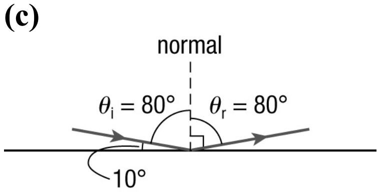
Section 9.1: Properties of Waves and Light

Section 9.1 Questions, page 443

1. The frequency of a wave is determined by the frequency of the wave's source.
2. The speed of a wave is determined by the medium in which it travels.
3. The amplitude of a wave is determined partly by its source and partly by the conditions of the medium in which it travels.
4. The wavelength of a wave is determined by both the wave speed and the frequency. This mathematical relationship is called the universal wave equation.
5. (a) Given: incident ray makes an angle of 10° with the surface
Required: angle of incidence, θ_i
Analysis: The angle of incidence is measured with respect to the normal. Therefore $\theta_i = 90° - 10°$.
Solution:
$$\theta_i = 90° - 10°$$
$$\theta_i = 80°$$
Statement: The angle of incidence is 80°.
(b) The angle of reflection, θ_r, equals the angle of incidence. Therefore θ_r = 80°.
(c)



6. Given: sketch of a wave; f = 40 Hz
Required: v
Analysis: The wavelength is the length of one complete wave. Measure the length of several complete waves on the sketch, and calculate an average value for λ. Then use the universal wave equation $v = f\lambda$ to determine v.
Solution: The wave first crosses the x-axis at approximately 0.1 cm. Three cycles later it crosses the x-axis at 4.0 cm.
$$\lambda = \frac{4.0\text{ cm} - 0.1\text{ cm}}{3}$$
$$\lambda = 1.3\text{ cm}$$
$$\begin{aligned} v &= f\lambda \\ &= \left(40\ \frac{1}{\text{s}}\right)(1.3\text{ cm}) \end{aligned}$$
$$v = 50\text{ cm/s}$$
Statement: The wave speed is 50 cm/s, or 0.5 m/s.
7. Given: Δd = 0.3 m; Δt = 3.5 s; f = 4.6 Hz
Required: λ
Analysis: Use the distance and time information to calculate the wave speed, $v = \frac{\Delta d}{\Delta t}$. Then rearrange the universal wave equation, $v = f\lambda$, to isolate and solve for wavelength.

$v = f\lambda$

$\lambda = \dfrac{v}{f}$

Solution: $v = \dfrac{\Delta d}{\Delta t}$

$= \dfrac{0.3 \text{ m}}{3.5 \text{ s}}$

$v = 0.0857$ m/s (two extra digits carried)

$\lambda = \dfrac{v}{f}$

$= \dfrac{0.0857 \text{ m}/\cancel{\text{s}}}{4.6 \dfrac{1}{\cancel{\text{s}}}}$

$\lambda = 2 \times 10^{-2} \text{ m}$

Statement: The wavelength is 2×10^{-2} m.

8. Given: $T = 0.05$ s

Required: f

Analysis: Frequency is the inverse of period, $f = \dfrac{1}{T}$.

Solution: $f = \dfrac{1}{T}$

$= \dfrac{1}{0.05 \text{ s}}$

$f = 20$ Hz

Statement: The frequency is 20 Hz.

9. Given: $v = 3.0 \times 10^8$ m/s; $f = 5.0 \times 10^{14}$ Hz

Required: λ

Analysis: Rearrange the universal wave equation, $v = f\lambda$, to isolate and solve for wavelength.

$v = f\lambda$

$\lambda = \dfrac{v}{f}$

Solution: $\lambda = \dfrac{v}{f}$

$= \dfrac{3.0 \times 10^8 \text{ m}/\cancel{\text{s}}}{5.0 \times 10^{14} \dfrac{1}{\cancel{\text{s}}}}$

$\lambda = 6.0 \times 10^{-7} \text{ m}$

Statement: The wavelength of the light is 6.0×10^{-7} m.

10. Given: $v = 3.0 \times 10^8$ m/s; $\lambda = 750$ nm $= 7.5 \times 10^{-9}$ m
Required: f
Analysis: Rearrange the universal wave equation, $v = f\lambda$, to isolate and solve for frequency.

$$v = f\lambda$$

$$f = \frac{v}{\lambda}$$

Solution:
$$\begin{aligned} f &= \frac{v}{\lambda} \\ &= \frac{3.0\times 10^{8}\ \cancel{\text{m}}/\text{s}}{7.5\times 10^{-7}\ \cancel{\text{m}}} \\ f &= 4.0\times 10^{14}\ \text{Hz} \end{aligned}$$

Statement: The frequency of the red light waves is 4.0×10^{14} Hz.

11. Given: $c = 3.0 \times 10^8$ m/s; $f = 6.0 \times 10^{14}$ Hz
Required: λ
Analysis: Rearrange the universal wave equation, $v = f\lambda$, to isolate and solve for wavelength.

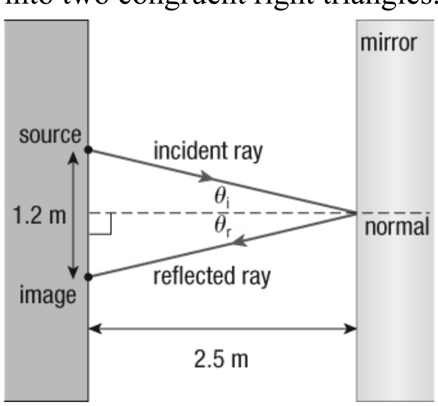
$$v = f\lambda$$

$$\lambda = \frac{v}{f}$$

Solution:
$$\begin{aligned} \lambda &= \frac{v}{f} \\ &= \frac{3.0\times 10^{8}\ \text{m}/\cancel{\text{s}}}{6.0\times 10^{14}\ \dfrac{1}{\cancel{\text{s}}}} \\ \lambda &= 5.0\times 10^{-7}\ \text{m} \end{aligned}$$

Statement: The wavelength of the violet light is 5.0×10^{-7} m.

12. Given: distance to mirror = 2.5 m;
distance between source and reflected ray at source wall = 1.2 m
Required: θ_i
Analysis: $\theta_i = \theta_r$; sketch the situation. The normal at the point of incidence divides the triangle into two congruent right triangles. Use the tangent ratio to determine θ_i.



Solution: $\theta_i = \tan^{-1}\left(\dfrac{0.6\ \cancel{\text{m}}}{2.5\ \cancel{\text{m}}}\right)$

$\theta_i = 13°$

Statement: The angle of incidence is 13°.

13. Given: $v = 1.5 \times 10^3$ m/s; $f = 4.4 \times 10^2$ Hz

Required: λ

Analysis: Rearrange the universal wave equation, $v = f\lambda$, to isolate and solve for wavelength.

$v = f\lambda$

$\lambda = \dfrac{v}{f}$

Solution: $\lambda = \dfrac{v}{f}$

$= \dfrac{1.5 \times 10^3\ \text{m}/\cancel{\text{s}}}{4.4 \times 10^2\ \dfrac{1}{\cancel{\text{s}}}}$

$\lambda = 3.4$ m

Statement: The wavelength of this frequency of sound in water is 3.4 m.

14. Given: $v = 20.0$ m/s; $\lambda = 2.0$ m

Required: f

Analysis: Rearrange the universal wave equation, $v = f\lambda$, to isolate and solve for frequency.

$v = f\lambda$

$f = \dfrac{v}{\lambda}$

Solution: $f = \dfrac{v}{\lambda}$

$= \dfrac{20.0\ \cancel{\text{m}}/\text{s}}{2.0\ \cancel{\text{m}}}$

$f = 10$ Hz

Statement: The frequency of the wave is 10 Hz.

15. Given: $f = 3.1$ kHz $= 3.1 \times 10^3$ Hz; $\lambda = 0.13$ m

Required: v

Analysis: $v = f\lambda$

Solution: $v = f\lambda$

$= \left(3.1 \times 10^3\ \dfrac{1}{\text{s}}\right)(0.13\ \text{m})$

$v = 4.0 \times 10^2$ m/s

Statement: The speed of the wave is 4.0×10^2 m/s.

