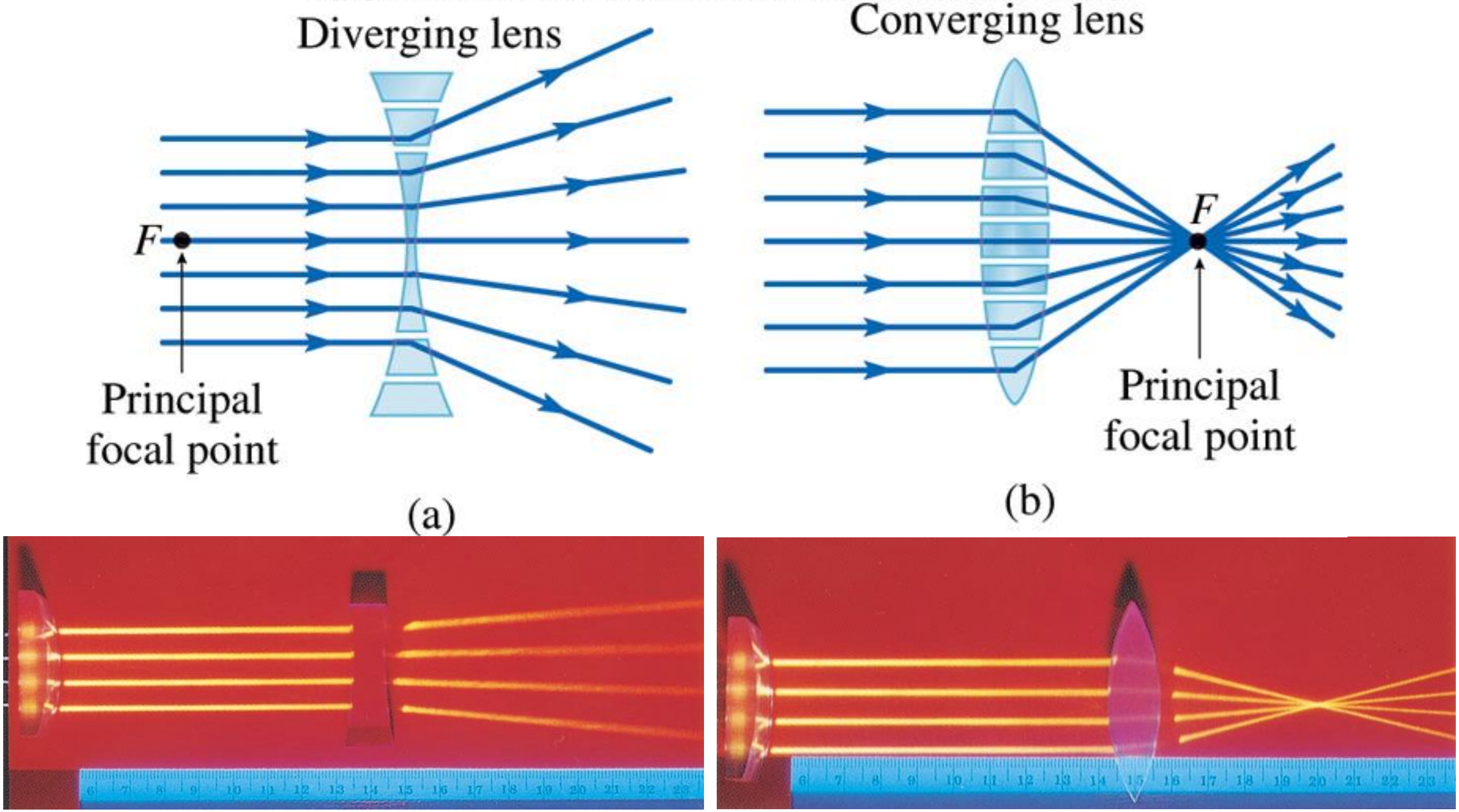


Figure 23.44

Focal Points and Principal Rays

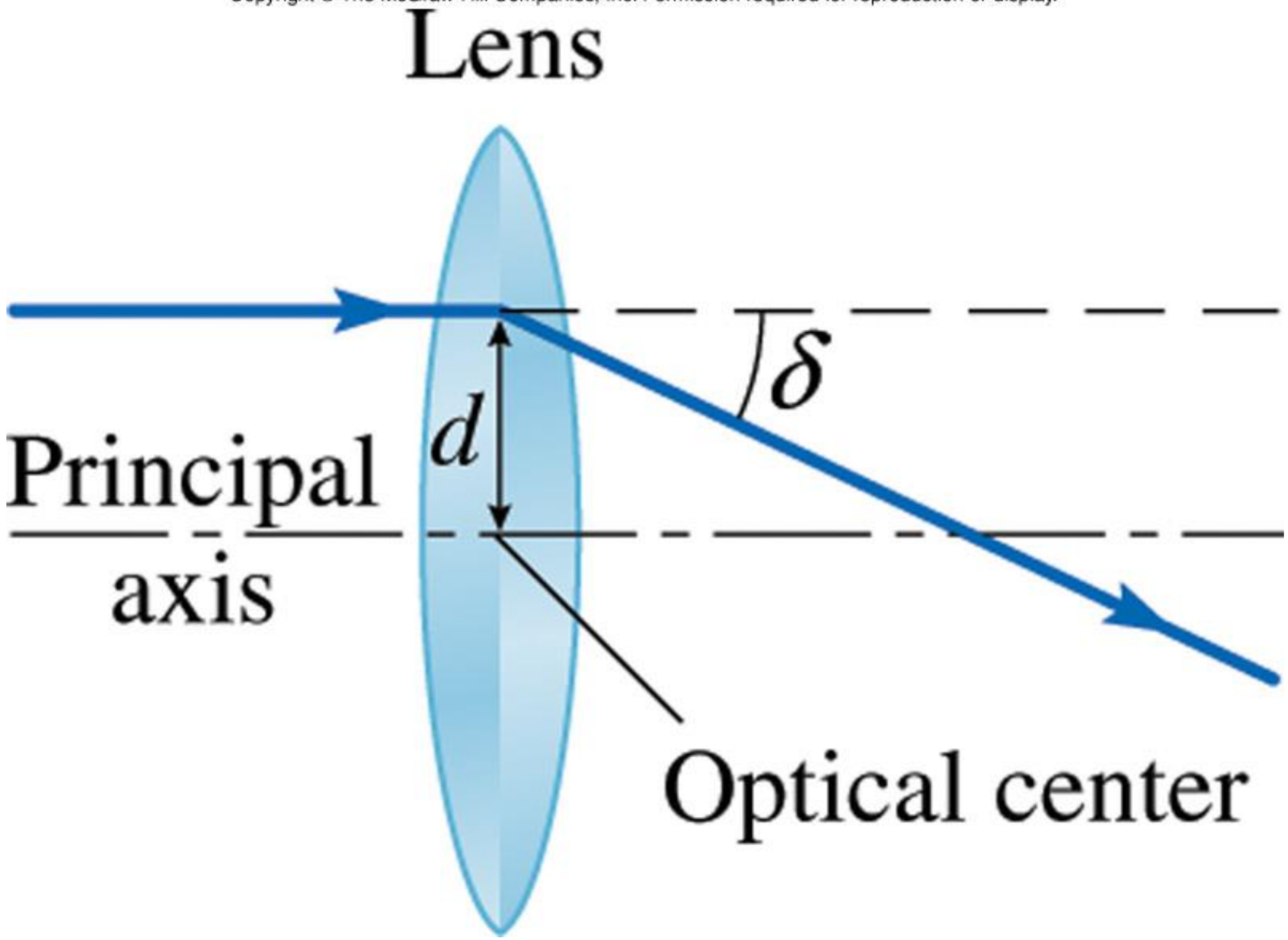


Figure 23.46

Shapes of Some Diverging & Converging Lenses

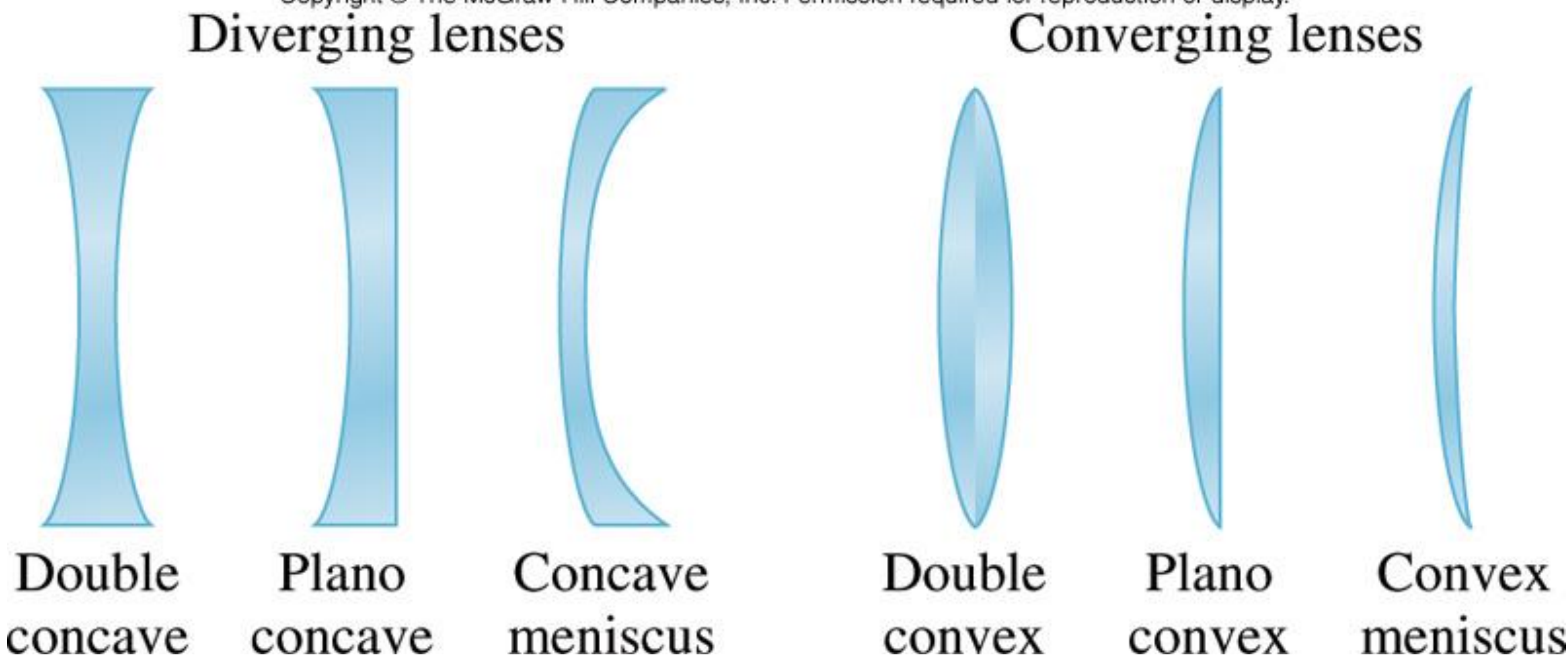


Figure 23.47a

Forming Real Images

