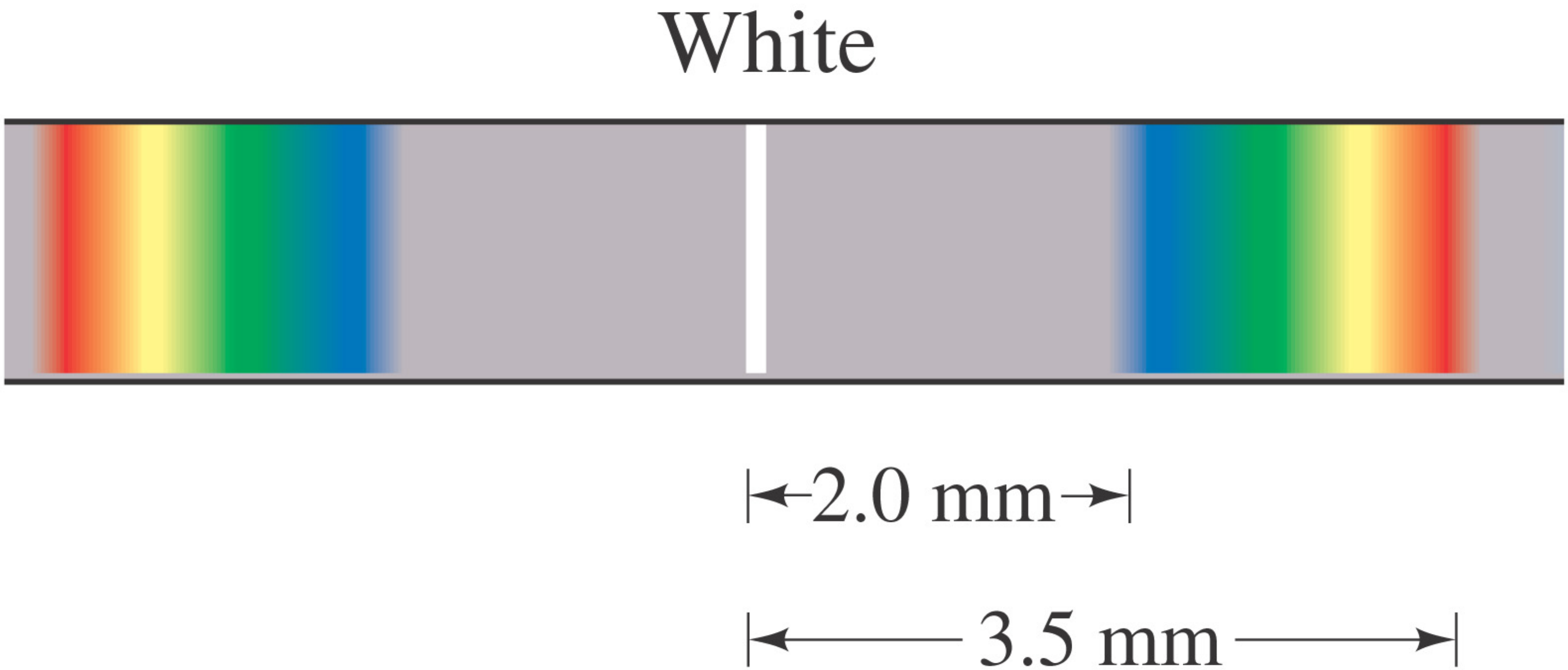
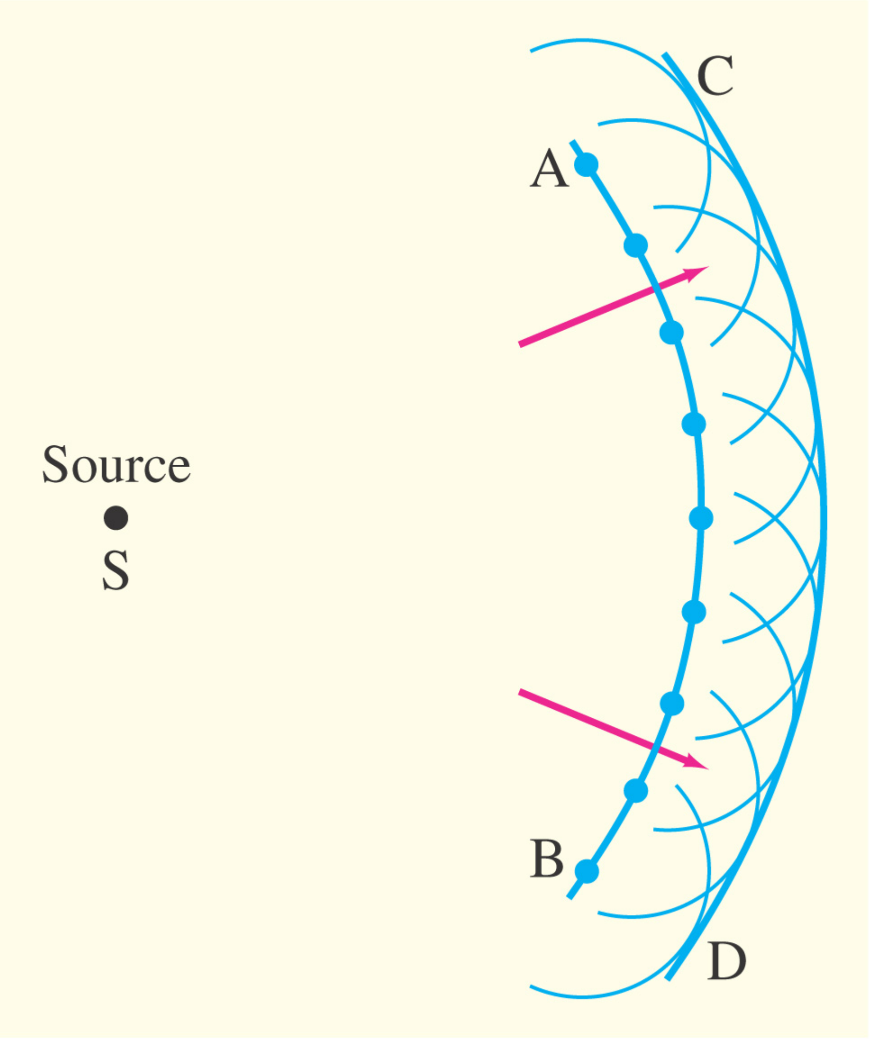
Chapter 24