16. Given: $f = 7.9 \times 10^{14}$ Hz; $v = 3.0 \times 10^8$ m/s

Required: λ

Analysis: Rearrange the universal wave equation, $v = f\lambda$, to isolate and solve for wavelength.

$$v = f\lambda$$

$$\lambda = \frac{v}{f}$$

Solution: $\lambda = \frac{v}{f}$

$$= \frac{3.0\times 10^{8}\ \text{m}/\cancel{\text{s}}}{7.9\times 10^{14}\ \frac{1}{\cancel{\text{s}}}}$$

$$\lambda = 3.8\times 10^{-7}\ \text{m}$$

Statement: The wavelength of the radiation is 3.8×10^{-7} m.

17. Given: f = 310 MHz = 3.1×10^{8} Hz; $v = 3.0 \times 10^{8}$ m/s

Required: λ

Analysis: Rearrange the universal wave equation, $v = f\lambda$, to isolate and solve for wavelength.

$$v = f\lambda$$

$$\lambda = \frac{v}{f}$$

Solution: $\lambda = \frac{v}{f}$

$$= \frac{3.0\times 10^{8}\ \text{m/s}}{3.1\times 10^{8}\ \text{Hz}}$$

$$\lambda = 0.97\ \text{m}$$

Statement: The wavelength of the microwaves is 0.97 m.

18. Sample answer: Mirrors can reflect images because they have a smooth reflecting surface. When several incident light rays strike the mirror, they are reflected in the same direction, which creates a clear image to an observer. This is called specular reflection.

19. Answers may vary. Sample answers:

Method 1: Using proportional reasoning. Frequency and wavelength are related by the universal wave equation $v = f\lambda$. For fixed wave speed, wavelength is inversely proportional to frequency. If one frequency is a factor of three larger than another, its corresponding wavelength is one-third of the other wavelength.

Method 2: Using algebra. $v = f_1\lambda_1$ and $v = f_2\lambda_2$; $f_2 = 3f_1$. Set the two values for v equal to each other.

$$f_2\lambda_2 = f_1\lambda_1$$
$$\frac{\lambda_2}{\lambda_1} = \frac{f_1}{f_2}$$
$$= \frac{\cancel{f_1}}{3\cancel{f_1}}$$
$$\frac{\lambda_2}{\lambda_1} = \frac{1}{3}$$
$$\lambda_2 = \frac{\lambda_1}{3}$$
The ratio of the second wavelength to the first wavelength is 3 : 1.

20. Given: f_1 = 0.13 Hz; λ_1 = 0.56 m; f_2 = 0.45 Hz

Required: λ_2

Analysis: Use the universal wave equation, $v = f\lambda$, to calculate the wave speed. Then use the wave speed and f_2 to determine λ_2.

Solution: $v = f\lambda$

$= (0.83 \text{ Hz})(0.56 \text{ m})$

$v = 0.4648 \text{ m/s}$ (two extra digits carried)

$$\lambda_2 = \frac{v}{f_2}$$
$$= \frac{0.4648 \text{ m}/\cancel{\text{s}}}{0.45\ \frac{1}{\cancel{\text{s}}}}$$
$$\lambda_2 = 1.0 \text{ m}$$

Statement: When the frequency is 0.45 Hz, the new wavelength is 1.0 m.

21. (a) Sample answer: A flat mirror causes *specular* reflection because its surface is smooth and regular and reflects the rays of a parallel beam of light in one direction.

(b) Sample answer: A piece of notebook paper causes *diffuse* reflection because the paper fibres have many orientations and reflect the rays of a parallel beam of light in many different directions.

(c) Sample answer: The surface of a puddle on a calm day causes *specular* reflection because it is smooth and regular and reflects the rays of a parallel beam of light in one direction.

(d) Sample answer: The surface of a lake on a windy day causes *diffuse* reflection because the rough waves reflect the rays of a parallel beam of light in many directions.

Section 9.2: Refraction and Total Internal Reflection

Tutorial 1 Practice, page 449

1. The angle of incidence is 65°. The fact that the experiment takes place in water does not change the angle of incidence.

2. Given: $\theta_i = 47.5°$; $\theta_R = 34.0°$; $n_{air} = 1.0003$

Required: n_2

Analysis: Index of refraction is a physical property that can be used to identify a substance. Use Snell's law, $n_1 \sin\theta_1 = n_2 \sin\theta_2$, to calculate the index of refraction of the medium. Then match it to a substance in Table 1.

Solution: $n_1 \sin\theta_1 = n_2 \sin\theta_2$

$$n_2 = \frac{n_1 \sin\theta_1}{\sin\theta_2}$$

$$= \frac{(1.0003)\sin 47.5°}{\sin 34.0°}$$

$$n_2 = 1.32$$

According to Table 1, the index of refraction lies between that of ice and liquid water but is closer to water.

Statement: The medium is probably water.

3. Given: $\theta_1 = 35°$; $\theta_R = 25°$; $n_{air} = 1.0003$

Required: n_2

Analysis: $n_1 \sin\theta_1 = n_2 \sin\theta_2$

Solution: $n_1 \sin\theta_1 = n_2 \sin\theta_2$

$$n_2 = \frac{n_1 \sin\theta_1}{\sin\theta_2}$$

$$= \frac{(1.0003)\sin 35°}{\sin 25°}$$

$$n_2 = 1.36$$

Statement: The index of refraction of the water is 1.36.

4. Given: $n = 2.42$; $c = 3.0 \times 10^8$ m/s

Required: v

Analysis: Use the definition of index of refraction, $n = \frac{v}{c}$, to solve for the speed v.

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

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

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

$$= \frac{3.0 \times 10^8 \text{ m/s}}{2.42}$$

$$v = 1.2 \times 10^8 \text{ m/s}$$

Statement: The speed of light in diamond is 1.2×10^8 m/s.

5. Given: $n = 1.46$; $\lambda_1 = 5.6 \times 10^{-7}$ m

Required: λ_2

Analysis: Use the alternative definition of index of refraction, $n = \frac{\lambda_1}{\lambda_2}$, to solve for λ_2.

$$n = \frac{\lambda_1}{\lambda_2}$$

$$\lambda_2 = \frac{\lambda_1}{n}$$

Solution: $\lambda_2 = \frac{\lambda_1}{n}$

$$= \frac{5.6 \times 10^{-7} \text{ m}}{1.46}$$

$$\lambda_2 = 3.8 \times 10^{-7} \text{ m}$$

Statement: The wavelength of light in quartz is 3.8×10^{-7} m.

6. Given: $n = 1.45$; $\lambda_1 = 450 \text{ nm} = 4.5 \times 10^{-7}$ m

Required: f_2

Analysis: The frequency of light does not change when light passes from one medium into another. The frequency of the light inside the glass is the same as in vacuum. Rearrange the universal wave equation, $v = f\lambda$, to solve for *f*.

$$v = f\lambda$$

$$f = \frac{v}{\lambda}$$

Solution: $f = \frac{v}{\lambda}$

$$= \frac{3.0 \times 10^8 \cancel{\text{m}}/\text{s}}{4.5 \times 10^{-7} \cancel{\text{m}}}$$

$$f = 6.7 \times 10^{14} \text{ Hz}$$

Statement: The frequency of the light is 6.7×10^{14} Hz.

Tutorial 2 Practice, page 452

1. (a) Given: $\theta_1 = 40.0°$; $n_1 = 1.0003$; $n_2 = 1.465$

Required: θ_2

Analysis: $n_1 \sin\theta_1 = n_2 \sin\theta_2$

Solution: $n_1 \sin\theta_1 = n_2 \sin\theta_2$

$$\sin\theta_2 = \frac{n_1 \sin\theta_1}{n_2}$$

$$\theta_2 = \sin^{-1}\left(\frac{n_1 \sin\theta_1}{n_2}\right)$$

$$= \sin^{-1}\left(\frac{(1.0003)\sin 40.0°}{1.465}\right)$$

$$= 26.033° \text{ (two extra digits carried)}$$

$$\theta_2 = 26.0°$$

Statement: The angle of refraction at the left boundary of the prism is 26.0°.

