Chapter 28 Physical Optics: Interference and Diffraction

28-1 Superposition and Interference

28-2 Young's Two-Slit Experience

28-4 Diffraction

28-5 Resolution

28-1 Superposition and Interference

One important aspects of the wave is superposition/interference of two waves.

Same wavelength from same light source

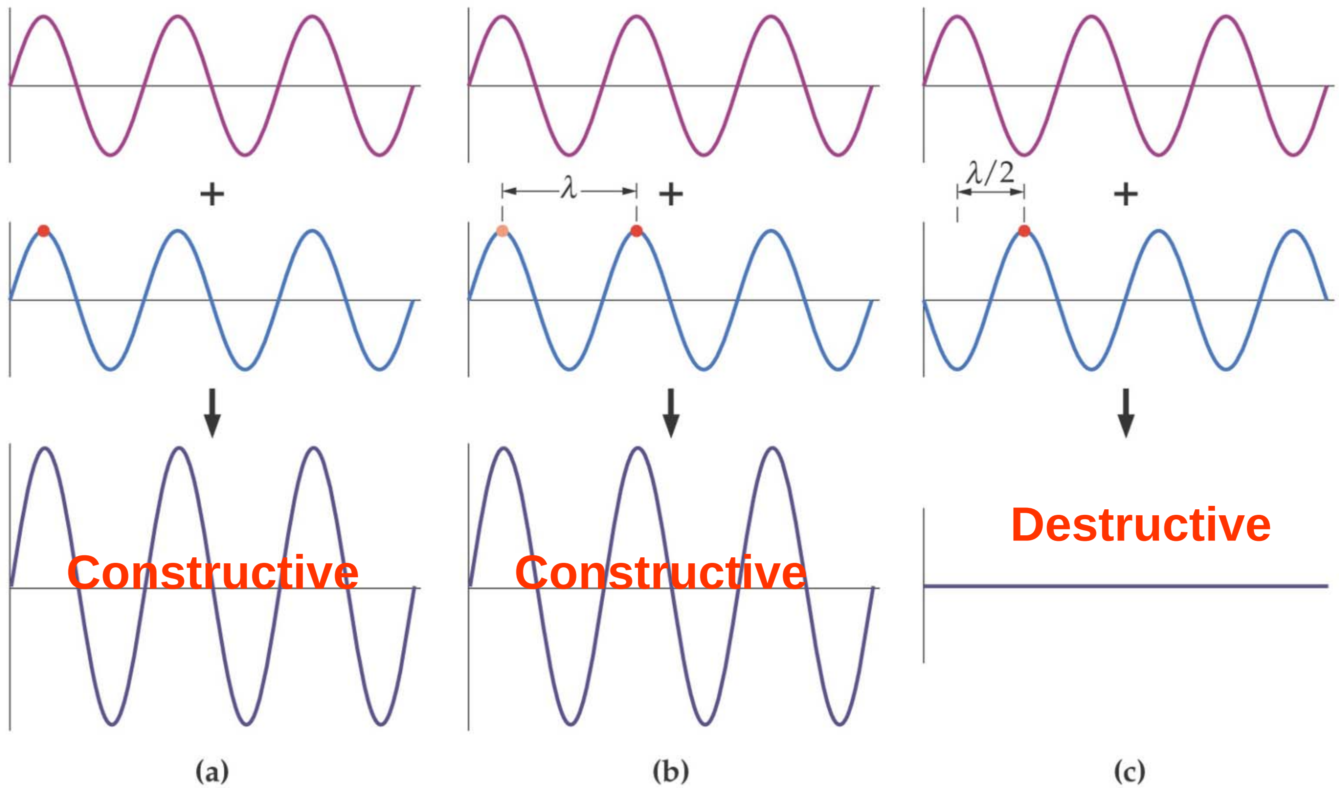


Figure 28-1 Constructive and Destructive Interference
(a) In phase, (a) 360º (λ) out of phase, (c) 180º (λ/2) out of phase.

The conditions for two wave Interference:

1) Monochromatic light;

2) Coherence: the two wave must have constant phase difference.

Incoherence: wave source whose relative phases vary randomly. Such as 2 different light sources.

Laser light is very good coherent light source. Largely used for the interferometer.

We only limit our discussion on Monochromatic and coherence waves. That is, you can imagine that Monochromatic waves from the same light source.