The Wave Nature of Light



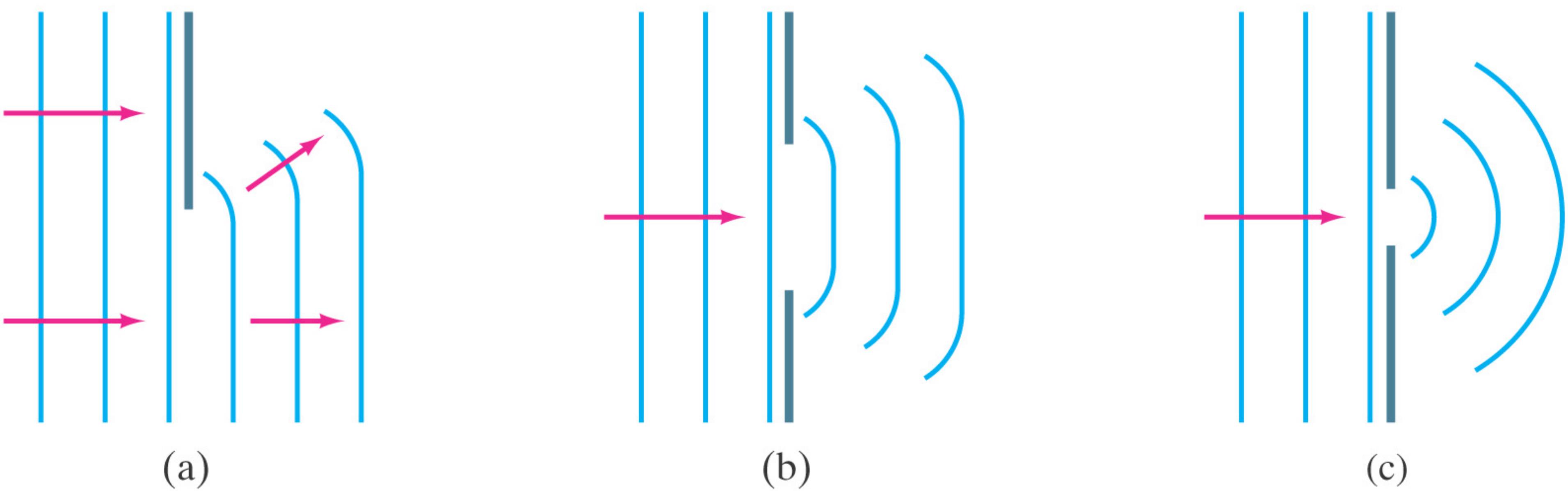
24.1 Waves Versus Particles; Huygens' Principle and Diffraction

Huygens' principle: Every point on a wave front acts as a point source; the wavefront as it develops is tangent to its envelope



24.1 Waves Versus Particles; Huygens' Principle and Diffraction

Huygens' principle is consistent with diffraction:



24.2 Huygens' Principle and the Law of Refraction

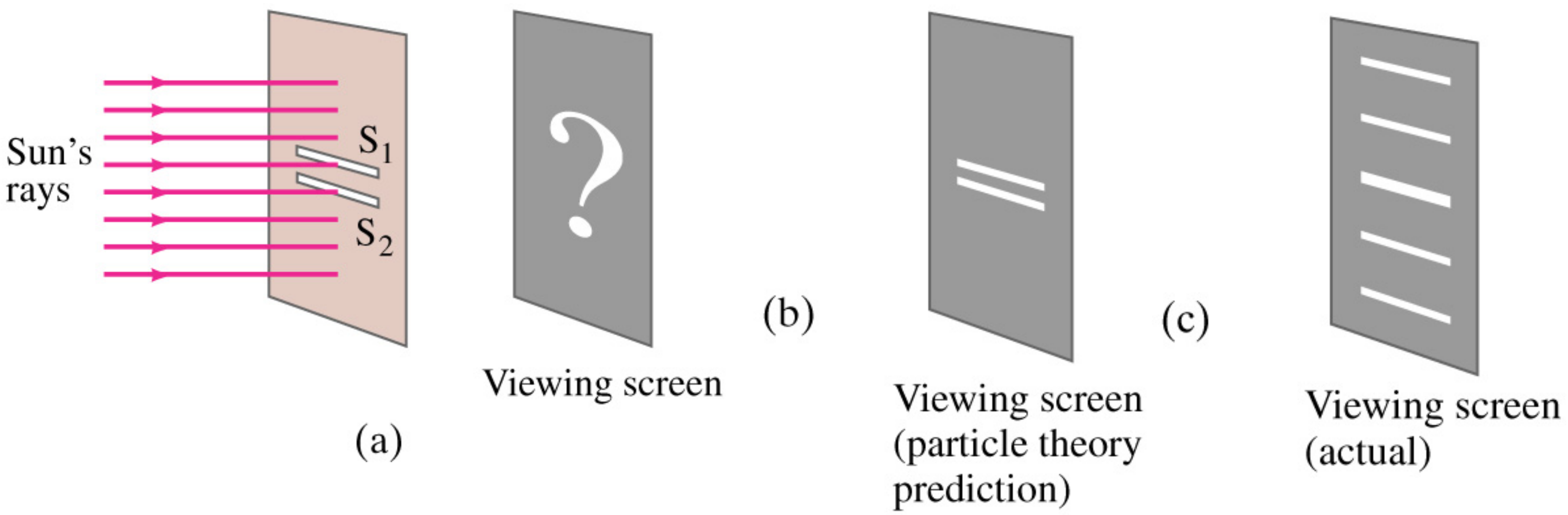
The frequency of the light does not change, but the wavelength does as it travels into a new medium.

$$\lambda_n = \frac{\lambda}{n} \qquad \textbf{(24-1)}$$

24.3 Interference – Young's Double-Slit Experiment

If light is a wave, interference effects will be seen, where one part of wavefront can interact with another part.

One way to study this is to do a double-slit experiment:



Interference

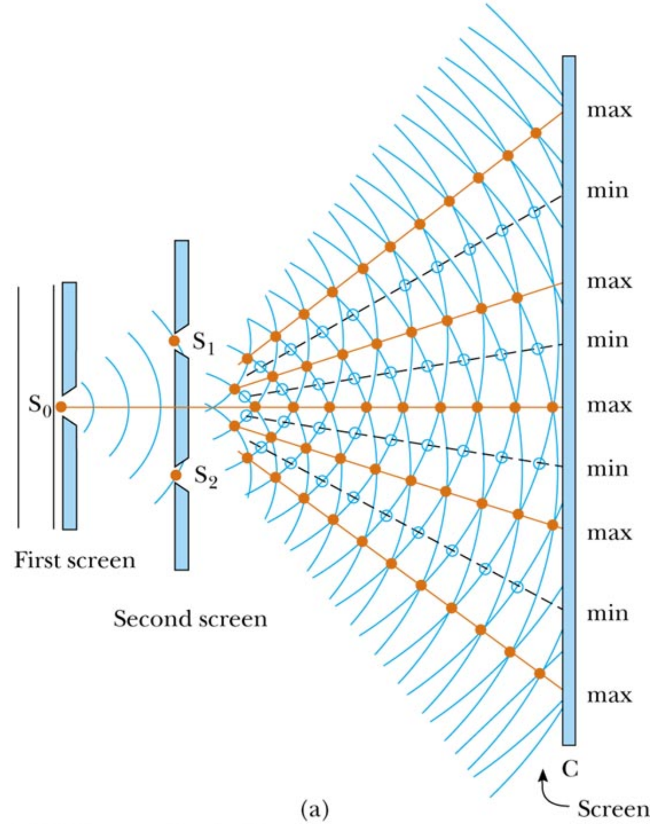
- Light waves interfere with each other much like mechanical waves do
- All interference associated with light waves arises when the electromagnetic fields that constitute the individual waves combine

Uses for Young's Double Slit Experiment

- Young's Double Slit Experiment provides a method for measuring wavelength of the light
- This experiment gave the wave model of light a great deal of credibility
  - It is inconceivable that particles of light could cancel each other
- Who cares other than physicists?
  - Users of computers, GPS, cars, digital cameras to name a few . . .