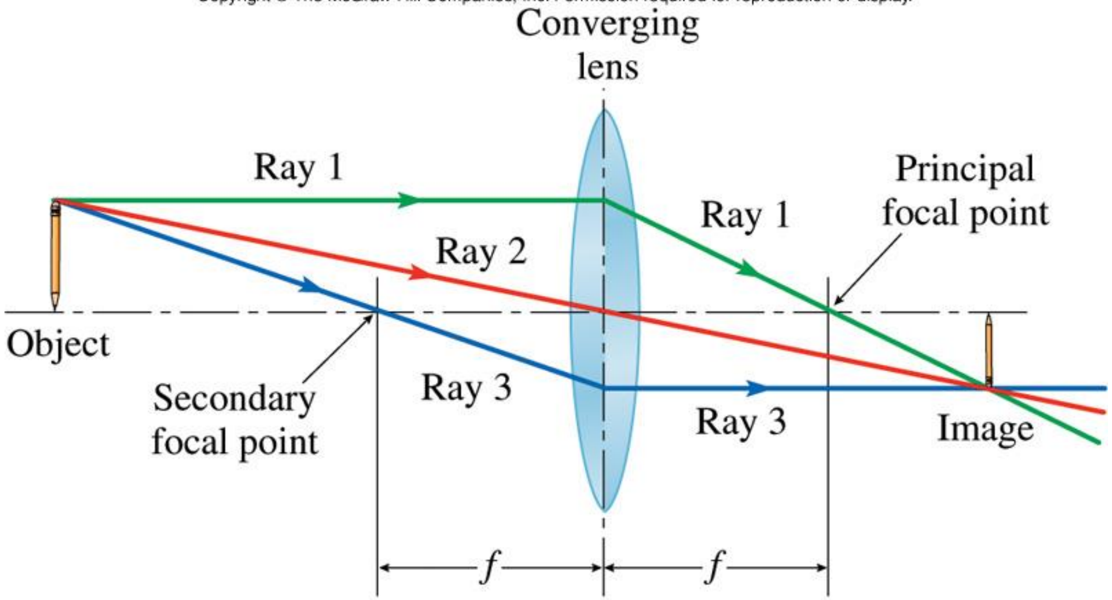


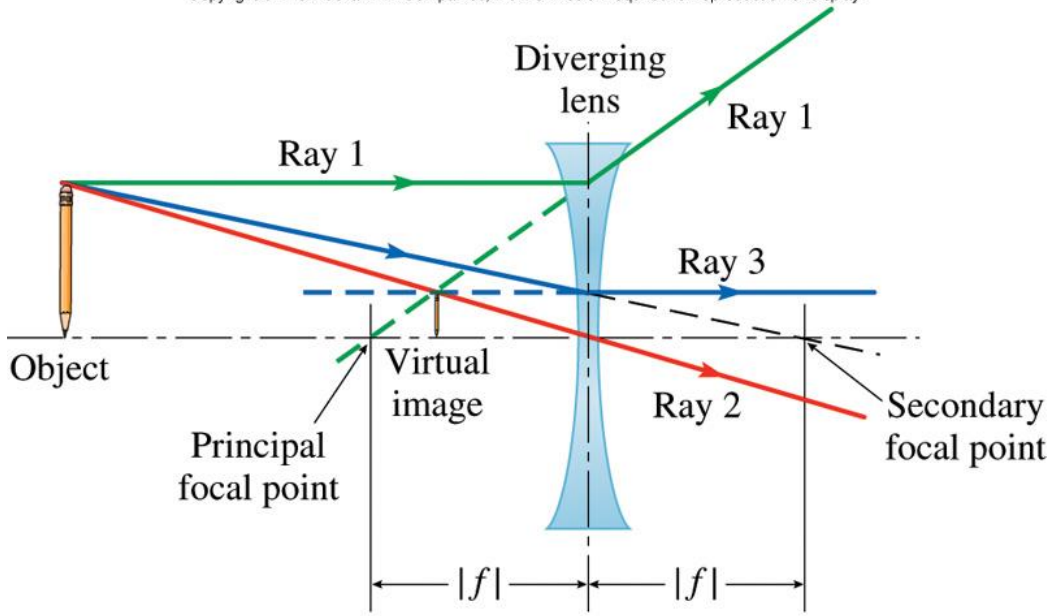
Table 23.3

Principal Rays and Principal Focal Points for Thin Lenses

	Converging Lens	Diverging Lens
Ray 1. An incident ray parallel to the principal axis	Passes through the principal focal point	Appears to come from the principal focal point
Ray 2. A ray incident at the optical center	Passes straight through the lens	Passes straight through the lens
Ray 3. A ray that *emerges* parallel to the principal axis	Appears to come from the secondary focal point	Appears to have been heading for the secondary focal point
Location of the principal focal point	Past the lens	Before the lens

Figure 23.47b

Forming Virtual Images



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Principal Rays and Principal Focal Points for Thin Lenses

