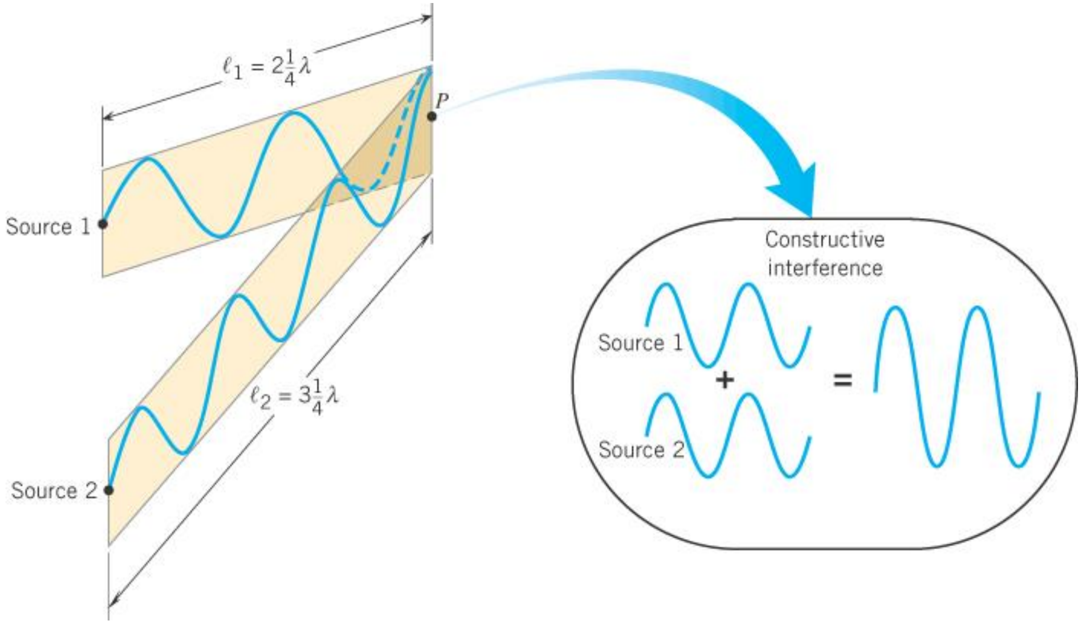
Chapter 27

Interference and the Wave Nature of Light

27.1 The Principle of Linear Superposition

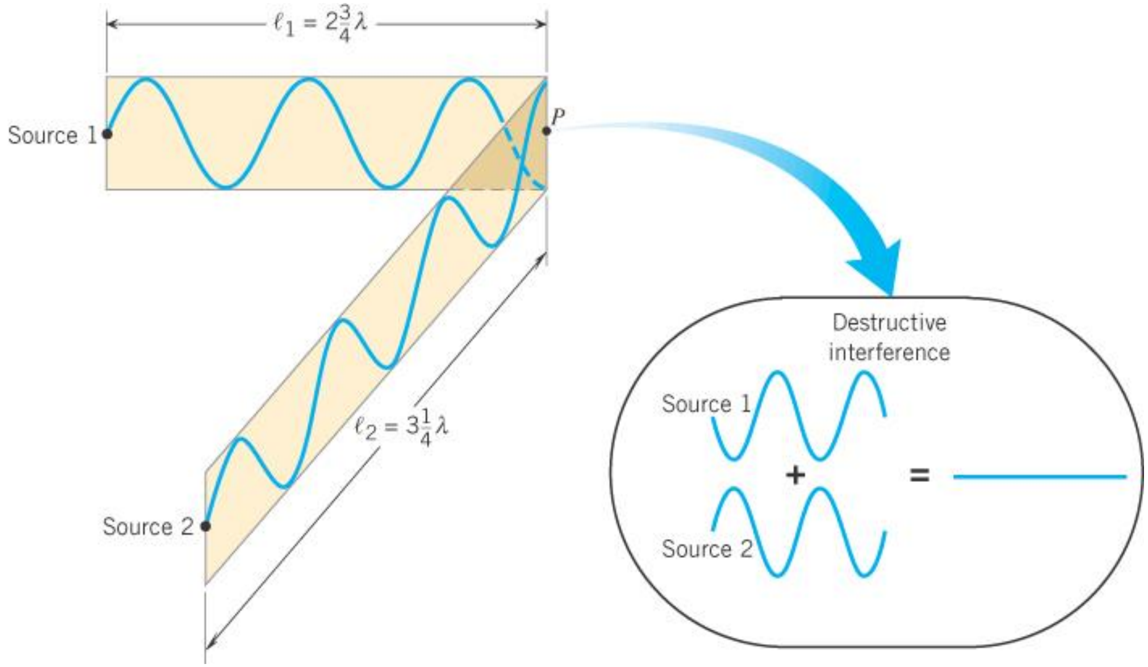
When two or more light waves pass through a given point, their electric fields combine according to the principle of superposition.



The waves emitted by the sources start out in phase and arrive at point P in phase, leading to ***constructive interference.***

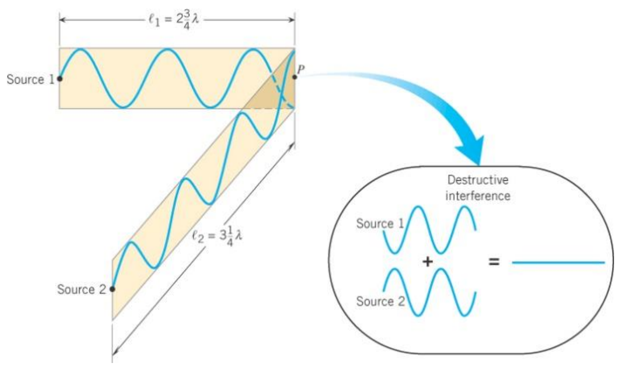
$$\ell_2 - \ell_1 = m\lambda \qquad m = 0, 1, 2, 3, \ldots$$

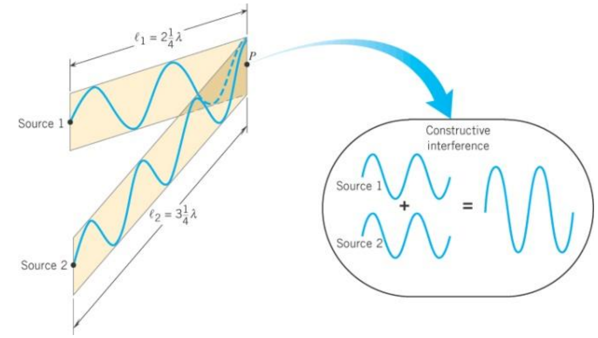
27.1 The Principle of Linear Superposition



The waves emitted by the sources start out in phase and arrive at point P out of phase, leading to ***destructive interference.***

$$\ell_2 - \ell_1 = \left(m + \tfrac{1}{2}\right)\lambda \qquad m = 0,1,2,3,\ldots$$

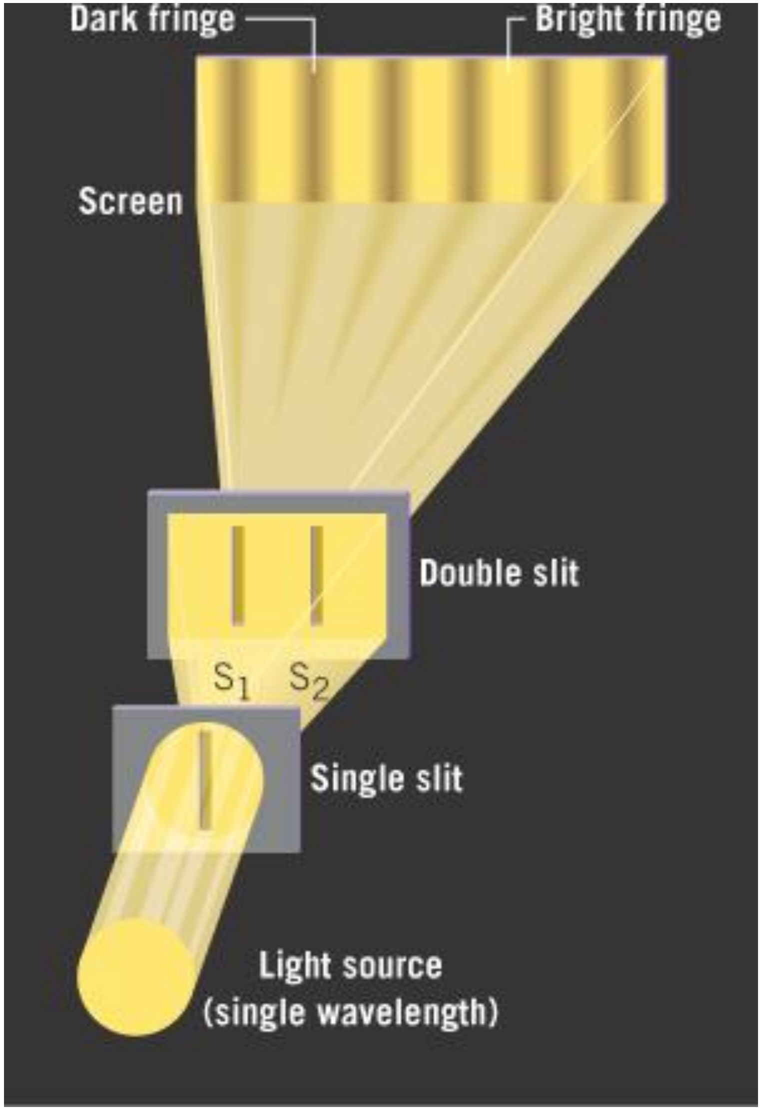




If constructive or destructive interference is to continue ocurring at a point, the sources of the waves must be ***coherent sources***.

Two sources are coherent if the waves they emit maintain a constant phase relation.

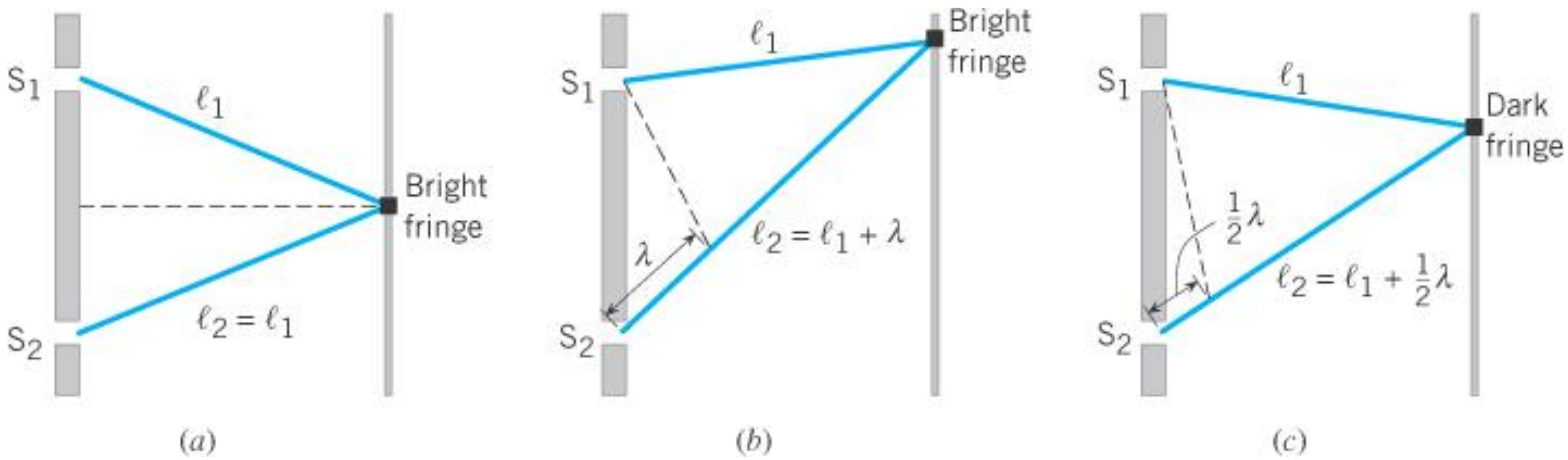
27.2 Young's Double Slit Experiment



In Young's experiment, two slits acts as coherent sources of light.