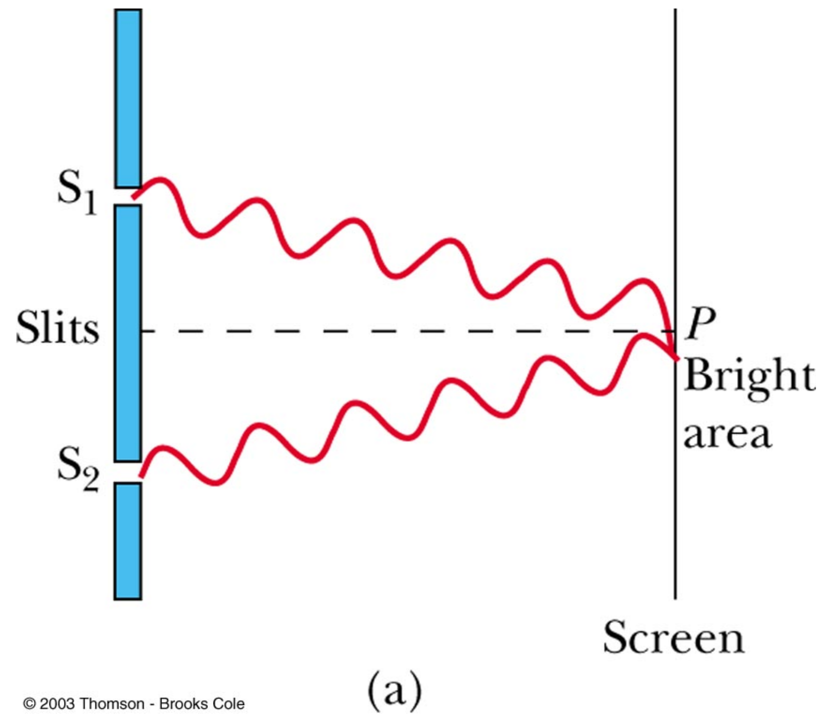
Young's Double Slit Experiment, Diagram

- The narrow slits, S_1 and S_2 act as sources of waves
- The waves emerging from the slits originate from the same wave front and therefore are always in phase



Interference Patterns

- Constructive interference occurs at the center point
- The two waves travel the same distance
  - Therefore, they arrive in phase

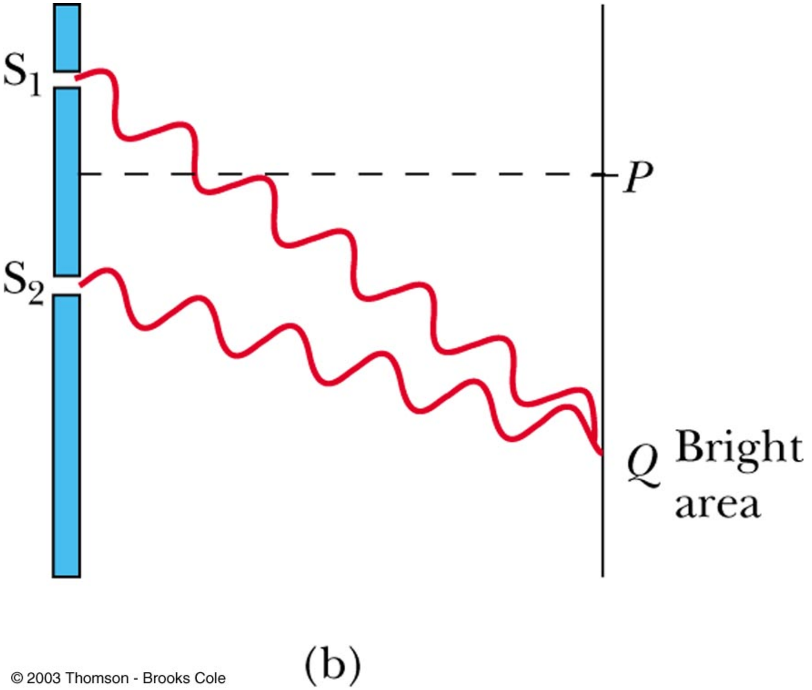


Young's Double Slit Experiment

- Thomas Young first demonstrated interference in light waves from two sources in 1801
- Light is incident on a screen with a narrow slit, S_o
- The light waves emerging from this slit arrive at a second screen that contains two narrow, parallel slits, S_1 and S_2

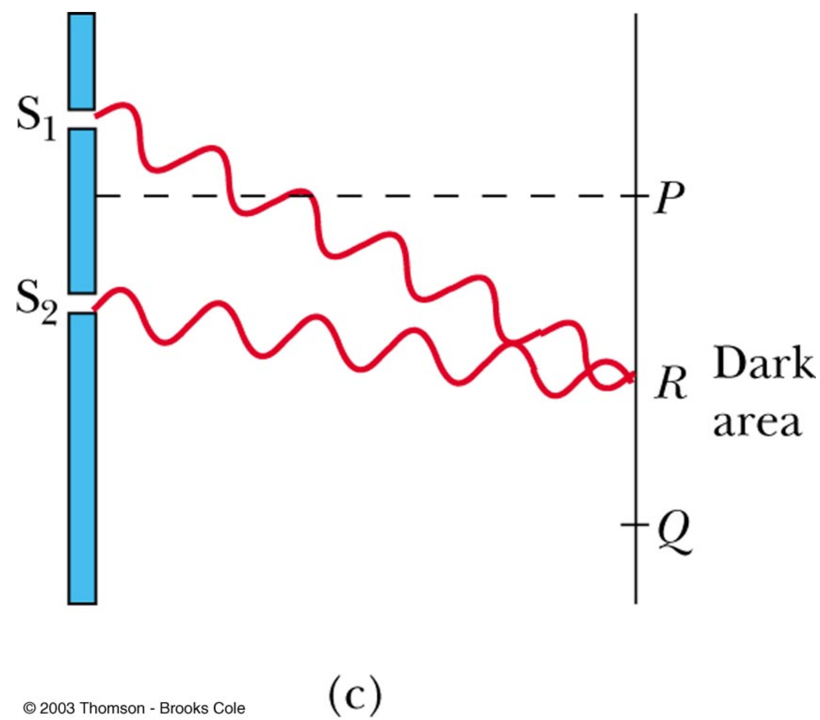
Interference Patterns, 2

- The upper wave has to travel farther than the lower wave
- The upper wave travels one wavelength farther
  - Therefore, the waves arrive in phase
- A bright fringe occurs

