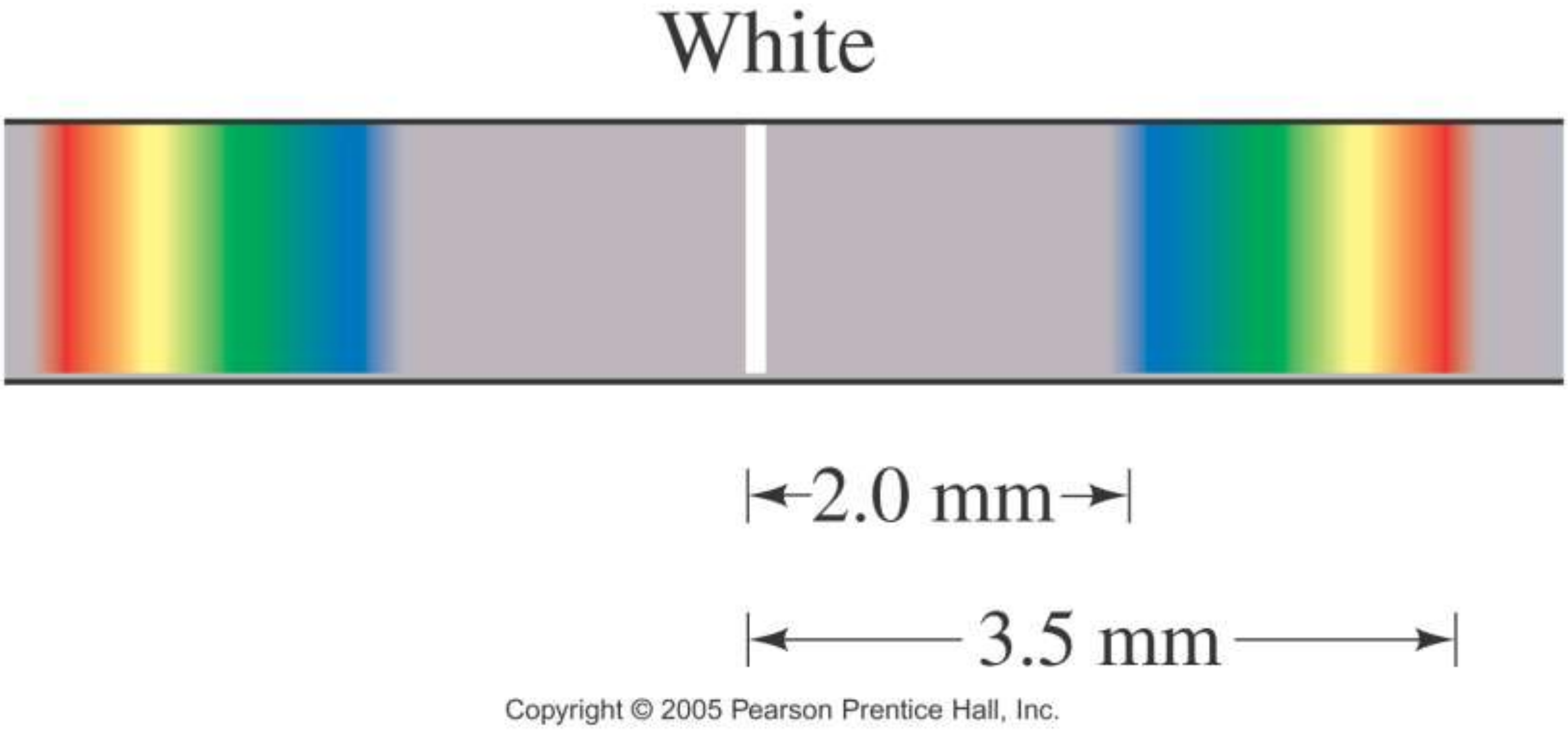
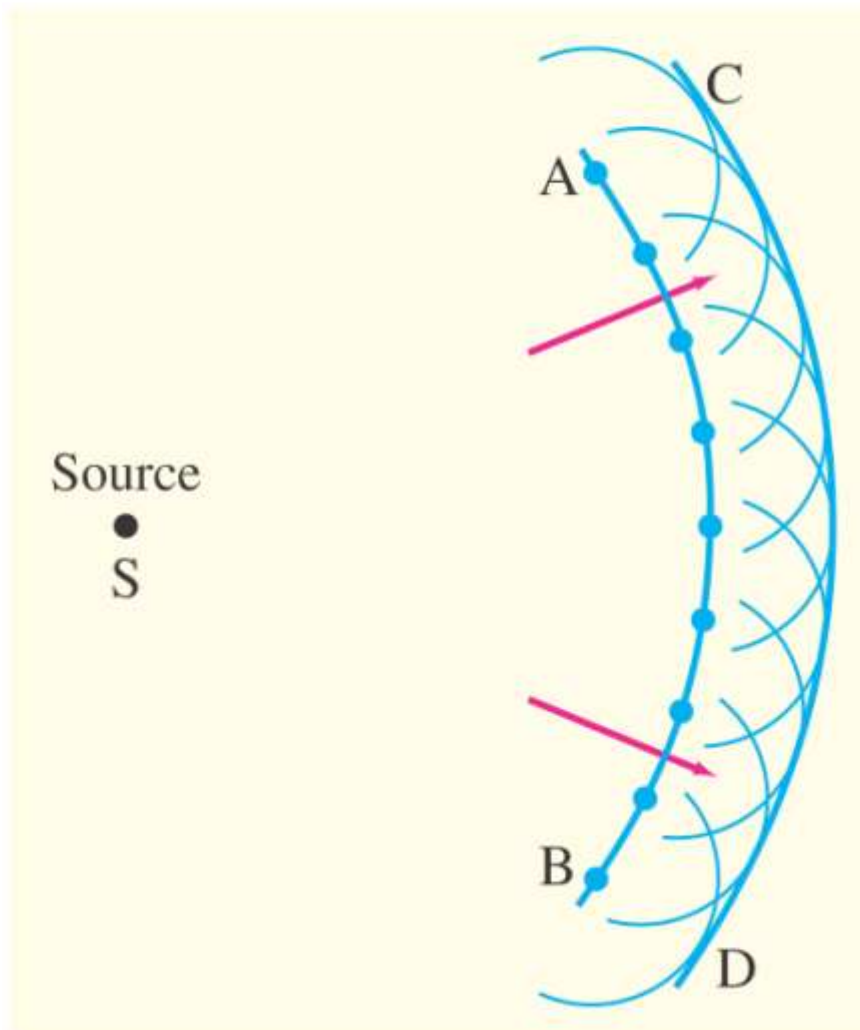
Chapter 24

The Wave Nature of Light



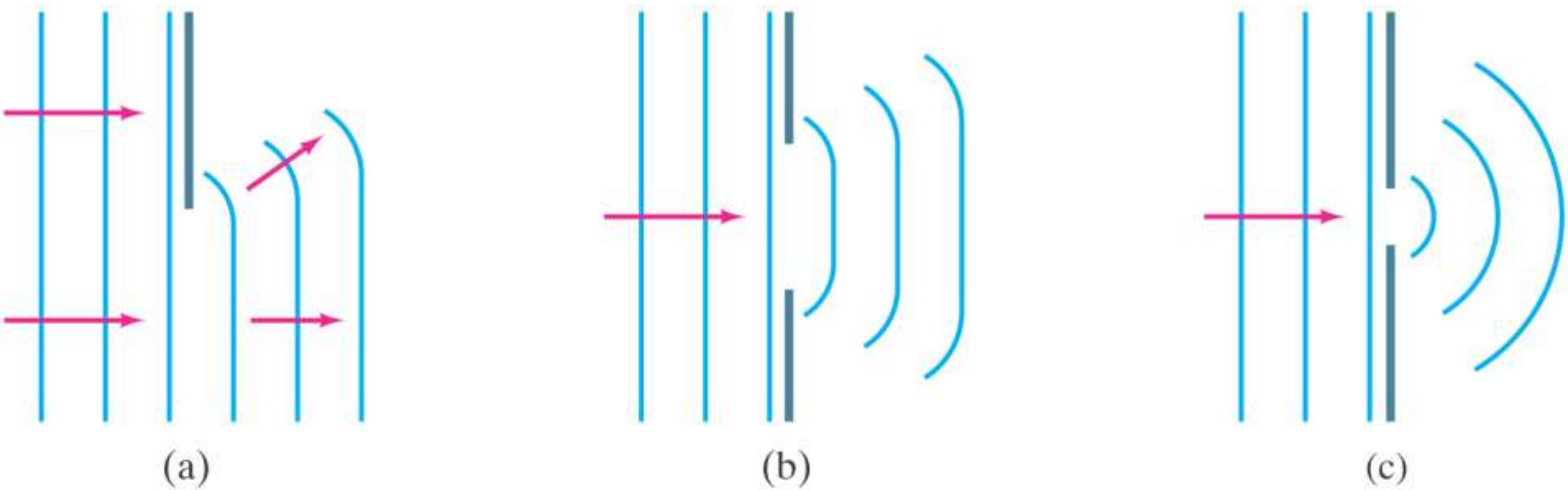
24.1 Waves Versus Particles; Huygens' Principle and Diffraction

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

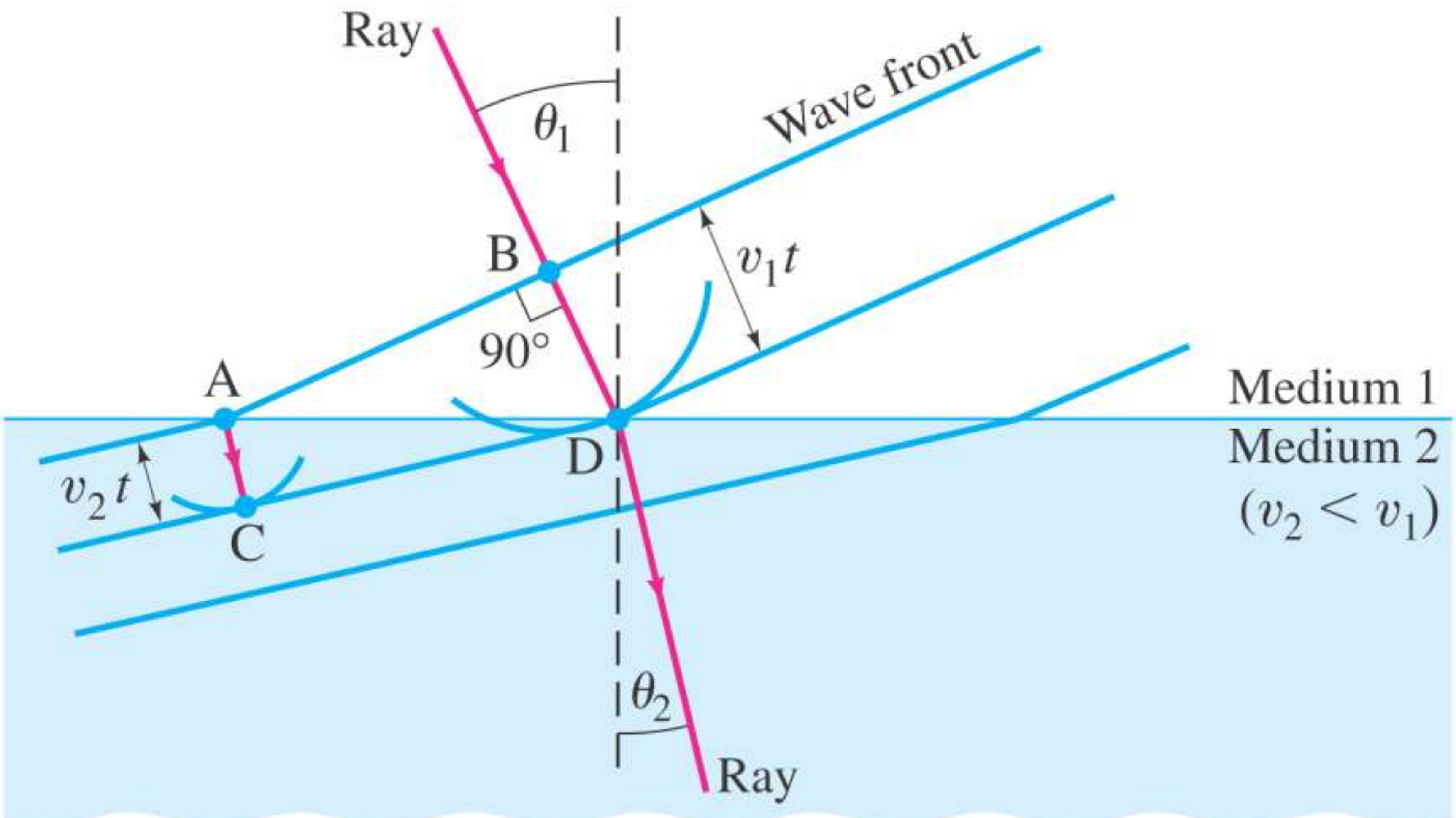


24.1 Waves Versus Particles; Huygens' Principle and Diffraction

Huygens' principle is consistent with diffraction:



24.2 Huygens' Principle and the Law of Refraction



24.2 Huygens' Principle and the Law of Refraction

Huygens' principle can also explain the law of refraction.