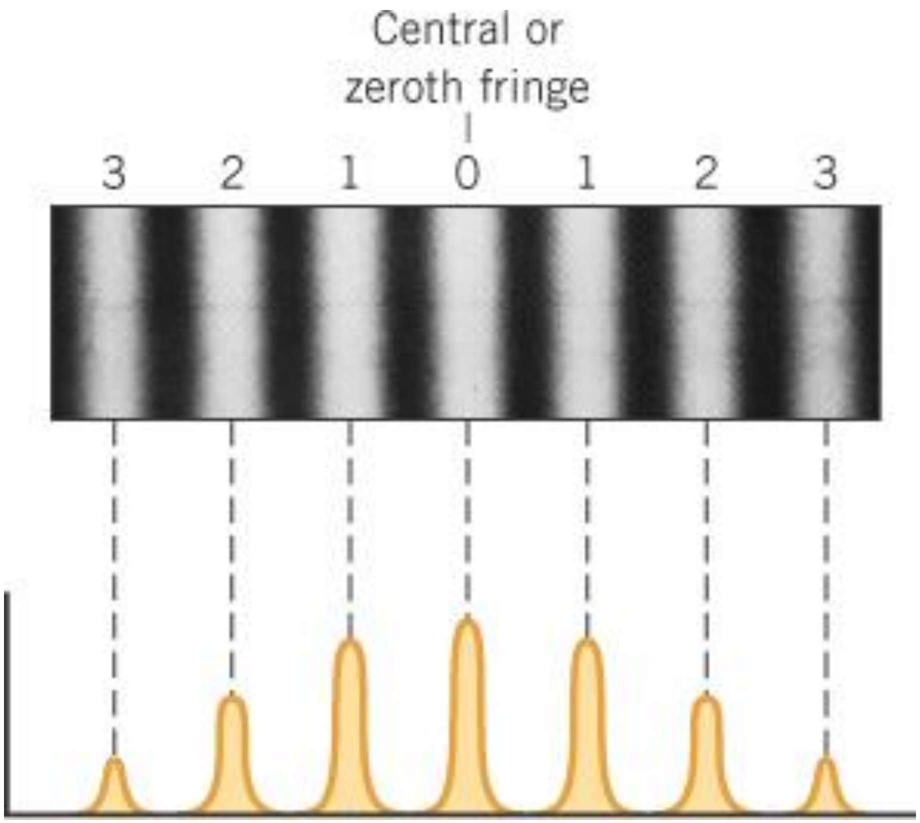
Light waves from these slits interfere constructively and destructively on the screen.

27.2 Young's Double Slit Experiment

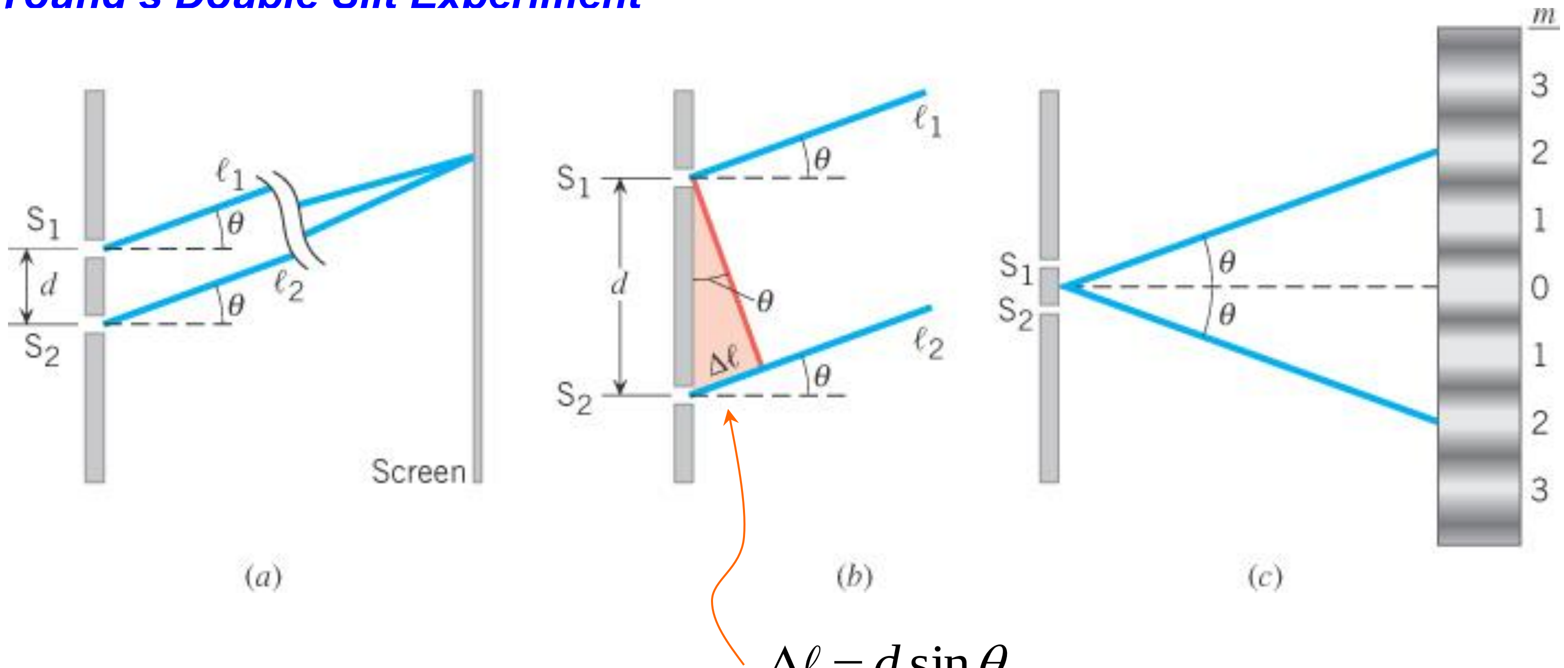


The waves coming from the slits interfere constructively or destructively, depending on the difference in distances between the slits and the screen.

27.2 Young's Double Slit Experiment



27.2 Young's Double Slit Experiment



$$\Delta\ell = d\sin\theta$$

Bright fringes of a double-slit

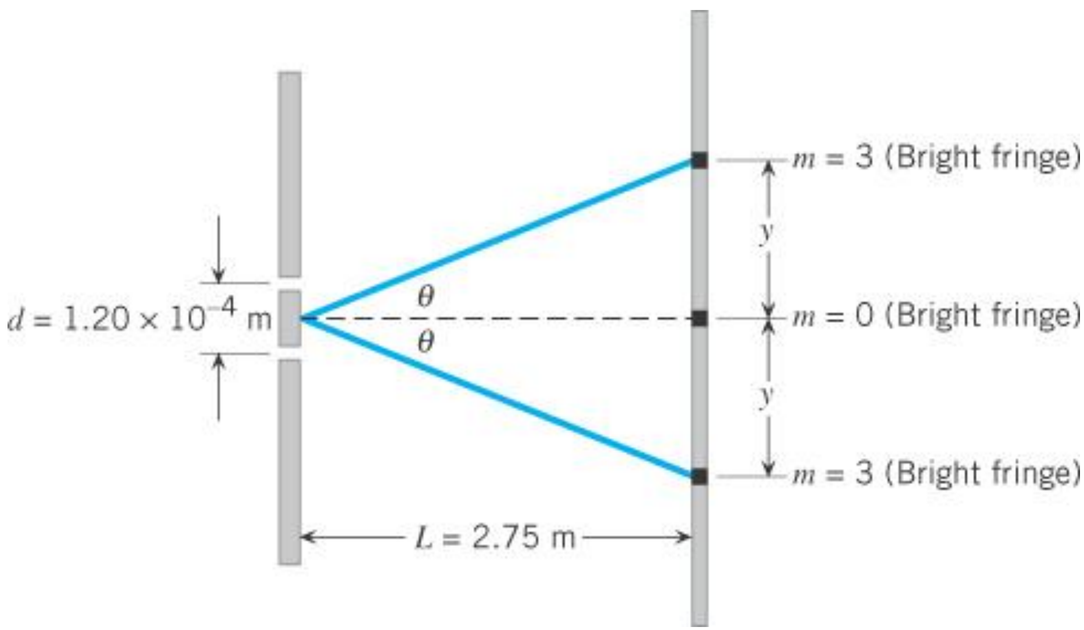
$$\sin\theta = m\frac{\lambda}{d} \qquad m = 0,1,2,3,\ldots$$

Dark fringes of a double-slit

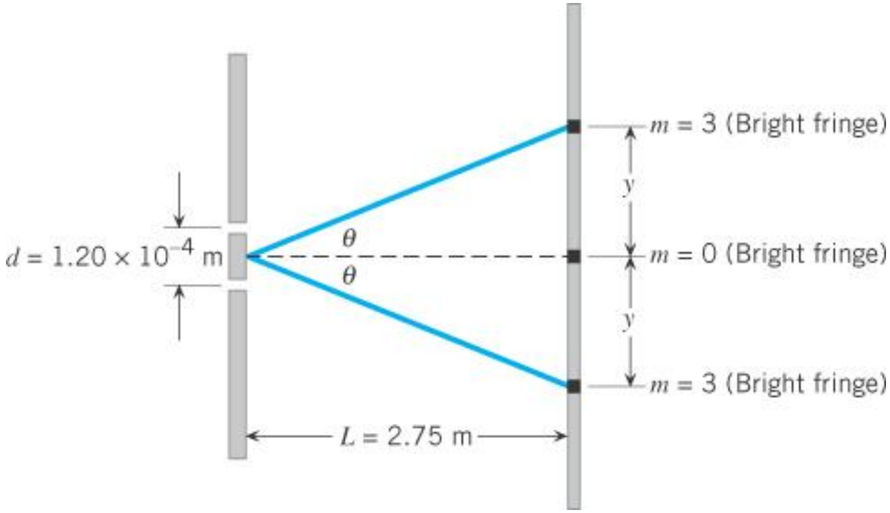
$$\sin\theta = \left(m+\tfrac{1}{2}\right)\frac{\lambda}{d} \qquad m = 0,1,2,3,\ldots$$

Example 1 Young's Double-Slit Experiment

Red light (664 nm) is used in Young's experiment with slits separated by 0.000120 m. The screen is located a distance 2.75 m from the slits. Find the distance on the screen between the central bright fringe and the third-order bright fringe.