The interference of two waves

The conditions for constructive and destructive interferences are:

$$l_2 - l_1 = m\lambda \qquad (constructive)$$

$$l_2 - l_1 = m\lambda - \frac{\lambda}{2} \qquad (destructive), \qquad m = 0, \ \pm 1, \ \pm 2 \cdots$$

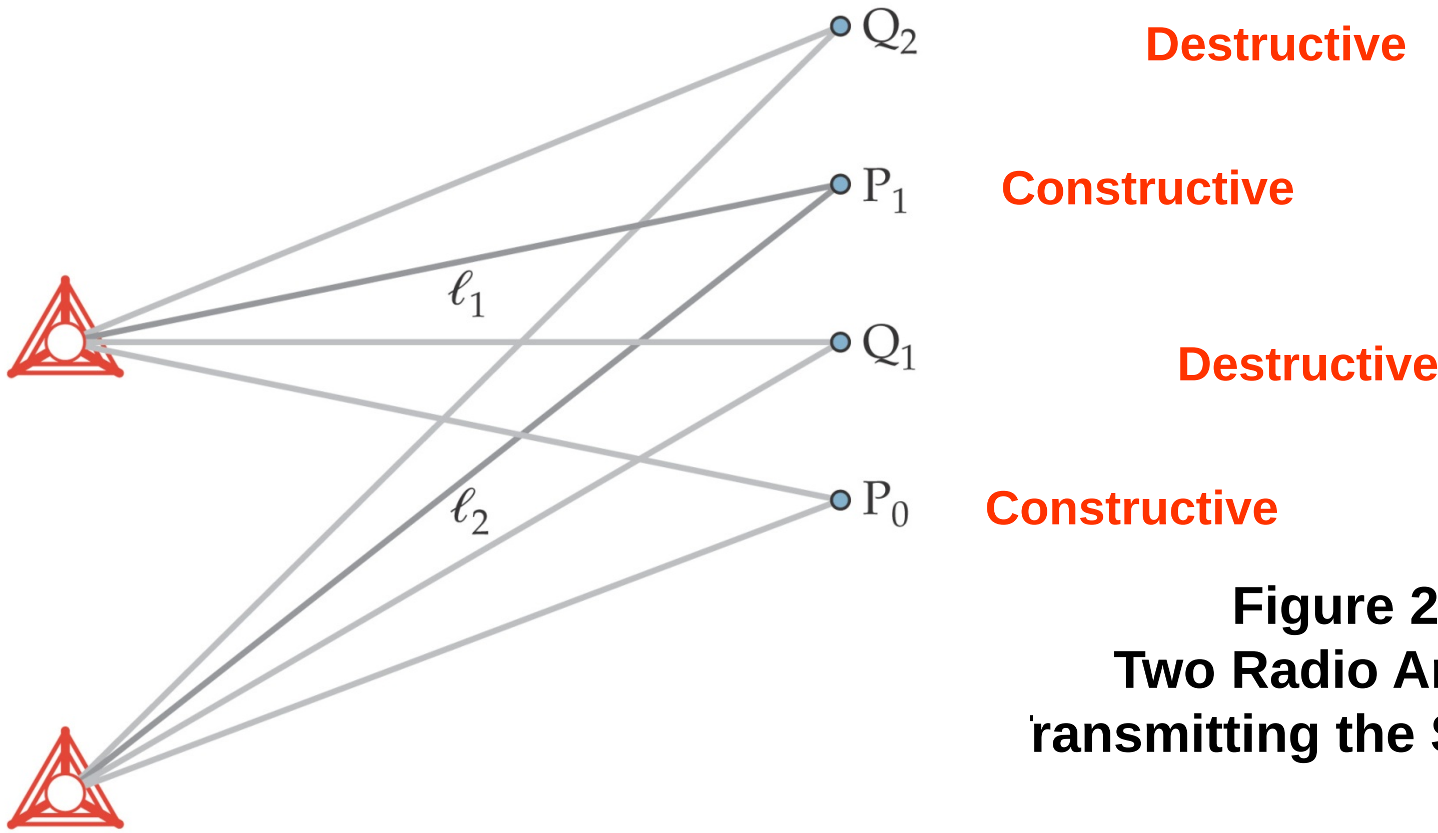
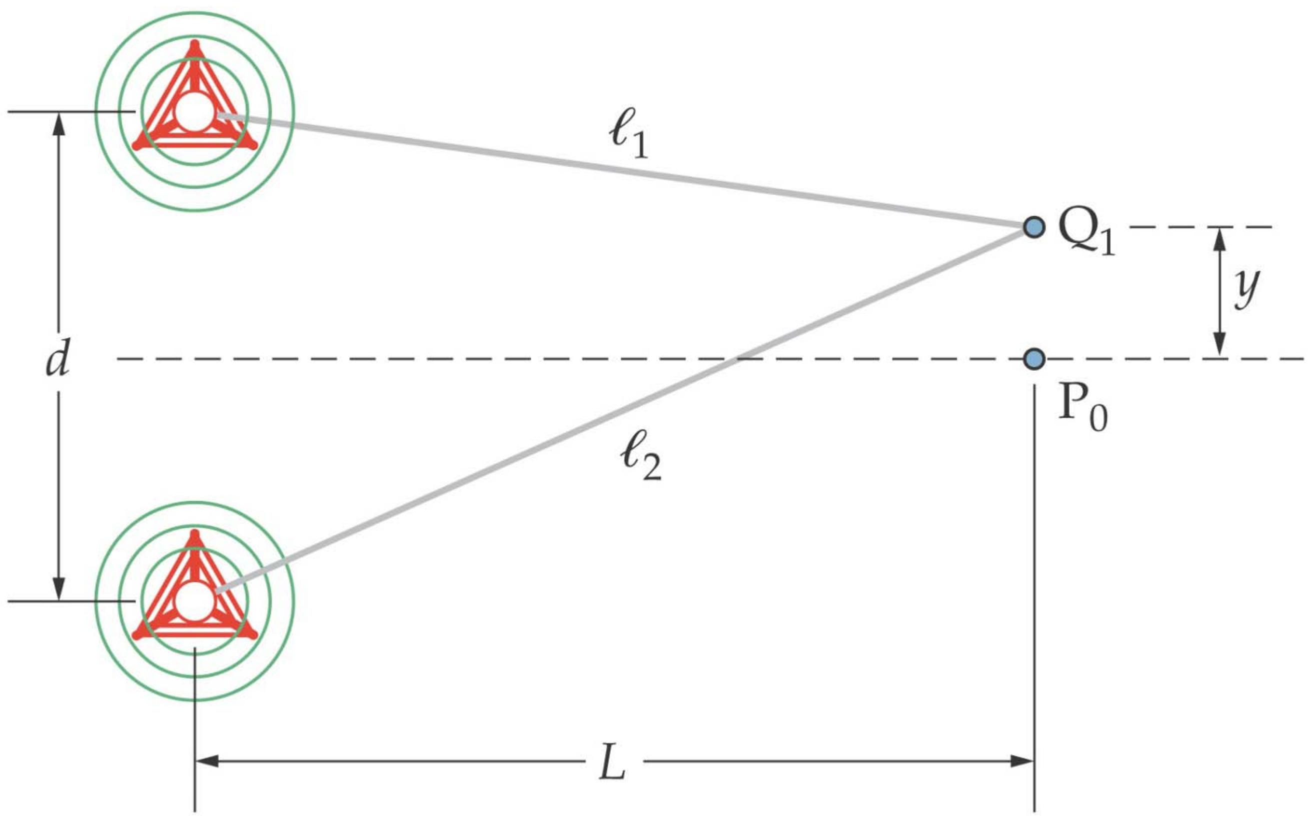