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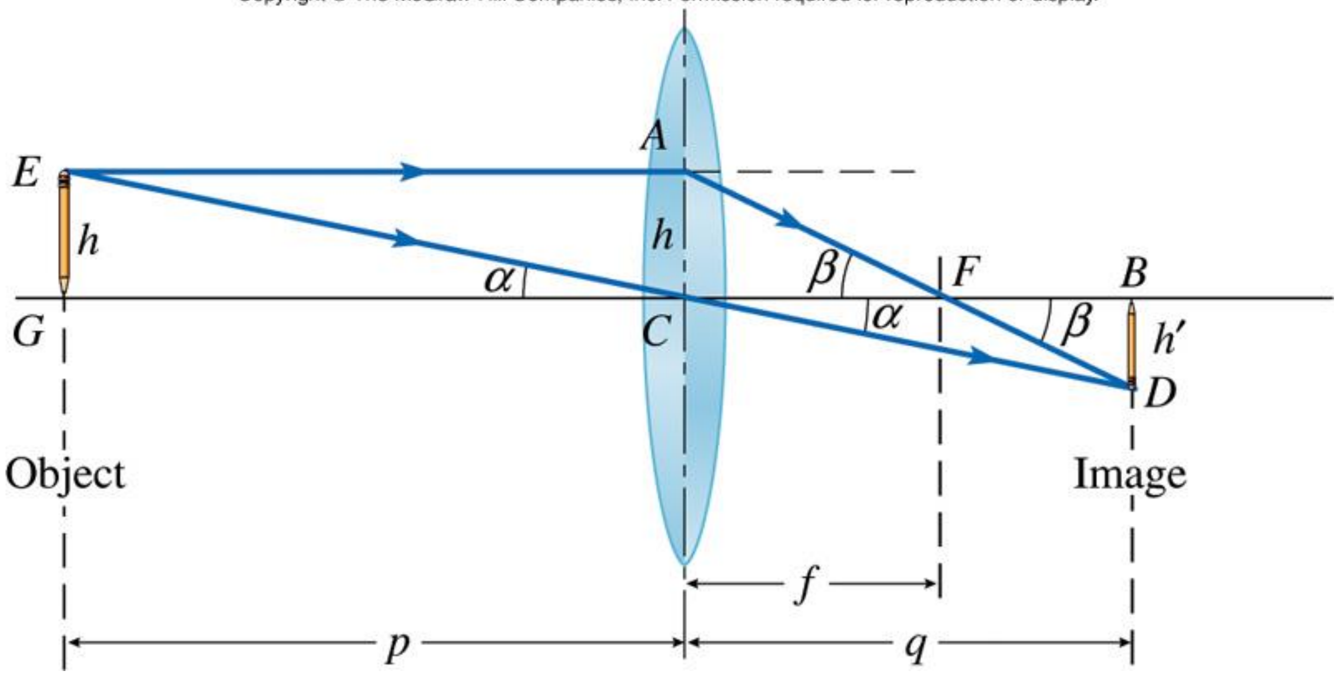
Ray 3. A ray that *emerges* parallel to the principal axis	Appears to come from the secondary focal point	Appears to have been heading for the secondary focal point
Location of the principal focal point	Past the lens	Before the lens

Figure 23.49

The Magnification & Thin Lens Equation



Magnification equation:

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

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

Table 23.04

Sign Conventions for Mirrors and Lenses

Table 23.4

Sign Conventions for Mirrors and Lenses

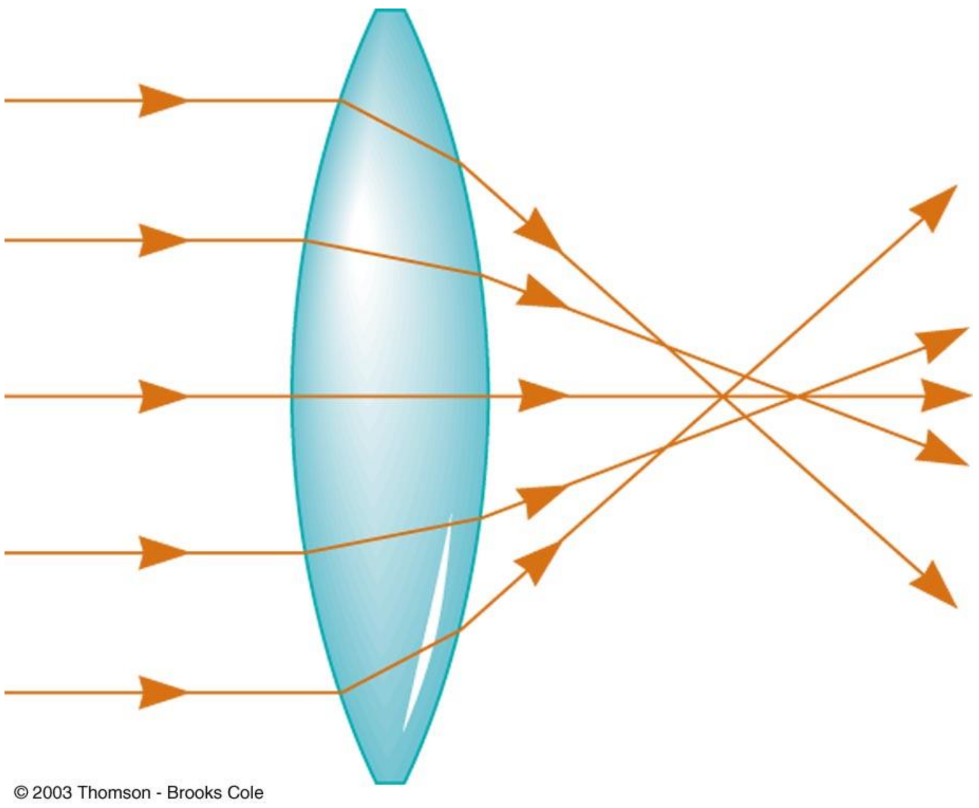
Quantity	When Positive (+)	When Negative (–)
Object distance p	Always (for now)	Never (for now)
Image distance q	Real image	Virtual image
Focal length f	Converging lens or mirror	Diverging lens or mirror
Magnification m	Upright image	Inverted image