27.2 Young's Double Slit Experiment

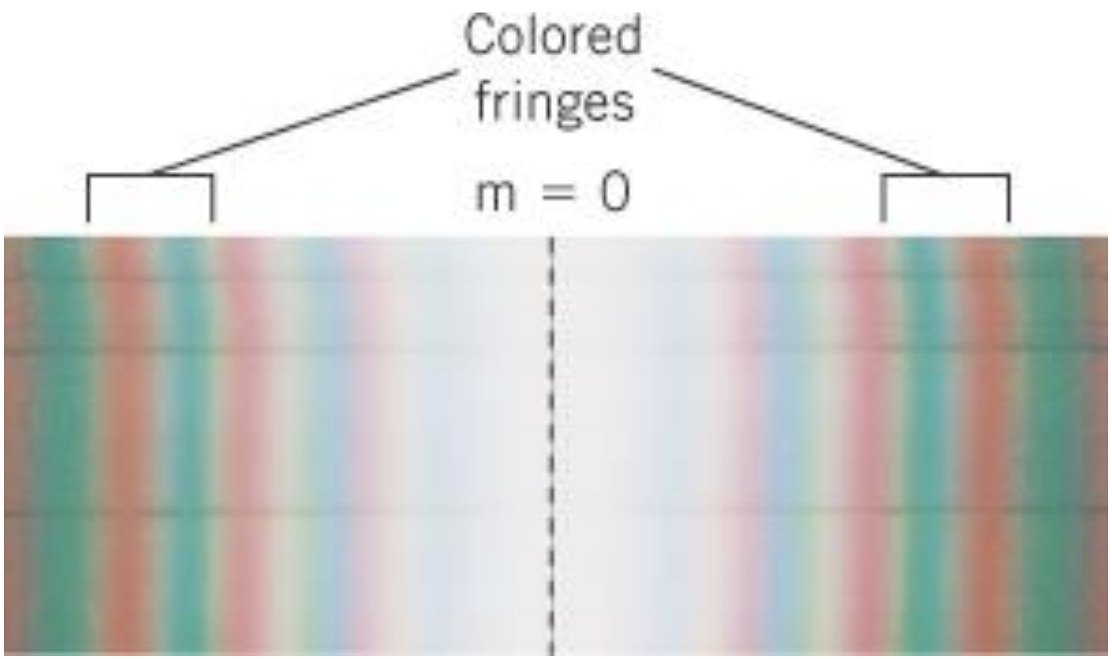


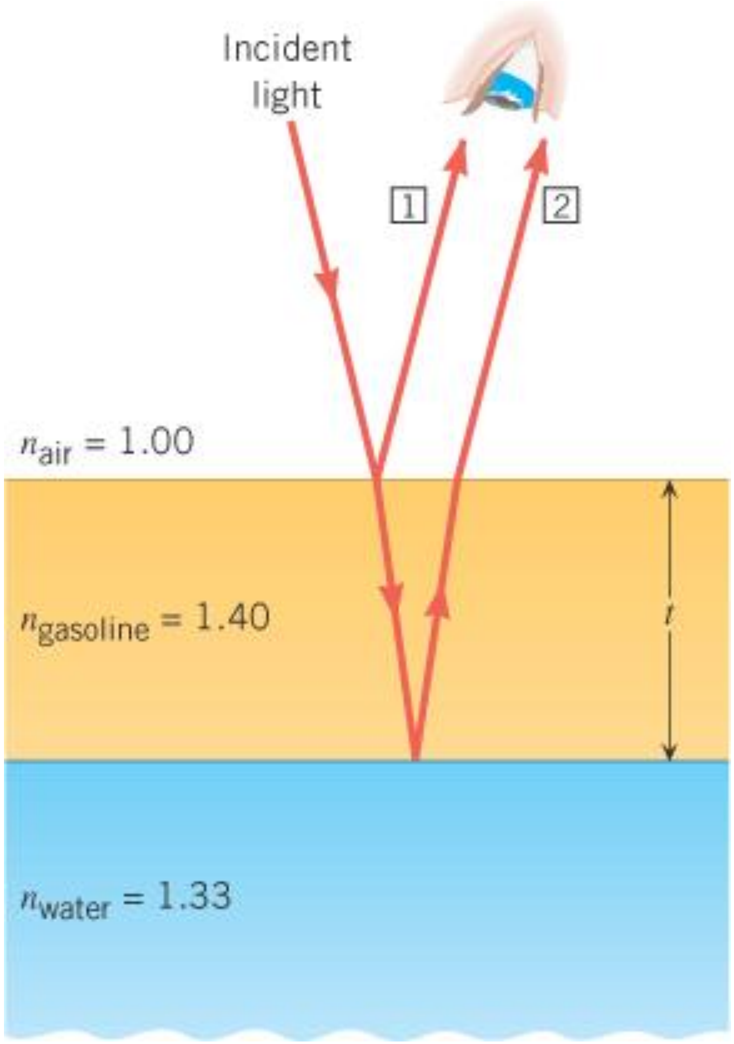
$$\theta = \sin^{-1}\left(m\frac{\lambda}{d}\right) = \sin^{-1}\left(3\frac{664\times10^{-9}\,\text{m}}{1.20\times10^{-4}\,\text{m}}\right) = 0.951^{\circ}$$

$$y = L\tan\theta = (2.75\,\text{m})\tan(0.951^{\circ}) = 0.0456\,\text{m}$$

Conceptual Example 2 White Light and Young's Experiment

The figure shows a photograph that illustrates the kind of interference fringes that can result when white light is used in Young's experiment. Why does Young's experiment separate white light into its constituent colors? In any group of colored fringes, such as the two singled out, why is red farther out from the central fringe than green is? Why is the central fringe white?

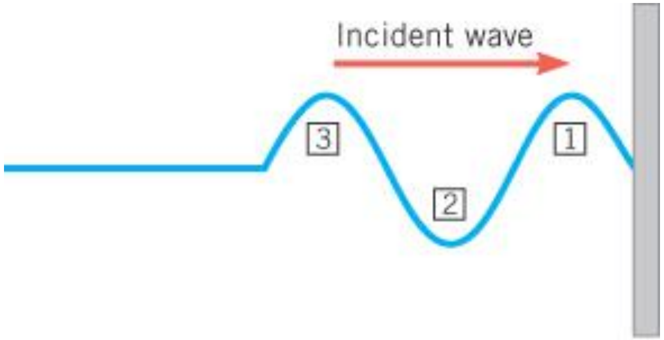




Because of reflection and refraction, two light waves enter the eye when light shines on a thin film of gasoline floating on a thick layer of water.

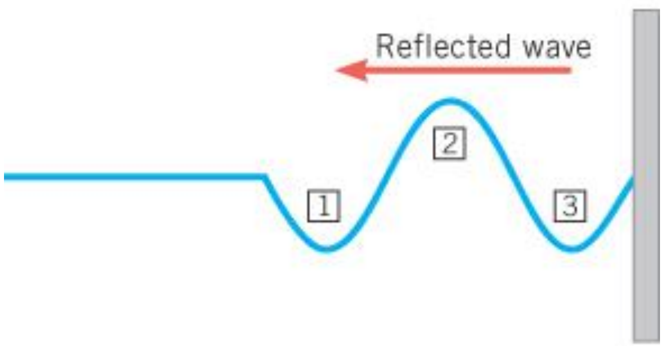
Because of the extra distance traveled, there can be interference between the two waves.

$$\lambda_{\text{film}} = \frac{\lambda_{\text{vacuum}}}{n}$$



(a)

When light travels through a material with a smaller refractive index towards a material with a larger refractive index, reflection at the boundary occurs along with a phase change that is equivalent to one-half of a wavelength in the film.

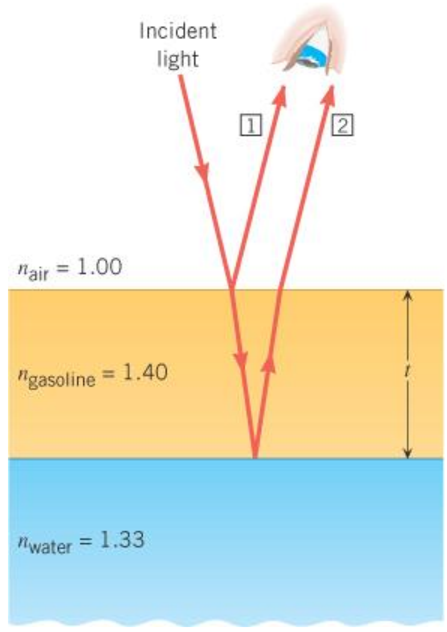


(b)

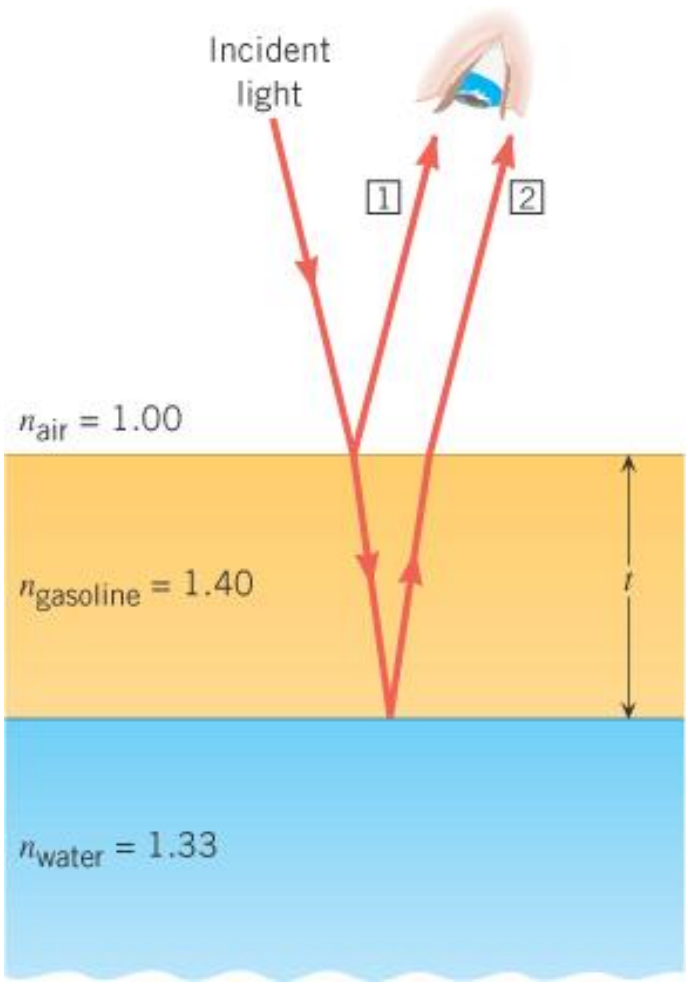
When light travels from a larger towards a smaller refractive index, there is no phase change upon reflection.

Example 3 A Colored Thin Film of Gasoline

A thin film of gasoline floats on a puddle of water. Sunlight falls perpendicularly on the film and reflects into your eyes. The film has a yellow hue because destructive interference eliminates the color of blue (469 nm) from the reflected light. The refractive indices of the blue light in gasoline and water are 1.40 and 1.33. Determine the minimum non-zero thickness of the film.



27.3 Thin Film Interference



$$2t + \tfrac{1}{2}\lambda_{\text{film}} = \tfrac{1}{2}\lambda_{\text{film}}, \tfrac{3}{2}\lambda_{\text{film}}, \tfrac{5}{2}\lambda_{\text{film}}$$

$$t = \frac{m\lambda_{\text{film}}}{2}$$

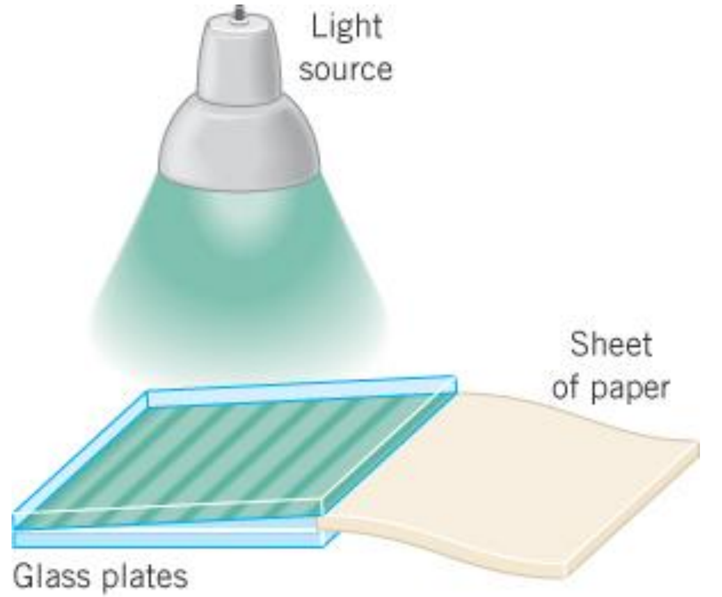
$$t = \frac{m\lambda_{\text{film}}}{2} = \frac{(1)(469\ \text{nm}/1.40)}{2} = 168\ \text{nm}$$

Conceptual Example 4 Multicolored Thin Films

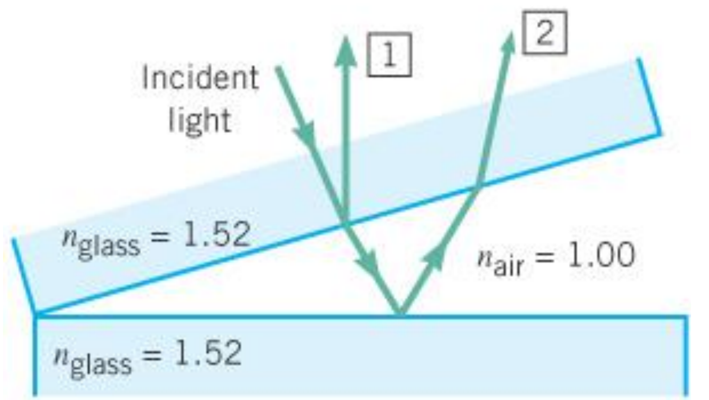
Under natural conditions, thin films, like gasoline on water or like the soap bubble in the figure, have a multicolored appearance that often changes while you are watching them. Why are such films multicolored and why do they change with time?