Figure 28-2
Two Radio Antennas
Transmitting the Same Signal

Example 28-1

Two friend tune their radios to the same frequency and pick up a signal transmitted simultaneously by a pair of antennas. The friend at p_0 received a strong signal. The friend at point Q_1 received a very weak signal. Find the wavelength of the radio wave, if d=7.5 km, L= 14.0 km, and y=1.88 km. Assuming Q_1 is the first point of minimum signal as one moves away from center point P_0 in the y direction.



Example 28-1
Two May Not Be Better than One

Solution:

1) Calculate l_1 and l_2:

$$l_1 = \sqrt{L^2 + (\frac{d}{2} - y)^2}$$

$$= \sqrt{(14.0km)^2 + (\frac{7.5km}{2} - 1.88)^2} = 14.1 \quad km$$

$$l_2 = \sqrt{L^2 + (\frac{d}{2} + y)^2}$$

$$= \sqrt{(14.0km)^2 + (\frac{7.5km}{2} + 1.88)^2} = 15.1 \quad km$$

2) For “first-order” destructive interference:

$$l_2 - l_1 = \frac{1}{2}\lambda$$

$$\lambda = 2(l_2 - l_1) = 2(15.1km - 14.1km) = 2.0 \quad km$$

28-2 Young's Two-Slit Experience