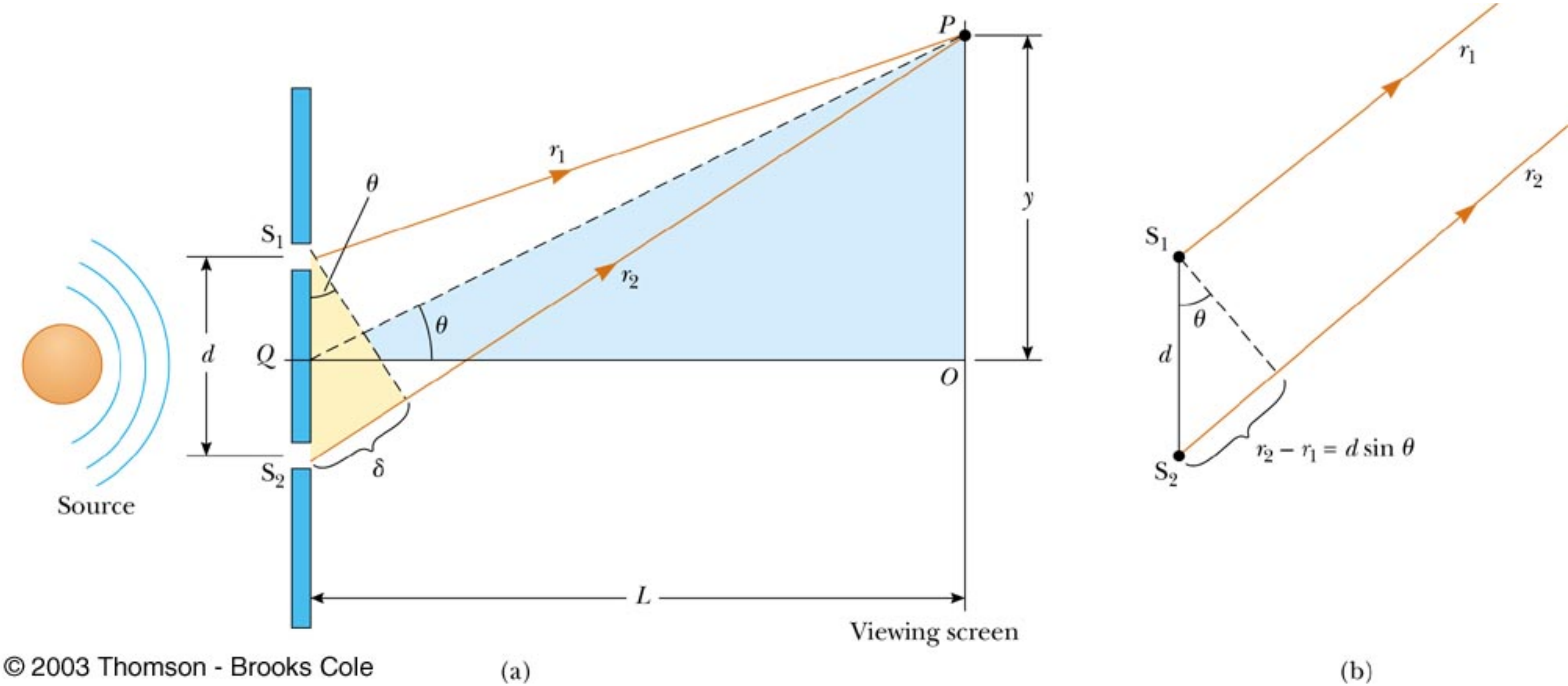


Interference Patterns, 3

- The upper wave travels one-half of a wavelength farther than the lower wave
- The trough of the bottom wave overlaps the crest of the upper wave
- This is destructive interference
  - A dark fringe occurs



Interference Equations



- The path difference, δ, is found from the triangle shown
- $\delta = r_2 - r_1 = d \sin\theta$
  - This assumes the paths are parallel
  - Not exactly, but a very good approximation

Interference Equations, final

- For bright fringes

$$y_{bright} = \frac{\lambda L}{d} m \quad m = 0, \pm 1, \pm 2 \ldots$$

- For dark fringes

$$y_{dark} = \frac{\lambda L}{d}\left(m + \frac{1}{2}\right) \quad m = 0, \pm 1, \pm 2 \ldots$$

m = 0, ±1, ±2, …
m is called the *order number*

When m = 0, it is the zeroth order maximum
When m = ±1, it is called the first order maximum

24.3 Interference – Young's Double-Slit Experiment

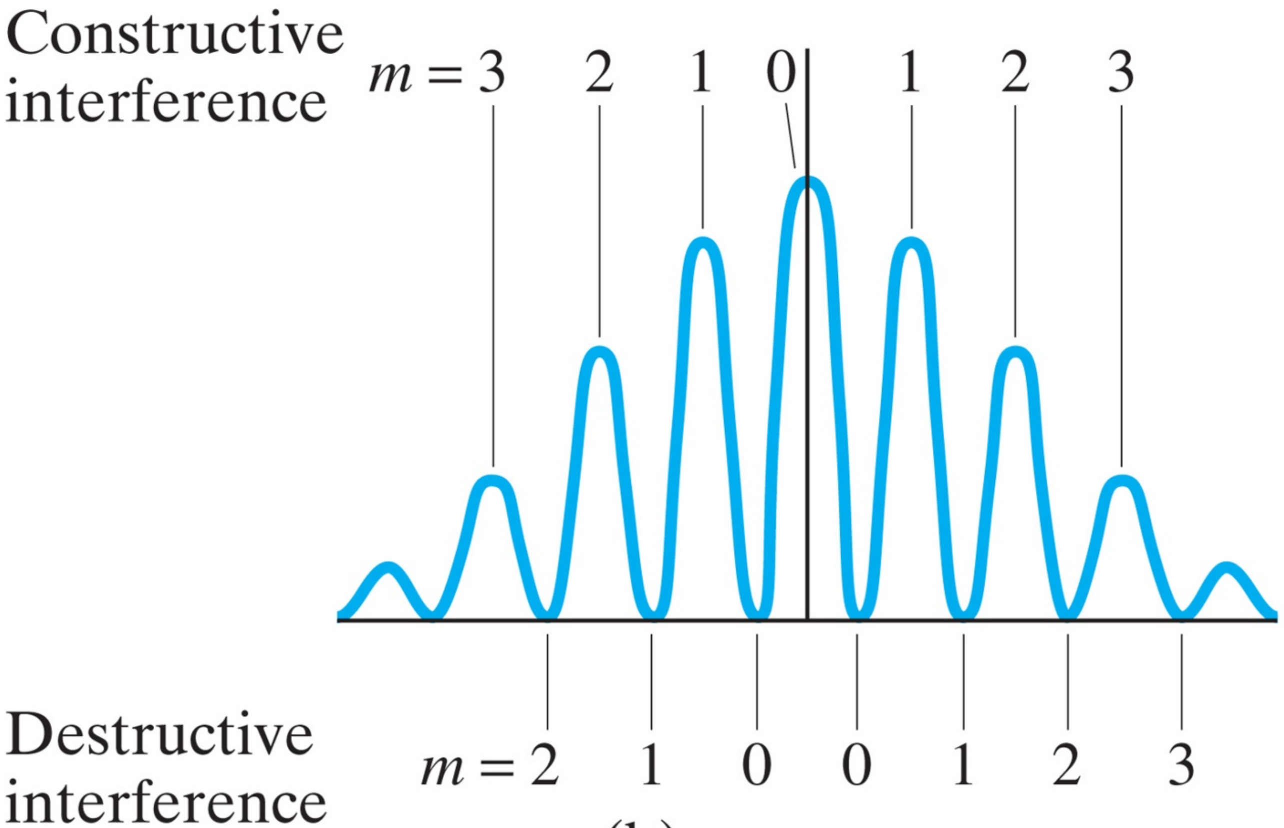
We can use geometry to find the conditions for constructive and destructive interference:

$$d \sin\theta = m\lambda, \qquad m = 0, 1, 2, \cdots. \qquad \begin{bmatrix} \text{constructive} \\ \text{interference} \\ \text{(bright)} \end{bmatrix} \tag{24-2a}$$

$$d \sin\theta = \left(m + \tfrac{1}{2}\right)\lambda, \qquad m = 0, 1, 2, \cdots. \qquad \begin{bmatrix} \text{destructive} \\ \text{interference} \\ \text{(dark)} \end{bmatrix} \tag{24-2b}$$