27.3 Thin Film Interference

The wedge of air formed between two glass plates causes an interference pattern of alternating dark and bright fringes.

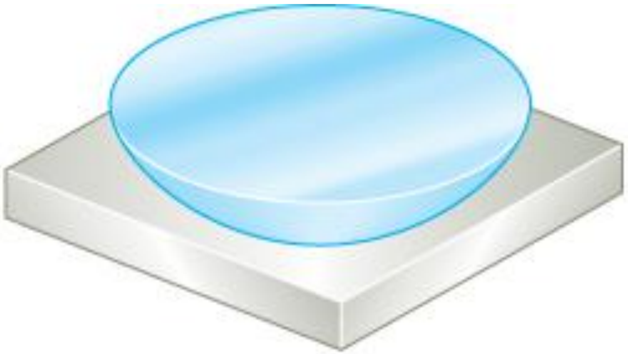


(a)

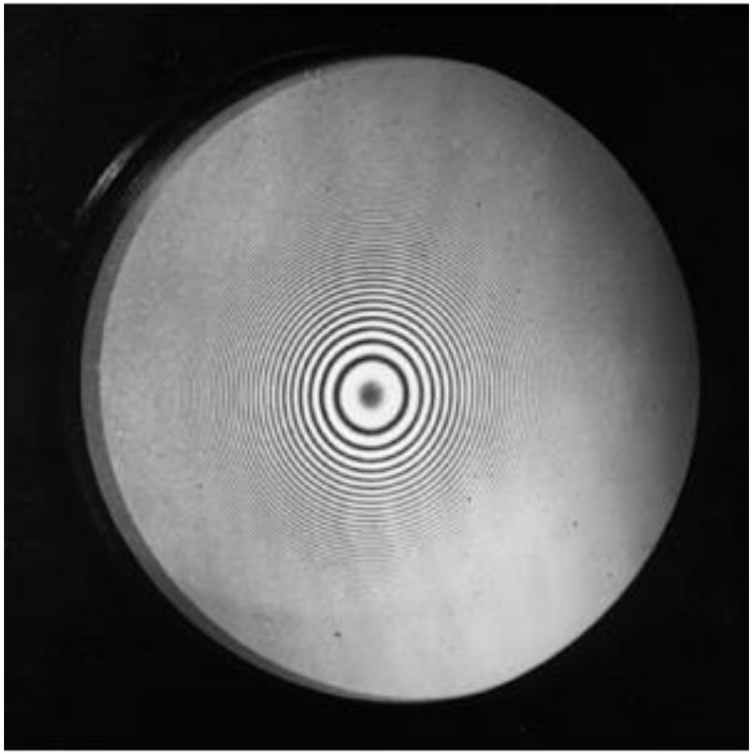


(b)

27.3 Thin Film Interference



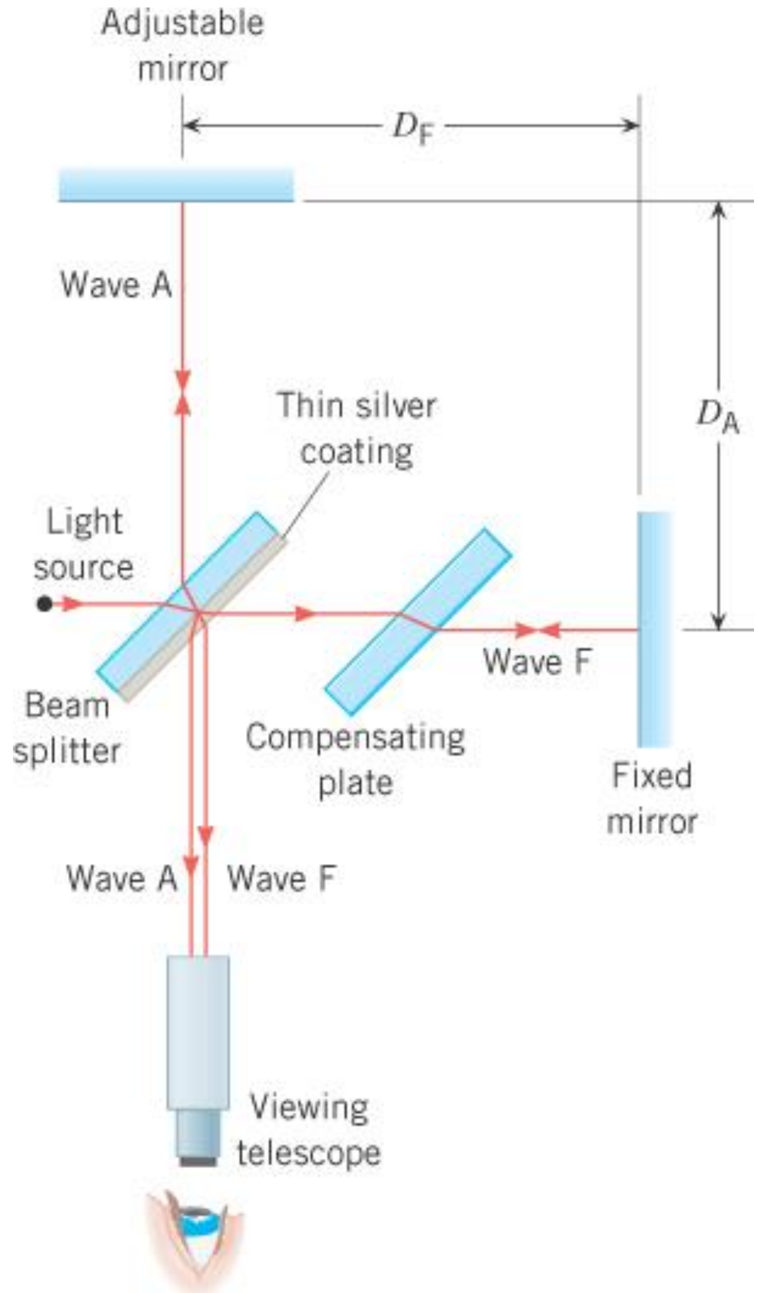
(a)



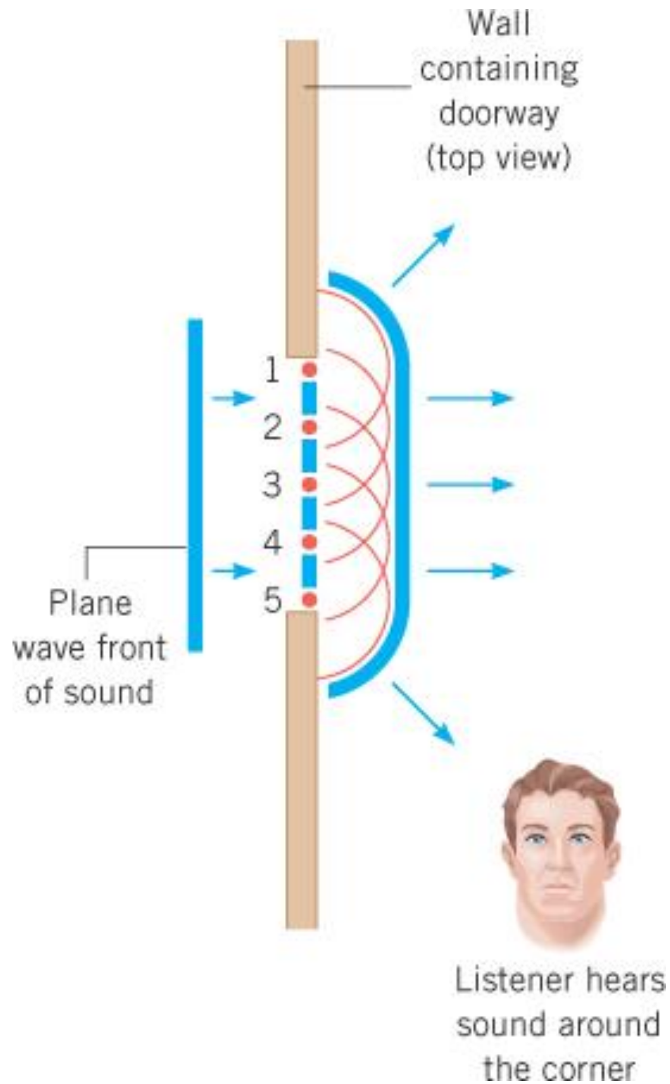
(b)

27.4 The Michelson Interferometer

A schematic drawing of
a Michelson interferometer.



27.5 Diffraction

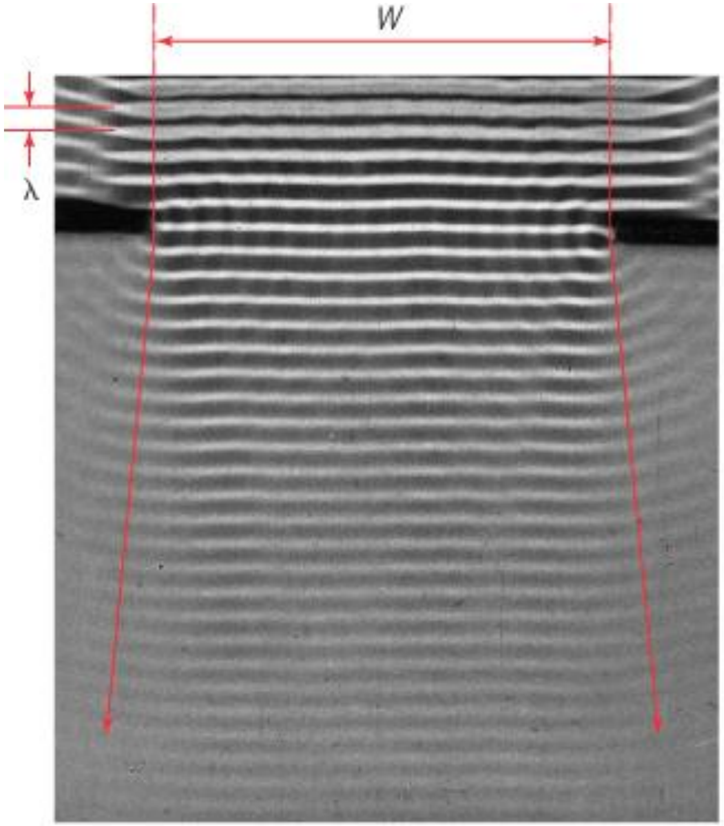


Diffraction is the bending of waves around obstacles or the edges of an opening.

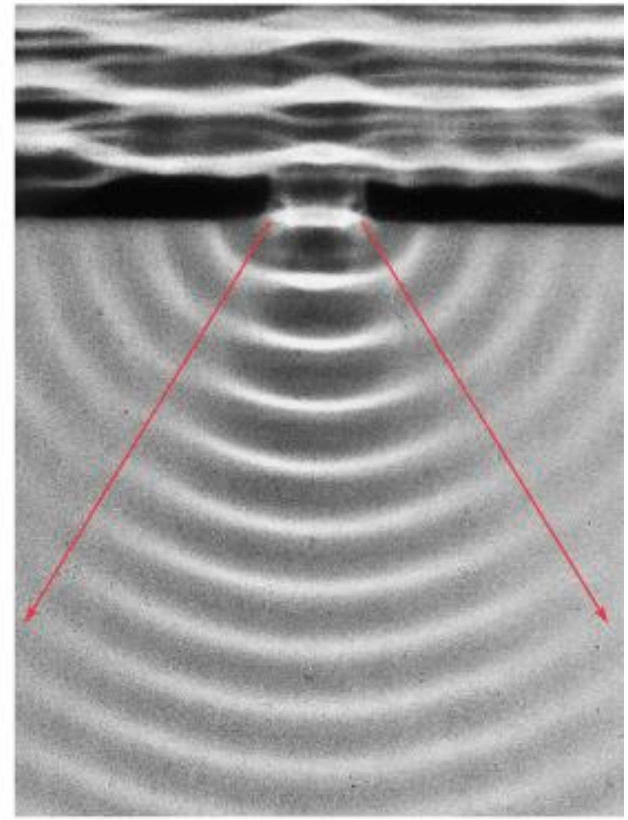
Huygens' principle

Every point on a wave front acts as a source of tiny wavelets that move forward with the same speed as the wave; the wave front at a later instant is the surface that is tangent to the wavelets.