Lens and Mirror Aberrations

- One of the basic problems is the imperfect quality of the images
  - Largely the result of defects in shape and form
- Two common types of aberrations exist
  - Spherical aberration
  - Chromatic aberration

Spherical Aberration

- Results from the focal points of light rays far from the principle axis are different from the focal points of rays passing near the axis
- For a mirror, parabolic shapes can be used to correct for spherical aberration



Chromatic Aberration

- Different wavelengths of light refracted by a lens focus at different points
  - Violet rays are refracted more than red rays
  - The focal length for red light is greater than the focal length for violet light
- Chromatic aberration can be minimized by the use of a combination of converging and diverging lenses

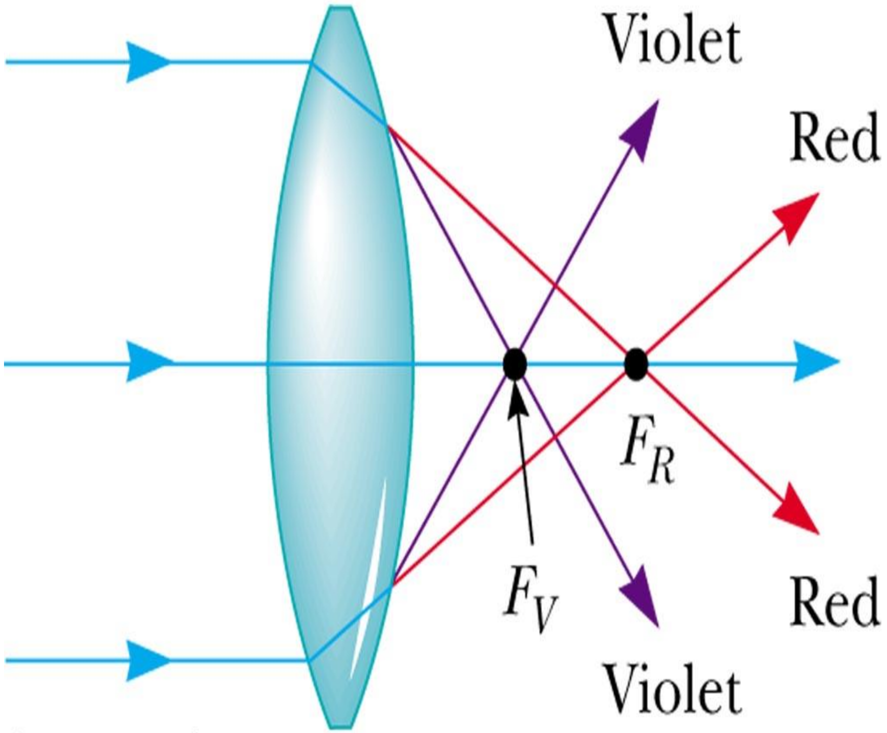


Figure 23.49

End of Chapter 2