24.3 Interference – Young's Double-Slit Experiment

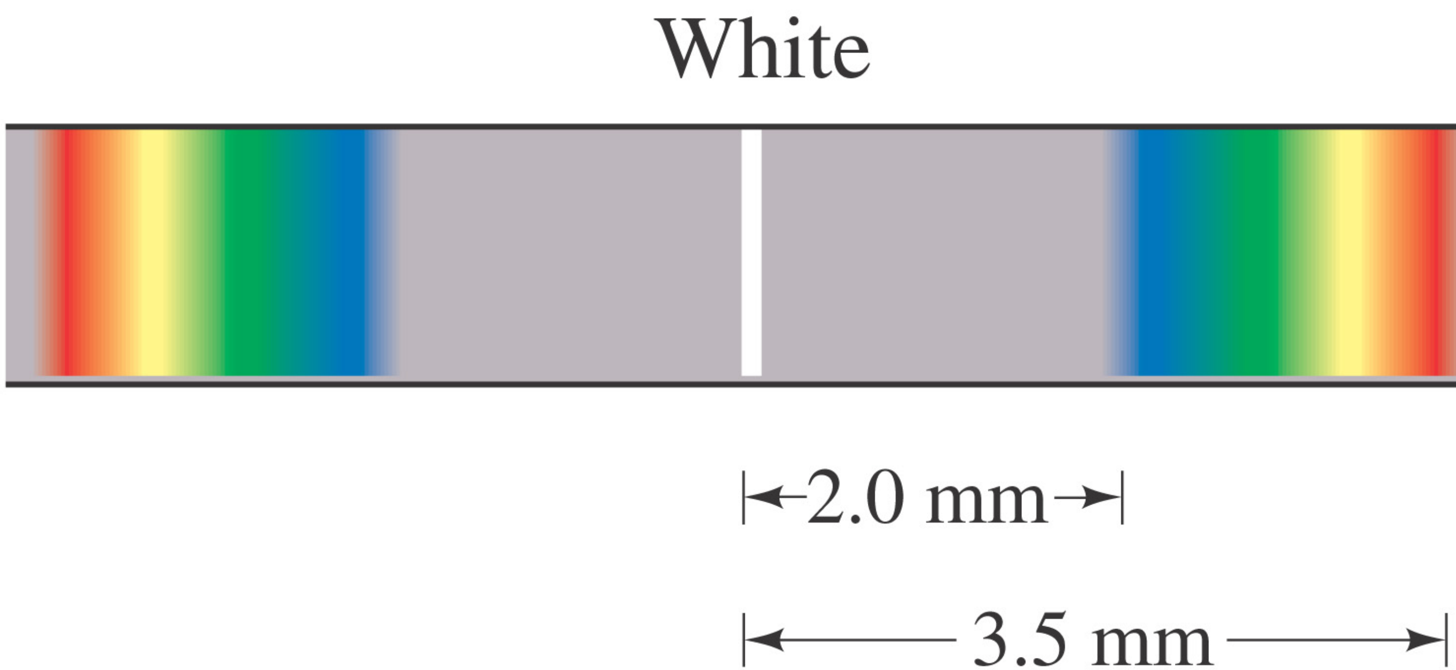
Between the maxima and the minima, the interference varies smoothly.



(b)

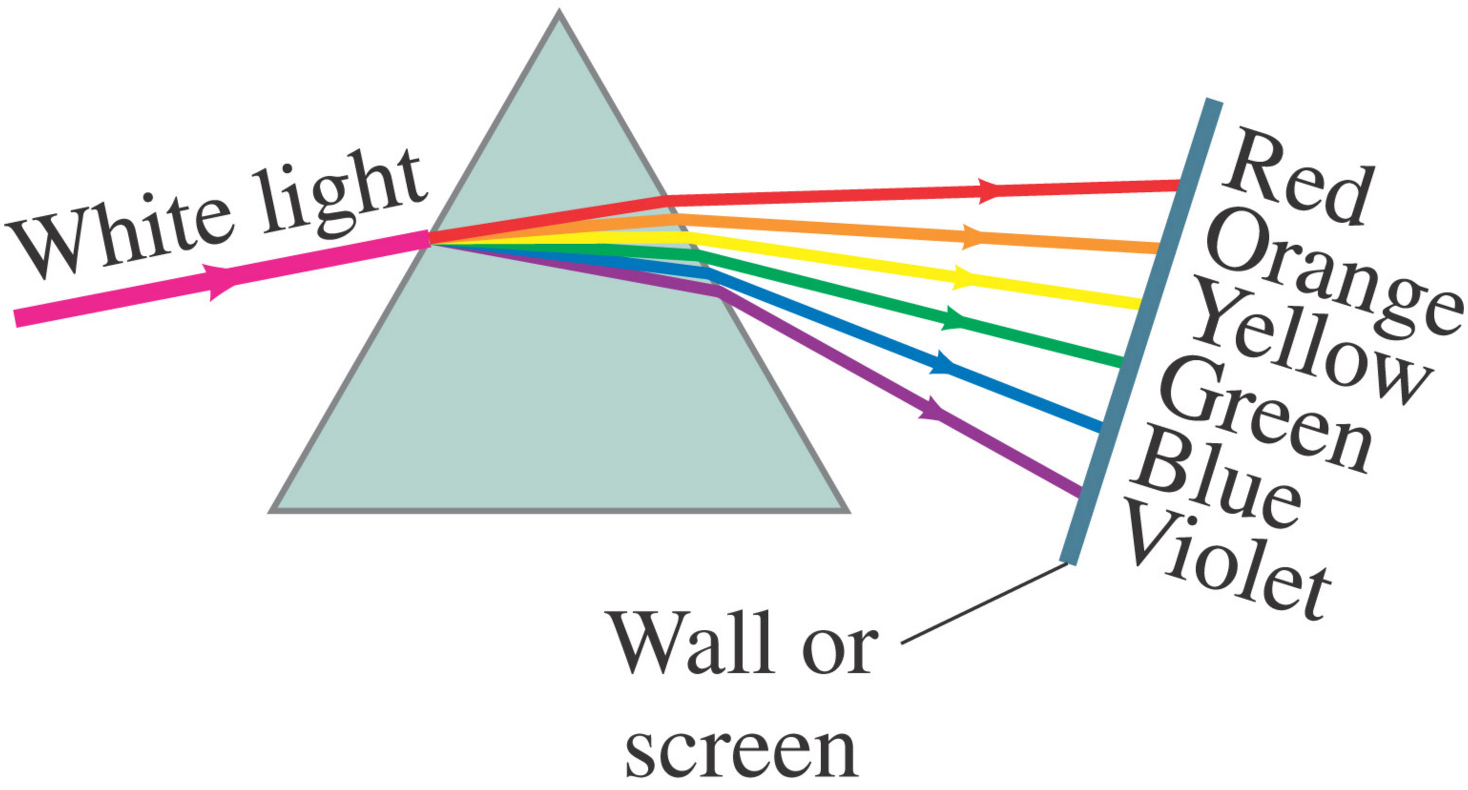
24.3 Interference – Young's Double-Slit Experiment

Since the position of the maxima (except the central one) depends on wavelength, the first- and higher-order fringes contain a spectrum of colors.