27.5 Diffraction



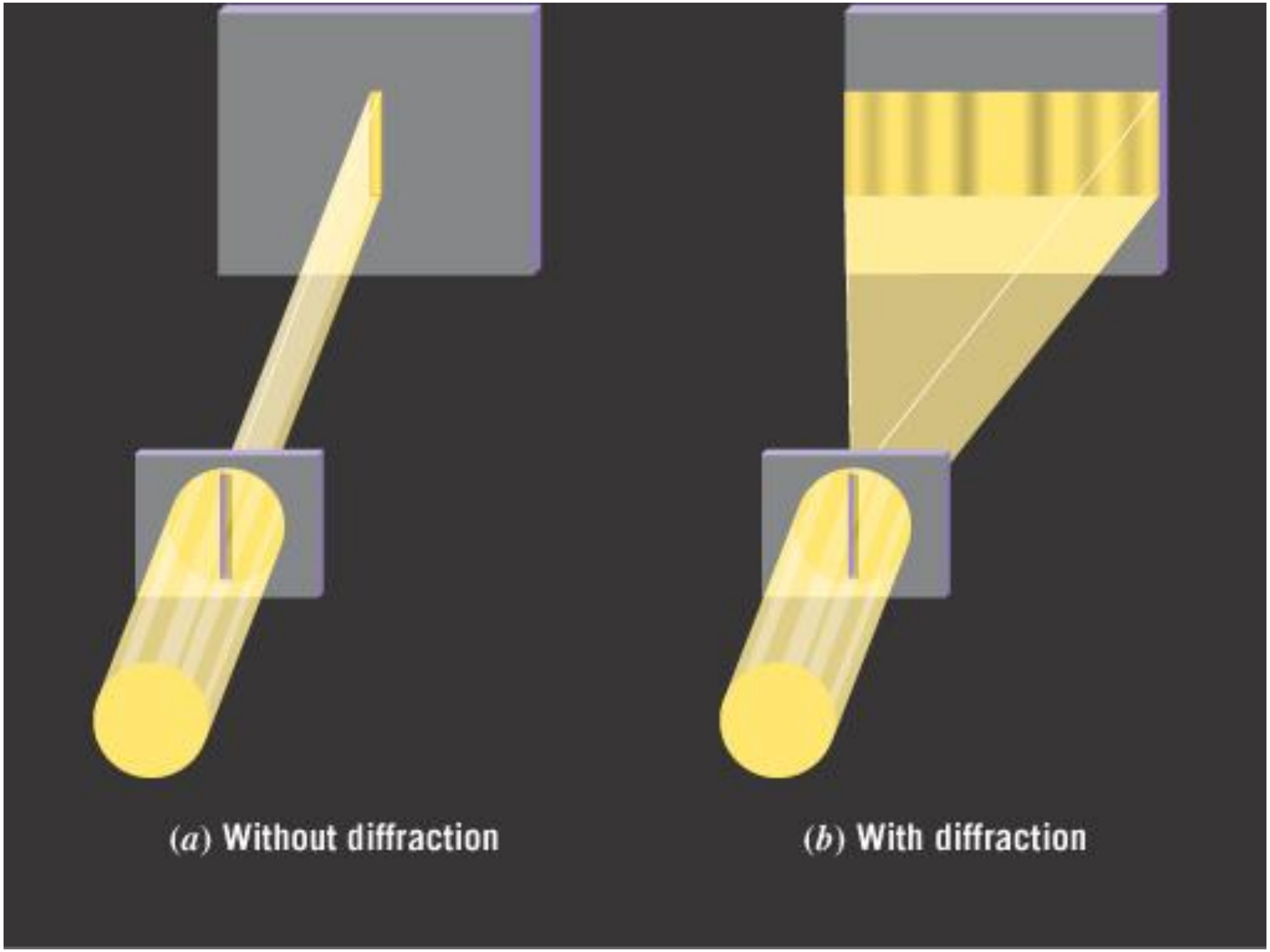
(*a*) Smaller value for λ/*W*, less diffraction.

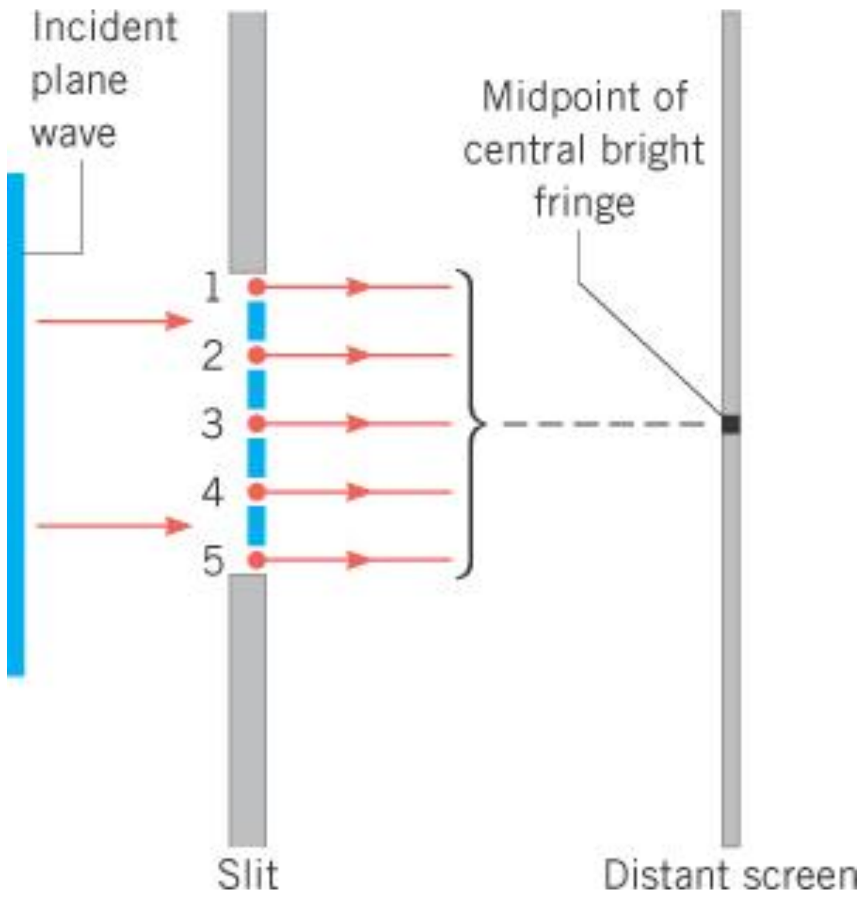


(*b*) Larger value for λ/*W*, more diffraction.

The extent of the diffraction increases as the ratio of the wavelength to the width of the opening increases.

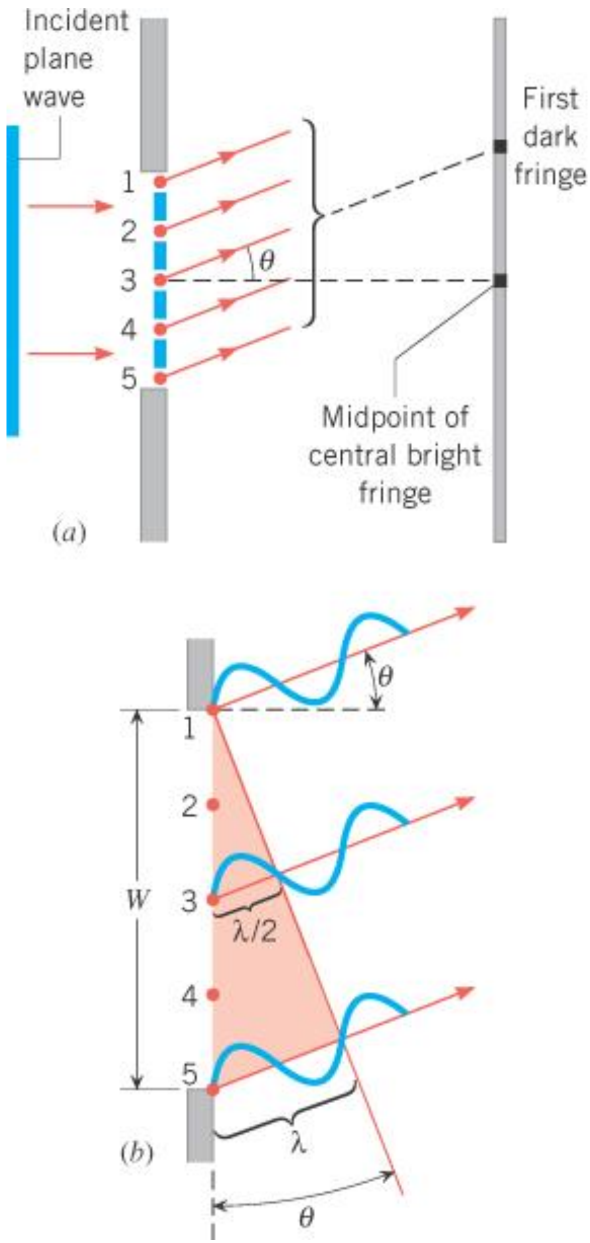
27.5 Diffraction





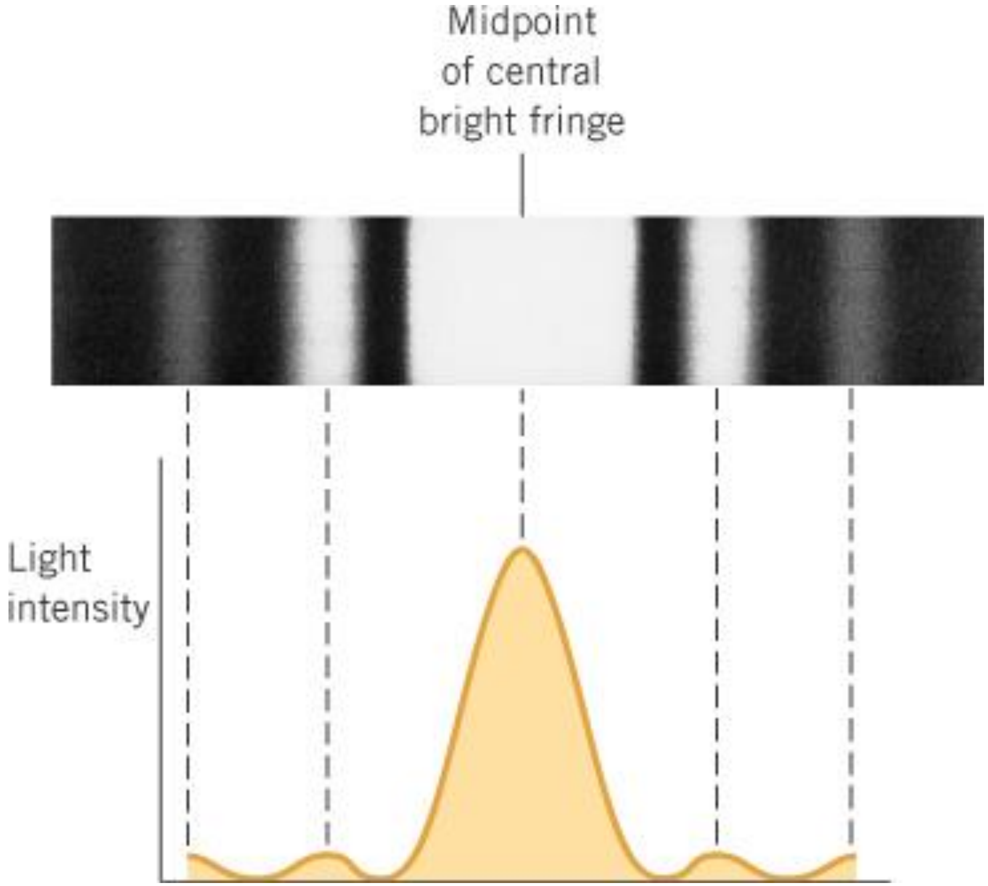
This top view shows five sources of Huygens' wavelets.

27.5 Diffraction



These drawings show how destructive interference leads to the first dark fringe on either side of the central bright fringe.