As the wavelets propagate from each point, they propagate more slowly in the medium of higher index of refraction.

This leads to a bend in the wavefront and therefore in the ray.

24.2 Huygens' Principle and the Law of Refraction

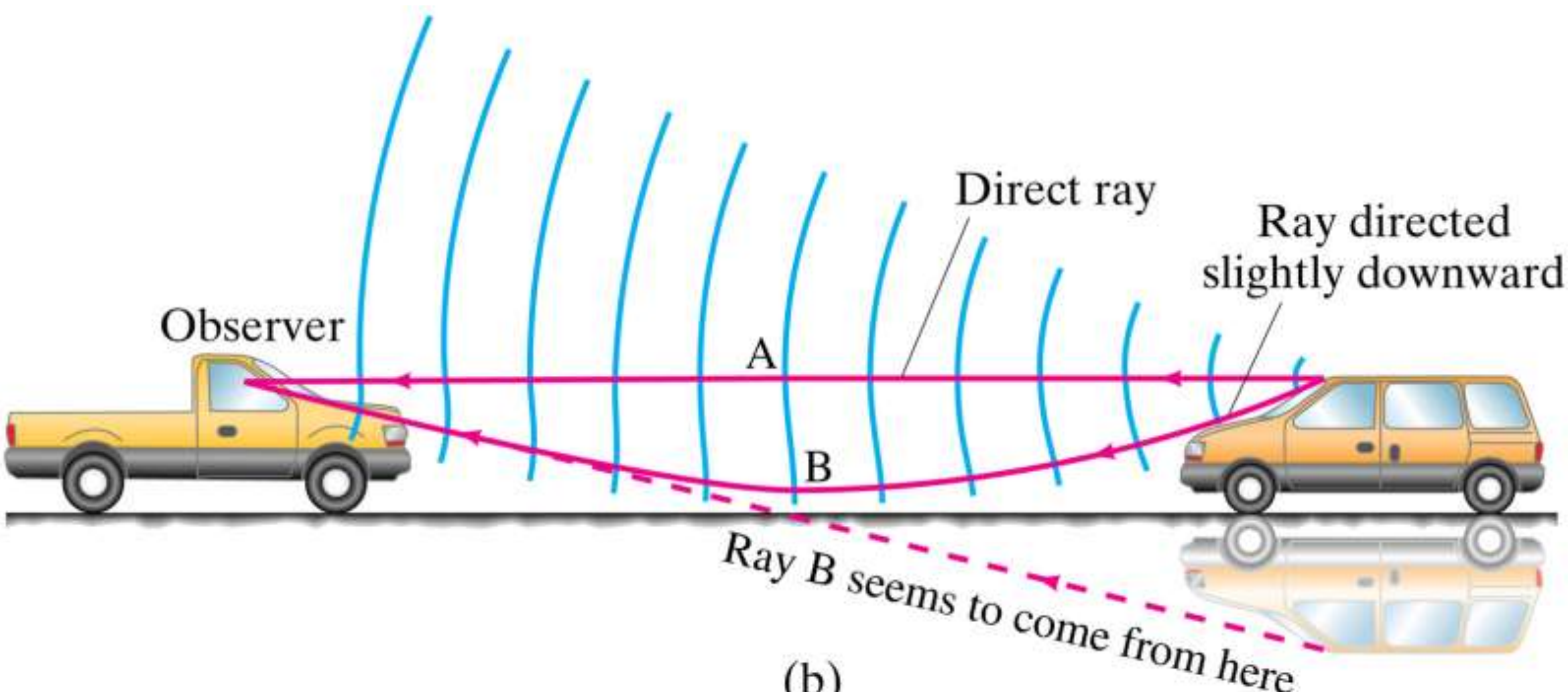
The frequency of the light does not change, but the wavelength does as it travels into a new medium.

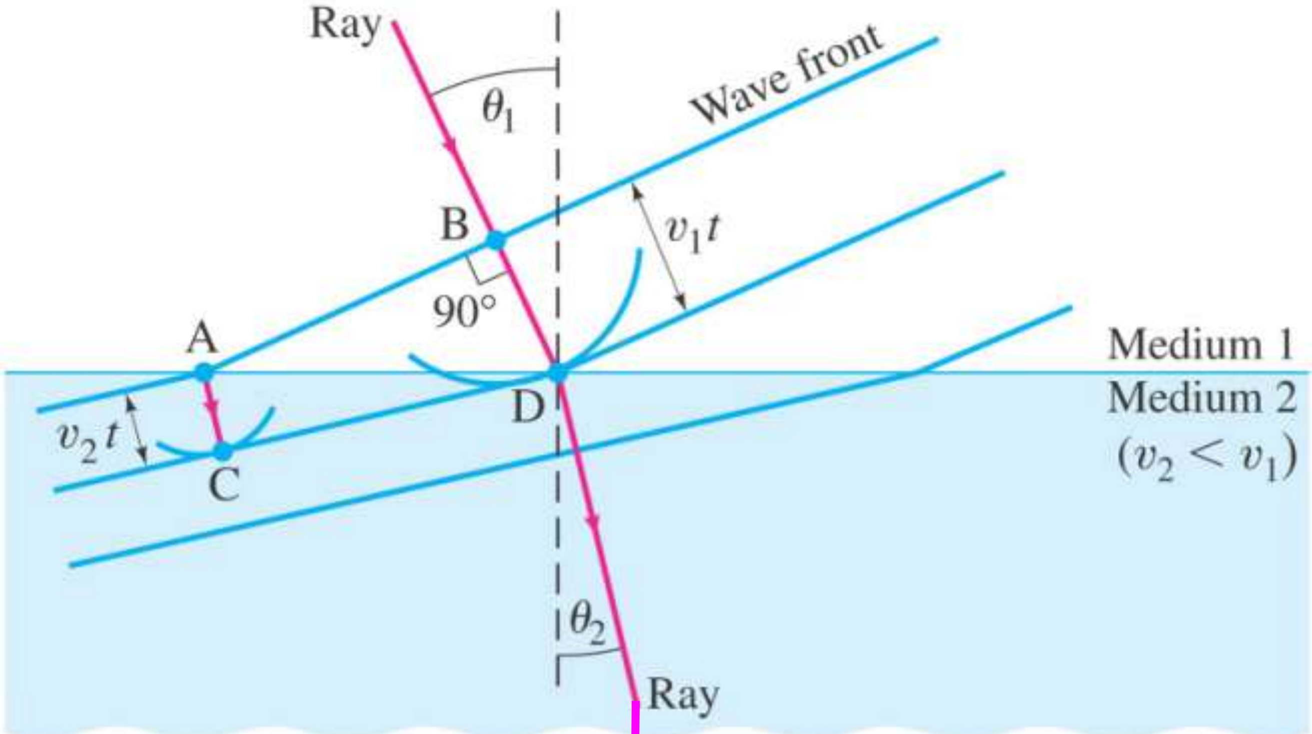
$$\frac{\lambda_2}{\lambda_1} = \frac{v_2 t}{v_1 t} = \frac{v_2}{v_1} = \frac{n_1}{n_2}$$

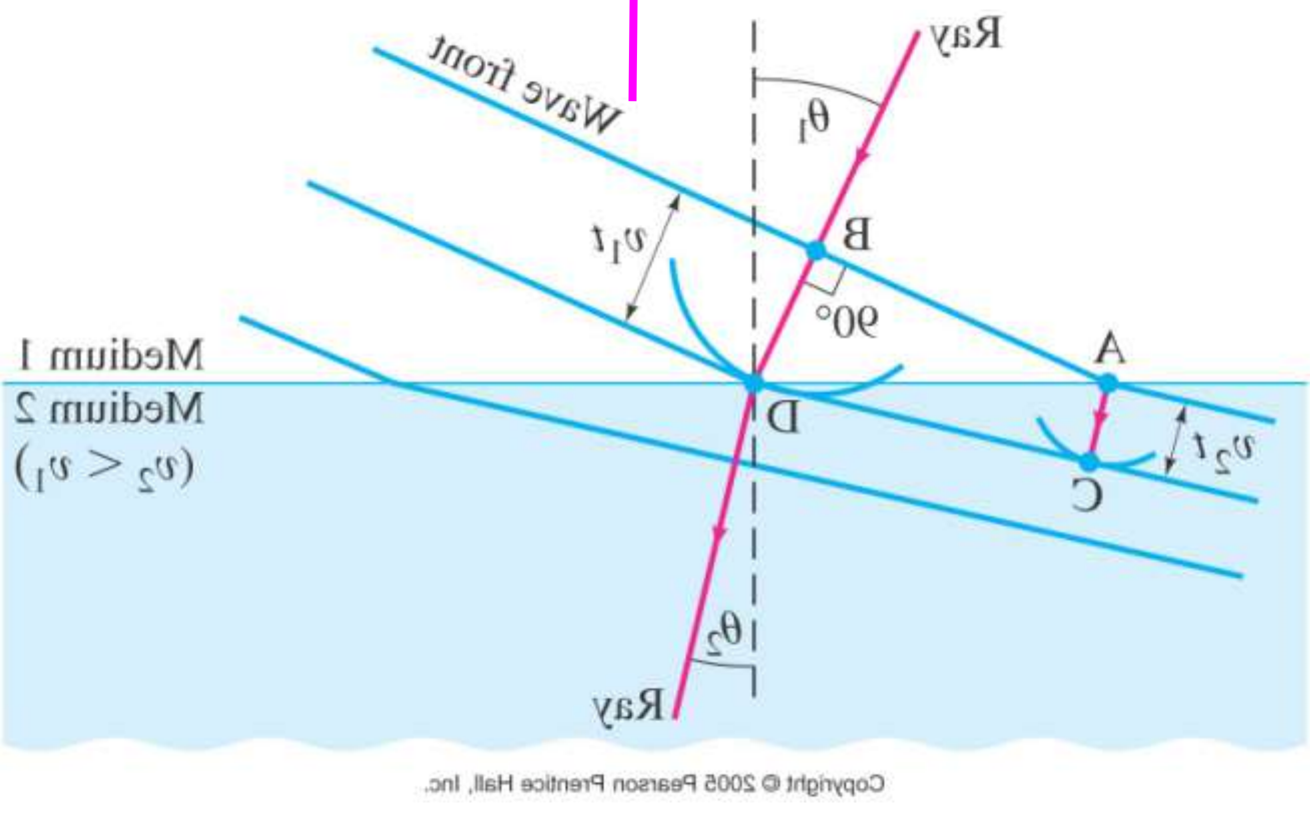
$$\lambda_n = \frac{\lambda}{n} \qquad \textbf{(24-1)}$$

24.2 Huygens' Principle and the Law of Refraction

Highway mirages are due to a gradually changing index of refraction in heated air.