(b) Given: $\theta_2 = 26.033°$; $n_3 = 1.465$

Required: θ_4

Analysis: From the geometry of the prism, the angle of incidence at the right boundary, θ_3, is $\theta_3 = 60.0° - \theta_2$. Determine θ_2, then use Snell's law, $n_3 \sin\theta_3 = n_4 \sin\theta_4$, to calculate the angle of refraction, θ_4.

Solution: $\theta_3 = 60.0° - \theta_2$

$$= 60.0° - 26.033°$$

$$\theta_3 = 33.967° \text{ (two extra digits carried)}$$

$$n_3 \sin\theta_3 = n_4 \sin\theta_4$$

$$\sin\theta_4 = \frac{n_3 \sin\theta_3}{n_4}$$

$$\theta_4 = \sin^{-1}\left(\frac{n_3 \sin\theta_3}{n_4}\right)$$

$$= \sin^{-1}\left(\frac{(1.465)\sin 33.967°}{1.0003}\right)$$

$$\theta_4 = 54.9°$$

Statement: The angle of refraction of the exiting light is 54.9°.

2. Sample answer: The light entered and exited the prism on faces that were not parallel. You would only see the exit angle equal to the incident angle if the faces were parallel, as in a sheet of glass.

3. Given: $\theta_1 = 55°$; $n = 1.60$

Required: θ, the angle of the outgoing ray as measured with the horizontal

Analysis: Calculate the first angle of refraction, θ_2, using Snell's law, $n_1 \sin\theta_1 = n_2 \sin\theta_2$. Then determine the second angle of incidence, θ_3, using $\theta_3 = 60.0° - \theta_2$. Use Snell's law to calculate the second angle of refraction, θ_4. Determine the exit angle, θ, with respect to the horizontal.

Solution:

The first angle of refraction is θ_2.

$$
\begin{aligned}
n_1 \sin\theta_1 &= n_2 \sin\theta_2 \\
\sin\theta_2 &= \frac{n_1 \sin\theta_1}{n_2} \\
\theta_2 &= \sin^{-1}\left(\frac{n_1 \sin\theta_1}{n_2}\right) \\
&= \sin^{-1}\left(\frac{(1.0003)\sin 55°}{1.60}\right) \\
\theta_2 &= 30.81° \text{ (two extra digits carried)}
\end{aligned}
$$

The second angle of incidence is θ_3.

$$
\begin{aligned}
\theta_3 &= 60.0° - \theta_2 \\
&= 60.0° - 30.81° \\
\theta_3 &= 29.19° \text{ (two extra digits carried)}
\end{aligned}
$$

The second angle of refraction is θ_4.

$$
\begin{aligned}
n_3 \sin\theta_3 &= n_4 \sin\theta_4 \\
\sin\theta_4 &= \frac{n_3 \sin\theta_3}{n_4} \\
\theta_4 &= \sin^{-1}\left(\frac{n_3 \sin\theta_3}{n_4}\right) \\
&= \sin^{-1}\left(\frac{(1.60)\sin 29.19°}{1.0003}\right) \\
\theta_4 &= 51°
\end{aligned}
$$

The normal on the right side of the prism is directed at 30° above the horizontal, so the exit angle is $\theta = \theta_4 - 30°$

$$
\begin{aligned}
&= 51° - 30° \\
\theta &= 21°
\end{aligned}
$$

Statement: The light exits at 21° below the horizontal.

Research This: Using Spectroscopy to Determine Whether Extra-Solar Planets Can Support Life, page 452

A. Answers may vary. Sample answers: Light reflected from other planets can be seen and analyzed on Earth. When the light passes through a spectrometer, it is dispersed (broken up) into its component colours and makes a spectrum similar to the one shown in the text. Scientists use the dark lines in the spectrum to identify the atom or molecule that absorbed the missing colours. This atom or molecule had to be on the planet where the light was reflected.
B. Answers may vary. Sample answers: Astrophysicists and astrobiologists look for oxygen, carbon, nitrogen, and hydrogen. On Earth, these are the main elements involved in biological processes. Finding these elements elsewhere could indicate the right conditions for extraterrestrial life.
C. Answers may vary. Sample answers: Scientists think of light as a wave when using a diffraction grating in a spectrometer. But they also think of light as particle when it is absorbed by or emitted from an atom.

Tutorial 3 Practice, page 457

1. Answers may vary. Sample answer: I will use a liquid with $n = 1.20$ for my comparison.
Given: $n_1 = 1.20$; $n_2 = 1.0003$
Required: θ_c
Analysis: $\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$
Solution: $\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$

$$= \sin^{-1}\left(\frac{1.0003}{1.20}\right)$$

$$\theta_c = 56.4°$$

Statement: If the index of refraction of the liquid is decreased to 1.20, then the critical angle increases to 56.4°. As the index of refraction decreases, the critical angle increases.
2. Given: $n_1 = 1.50$; $n_2 = 1.33$
Required: θ_c
Analysis: $\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$
Solution: $\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$

$$= \sin^{-1}\left(\frac{1.33}{1.50}\right)$$

$$\theta_c = 62.5°$$

Statement: The critical angle for light at the benzene–water boundary is 62.5°.

3. Given: $n_1 = 1.40$; $n_2 = 1.0003$

Required: θ_c

Analysis: $\theta_c = \sin^{-1}\left(\dfrac{n_2}{n_1}\right)$

Solution: $\theta_c = \sin^{-1}\left(\dfrac{n_2}{n_1}\right)$

$$= \sin^{-1}\left(\frac{1.0003}{1.40}\right)$$

$$\theta_c = 45.6°$$

Statement: The critical angle for light on the glass–air boundary is 45.6°.

4. Given: $n_d = 2.42$; $n_g = 1.52$; $n_z = 1.92$; $n_{air} = 1.0003$

Required: θ_c; θ_g; θ_z

Analysis: $\theta_c = \sin^{-1}\left(\dfrac{n_{air}}{n_{med}}\right)$

Solution:

Diamond:

$$\theta_{c,d} = \sin^{-1}\left(\frac{n_{air}}{n_d}\right)$$
$$= \sin^{-1}\left(\frac{1.0003}{2.42}\right)$$
$$\theta_{c,d} = 24.4°$$

Crown glass:

$$\theta_{c,g} = \sin^{-1}\left(\frac{n_{air}}{n_g}\right)$$
$$= \sin^{-1}\left(\frac{1.0003}{1.52}\right)$$
$$\theta_{c,g} = 41.2°$$

Zircon:

$$\theta_{c,z} = \sin^{-1}\left(\frac{n_{air}}{n_z}\right)$$
$$= \sin^{-1}\left(\frac{1.0003}{1.92}\right)$$
$$\theta_{c,z} = 31.4°$$

Statement: The critical angle for diamond is 24.4°. The critical angle for zircon is 31.4°. The critical angle for crown glass is 41.2°.

Diamond has a smaller critical angle than crown glass and zircon, so a light ray passing through diamond is more likely to reflect off the surface. If the light passes into the diamond from an angle that is less than the normal angle of 90° (most probable), then the refraction will be more likely to disperse the spectrum than a material such as glass, which has a far lower index of refraction. The diamond appears to glitter.

Additional information: Light rays that pass through a piece of material like diamond may reflect off the surface several times before finally passing out of the material in a different direction than when they entered. This effect gives a viewer the impression that light sources inside the material produced the light, even if the light came from a source outside the material.