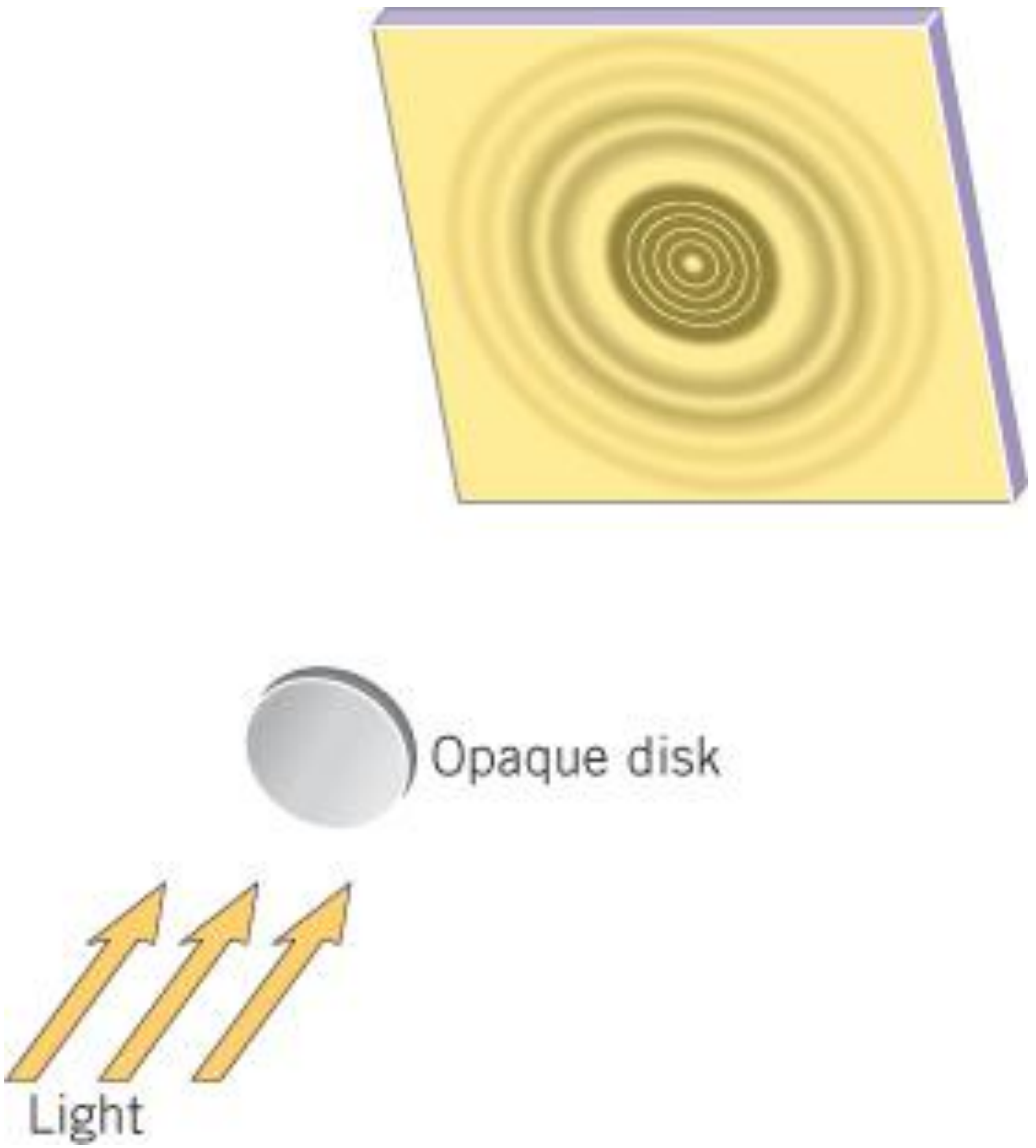
27.5 Diffraction



Dark fringes for single slit diffraction

$$\sin\theta = m\frac{\lambda}{W} \qquad m = 1, 2, 3, \ldots$$

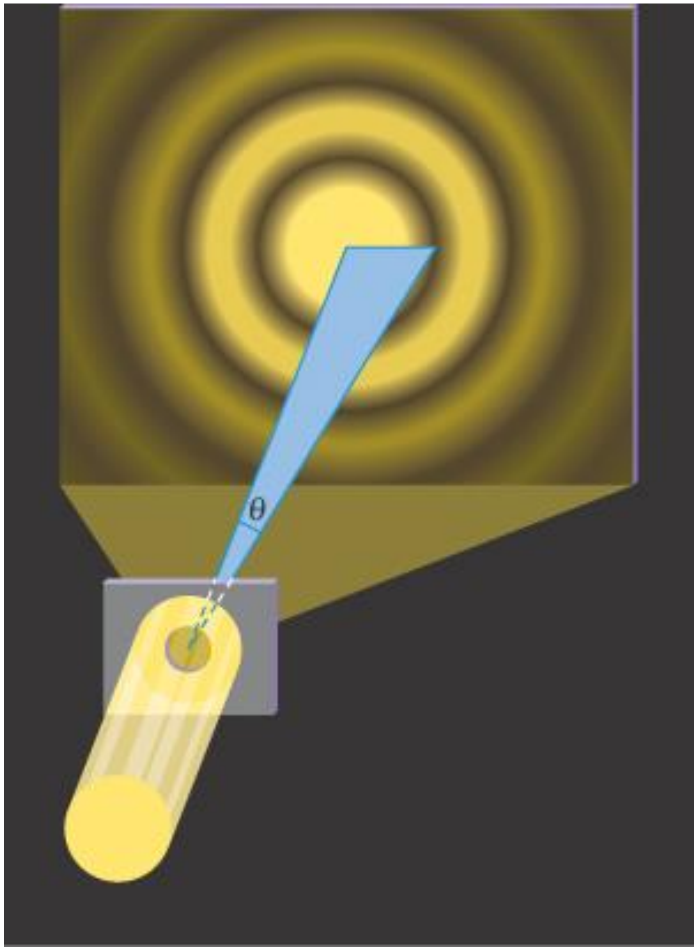
27.5 Diffraction



27.6 Resolving Power

(a) (b) (c)

Three photographs of an automobile's headlights, taken at progressively greater distances.

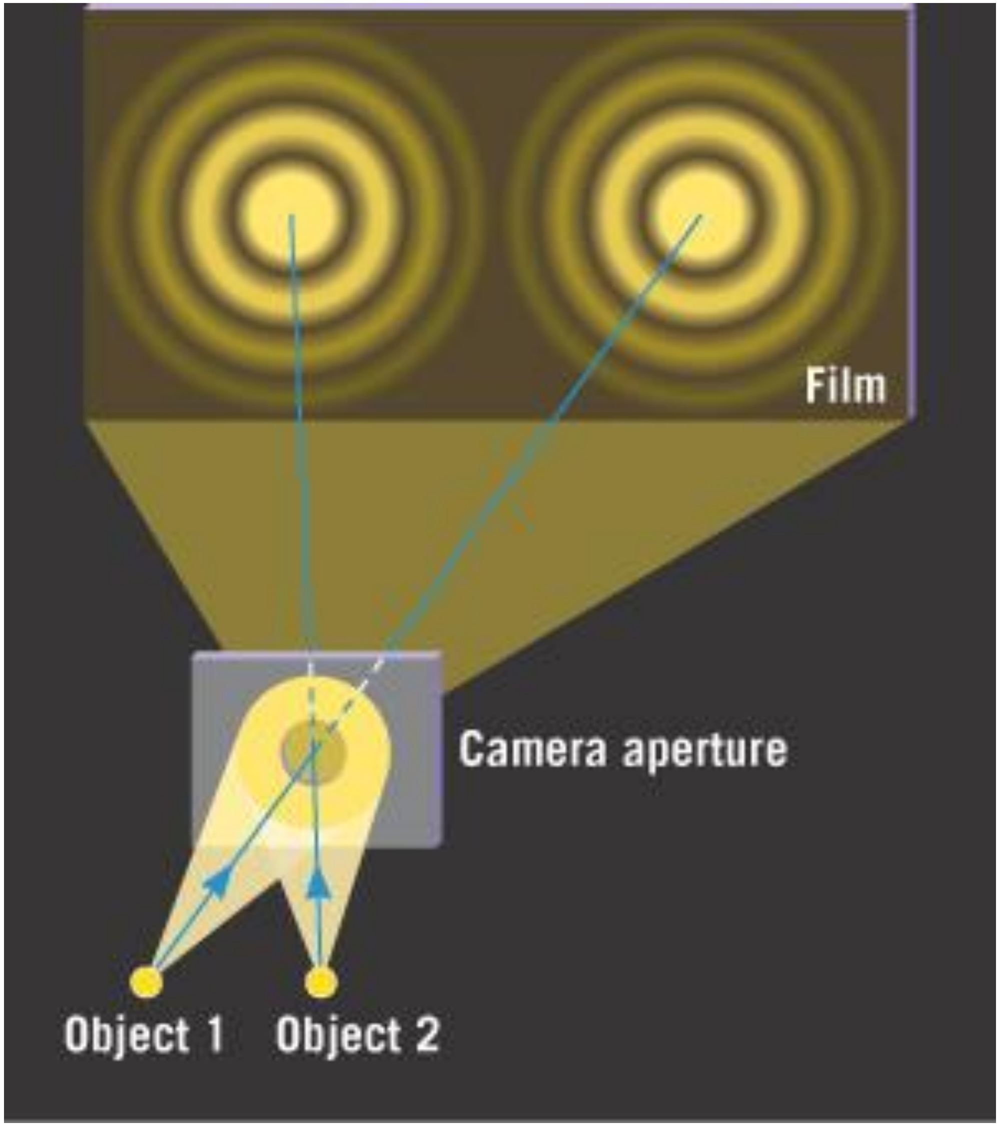


First minimum of a circular diffraction pattern

$$\sin\theta = 1.22\frac{\lambda}{D}$$

diameter of hole

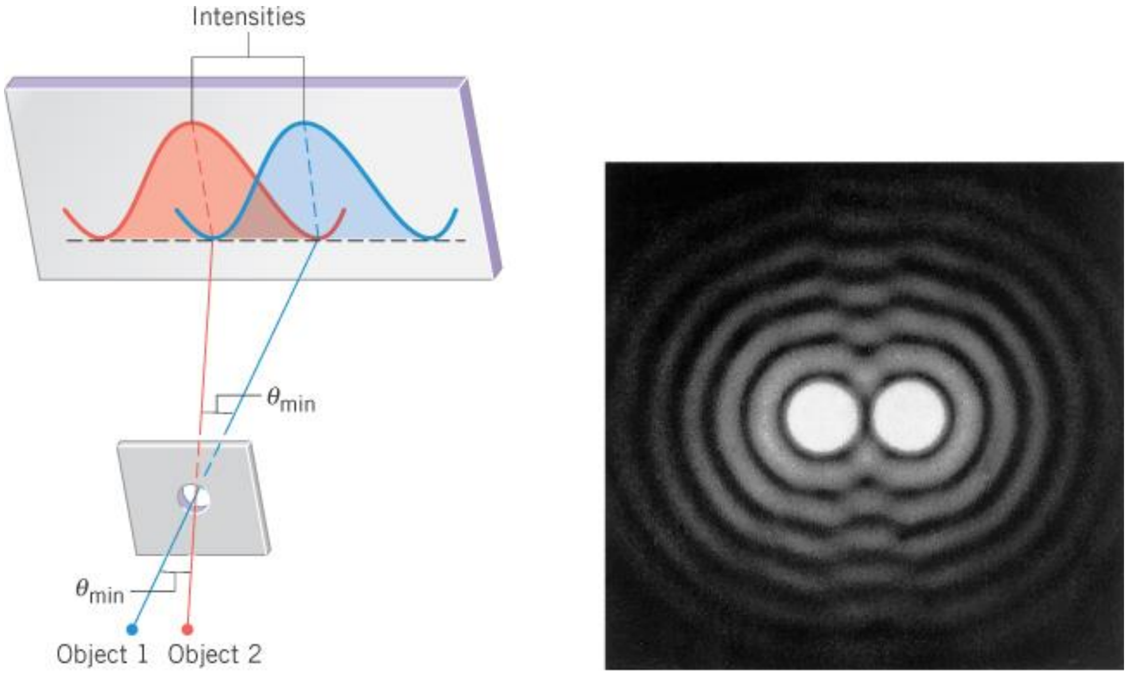
27.6 Resolving Power



27.6 Resolving Power

Rayleigh criterion

Two point objects are just resolved when the first dark fringe in the diffraction pattern of one falls directly on the central bright fringe in the diffraction patter of the other.