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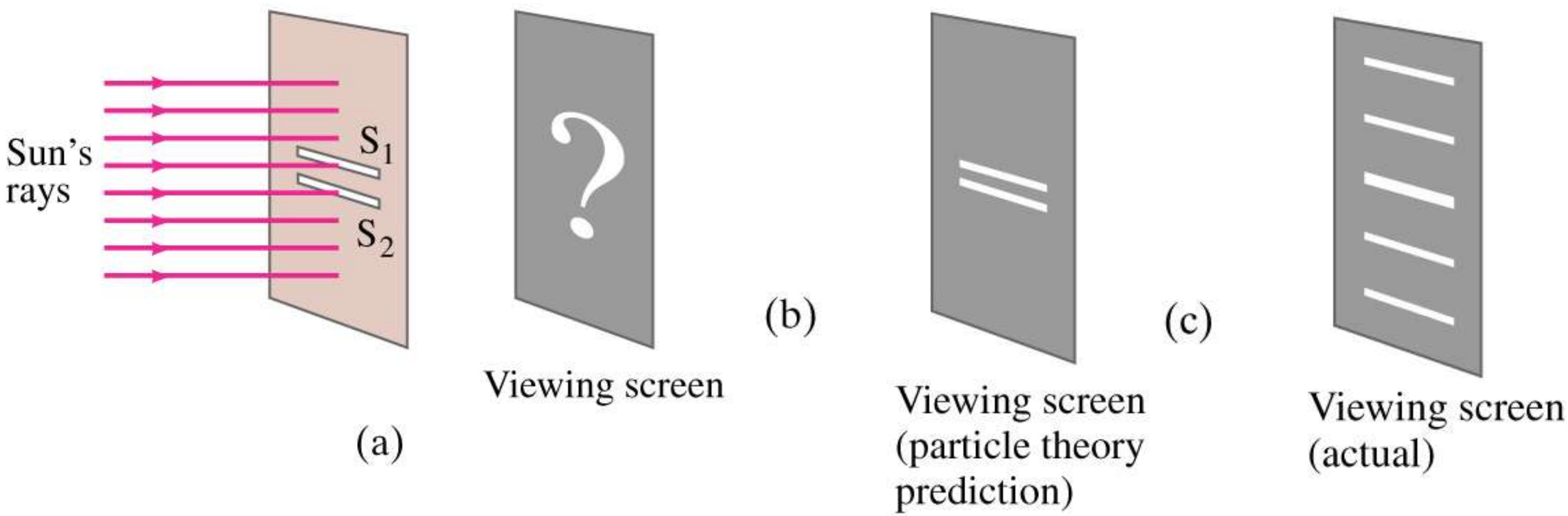
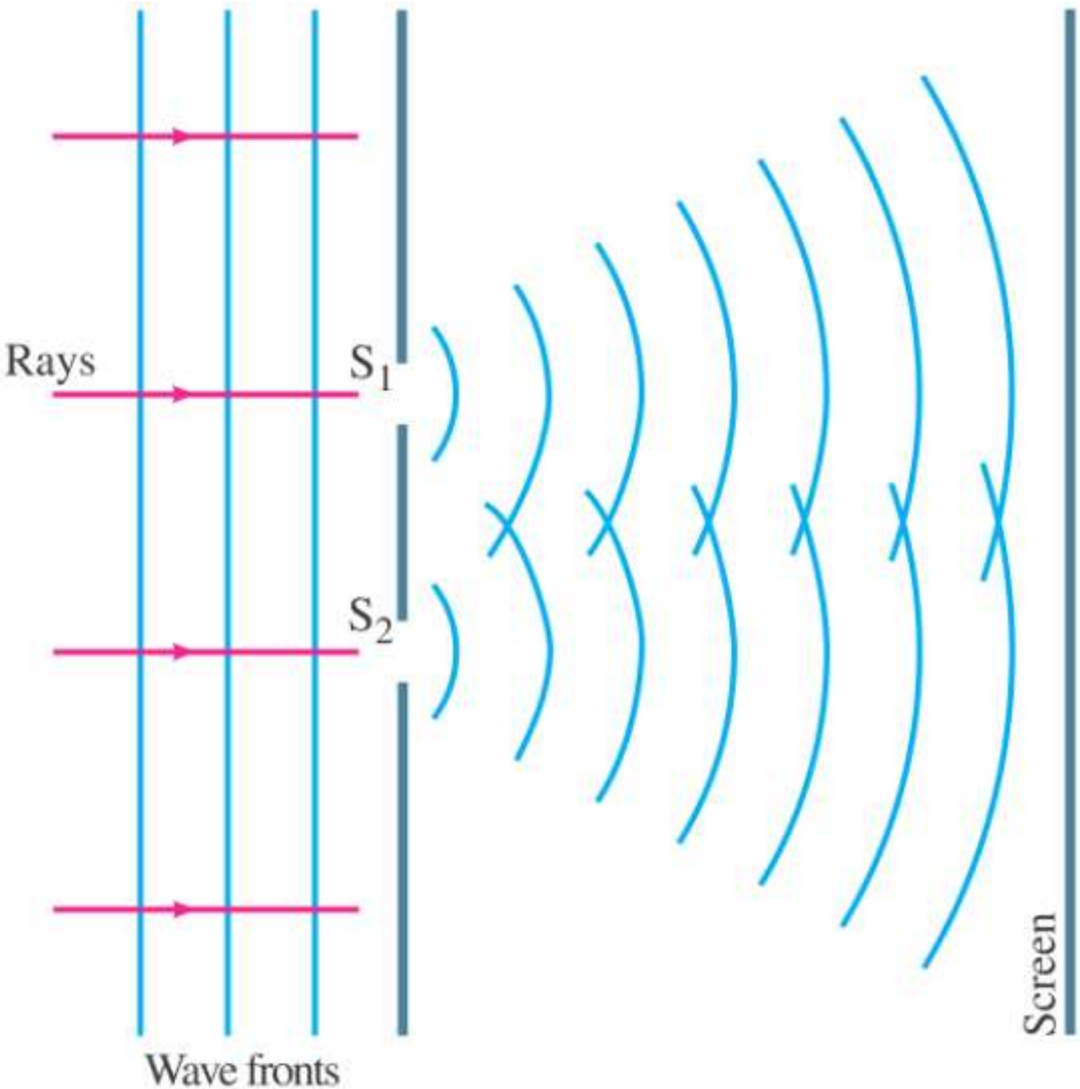
24.3 Interference – Young's Double-Slit Experiment

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:



24.3 Interference – Young's Double-Slit Experiment



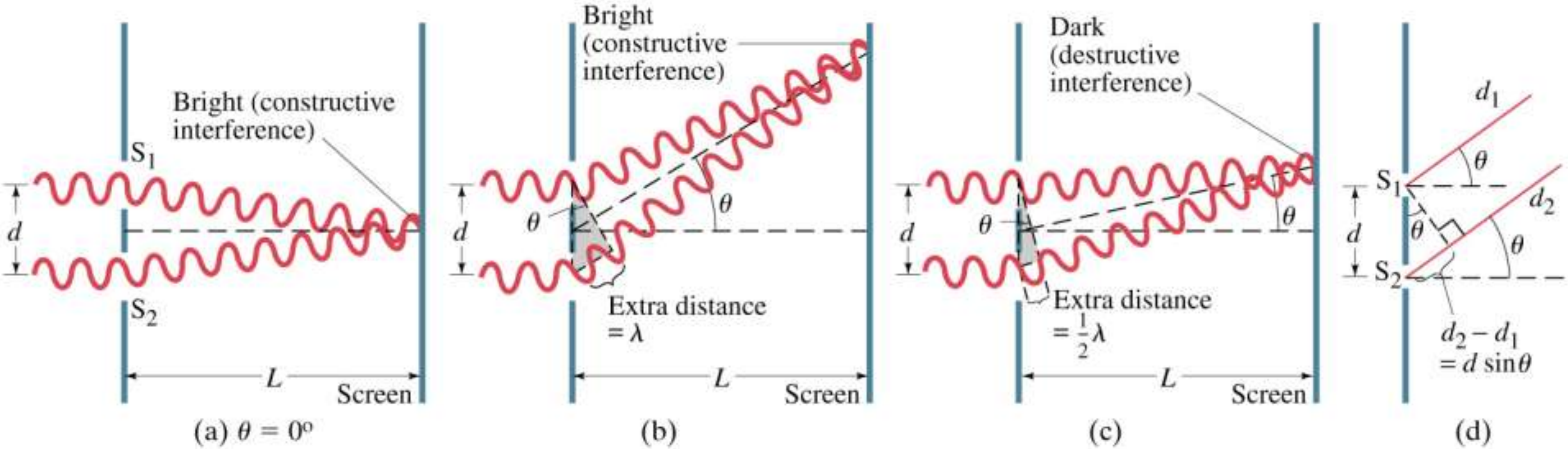
If light is a wave, there should be an interference pattern.

24.3 Interference – Young's Double-Slit Experiment

[Time for a Gizmo!]

24.3 Interference – Young's Double-Slit Experiment

The interference occurs because each point on the screen is not the same distance from both slits. Depending on the path length difference, the wave can interfere constructively (bright spot) or destructively (dark spot).