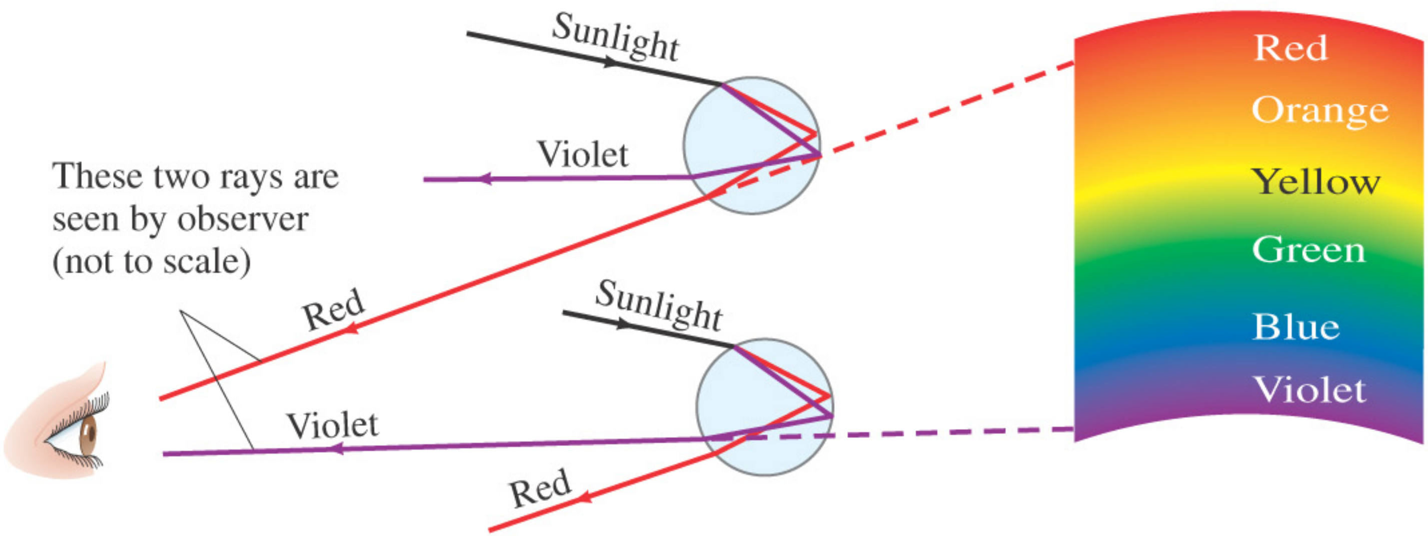
24.4 The Visible Spectrum and Dispersion

This variation in refractive index is why a prism will split visible light into a rainbow of colors.



24.4 The Visible Spectrum and Dispersion

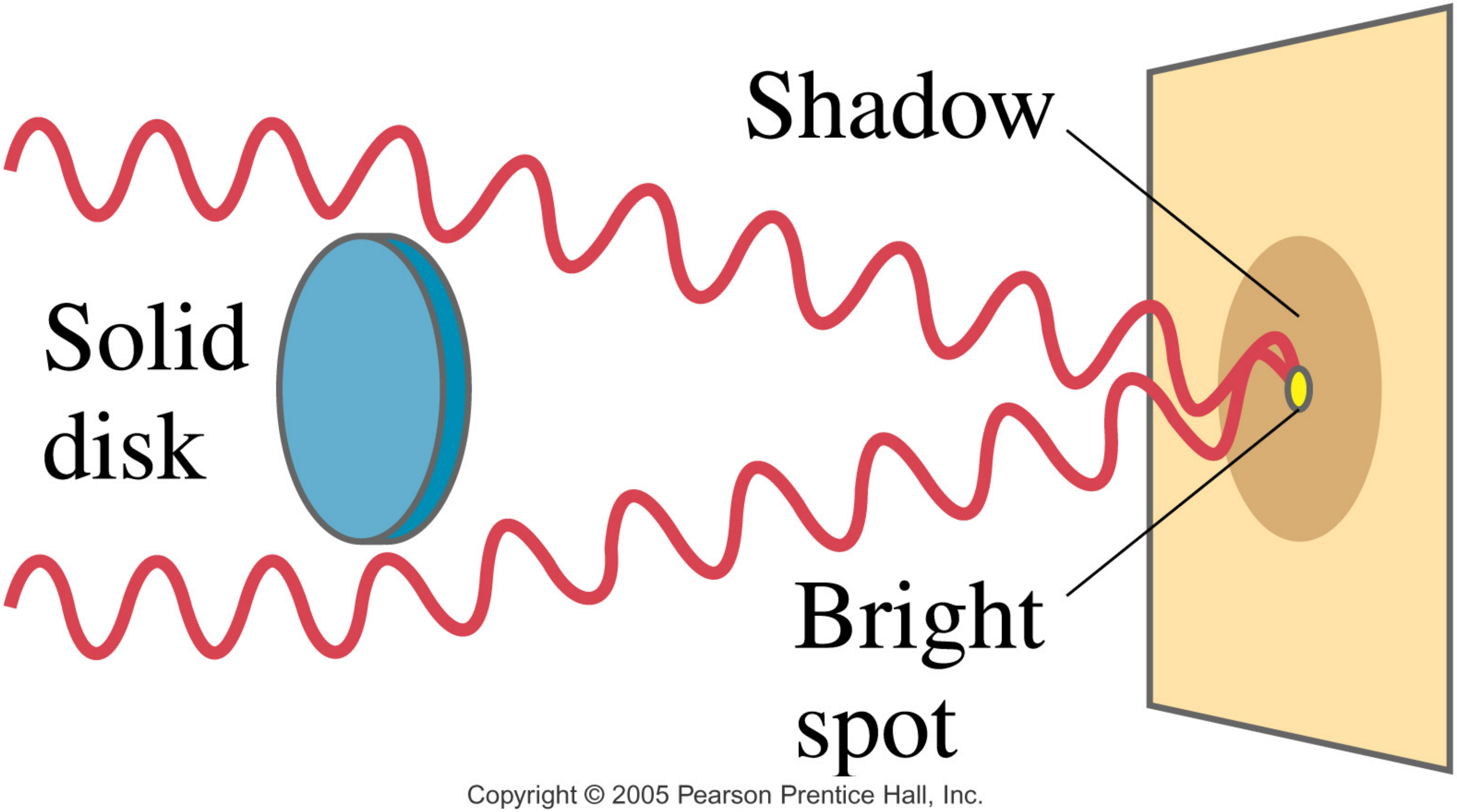
Actual rainbows are created by dispersion in tiny drops of water.