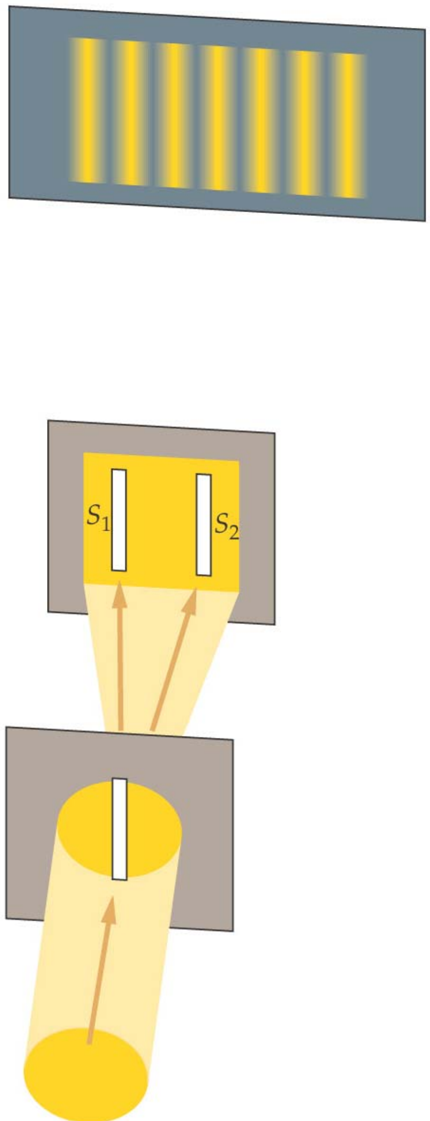


Figure 28-3
Young's Two-Slit Experiment

Figure 28-4
Huygens's Principle

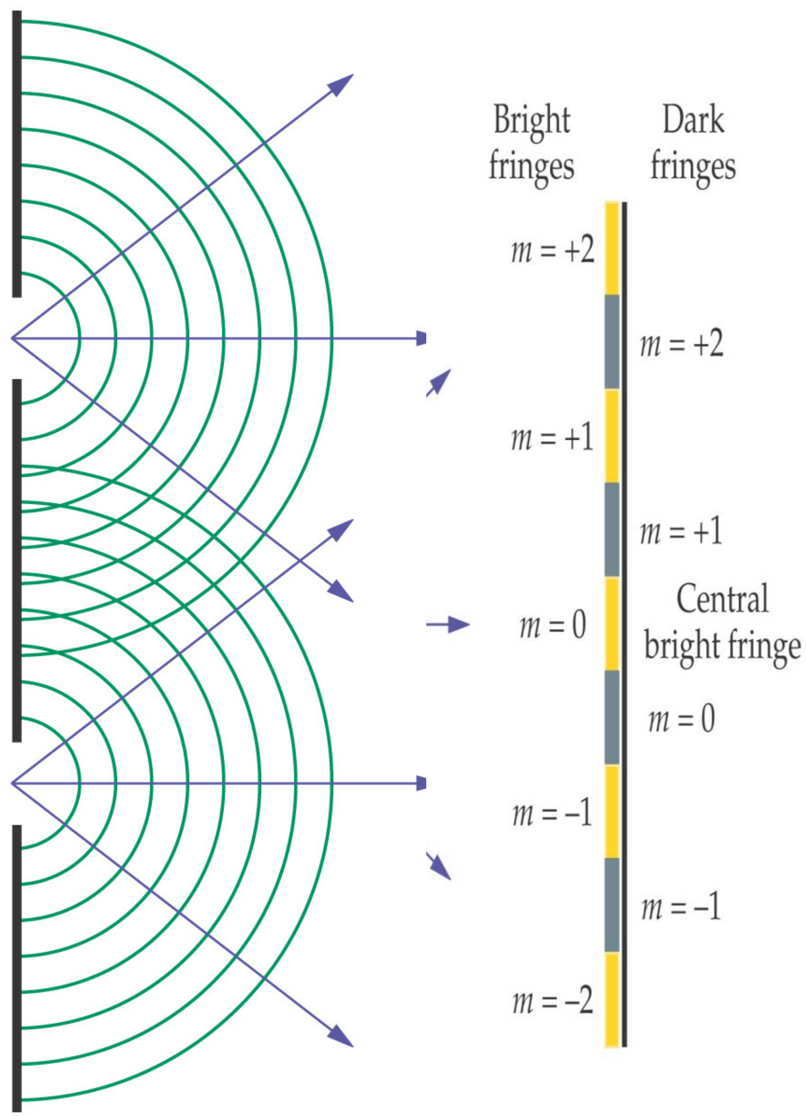
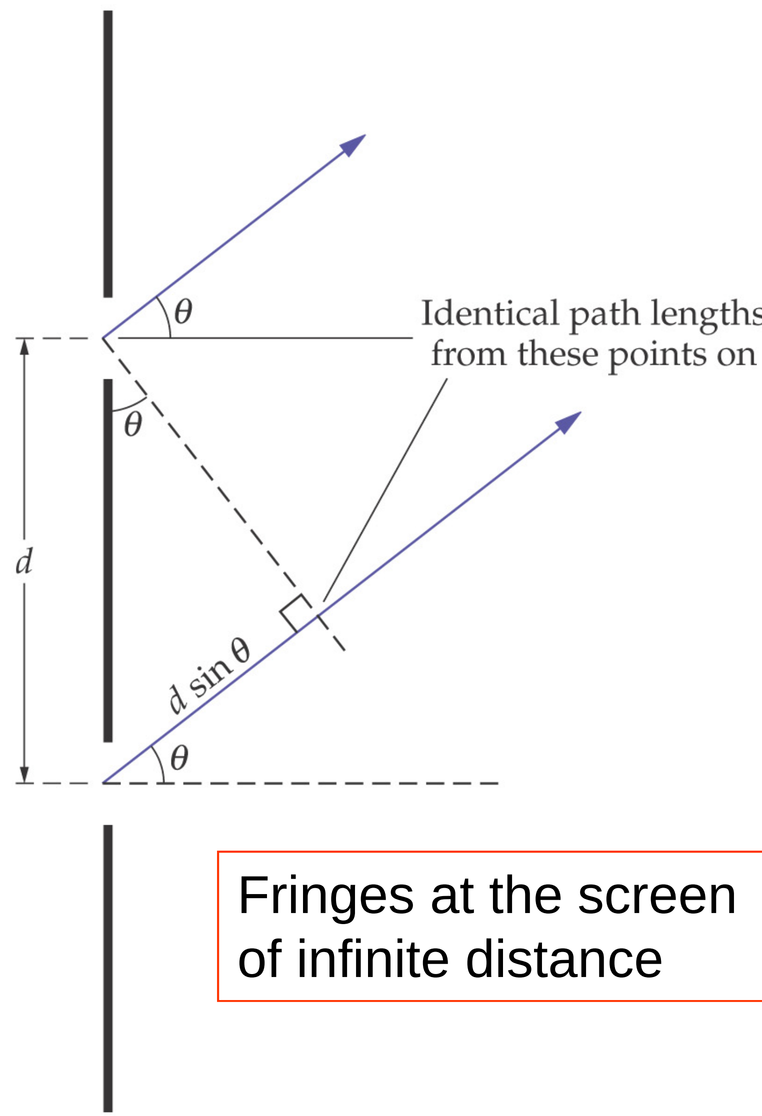


Figure 28-5
Path Difference in the Two-Slit Experiment



Fringes at the screen of infinite distance

Condition for Bright Fringe (constructive Interference) in the two-slit experiment

$$d\sin\theta = m\lambda \qquad m = 0, \pm 1, \pm 2 \cdots \qquad (28-1)$$

M=0,   central bright fringe.

M=1,   first bright fringe.

Condition for Dark Fringe (destructive Interference) in the two-slit experiment

$$d\sin\theta = m\lambda - \frac{\lambda}{2} \qquad m = 0, \pm 1, \pm 2 \cdots \qquad (28-2)$$

M=1, first dark fringe.

Exercise 28-1

Red light (λ = 752 nm) passes through a pair of slits with a separation of 6.20×10^{-5} m. Find the angles corresponding to (a) the first bright fringe and (b) the second dark fringe above the central fringe.