24.3 Interference – Young's Double-Slit Experiment

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

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

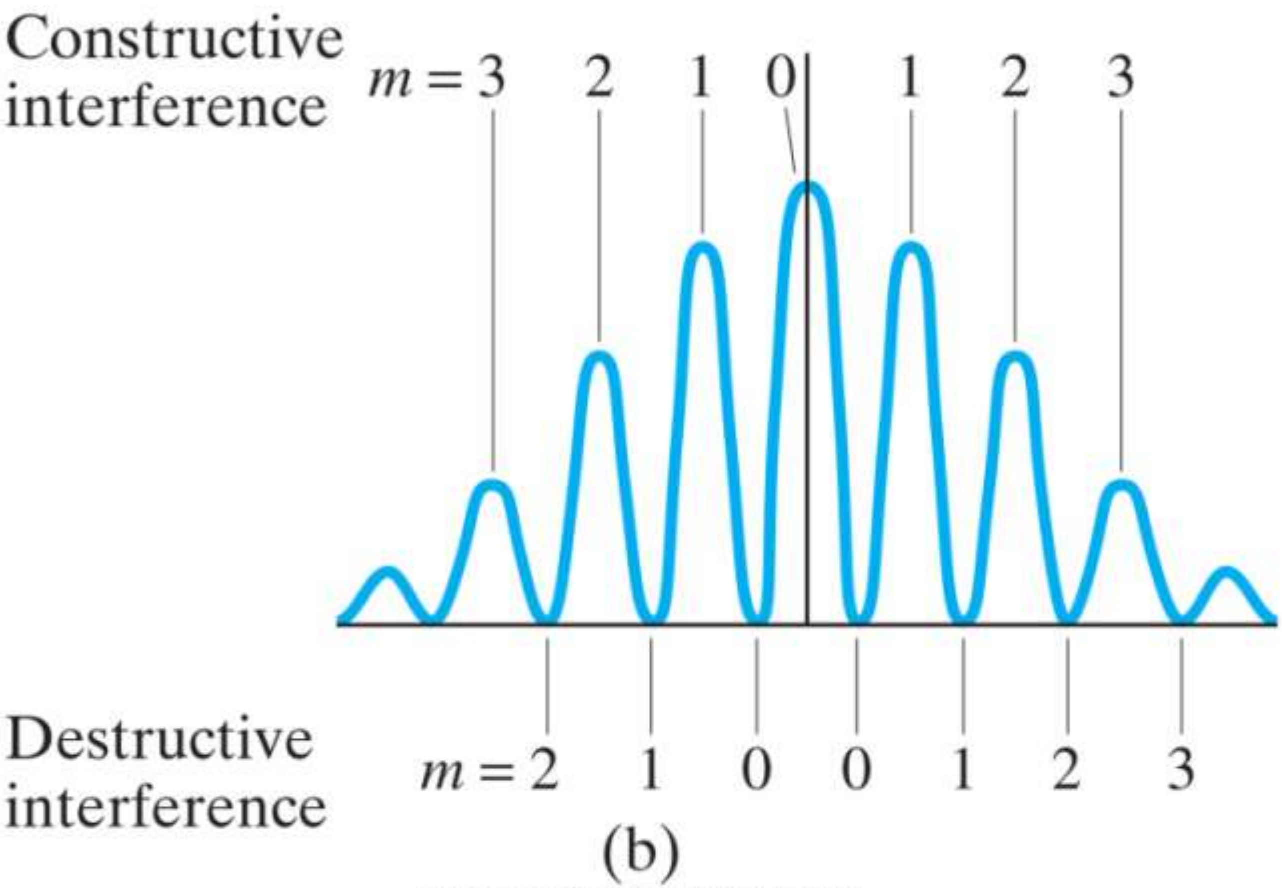
(24-2a)

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

(24-2b)

24.3 Interference – Young's Double-Slit Experiment

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



24.3 Interference – Young's Double-Slit Experiment

Since the position of the maxima (except the central one) depends on wavelength,

$$d \sin\theta = m\lambda, \qquad m = 0, 1, 2, \cdots. \qquad \left[\begin{array}{c}\text{constructive}\\ \text{interference}\\ \text{(bright)}\end{array}\right]$$

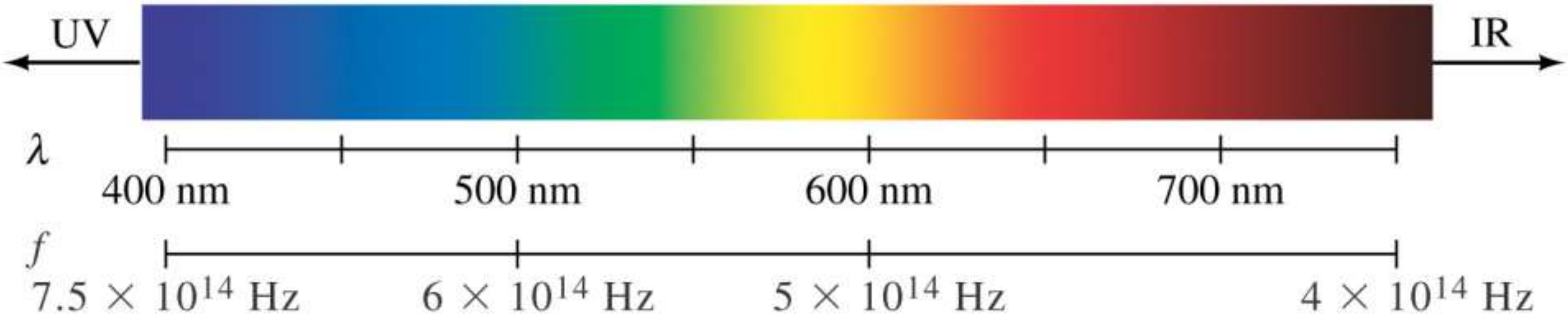
the first- and higher-order fringes contain a spectrum of colors.

White

24.4 The Visible Spectrum and Dispersion

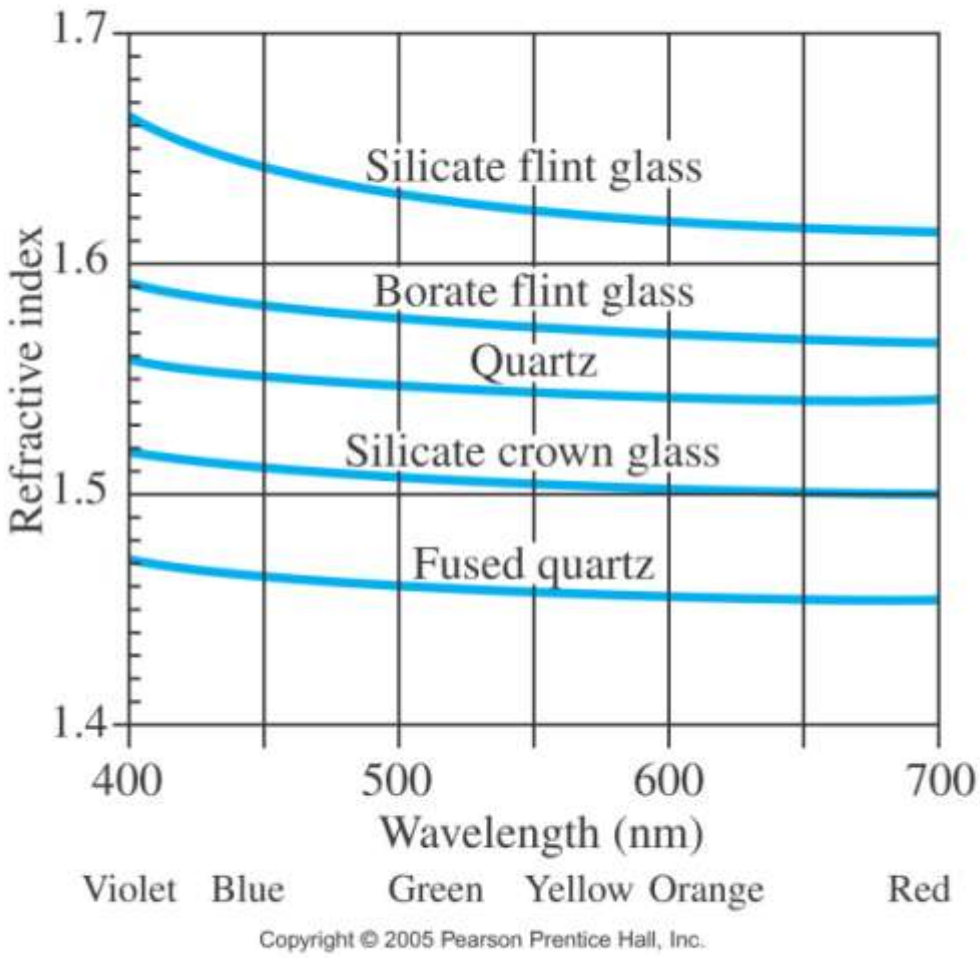
Wavelengths of visible light: 400 nm to 750 nm

Shorter wavelengths are ultraviolet; longer are infrared



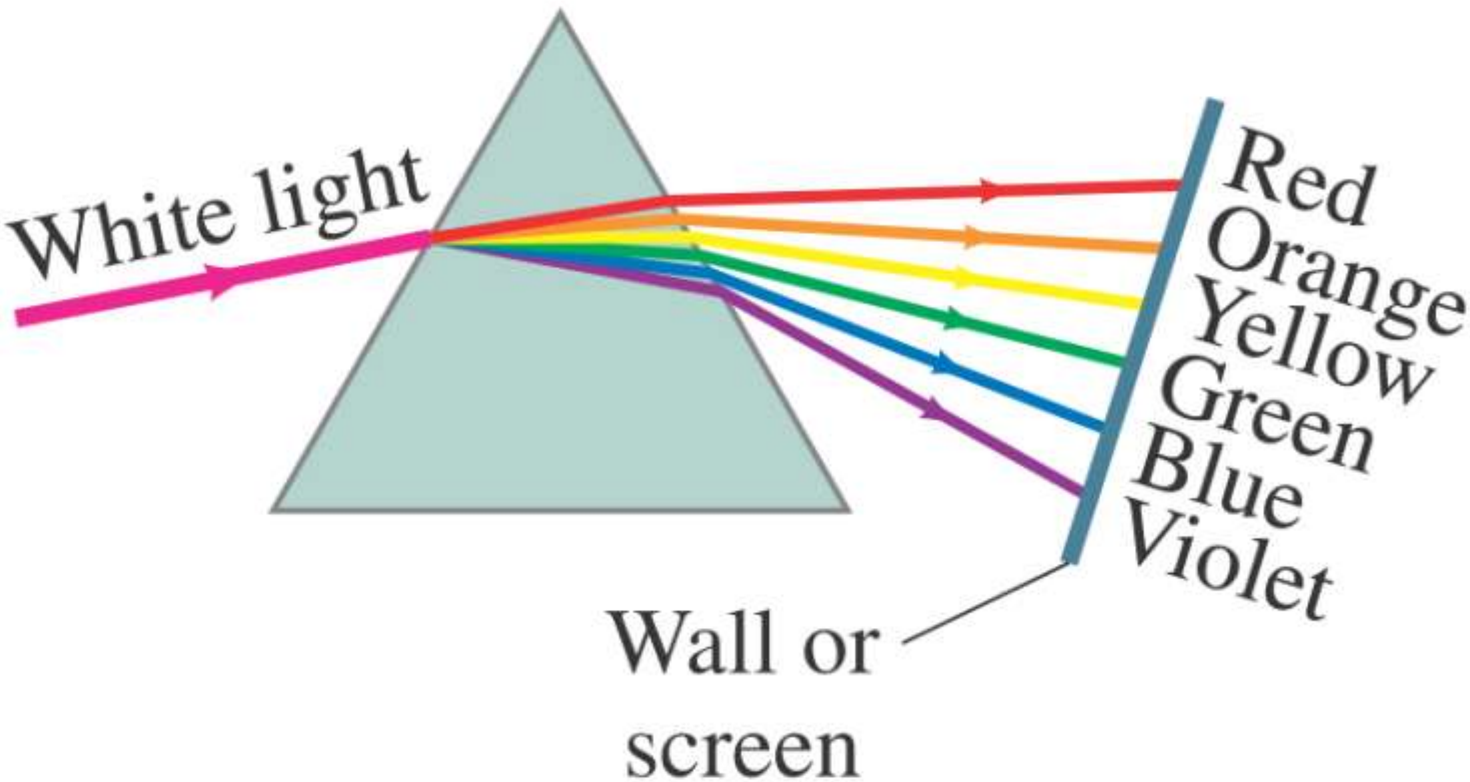
24.4 The Visible Spectrum and Dispersion

The index of refraction of a material varies somewhat with the wavelength of the light.