Section 9.2 Questions, page 458

1. Answers may vary. Sample answer: When light travels from one medium to another, its direction of propagation changes. This change in direction during refraction makes the light ray appear to "bend."

2. When light is reflected or refracted, its direction changes. The change in angle between the incident ray and the outgoing ray is the angle of deviation.

3. Given: $n = 1.33$; $\lambda_1 = 630 \text{ nm} = 6.3 \times 10^{-7} \text{ m}$

Required: λ_2

Analysis: Rearrange the equation for index of refraction, $n = \dfrac{\lambda_1}{\lambda_2}$, to solve for wavelength.

$$n = \frac{\lambda_1}{\lambda_2}$$

$$\lambda_2 = \frac{\lambda_1}{n}$$

Solution:
$$\begin{aligned}\lambda_2 &= \frac{\lambda_1}{n} \\ &= \frac{6.3 \times 10^{-7} \text{ m}}{1.33} \\ \lambda_2 &= 4.7 \times 10^{-7} \text{ m}\end{aligned}$$

Statement: In water, the laser light has a wavelength of 4.7×10^{-7} m, or 470 nm.

4. Given: $v = 3.0 \times 10^8$ m/s; $c = 3.0 \times 10^8$ m/s

Required: n

Analysis: $n = \dfrac{v}{c}$

Solution:
$$\begin{aligned}n &= \frac{v}{c} \\ &= \frac{3.0 \times 10^8 \cancel{\text{m/s}}}{3.0 \times 10^8 \cancel{\text{m/s}}} \\ n &= 1.0\end{aligned}$$

Statement: The index of refraction of the medium is 1.0.

5. Given: $\theta_1 = 30.0°$; $n_1 = 1.47$; $n_2 = 1.33$; $n_3 = 1.0003$

Required: θ_3

Analysis: One method is to use Snell's law, $n_1 \sin\theta_1 = n_2 \sin\theta_2$, to determine the angle of refraction in the water film. This angle is the incident angle for the second refraction into air. Use Snell's law to determine the angle of refraction in air. A second method recognizes that the film of water does not matter because its surfaces are parallel. We could use Snell's law to go directly from glass to air.

Solution:
First method:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

$$\sin\theta_2 = \frac{n_1 \sin\theta_1}{n_2}$$

$$\theta_2 = \sin^{-1}\left(\frac{n_1 \sin\theta_1}{n_2}\right)$$

$$= \sin^{-1}\left(\frac{(1.47)\sin 30.0°}{1.33}\right)$$

$$\theta_2 = 33.548° \text{ (two extra digits carried)}$$

$$n_2 \sin\theta_2 = n_3 \sin\theta_3$$

$$\sin\theta_3 = \frac{n_2 \sin\theta_2}{n_3}$$

$$\theta_3 = \sin^{-1}\left(\frac{n_2 \sin\theta_2}{n_3}\right)$$

$$= \sin^{-1}\left(\frac{(1.33)\sin 33.548°}{1.0003}\right)$$

$$\theta_3 = 47.3°$$

Second method:

$$n_1 \sin\theta_1 = n_3 \sin\theta_3$$

$$\sin\theta_3 = \frac{n_1 \sin\theta_1}{n_3}$$

$$\theta_3 = \sin^{-1}\left(\frac{n_1 \sin\theta_1}{n_3}\right)$$

$$= \sin^{-1}\left(\frac{(1.47)\sin 30.0°}{1.0003}\right)$$

$$\theta_3 = 47.3°$$

Statement: The angle of refraction of the final outgoing ray is 47.3°.

6. Given: $\theta_1 = 30.0°$; $n_1 = 1.44$; $n_2 = 1.0003$

Required: n_2

Analysis: $n_1 \sin\theta_1 = n_2 \sin\theta_2$

Solution: $n_1 \sin\theta_1 = n_2 \sin\theta_2$

$$\sin\theta_2 = \frac{n_1 \sin\theta_1}{n_2}$$

$$\theta_2 = \sin^{-1}\left(\frac{n_1 \sin\theta_1}{n_2}\right)$$

$$= \sin^{-1}\left(\frac{(1.44)\sin 30.0°}{1.0003}\right)$$

$$\theta_2 = 46.0°$$

Statement: The angle of refraction is 46.0°.

7. Given: $\theta_1 = 50.0°$; $n_1 = 1.33$; $n_2 = 1.0003$

Required: n_2

Analysis: $n_1 \sin\theta_1 = n_2 \sin\theta_2$

Solution: $n_1 \sin\theta_1 = n_2 \sin\theta_2$

$$\sin\theta_2 = \frac{n_1 \sin\theta_1}{n_2}$$

$$\theta_2 = \sin^{-1}\left(\frac{n_1 \sin\theta_1}{n_2}\right)$$

$$= \sin^{-1}\left(\frac{(1.33)\sin 50.0°}{1.0003}\right)$$

$\theta_2 = \sin^{-1}(1.0185)$ There is no solution for θ_2.

Statement: The incident angle of the laser beam in water is greater than the critical angle in water. The laser beam undergoes total internal reflection.

8. (a) Given: $n_1 = 1.65$; $n_2 = 1.33$

Required: θ_c

Analysis: $\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$

Solution: $\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$

$$= \sin^{-1}\left(\frac{1.33}{1.65}\right)$$

$$\theta_c = 53.7°$$

Statement: The critical angle for light at a glass–water boundary is 53.7°.

(b) The light starts in the medium with the higher index of refraction, which is the glass. There can be no total internal reflection if the light starts in the medium with the lower index of refraction.

9. (a) Given: $\theta_2 = 45°$; $n_1 = 1.0003$; $n_2 = 1.30$

Required: $\theta_i = \theta_1$

Analysis: $n_1 \sin\theta_1 = n_2 \sin\theta_2$

Solution:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

$$\sin\theta_1 = \frac{n_2 \sin\theta_2}{n_1}$$

$$\theta_1 = \sin^{-1}\left(\frac{n_2 \sin\theta_2}{n_1}\right)$$

$$= \sin^{-1}\left(\frac{1.30 \sin 45°}{1.0003}\right)$$

$$\theta_1 = 67°$$

Statement: The angle of incidence is 67°.

(b) Given: $n_1 = 1.30$; $n_2 = 1.0003$

Required: θ_c

Analysis: $\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$

Solution: $\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$

$$= \sin^{-1}\left(\frac{1.0003}{1.30}\right)$$

$$\theta_c = 50.3°$$

Statement: The critical angle for light at the transparent material–air boundary is 50.3°.

10. (a) Given: $\theta_1 = 30.0°$; $n_1 = 1.33$; $n_2 = 1.63$

Required: $\theta_R = \theta_2$

Analysis: $n_1 \sin\theta_1 = n_2 \sin\theta_2$

Solution: $n_1 \sin\theta_1 = n_2 \sin\theta_2$

$$\sin\theta_2 = \frac{n_1 \sin\theta_1}{n_2}$$

$$\theta_2 = \sin^{-1}\left(\frac{n_1 \sin\theta_1}{n_2}\right)$$

$$= \sin^{-1}\left(\frac{(1.33)\sin 30.0°}{1.63}\right)$$

$$\theta_2 = 24.1°$$

Statement: The angle of refraction is 24.1°.

(b) Light incident on a water–carbon disulfide boundary cannot undergo total internal reflection because the index of refraction of carbon disulfide is greater than the index of refraction of water.

11. Answers may vary. Sample answer: Fibre optics, which use total internal reflection, are used in medicine to view inside various parts of the body. One example of an instrument that uses fibre optics is the endoscope. Doctors use an endoscope to examine a patient's internal tissues and organs.

Additional information: An angioscope is a coated fibre optic cable with a fish-eye lens that can be inserted into a blood vessel to diagnose constrictions, blockages, or weaknesses. A gastroscope is another variation of fibre optic cable that is swallowed and is used to view the esophagus, stomach, and some of the small intestine. Most medical fibre optic scopes also have mechanisms for taking tissue samples or for removing diseased tissue.