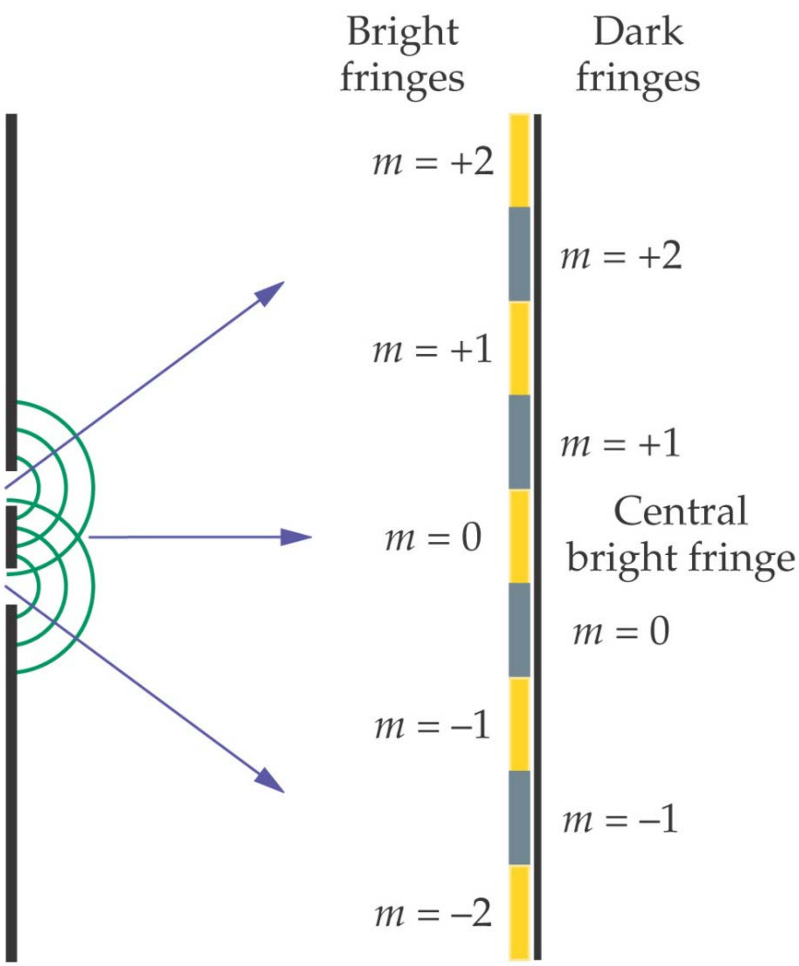


Figure 28-6
The Two-Slit Pattern

Solution:

(a) For the first bright fringe, m=1,

$$d\sin\theta = m\lambda = \lambda$$

$$6.20\times10^{-5}(meter)\times\sin\theta = 7.52\times10^{-7}(meter), \qquad \theta = 0.695^\circ$$

(b) For the second dark fringe, m=2,

$$d\sin\theta = m\lambda - \frac{\lambda}{2} = 2\lambda - \lambda/2 = 1.5\lambda$$

$$6.20\times10^{-5}\sin\theta = 1.5\times(7.52\times10^{-7}), \qquad \theta = 1.04^\circ$$

CONCEPTUAL CHECKPOINT 28–1

A two-slit experiment is performed in the air. Later, the same apparatus is immersed in water, and the experiment is repeated. When the apparatus is in water, are the interference fringes **(a)** more closely spaced, **(b)** more widely spaced, or **(c)** spaced the same as when the apparatus is in air?

CONCEPTUAL CHECKPOINT 28–1

A two-slit experiment is performed in the air. Later, the same apparatus is immersed in water, and the experiment is repeated. When the apparatus is in water, are the interference fringes **(a)** more closely spaced, **(b)** more widely spaced, or **(c)** spaced the same as when the apparatus is in air?

Reasoning and Discussion

The angles coresponding to bright fringes are related to the wavelength by the equation $d \sin \theta = m\lambda$. From this relation it is clear that if λ is increased, the angle θ (and hence the spacing between fringes) also increases; if λ is decreased, the angle θ decreases. Thus, the behavior of the two-slit experiment in water depends on how the wavelength of light changes in water.

Recall that when light goes from air ($n = 1.00$) to a medium in which the index of refraction is $n > 1$, the speed of propagation decreases by the factor n:

$$v = \frac{c}{n}$$

The frequency of light, f, is unchanged throughout as it goes from one medium to another. Therefore, the fact that the speed $v = \lambda f$ decreases by a factor n means that the wavelength λ decreases by the same factor. Hence, if the wavelength of light is λ when $n = 1$, its wavelength in a medium with an index of refraction $n > 1$ is

$$\lambda_n = \frac{\lambda}{n} \qquad \textbf{28–4}$$

As a result, the wavelength of light is less in water than in air, and therefore the interference fringes are more closely spaced when the experiment is performed in water.

Answer:

(a) The fringes are more closely spaced.