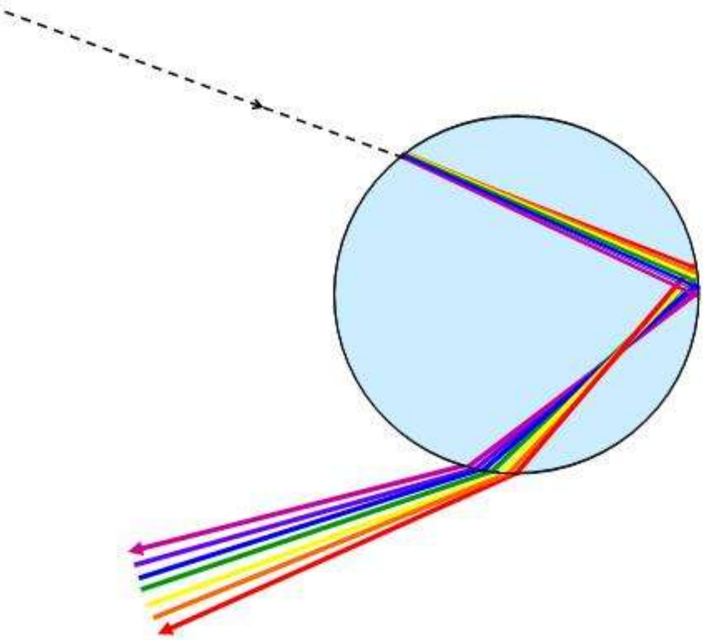
24.4 The Visible Spectrum and Dispersion

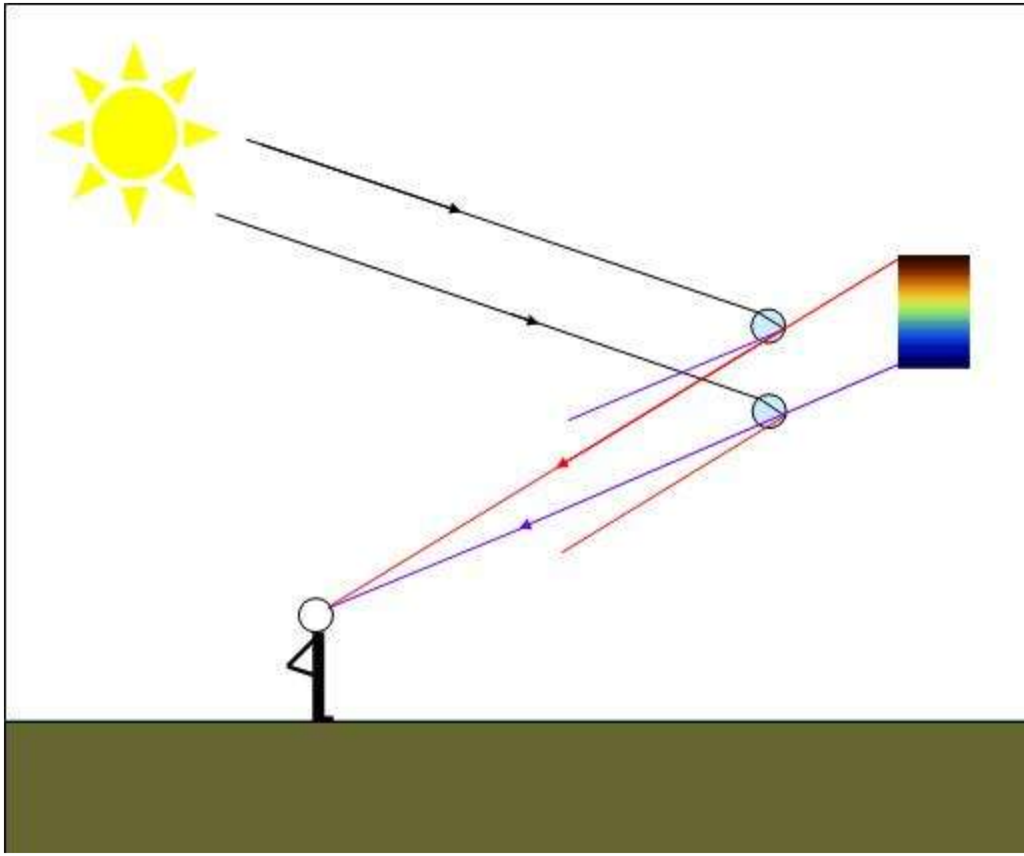
This variation in refractive index is why a prism will split visible light into a rainbow of colors.



24.4 The Visible Spectrum and Dispersion

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





24.4 The Visible Spectrum and Dispersion

Time for a Gizmo!

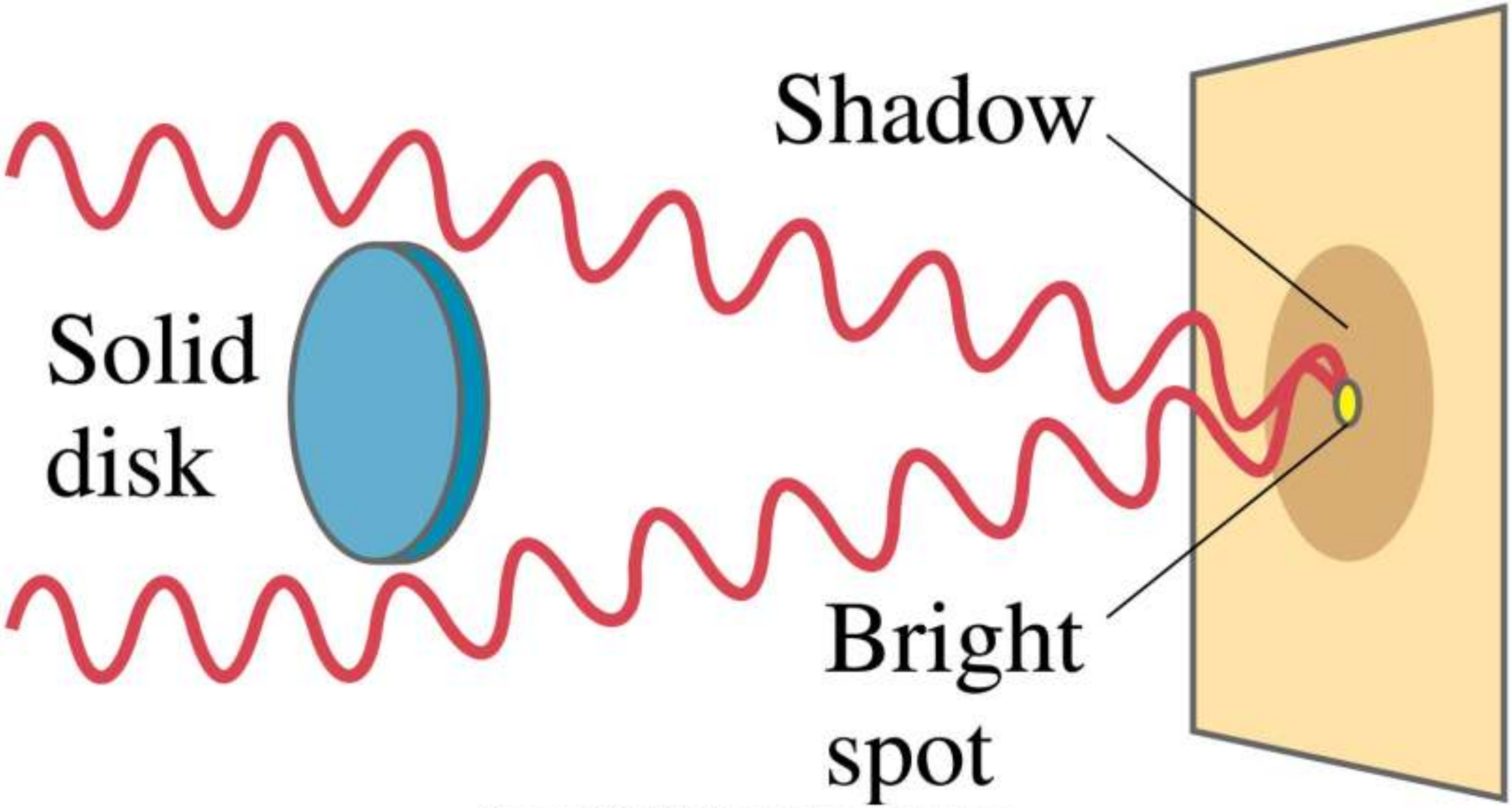
Double Rainbow at Fenway

Sometimes you can see a second rainbow, when two reflections of light within the drop occur. The intensity of this secondary rainbow is much lower than that of the main one and the colors are reversed.

Circle Rainbows

24.5 Diffraction by a Single Slit or Disk

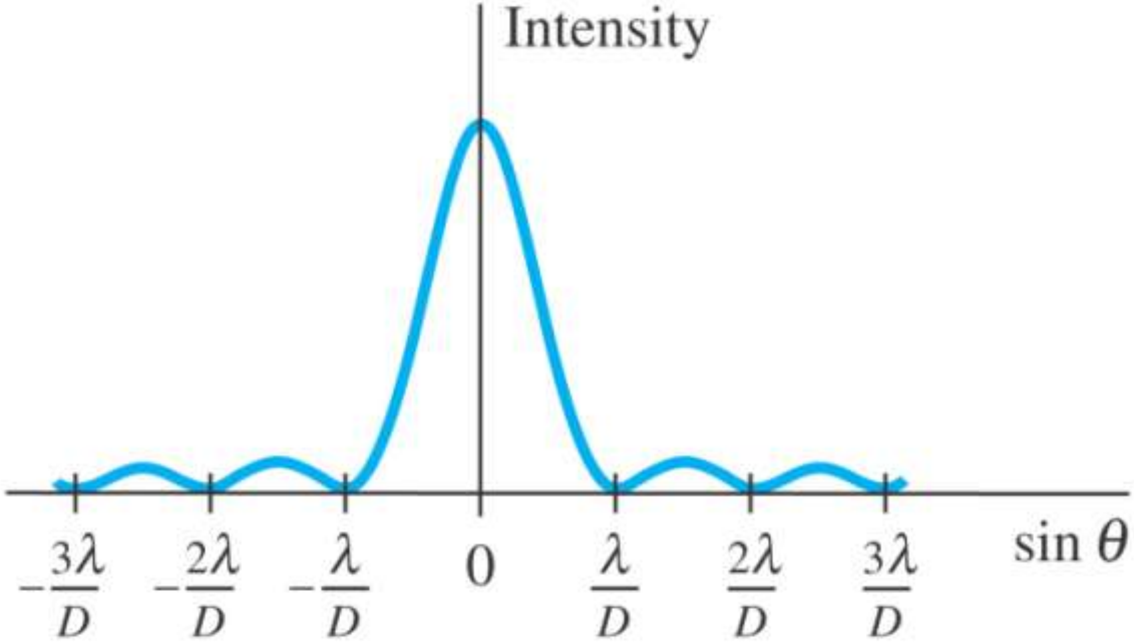
Light will also diffract around a single slit or obstacle.



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.