(a) (b)

$$\theta_{\min} \approx 1.22 \frac{\lambda}{D}$$

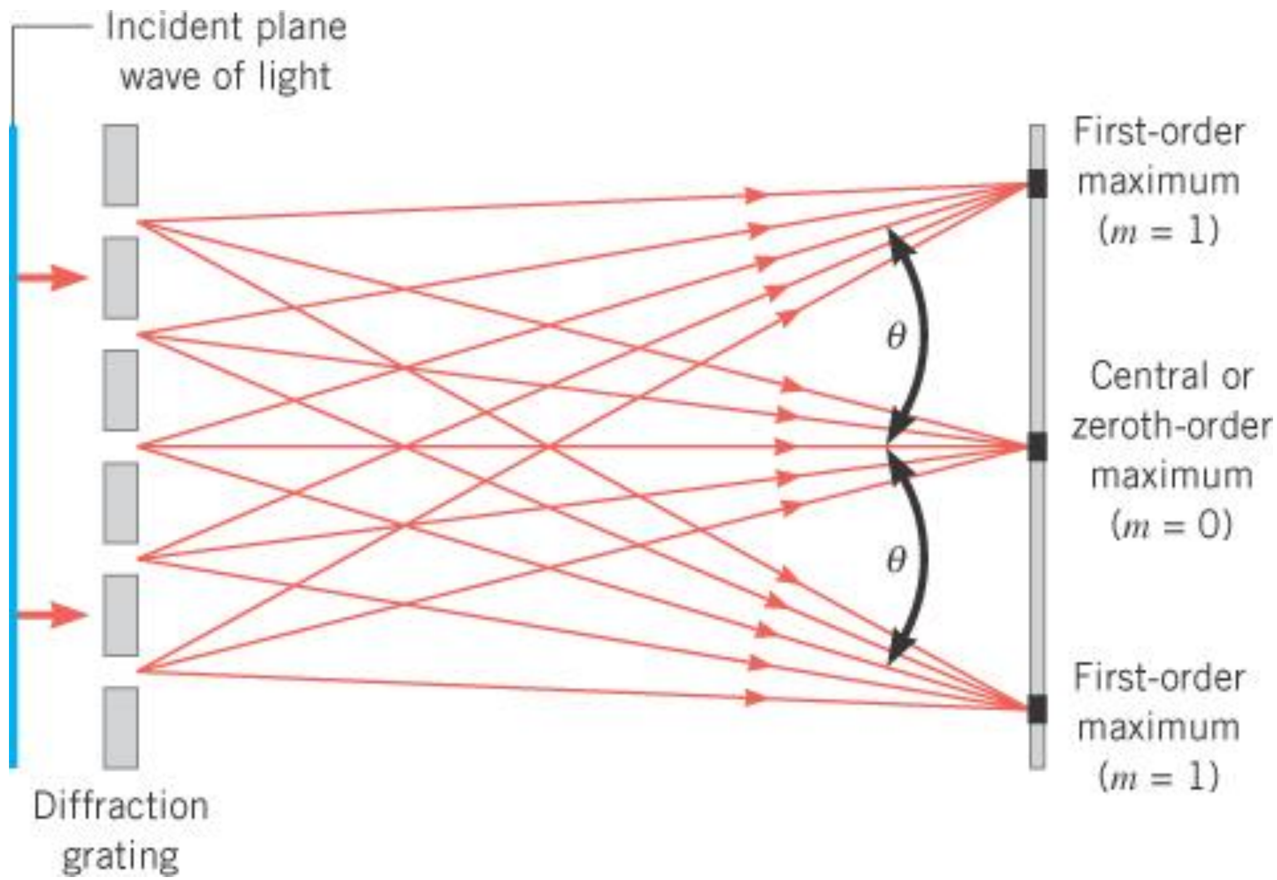
Conceptual Example 8 What You See is Not What You Get

The French postimpressionist artist Georges Seurat developed a technique of painting in which dots of color are placed close together on the canvas. From sufficiently far away the individual dots are not distinguishable, and the images in the picture take on a more normal appearance.

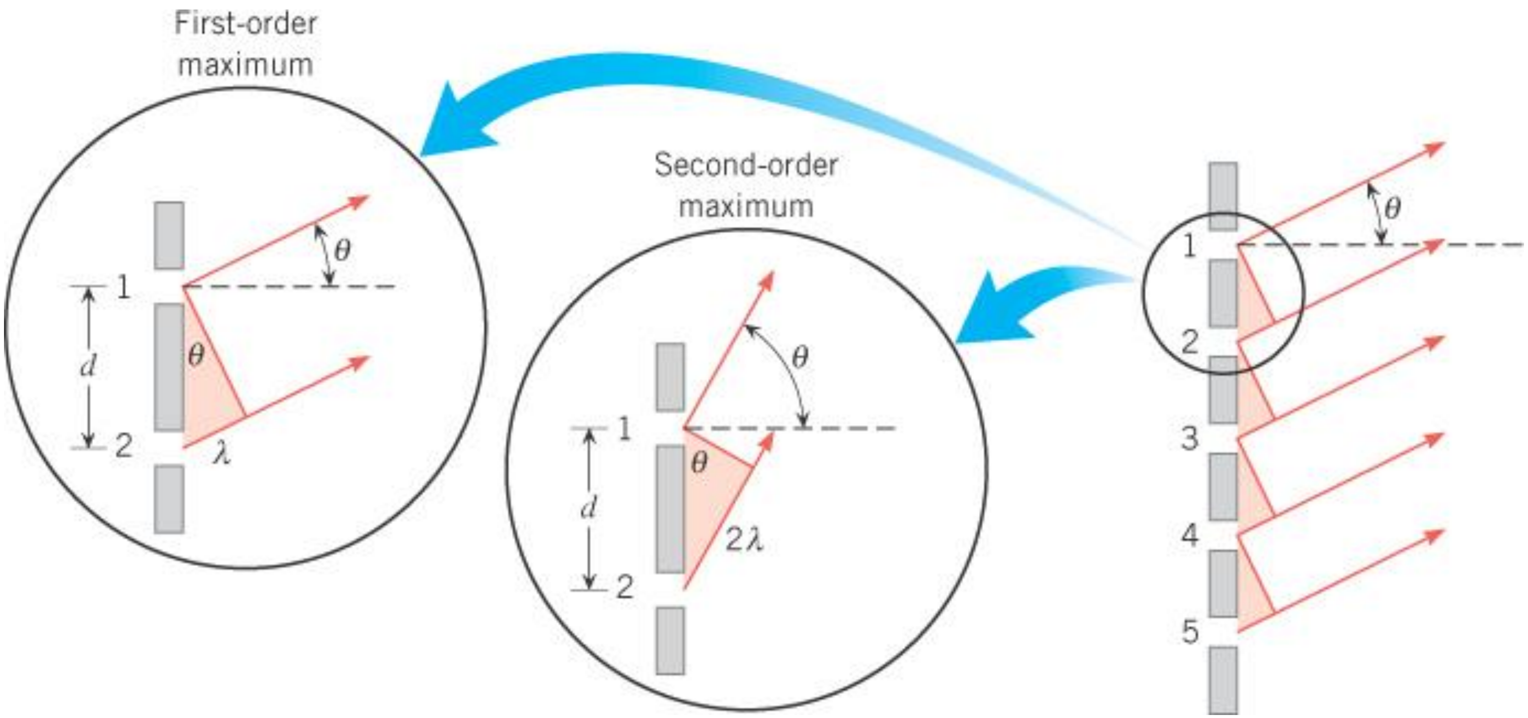
Why does the camera resolve the dots, while his eyes do not?

27.7 The Diffraction Grating

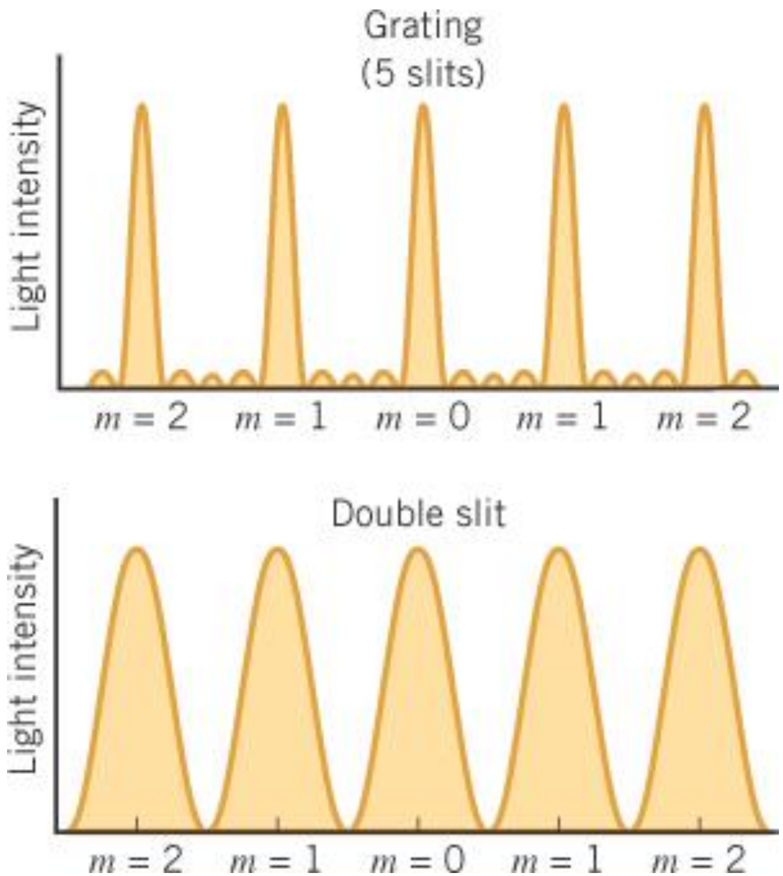
An arrangement consisting of a large number of closely spaced, parallel slits is called a ***diffraction grating.***



27.7 The Diffraction Grating



The conditions shown here lead to the first- and second-order intensity maxima in the diffraction pattern.



The bright fringes produced by a diffraction grating are much narrower than those produced by a double slit.

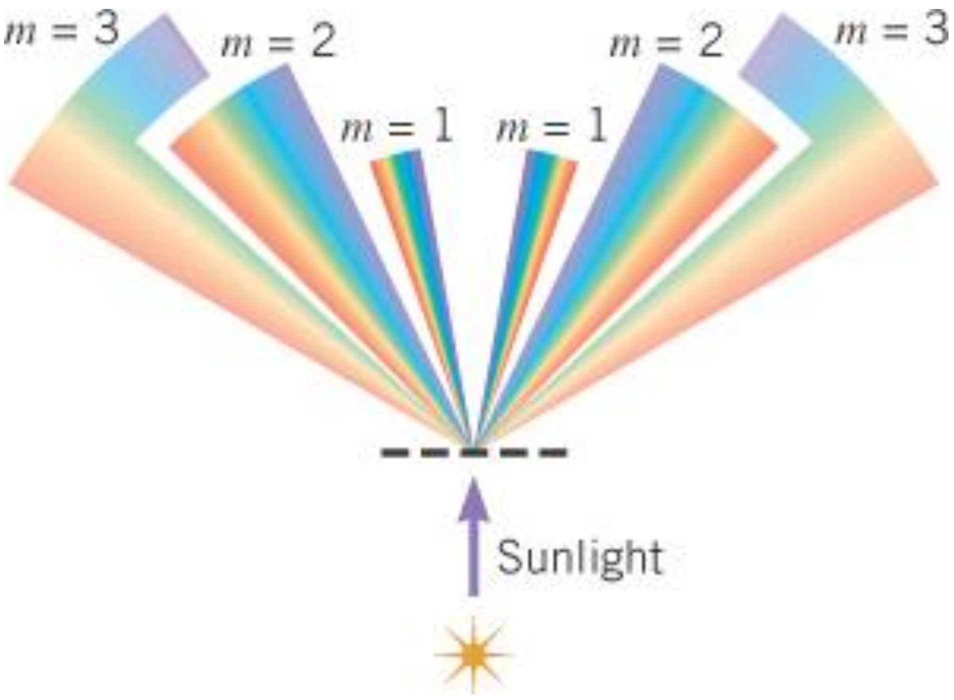
Principal maxima of a diffraction grating

$$\sin\theta = m\frac{\lambda}{d} \qquad m = 0,1,2,3,\ldots$$

distance between slits

Example 9 Separating Colors With a Diffraction Grating

A mixture of violet (410 nm) light and red (660 nm) light falls onto a grating that contains 1.0×10^4 lines/cm. For each wavelength, find the angle that locates the first-order maximum.