(a)

24.5 Diffraction by a Single Slit or Disk

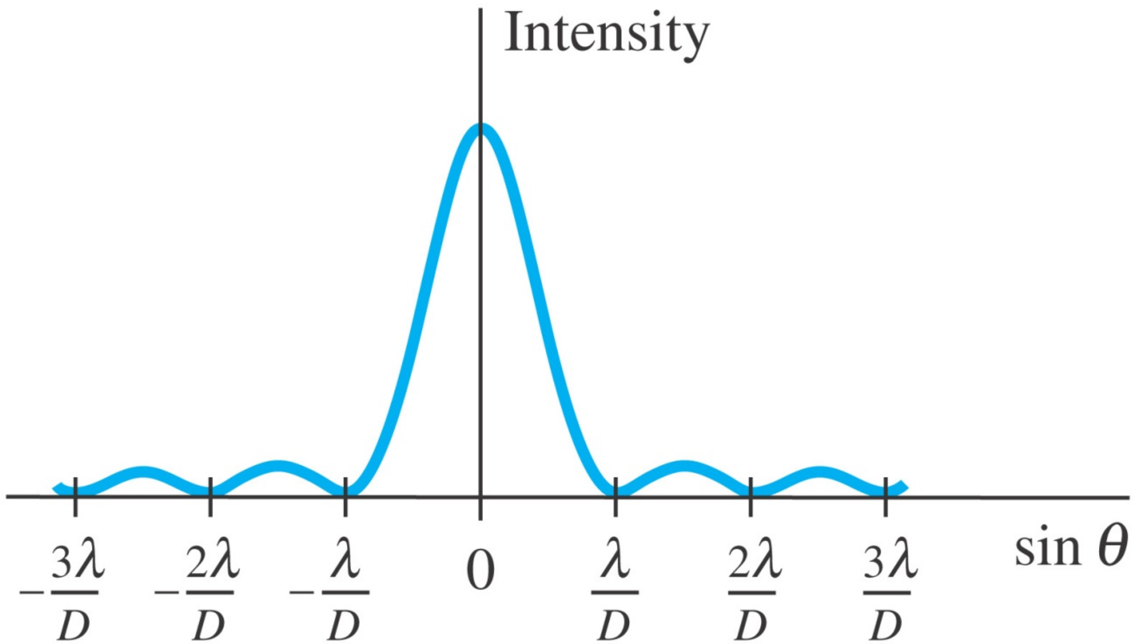
Light will also diffract around a single slit or obstacle.



24.5 Diffraction by a Single Slit or Disk

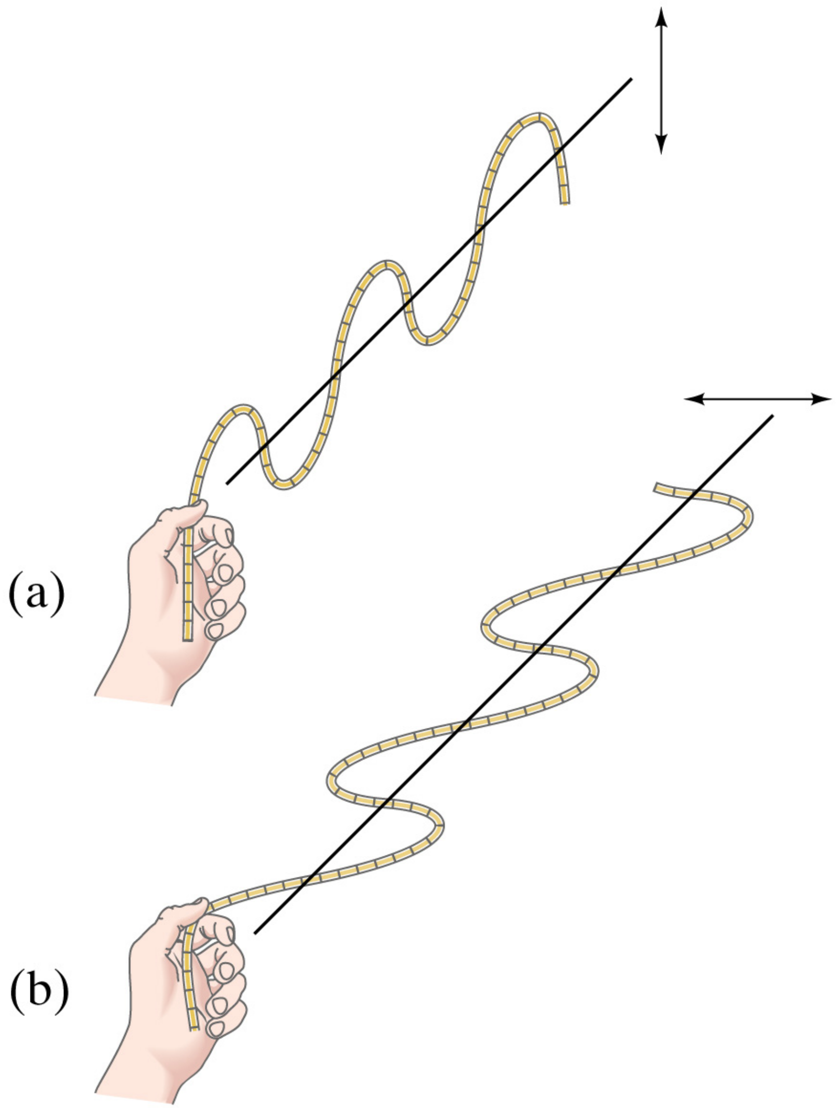
The resulting pattern of light and dark stripes is called a diffraction pattern.

This pattern arises because different points along a slit create wavelets that interfere with each other just as a double slit would.



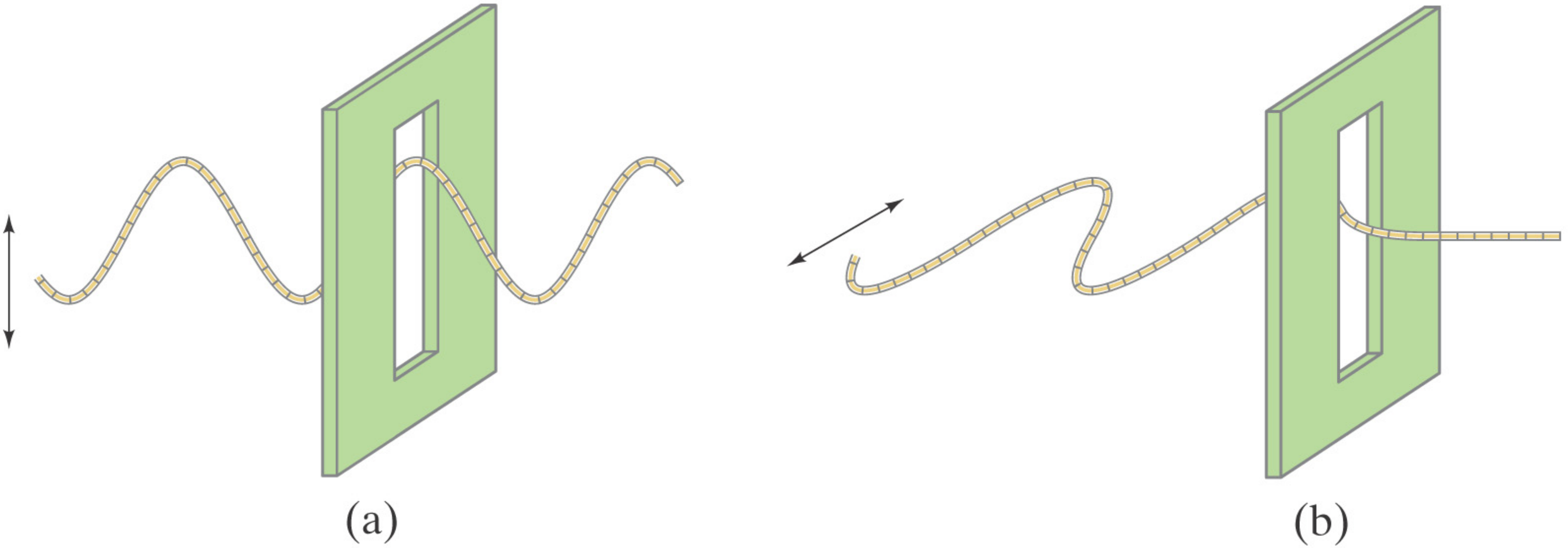
24.10 Polarization

Light is polarized when its electric fields oscillate in a single plane, rather than in any direction perpendicular to the direction of propagation.