24.5 Diffraction by a Single Slit or Disk

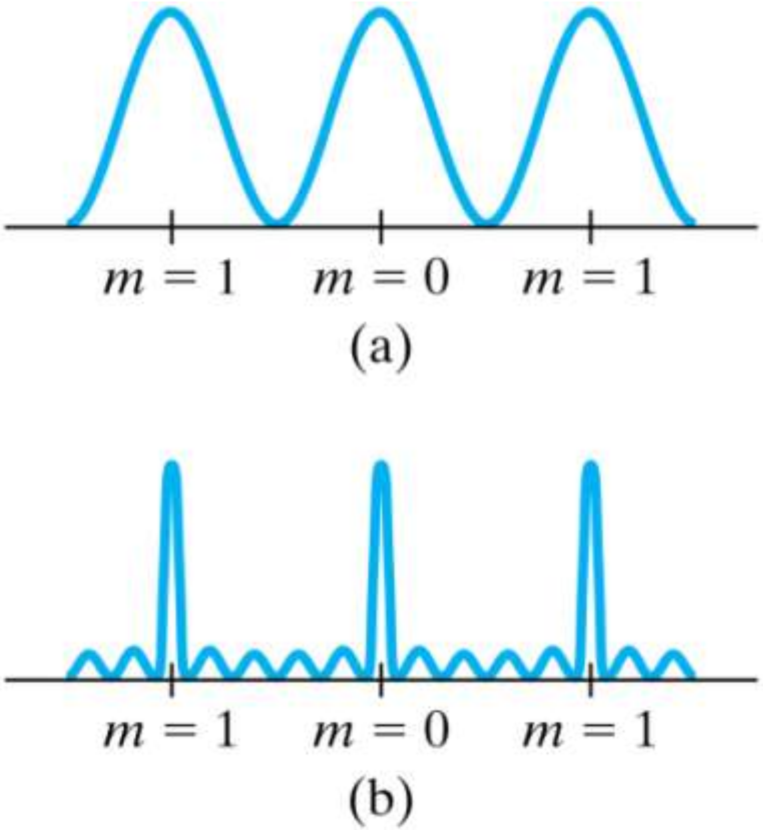
The minima of the single-slit diffraction pattern occur when

$$D \sin\theta = m\lambda, \qquad m = 1, 2, 3, \cdots \qquad \textbf{(24-3b)}$$

24.6 Diffraction Grating

A diffraction grating consists of a large number of equally spaced narrow slits or lines. A transmission grating has slits, while a reflection grating has lines that reflect light.

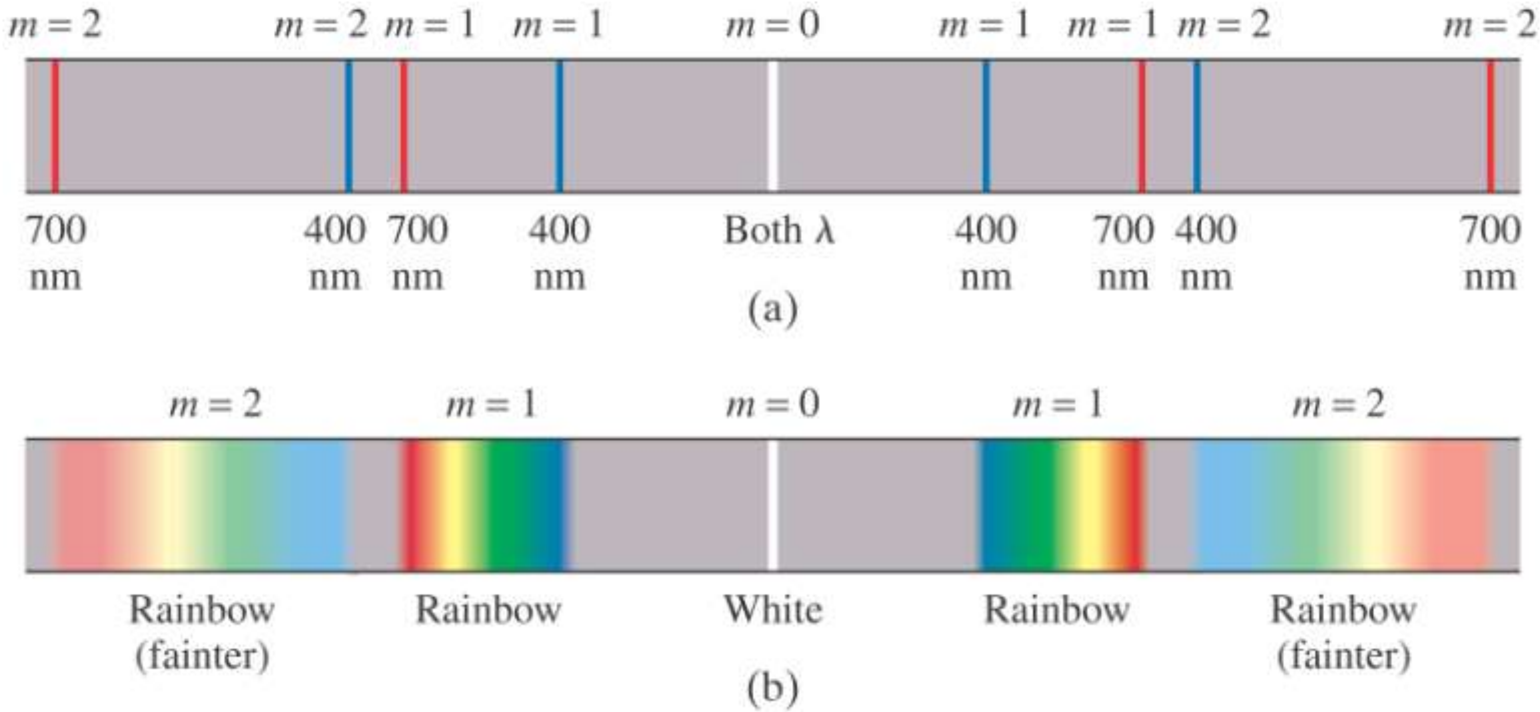
The more lines or slits there are, the narrower the peaks.



24.6 Diffraction Grating

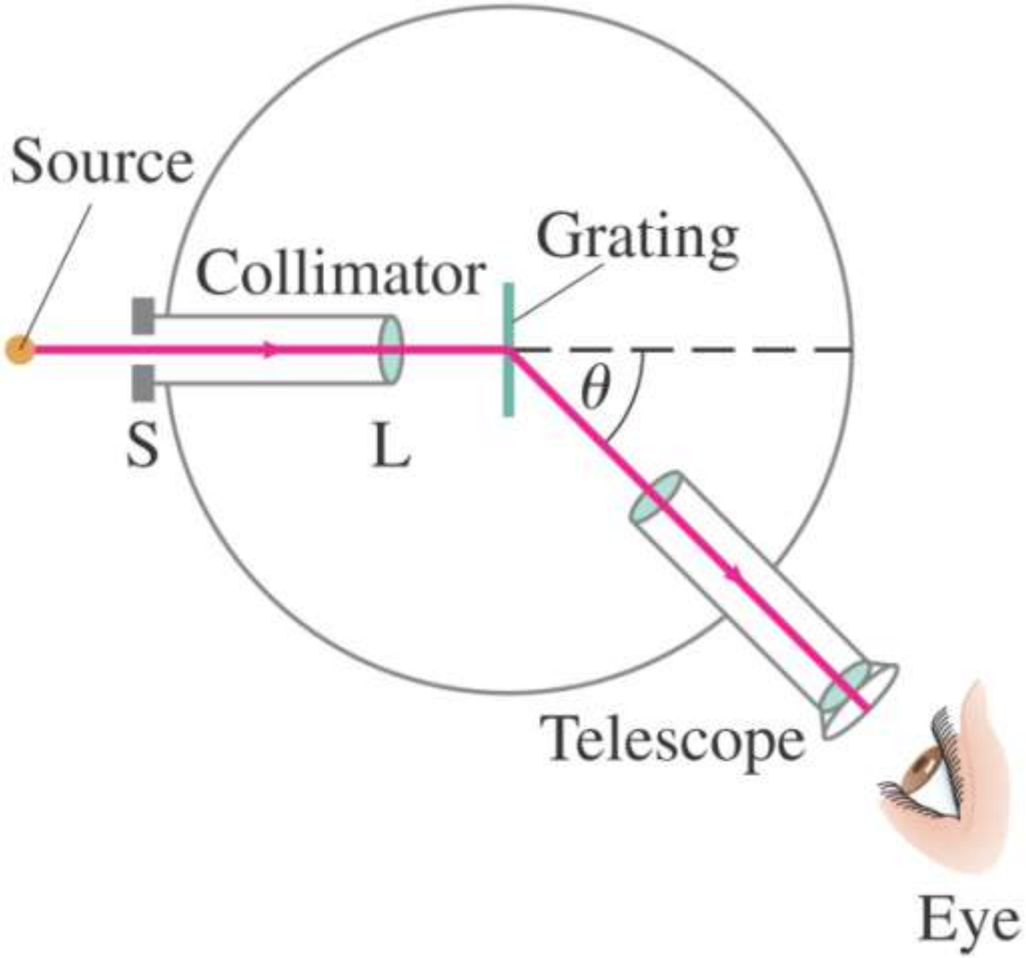
The maxima of the diffraction pattern are defined by

$$\sin\theta = \frac{m\lambda}{d}, \qquad m = 0, 1, 2, \qquad \textbf{(24-4)}$$



24.7 The Spectrometer and Spectroscopy

A spectrometer makes accurate measurements of wavelengths using a diffraction grating or prism.



24.7 The Spectrometer and Spectroscopy

The wavelength can be determined to high accuracy by measuring the angle at which the light is diffracted.

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

Atoms and molecules can be identified when they are in a thin gas through their characteristic emission lines.

24.8 Interference by Thin Films

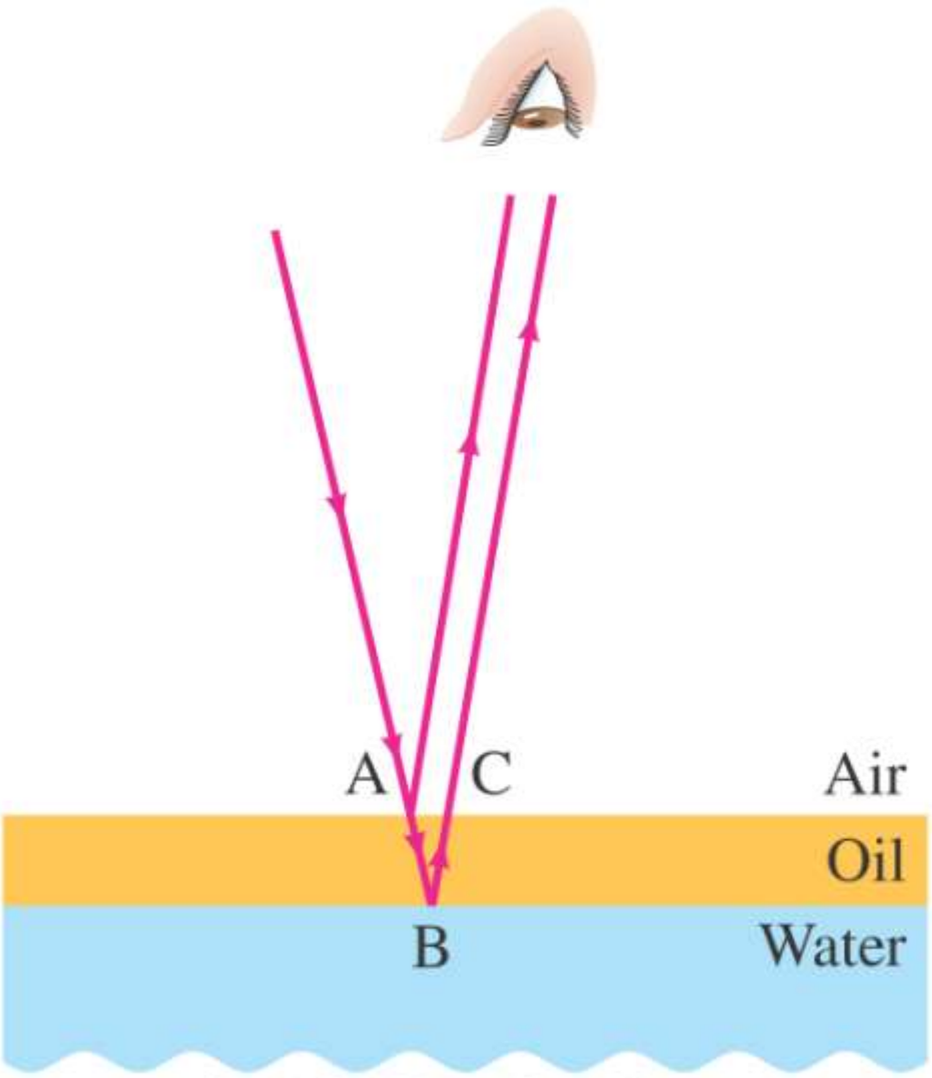
Another way path lengths can differ, and waves interfere, is if the travel through different media.