12. (a) Answers may vary. Sample answer: Hibernia Atlantic and Emerald Express are two international companies with plans for new fibre optic transatlantic cables.

(b) The biggest advantage of submarine cables is that the time for transmission and reception of the signal is significantly shorter than when using satellite communication. This may not seem like a major advantage for conversations, but most transatlantic communication involves investment trading, when every millisecond counts. The newest cables are aiming for round-trip transit times of 60 ms. The biggest disadvantage of submarine cables is cost. This technology contributes to the escalating prices for communications.

13. Answers may vary. Sample answer: Signal reduction, usually called attenuation, in optical fibres occurs for a number of reasons. One reason is that impurities in the fibre may absorb the signal. More significantly, there are losses due to reflection from the core or cladding, and losses due to splicing of the cables. These losses occur because the signal reflects off these surfaces at an angle that will allow transmission out of the fibre.

Section 9.3: Diffraction and Interference of Water Waves

Tutorial 1 Practice, page 461

1. Given: $\lambda = 1.0$ m; $w = 0.5$ m

Required: $\dfrac{\lambda}{w}$

Analysis: Diffraction should be noticeable if $\dfrac{\lambda}{w} \geq 1$, so solve for $\dfrac{\lambda}{w}$.

Solution:

$$\frac{\lambda}{w} = \frac{1.0\text{ m}}{0.5\text{ m}}$$

$$\frac{\lambda}{w} = 2$$

Statement: Yes, the diffraction should be noticeable because $\dfrac{\lambda}{w}$ is greater than 1.

2. Given: λ = 630 nm = 6.3×10^{-7} m

Required: maximum width w for noticeable diffraction

Analysis: Use the condition that $\dfrac{\lambda}{w} \geq 1$.

Solution:

$$\frac{\lambda}{w} \geq 1$$

$$\lambda \geq w$$

$$6.3 \times 10^{-7}\text{ m} \geq w$$

Statement: The maximum slit width for significant diffraction to be produced is 6.3×10^{-7} m.

Mini Investigation: Interference from Two Speakers, page 464

A. Answers may vary. Sample answer: The distances to the two speakers should differ by zero or a whole number of wavelengths to get constructive interference.

B. Answers may vary. Sample answers: The distances to the two speakers should differ by a half-whole number of wavelengths to get destructive interference.

C. Answers may vary. Sample answers: If a sound of known frequency and wavelength is played, students can compare their estimates with the known values.

Tutorial 2 Practice, page 468

1. Given: two-source interference; $\lambda = 2.5$ m

Required: d, smallest path difference for a node

Analysis: Use $\left|P_nS_1 - P_nS_2\right| = \left(n - \dfrac{1}{2}\right)\lambda$ with n = 1.

Solution: $\left|P_nS_1 - P_nS_2\right| = \left(n - \dfrac{1}{2}\right)\lambda$

$$= \left(1 - \frac{1}{2}\right)(2.5\text{ m})$$

$$\left|P_1S_1 - P_1S_2\right| = 1.2\text{ m}$$

Statement: The smallest path difference for a node is 1.2 m.

2. (a) Given: $n = 3$; $P_3S_1 = 35\text{ cm}$; $P_3S_2 = 42\text{ cm}$

Required: λ

Analysis: $\left|P_nS_1 - P_nS_2\right| = \left(n - \dfrac{1}{2}\right)\lambda$

$$\lambda = \frac{\left|P_nS_1 - P_nS_2\right|}{n - \frac{1}{2}}$$

Solution: $\lambda = \dfrac{\left|P_3S_1 - P_3S_2\right|}{n - \frac{1}{2}}$

$$= \frac{\left|35\text{ cm} - 42\text{ cm}\right|}{2.5}$$

$$\lambda = 2.8\text{ cm}$$

Statement: The wavelength of the waves is 2.8 cm.

(b) Given: $f = 10.5\text{ Hz}$; $\lambda = 2.8\text{ cm}$

Required: v

Analysis: $v = f\lambda$

Solution: $v = f\lambda$

$$= (10.5\text{ Hz})(2.8\text{ cm})$$

$$v = 29\text{ cm/s}$$

Statement: The speed of the waves is 29 cm/s.

3. (a) Given: $n = 2$; $P_2S_1 = 29.5\text{ cm}$; $P_2S_2 = 25.0\text{ cm}$; $v = 7.5\text{ cm/s}$

Required: λ

Analysis: $\left|P_nS_1 - P_nS_2\right| = \left(n - \dfrac{1}{2}\right)\lambda$

$$\lambda = \frac{\left|P_nS_1 - P_nS_2\right|}{n - \frac{1}{2}}$$

Solution: $\lambda = \dfrac{|P_2S_1 - P_2S_2|}{n - \dfrac{1}{2}}$

$$= \frac{|29.5\text{ cm} - 25.0\text{ cm}|}{1.5}$$

$$\lambda = 3.0\text{ cm}$$

Statement: The wavelength of the waves is 3.0 cm.

(b) Given: $v = 7.5\text{ cm/s}$; $\lambda = 3.0\text{ cm}$

Required: f

Analysis: $v = f\lambda$

$$f = \frac{v}{\lambda}$$

Solution: $f = \dfrac{v}{\lambda}$

$$= \frac{7.5\ \frac{\cancel{\text{cm}}}{\text{s}}}{3.0\ \cancel{\text{cm}}}$$

$$f = 2.5\text{ Hz}$$

Statement: The frequency at which the sources are vibrating is 2.5 Hz.

Section 9.3 Questions, page 469

1. Diffraction of waves through a slit is maximized when the wavelength is comparable to or somewhat greater than the slit width.

2. Answers may vary. Sample answer: When the waves reach my friend in phase, there is constructive interference and he hears a loud sound. When the phase of one speaker is changed by 180°, the waves reach my friend out of phase and he hears a sound with decreased volume.

3. (a) Given: $\lambda = 6.3 \times 10^{-4}\text{ m}$

Required: maximum width w for noticeable diffraction

Analysis: Use the condition that $\dfrac{\lambda}{w} \geq 1$.

Solution:

$$\frac{\lambda}{w} \geq 1$$

$$\lambda \geq w$$

$$6.3 \times 10^{-4}\text{ m} \geq w$$

Statement: The maximum slit width for noticeable diffraction is 6.3×10^{-4} m.

(b) Sample answer: If the slit is wider than 6.3×10^{-4} m, there may still be some diffraction. The wider the slit is, the less diffraction will be noticeable.

4. Given: $d = 1.0$ m; $\lambda = 0.25$ m; $n = 1$

Required: θ_1

Analysis: $d \sin\theta_n = \left(n - \frac{1}{2}\right)\lambda$

$$\sin\theta_n = \frac{\left(n - \frac{1}{2}\right)\lambda}{d}$$

Solution:

$$\sin\theta_n = \frac{\left(n - \frac{1}{2}\right)\lambda}{d}$$

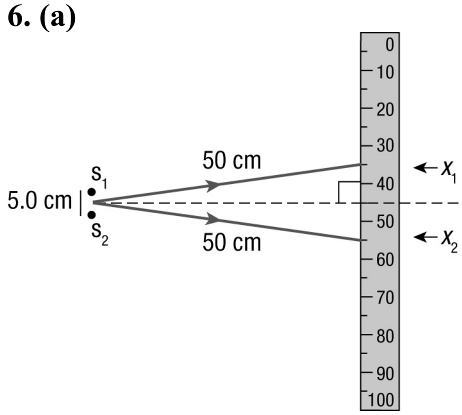
$$\theta_1 = \sin^{-1}\left(\frac{\left(1 - \frac{1}{2}\right)(0.25\ \cancel{\text{m}})}{1.0\ \cancel{\text{m}}}\right)$$

$$\theta_1 = 7.2°$$

Statement: The angle of the first nodal line is 7.2°.

5. Sample answer: For the interference pattern from a two-point source to be stable, the phase between the sources must not change.