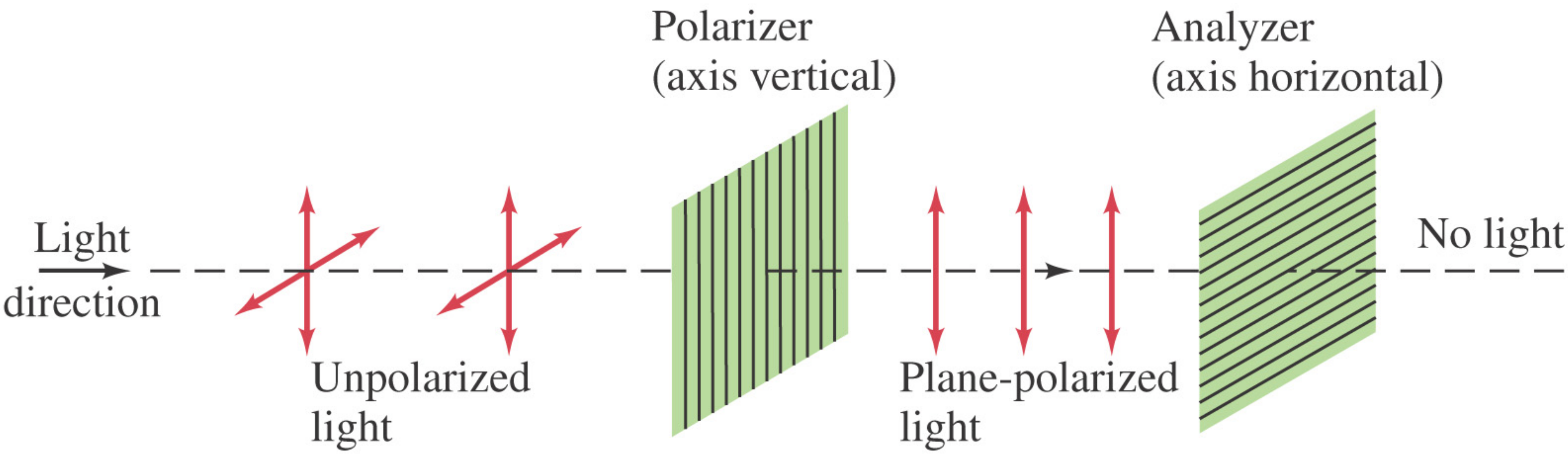
24.10 Polarization

Polarized light will not be transmitted through a polarized film whose axis is perpendicular to the polarization direction.



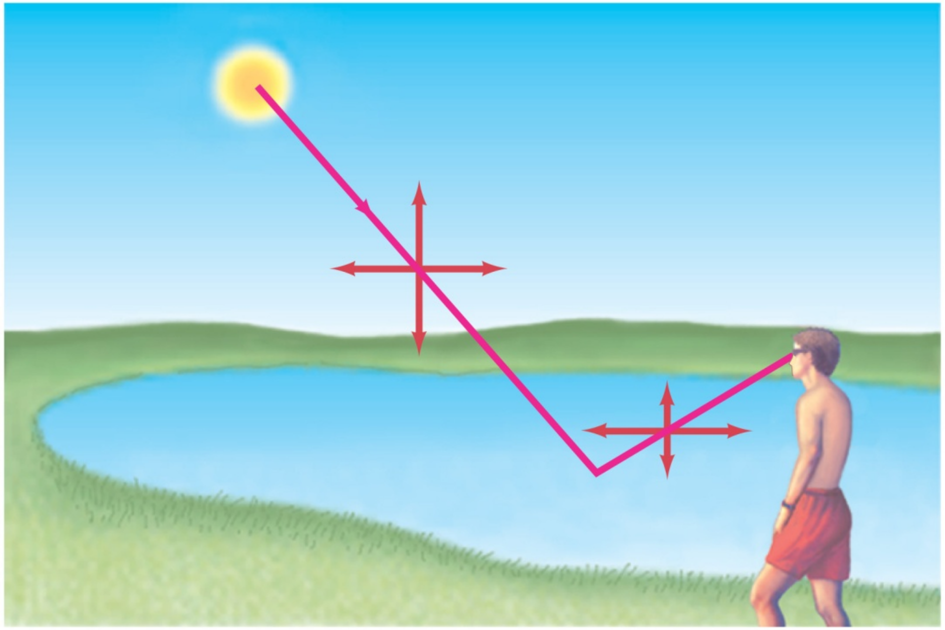
24.10 Polarization

This means that if initially unpolarized light passes through crossed polarizers, no light will get through the second one.



24.10 Polarization

Light is also partially polarized after reflecting from a nonmetallic surface. At a special angle, called the polarizing angle or Brewster's angle, the polarization is 100%.



$$\tan \theta_p = \frac{n_2}{n_1} \qquad \textbf{(24-6a)}$$

Summary of Chapter 24

- The wave theory of light is strengthened by the interference and diffraction of light

- Huygens' principle: every point on a wavefront is a source of spherical wavelets

- Wavelength of light in a medium with index of refraction n:

$$\lambda_n = \frac{\lambda}{n}$$

- Young's double-slit experiment demonstrated interference

Summary of Chapter 24

- In the double-slit experiment, constructive interference occurs when

$$\sin\theta = m\frac{\lambda}{d}$$

- and destructive interference when

$$\sin\theta = \left(m + \tfrac{1}{2}\right)\frac{\lambda}{d}$$

- Two sources of light are coherent if they have the same frequency and maintain the same phase relationship

Summary of Chapter 24

- Visible spectrum of light ranges from 400 nm to 750 nm (approximately)
- Index of refraction varies with wavelength, leading to dispersion
- Diffraction grating has many small slits or lines, and the same condition for constructive interference
- Wavelength can be measured precisely with a spectroscope

Summary of Chapter 24

- Light bends around obstacles and openings in its path, yielding diffraction patterns
- Light passing through a narrow slit will produce a central bright maximum of width

$$\sin\theta = \frac{\lambda}{D}$$

- Interference can occur between reflections from the front and back surfaces of a thin film
- Light whose electric fields are all in the same plane is called plane polarized

Summary of Chapter 24

- The intensity of plane polarized light is reduced after it passes through another polarizer:

$$I = I_0 \cos^2 \theta$$

- Light can also be polarized by reflection; it is completely polarized when the reflection angle is the polarization angle:

$$\tan \theta_{\mathrm{p}} = n$$