If there is a very thin film of material – a few wavelengths thick – light will reflect from both the bottom and the top of the layer, causing interference.

This can be seen in soap bubbles and oil slicks, for example.

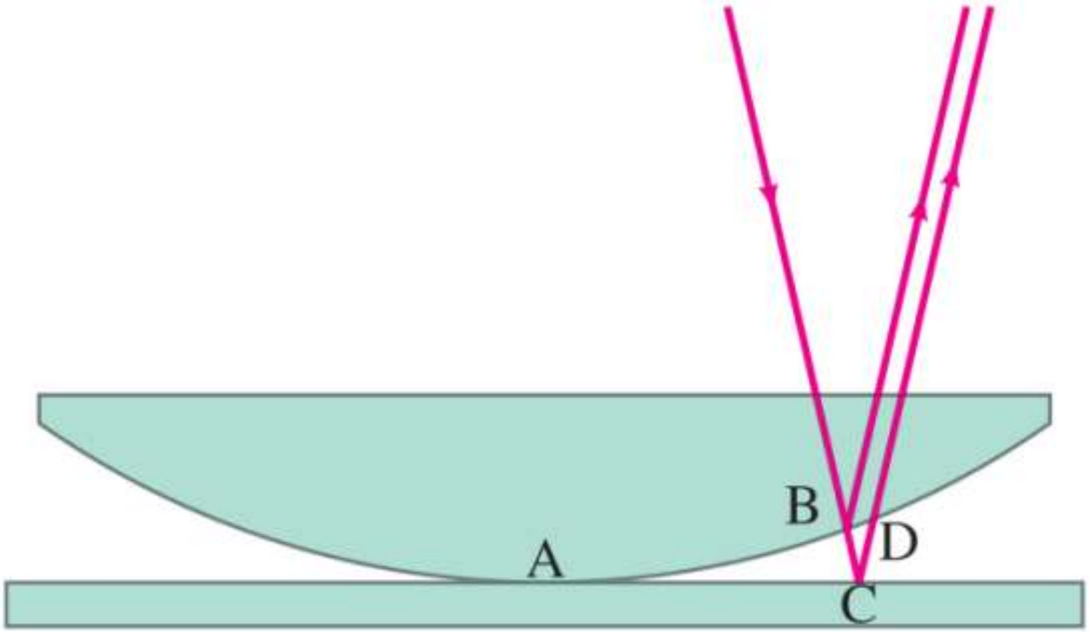
24.8 Interference by Thin Films

The wavelength of the light will be different in the oil and the air, and the reflections at points A and B may or may not involve reflection.



24.8 Interference by Thin Films

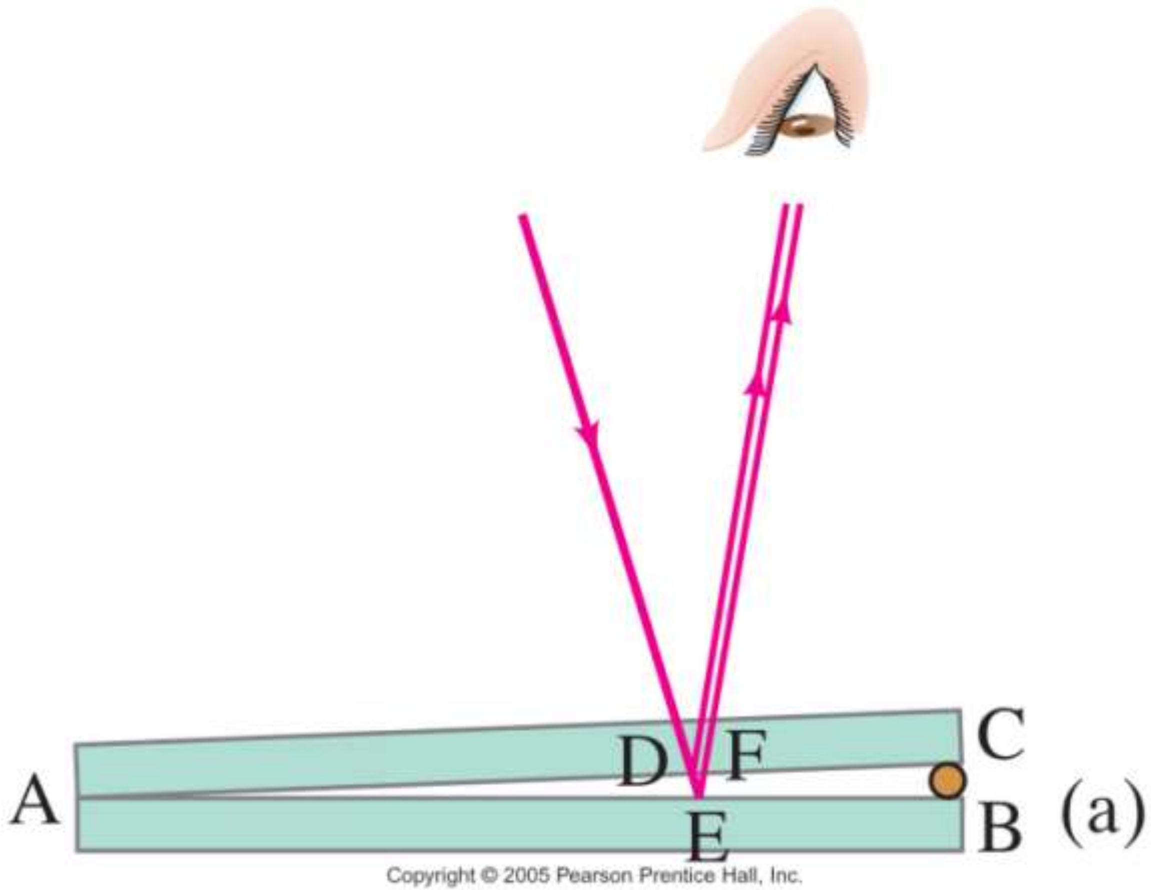
A similar effect takes place when a shallowly curved piece of glass is placed on a flat one. When viewed from above, concentric circles appear that are called Newton's rings.



(a)

24.8 Interference by Thin Films

One can also create a thin film of air by creating a wedge-shaped gap between two pieces of glass.



24.8 Interference by Thin Films

Problem Solving: Interference

1. Interference occurs when two or more waves arrive simultaneously at the same point in space.

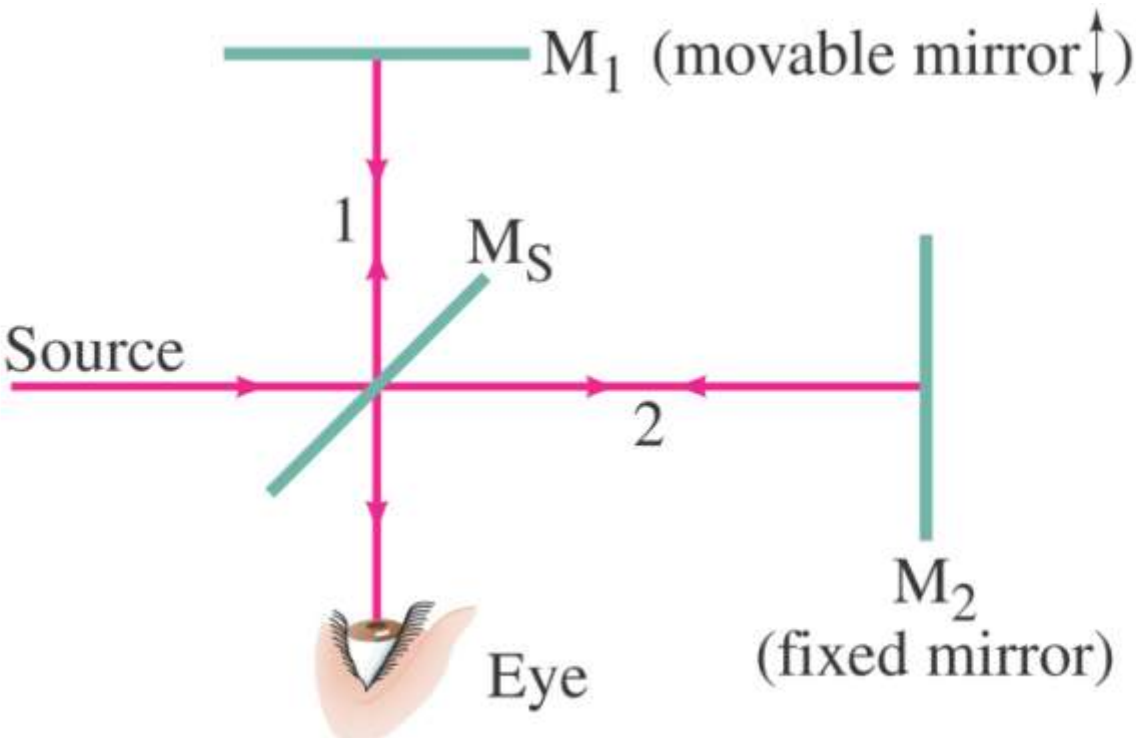
2. Constructive interference occurs when the waves are in phase.

3. Destructive interference occurs when the waves are out of phase.

4. An extra half-wavelength shift occurs when light reflects from a medium with higher refractive index.

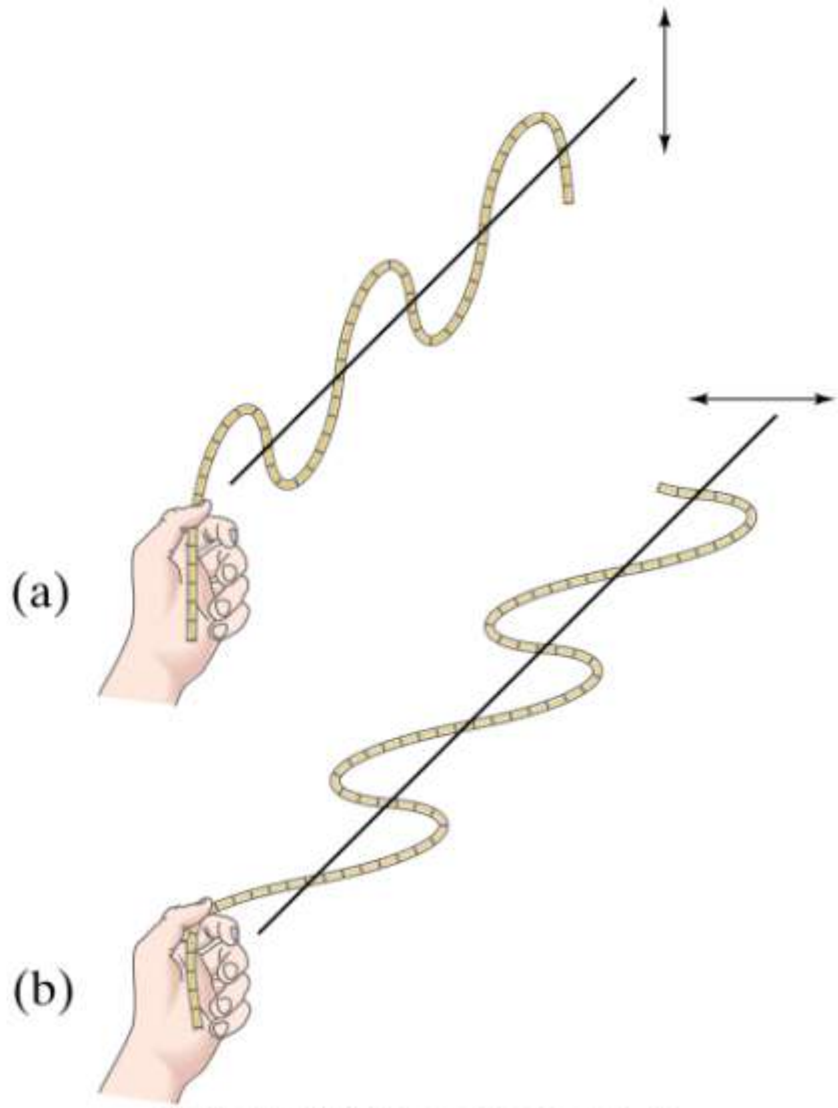
24.9 Michelson Interferometer

The Michelson interferometer is centered around a beam splitter, which transmits about half the light hitting it and reflects the rest. It can be a very sensitive measure of length.