6. (a)



(b) Given: $d = 5.0$ cm; $n = 1$; $x_1 = 45\text{ cm} - 35\text{ cm} = 10$ cm; $L = 50$ cm; $f = 6.0$ Hz

Required: λ

Analysis: The distance from the nodal points to the midpoint between the sources is close to the distance L between the line joining the sources and the metre stick. Rearrange $x_n = \left(n - \frac{1}{2}\right)\frac{L\lambda}{d}$ to determine the wavelength, $\lambda = \frac{x_n d}{\left(n - \frac{1}{2}\right)L}$.

Solution: $\lambda = \dfrac{x_n d}{\left(n - \dfrac{1}{2}\right)L}$

$= \dfrac{(10\text{ cm})(5.0\ \cancel{\text{cm}})}{\left(1 - \dfrac{1}{2}\right)(50\ \cancel{\text{cm}})}$

$\lambda = 2\text{ cm}$

Statement: The wavelength of the waves is 2 cm.

(c) Given: $\lambda = 2\text{ cm}; f = 6.0\text{ Hz}$

Required: v

Analysis: $v = f\lambda$

Solution: $v = f\lambda$

$= (6.0\text{ Hz})(2\text{ cm})$

$v = 12\text{ cm/s}$

Statement: The speed of the waves is 12 cm/s.

7. (a) Given: $n = 3$; $x_3 = 35\text{ cm}$; $L = 77\text{ cm}$; $d = 6.0\text{ cm}$; $\theta_3 = 25°$;
distance between 5 crests $= 4.2\text{ cm}$

Required: Calculate λ using three different methods.

Analysis: For the first method, use $x_n = \left(n - \dfrac{1}{2}\right)\dfrac{L\lambda}{d}$, with n = 3. For the second method, use $d\sin\theta_n = \left(n - \dfrac{1}{2}\right)\lambda$, with n = 3. For the third method, use the measurement between wave crests to determine the wavelength directly.

Solution:

First method:

$x_n = \left(n - \dfrac{1}{2}\right)\dfrac{L\lambda}{d}$

$\lambda = \dfrac{x_3 d}{\left(3 - \dfrac{1}{2}\right)L}$

$= \dfrac{(35\text{ cm})(6.0\ \cancel{\text{cm}})}{\left(3 - \dfrac{1}{2}\right)(77\ \cancel{\text{cm}})}$

$= 1.09\text{ cm}$ (one extra digit carried)

$\lambda = 1.1\text{ cm}$

Second method:

$$d\sin\theta_n = \left(n - \frac{1}{2}\right)\lambda$$

$$\lambda = \frac{d\sin\theta_n}{n - \frac{1}{2}}$$

$$= \frac{(6.0\text{ cm})\sin 25^\circ}{3 - \frac{1}{2}}$$

$$= 1.01\text{ cm} \ \ \text{(one extra digit carried)}$$

$$\lambda = 1.0\text{ cm}$$

Third method:

The distance between five consecutive crests corresponds to four whole wavelengths:

$$4\lambda = 4.2\text{ cm}$$

$$\lambda = \frac{4.2\text{ cm}}{4}$$

$$= 1.05\text{ cm} \ \ \text{(one extra digit carried)}$$

$$\lambda = 1.0\text{ cm}$$

Each of the three methods of analysis resulted in a wavelength between 1.0 cm and 1.1 cm, with an average of 1.0 cm.

Statement: The wavelength is 1.0 cm.

(b) Answers may vary. Sample answer: The three methods are based on data with two significant digits. The three results differed only by one unit in the last digit. I think that these results are consistent and that no particular measurement stands out as being incorrect.

Section 9.4: Light: Wave or Particle?

Research This: Very Long Baseline Interferometry, page 475

A. The Dominion Radio Astrophysical Observatory in Penticton, British Columbia, uses Very Long Baseline Interferometry (VLBI).

B. Answers may vary. Sample answer: Usually, data at each telescope are recorded digitally onto computer hard drives. The data from each telescope are combined to form an image.

C. Answers may vary. Sample answer: The signal is sampled at each telescope, then stored and shipped to a central location for later processing with data from other telescopes.

D. Answers may vary. Sample answer: Many scientists store the data on disc and ship the discs. Newer methods use Internet transfer to send the data to a central location.

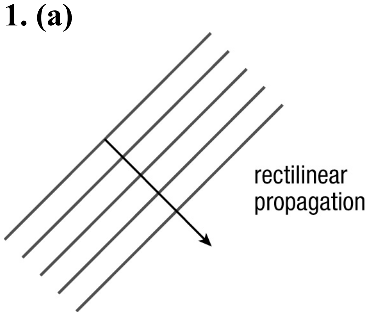
E. Answers may vary. Sample answer: When the data are played back, an atomic clock is used to synchronize the data with the time at different telescopes.

F. Answers may vary. Sample answers: The word “interferometry” is from the word “interferometer.” An interferometer uses interference patterns from electromagnetic radiation to form images. Interference is a wave-like property of light. The data from all the telescopes in a baseline array are combined to form interference patterns, which reveal information about the object under study. Another wave-like property used in interferometry is reflection. The electromagnetic radiation from the object reaches the large, parabolic radio telescope dishes, and the radio waves are reflected to a focus and then to a receiver. From the receiver, the signals are transmitted for image processing.

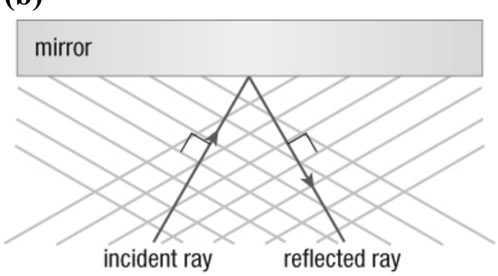
Additional information: Radio waves reveal different types of information in the object under study than visible light radiation. For example, quasars are massive, high-energy objects at the edges of the known universe. In visible light, through an optical telescope, for example, quasars appear as points of light. Images compiled from radio waves reveal the massive quantities of energy emanating from quasars, as well as their enormous size.

Section 9.4 Questions, page 476

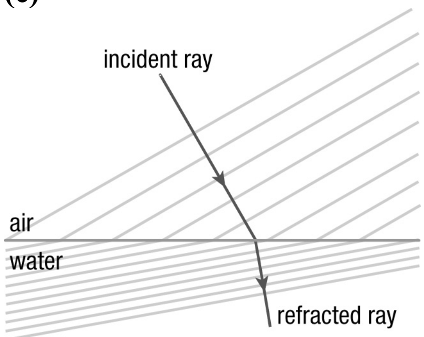
1. (a)



(b)



(c)



2. Answers may vary. Sample answer: Based on what I have learned in this section about the wave and particle properties of light, I think that the wave model explains properties of light better than the particle model. The wave model explains reflection, refraction, dispersion, and interference better than the particle model. The particle model partially explains rectilinear propagation.
Additional information: Newton's corpuscular model predicts that light does not need a medium in which to travel, which is true.
3. Sample answer: Double-slit interference patterns provide strong evidence that light is a wave.
4. Answers may vary. Sample answer: The frequency and wavelength of light do not change when light is reflected. So, according to the universal wave equation, $v = f\lambda$, the speed must stay the same.
5. Answers may vary. Sample answer: Newton did not detect any pressure from light, so he reasoned that the mass of a light particle is very low.
6. Answers may vary. Sample answer: Newton's theory of light was dominant for so long because Newton had a very high reputation in the physics community because of his successes in other studies, especially gravity. Another reason that Newton's theory took so long to refute was that the technology of Young's experiment did not exist until much later.
Additional information: Newton was also the powerful head of the British Royal Society and could influence the opinions of others.
7. Sample answer: Huygens' principle applies to all waves, including water and sound waves.
8. Answers may vary. Sample answer: Answers should indicate the student's understanding of the wave and particle models of light.
(a) Light travels from the Sun to Earth in a straight line, in a vacuum. Rectilinear propagation is explained by a particle model of light.
(b) The energy travelling for TV, radio, and X-ray technologies is best understood if light is considered to be a wave because waves carry energy.
9. (a) Answers may vary. Sample answer: The laser light passing through an open window shows no diffraction because the wavelength of the light is much smaller than the width of the window.