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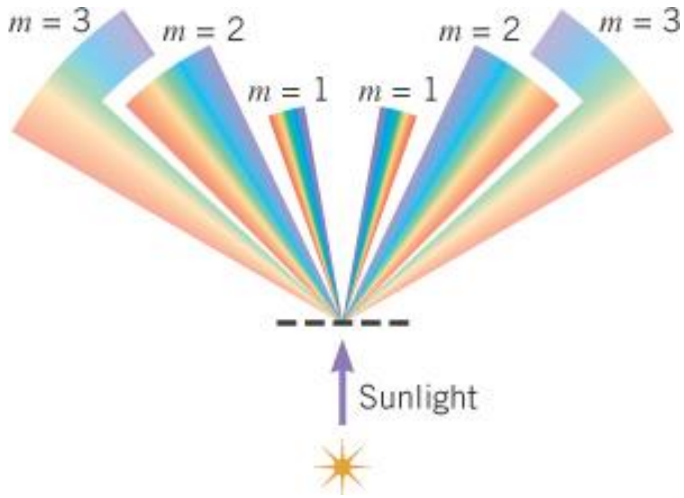
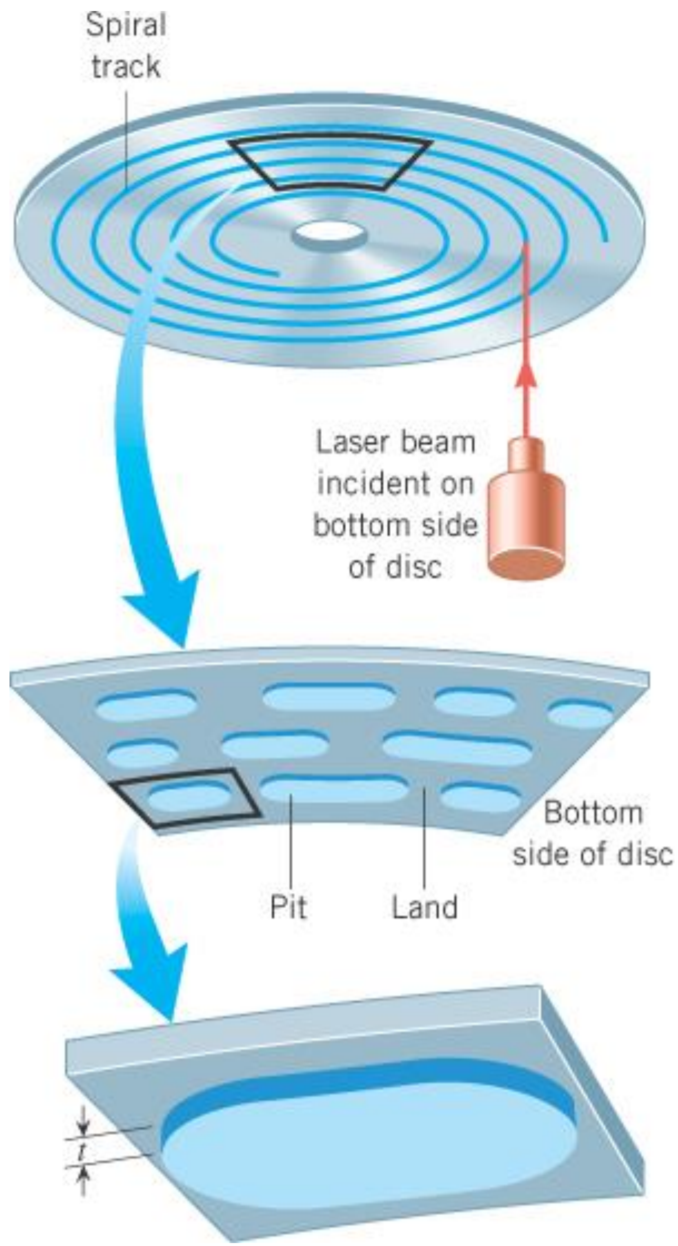
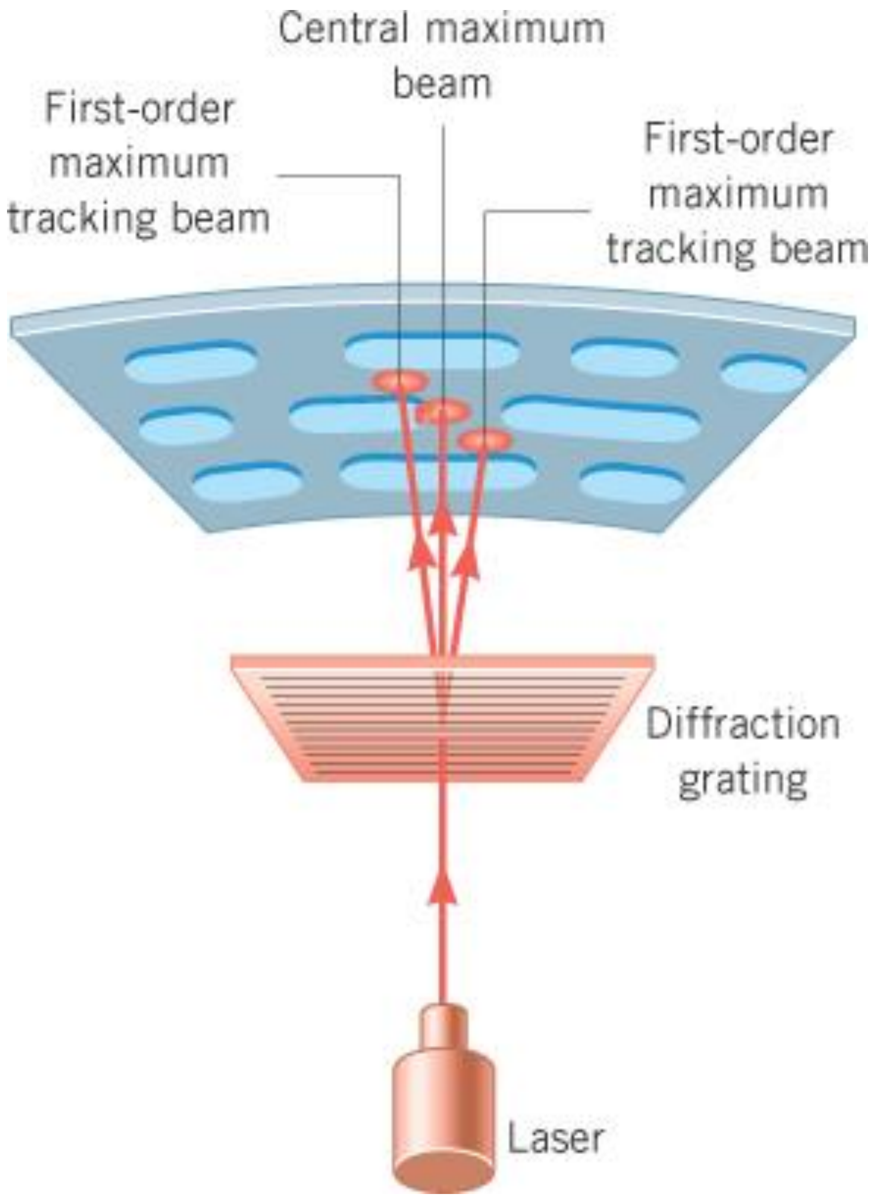


$$\theta = \sin^{-1}\left(\frac{\lambda_{\text{violet}}}{d}\right) = \sin^{-1}\left(\frac{410\times10^{-9}\,\text{m}}{1.0\times10^{-6}\,\text{m}}\right) = 24^{\circ}$$

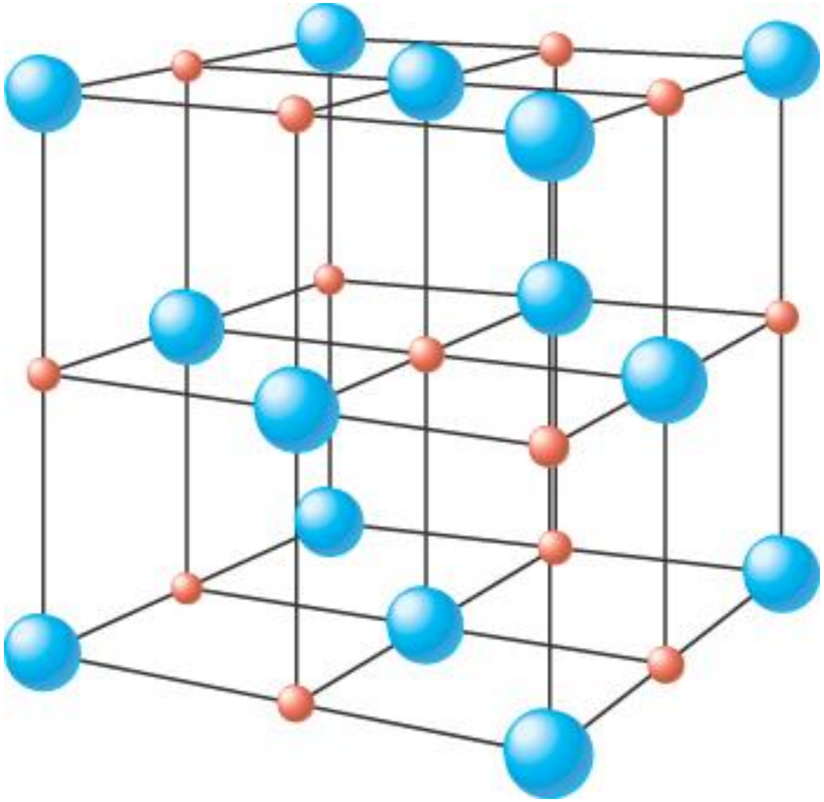
$$\theta = \sin^{-1}\left(\frac{\lambda_{\text{red}}}{d}\right) = \sin^{-1}\left(\frac{660\times10^{-9}\,\text{m}}{1.0\times10^{-6}\,\text{m}}\right) = 41^{\circ}$$


Spiral
track
Laser beam
incident on
bottom side
of disc
Bottom
side of disc
Pit
Land
t

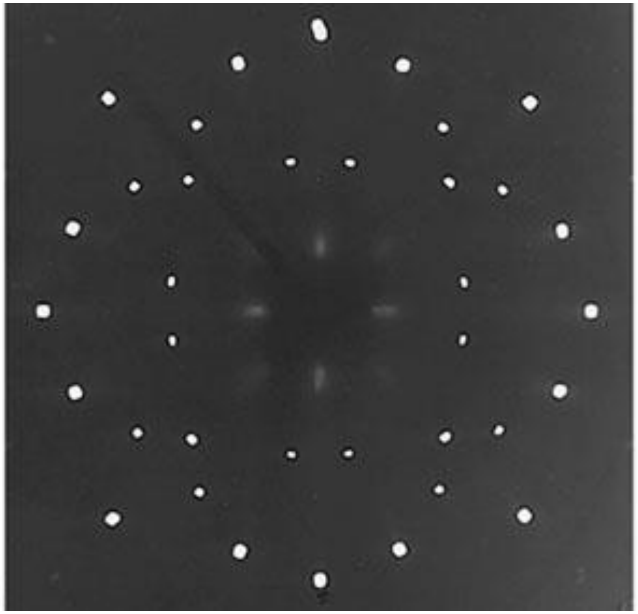
27.8 Compact Discs, Digital Video Discs, and the Use of Interference



27.9 X-Ray Diffraction



27.9 X-Ray Diffraction

(a)


(b)