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.

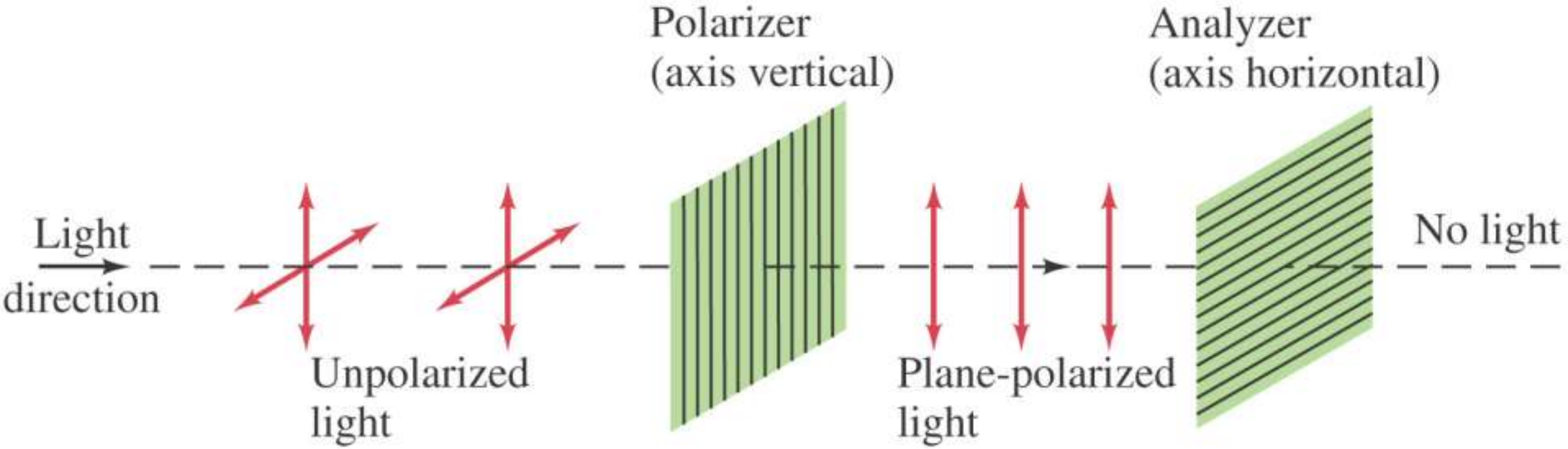


24.10 Polarization

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

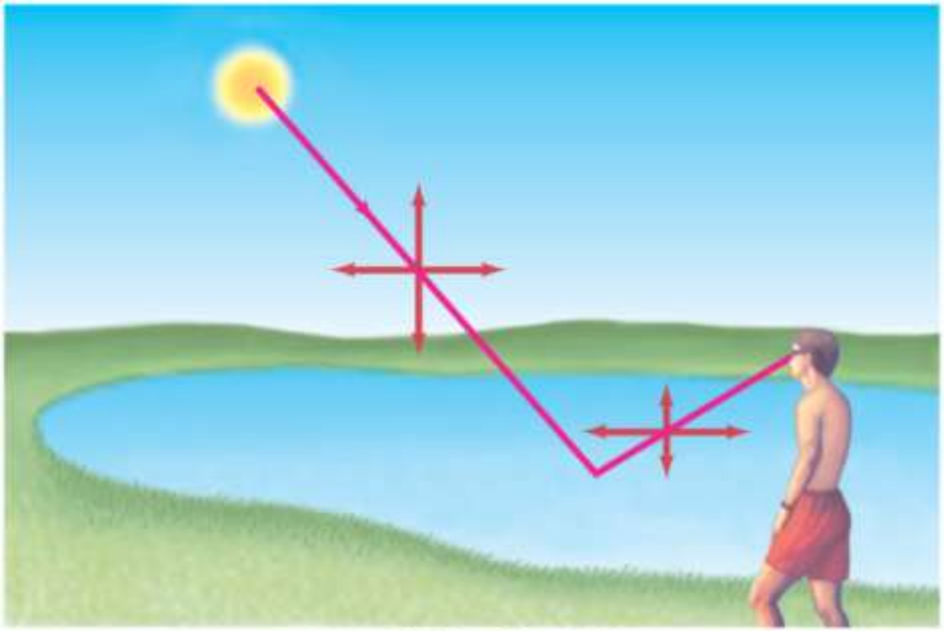
24.10 Polarization

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



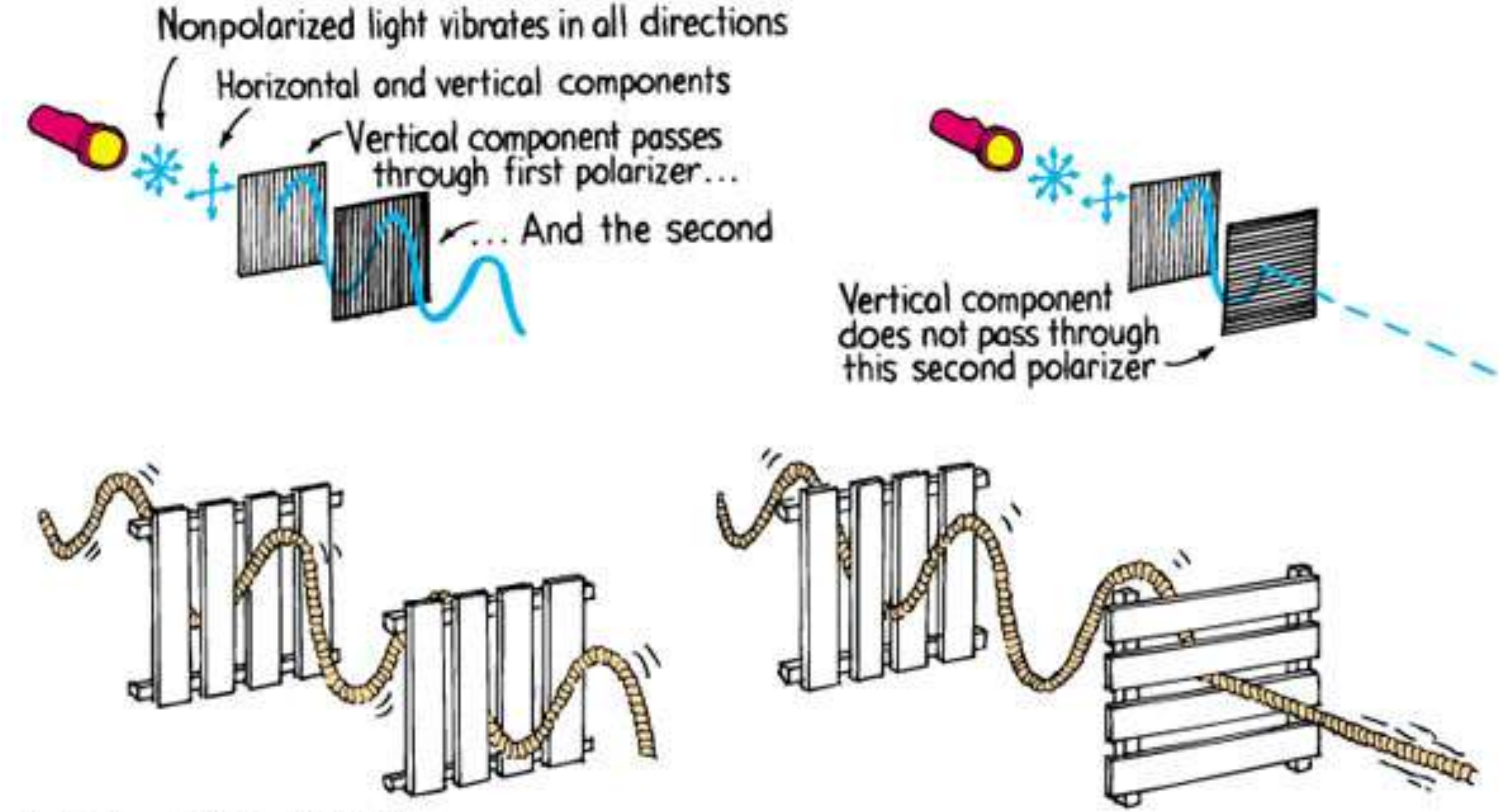
24.10 Polarization

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%.



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

24.10 Polarization



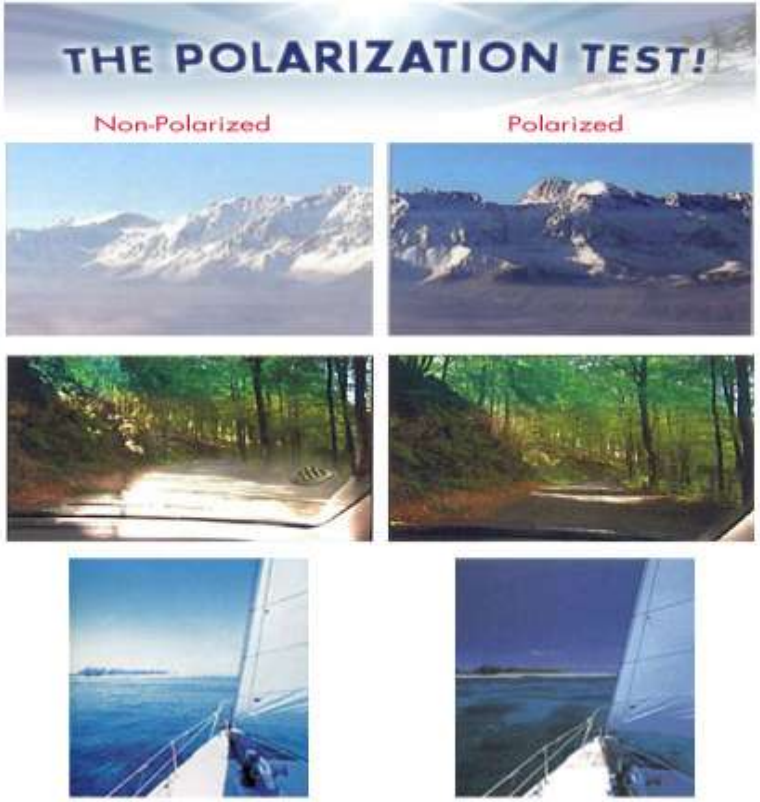
Hewitt, *Conceptual Physics*, Ninth Edition.

Polarization

[Time for a Gizmo!]

24.10 Polarization

Light that reflects off of a surface is horizontally polarized.



24.10 Polarization

Polarization movie