(b) Answers may vary. Sample answer: To have electromagnetic radiation diffract through a window, the wavelength of the radiation must be about the width of the window or somewhat greater. Based on my research for the Research This activity on baseline interferometry, I know that radio waves have long wavelengths and can reflect off the radio telescope dishes, so radio waves can probably also diffract, although it may not be enough to be noticeable. So I would use longer-wavelength and consider decreasing the size of the window, if that was an option. Additional information: Radio waves can penetrate walls, window frames, and glass.
10. Answers may vary. Sample answer: Young's double-slit experiment demonstrated that light waves can interfere, confirming that light is a wave. Therefore, Young's experiment contradicted Newton's corpuscular theory of light. Newton's corpuscular theory of light cannot account for the observed interference pattern.
11. (a) Answers may vary. Sample answer: Light waves cause the electrons to vibrate. These vibrations are called surface plasmons. A dielectric material is a material that does not conduct direct current. When a dielectric material is placed against a metallic surface, travelling waves of electron vibrations can be trapped in the interface between the materials. The travelling waves are called surface plasmon polaritons.
(b) Answers may vary. Sample answer: Surface plasmon polaritons have multiple applications in nanotechnology, for example, optical data storage.
12. Answers may vary. Sample answer: Newton believed that light was composed of particles, which he called corpuscles, and that corpuscles were subject to gravitational attraction. He therefore believed that these particles had mass. In explaining refraction, the attraction of a massive body (water or glass) caused the light to bend and speed up. Newton tried to disprove Grimaldi's beliefs about diffraction of light. Newton argued that Grimaldi's observations of light diffraction were a result of collisions between light particles at the edges of the slit, and not a result of waves of light spreading out. By the time Newton wrote *Opticks*, his book on light, he explained diffraction as a kind of refraction. This is since understood to be incorrect. Newton's greatest contribution to optics was the demonstration that light could be broken down into its spectral colours by a prism, and that after passing through a second prism the light would appear white. His theory could explain this at a time when other theories could not. However, in 1850, Foucault showed that light travels more slowly in water, not faster, and Newton's theory was put to rest. His entire theory of light has been demonstrated to be incorrect, except for the prediction that light does not need a medium in which to travel.
13. In his book *Micrographia*, published in 1665, Robert Hooke described light as vibrations, and compared the movement of light to the movement of water waves. Hooke suggested that the vibrations of light are perpendicular to the direction of travel. He also proposed that light was not made up of particles as Newton suggested.

Section 9.5: Interference of Light Waves: Young's Double-Slit Experiment

Tutorial 1 Practice, page 482

1. Given: double-slit interference; $n = 5$; $\theta_5 = 3.8°$; $d = 0.042$ mm $= 4.2 \times 10^5$ m

Required: λ

Analysis: Rearrange the equation $d\sin\theta_n = \left(n - \frac{1}{2}\right)\lambda$ to solve for wavelength;

$$d\sin\theta_n = \left(n - \frac{1}{2}\right)\lambda$$

$$\lambda = \frac{d\sin\theta_n}{n - \frac{1}{2}}$$

Solution:

$$\begin{aligned}\lambda &= \frac{d\sin\theta_n}{n - \frac{1}{2}} \\ &= \frac{(4.2\times10^{-5}\ \text{m})\sin 3.8°}{5 - \frac{1}{2}} \\ \lambda &= 6.2\times10^{-7}\ \text{m}\end{aligned}$$

Statement: The wavelength of the monochromatic light is 6.2×10^{-7} m.

2. Given: double-slit interference; $d = 0.050$ mm $= 5.0 \times 10^{-5}$ m; $\lambda = 650$ nm $= 6.5 \times 10^{-7}$ m; $L = 2.6$ m

Required: Δx, at the centre of the interference pattern

Analysis: $\Delta x = \frac{L\lambda}{d}$

Solution:

$$\begin{aligned}\Delta x &= \frac{L\lambda}{d} \\ &= \frac{(2.6\ \cancel{\text{m}})(6.5\times10^{-7}\ \text{m})}{5.0\times10^{-5}\ \cancel{\text{m}}} \\ &= 3.4\times10^{-2}\ \text{m} \\ \Delta x &= 3.4\ \text{cm}\end{aligned}$$

Statement: The fringe separation at the centre of the interference pattern is 3.4 cm.

3. Given: double-slit interference; $n = 3$; $\lambda = 652$ nm $= 6.52 \times 10^{-7}$ m; $d = 6.3 \times 10^{-6}$ m

Required: θ_3

Analysis: Rearrange the equation $d\sin\theta_n = \left(n - \frac{1}{2}\right)\lambda$ to solve for the angle of the fringe;

$$d\sin\theta_n = \left(n - \frac{1}{2}\right)\lambda$$

$$\theta_n = \sin^{-1}\left(\frac{\left(n - \frac{1}{2}\right)\lambda}{d}\right)$$

Solution:

$$\theta_n = \sin^{-1}\left(\frac{\left(n - \frac{1}{2}\right)\lambda}{d}\right)$$

$$= \sin^{-1}\left(\frac{\left(3 - \frac{1}{2}\right)(6.52\times10^{-7}\ \cancel{m})}{6.3\times10^{-6}\ \cancel{m}}\right)$$

$$\theta_3 = 15°$$

Statement: The fringe is observed at the angle 15°.

Mini Investigation: Wavelengths of Light, page 483

A. Both interference patterns consisted of a horizontal band of light filled with coloured and dark vertical fringes. The fringes were closer together with the green filter than with the red filter.

B. Table 1: Number of Lines between Two Sliders

Colour of light	Number of lines found between two sliders
red	9
green	11

C. Table 2: Calculating the Wavelength of Light

	Red light	Green light
L (m)	1.0	1.0
d (m)	1.76×10^{-4}	1.76×10^{-4}
n	6	7
x (m)	0.015	0.015
Δx (m)	2.5×10^{-3}	2.1×10^{-3}
λ (m)	4.4×10^{-7}	3.9×10^{-7}

Sample calculation: $\frac{\Delta x}{L} = \frac{\lambda}{d}$

$$\lambda = \frac{d\Delta x}{L}$$

$$= \frac{(1.76\times10^{-4}\ \cancel{m})(2.5\times10^{-3}\ \text{m})}{1.0\ \cancel{m}}$$

$$\lambda = 4.4\times10^{-7}\ \text{m}$$

The wavelength is 4.4×10^{-7} m.

Section 9.5 Questions, page 484

1. Answers may vary. Sample answer: When all other factors are kept constant, the fringes for the red light, λ = 650 nm, are more widely spaced than the fringes for the blue light, λ = 470 nm.

2. Given: double-slit interference; $d = 0.20 \text{ mm} = 2.0\times10^{-4}$ m; L = 3.5 m; n = 1 dark fringe; x_1 = 4.6 mm = 4.6×10^{-3} m

Required: λ

Analysis: Rearrange the equation $x_n = \left(n - \frac{1}{2}\right)\frac{L\lambda}{d}$ to solve for wavelength;

$$x_n = \left(n - \frac{1}{2}\right)\frac{L\lambda}{d}$$

$$\lambda = \frac{x_n d}{\left(n - \frac{1}{2}\right)L}$$

Solution:

$$\begin{aligned}\lambda &= \frac{x_n d}{\left(n - \frac{1}{2}\right)L} \\ &= \frac{(4.6\times10^{-3}\ \cancel{\text{m}})(2.0\times10^{-4}\ \text{m})}{\left(1 - \frac{1}{2}\right)(3.5\ \cancel{\text{m}})} \\ &= 5.3\times10^{-7}\ \text{m}\end{aligned}$$

$\lambda = 530$ nm

Statement: The wavelength of the light is 530 nm.

3. Answers may vary. Sample answer: An underwater double-slit experiment would have different results than a double-slit experiment in air because, in water, the speed of light is slower and the wavelength is shorter. The spacing between the resulting fringes would be closer together underwater than in air.

4. Given: double-slit interference; $d = 0.30\text{ mm} = 3.0\times10^{-4}\text{ m}$; n = 5 dark fringe; $x_5 = 12.8\times10^{-2}\text{ m}$; $\lambda = 4.5\times10^{-7}\text{ m}$

Required: L

Analysis: Rearrange the equation $x_n = \left(n - \frac{1}{2}\right)\frac{L\lambda}{d}$ to solve for distance to the screen;

$$x_n = \left(n - \frac{1}{2}\right)\frac{L\lambda}{d}$$

$$L = \frac{x_n d}{\left(n - \frac{1}{2}\right)\lambda}$$

Solution: $L = \dfrac{x_n d}{\left(n - \frac{1}{2}\right)\lambda}$

$$= \frac{(12.8\times10^{-2}\ \cancel{\text{m}})(3.0\times10^{-4}\text{ m})}{\left(5 - \frac{1}{2}\right)(4.5\times10^{-7}\ \cancel{\text{m}})}$$

$$L = 19\text{ m}$$

Statement: The distance at which the screen is placed is 19 m.

5. (a) Given: double-slit interference; d = 0.15 mm = 1.5×10^{-4} m; L = 2.0 m; $\Delta x = 0.56\text{ cm} = 5.6\times10^{-3}\text{ m}$

Required: λ

Analysis: Rearrange the equation $\Delta x = \frac{L\lambda}{d}$ to solve for wavelength

Solution: $\lambda = \dfrac{d\Delta x}{L}$

$$= \frac{(1.5\times10^{-4}\ \cancel{\text{m}})(5.6\times10^{-3}\text{ m})}{(2.0\ \cancel{\text{m}})}$$

$$\lambda = 4.2\times10^{-7}\text{ m}$$

Statement: The wavelength of the source is 4.2×10^{-7} m, or 420 nm.

(b) Given: double-slit interference; $d = 0.15\text{ mm} = 1.5\times10^{-4}\text{ m}$; L = 2.0 m; $\lambda = 600\text{ nm} = 6\times10^{-7}\text{ m}$

Required: Δx, of the dark fringes

Analysis: $\Delta x = \dfrac{L\lambda}{d}$

Solution: $\Delta x = \dfrac{L\lambda}{d}$

$$= \frac{(2.0\ \cancel{\text{m}})(6\times 10^{-7}\ \text{m})}{(1.5\times 10^{-4}\ \cancel{\text{m}})}$$

$$\Delta x = 8\times 10^{-3}\ \text{m}$$

Statement: The spacing of the dark fringes is 8×10^{-3} m, or 0.8 cm.

6. Given: double-slit interference; n = 2 dark fringes; θ_2 = 5.4°

Required: $\dfrac{d}{\lambda}$

Analysis: Rearrange the equation $d\sin\theta_n = \left(n - \dfrac{1}{2}\right)\lambda$ to solve for $\dfrac{d}{\lambda}$;

$$d\sin\theta_n = \left(n - \frac{1}{2}\right)\lambda$$

$$\frac{d}{\lambda} = \frac{n - \frac{1}{2}}{\sin\theta_n}$$

Solution:

$$\frac{d}{\lambda} = \frac{n - \frac{1}{2}}{\sin\theta_n}$$

$$= \frac{2 - \frac{1}{2}}{\sin 5.4°}$$

$$\frac{d}{\lambda} = 16$$

Statement: The ratio of the separation of the slits to the wavelength is 16:1.

7. (a) Given: double-slit interference; $d = 0.80\ \text{mm} = 8.0\times 10^{-4}\ \text{m}$; L = 49 cm = 0.49 m;
$\Delta x = 0.33\ \text{mm} = 3.3\times 10^{-4}\ \text{m}$

Required: λ

Analysis: Rearrange the equation $\Delta x = \dfrac{L\lambda}{d}$ to solve for wavelength;

$$\Delta x = \frac{L\lambda}{d}$$

$$\lambda = \frac{d\Delta x}{L}$$

Solution:

$$\Delta\lambda = \frac{d\Delta x}{L}$$

$$= \frac{(8.0\times10^{-4}\ \cancel{\text{m}})(3.3\times10^{-4}\ \text{m})}{(0.49\ \cancel{\text{m}})}$$

$$\lambda = 5.39\times10^{-7}\ \text{m}\ \ \text{(one extra digit carried)}$$

$$\lambda = 5.4\times10^{-7}\ \text{m}$$

Statement: The wavelength of the monochromatic light is 5.4×10^{-7} m, or 540 nm.

(b) Given: double-slit interference; $d = 0.60\ \text{mm} = 6.0\times10^{-4}\ \text{m}$; $L = 0.49$ m; $\lambda = 5.39 \times 10^{-7}$ m

Required: Δx, of the dark fringes

Analysis: $\Delta x = \frac{L\lambda}{d}$

Solution:

$$\Delta x = \frac{L\lambda}{d}$$

$$= \frac{(0.49\ \cancel{\text{m}})(5.39\times10^{-7}\ \text{m})}{(6.0\times10^{-4}\ \cancel{\text{m}})}$$

$$\Delta x = 4.4\times10^{-4}\ \text{m}$$

Statement: The spacing of the dark fringes is 4.4×10^{-4} m, or 0.44 mm.

8. (a) Given: double-slit interference; $L = 2.5$ m; $\lambda = 5.1\times10^{-7}$ m; $\Delta x = 12\ \text{mm} = 1.2\times10^{-2}\ \text{m}$

Required: d

Analysis: Rearrange the equation $\Delta x = \frac{L\lambda}{d}$ to solve for distance between the slits;

$$\Delta x = \frac{L\lambda}{d}$$

$$d = \frac{L\lambda}{\Delta x}$$

Solution:

$$d = \frac{L\lambda}{\Delta x}$$

$$= \frac{(2.5\ \cancel{\text{m}})(5.1\times10^{-7}\ \text{m})}{(1.2\times10^{-2}\ \cancel{\text{m}})}$$

$$d = 1.1\times10^{-4}\ \text{m}$$

Statement: The slit spacing is 1.1×10^{-4} m, or 0.11 mm.

(b) Solutions may vary. Sample solution: From $\Delta x = \frac{L\lambda}{d}$, the fringe separation is inversely proportional to the slit spacing. If the slit spacing is reduced by a factor of three, the fringe separation will increase by a factor of three. The fringe separation will change to 3×12 mm = 36 mm, or 3.6 cm.

9. Answers may vary. Student answers should include some of the following points. Newton developed a particle theory of light that explained rectilinear propagation and reflection well. His reputation put the work of others at the time in the shadows. Grimaldi was working on a theory for the diffraction and dispersion of light, and Hooke was looking a wave theory. Later, Newton's theory that light travelled faster in a medium than in a vacuum was shown experimentally to be incorrect. With this failure, Newton's explanations of refraction, colour, and dispersion were also refuted. Huygens' wave ideas and Young's double-slit interference experiment showed that light is definitely a wave. By 1900, all known properties of light could be explained by a wave model.

Chapter 9 Review, pages 494–499

Knowledge

1. (d)
2. (b)
3. (a)
4. (b)
5. (a)
6. (b)
7. (d)
8. (b)
9. (a)
10. (b)
11. (a)
12. (d)
13. False. The angle of incidence is measured between the incoming ray and *the normal to* the reflecting surface.
14. False. The amplitude of a water wave is the vertical distance from the top of a crest *to the rest position of the wave* or from the bottom of the trough *to the rest position of the wave*.
15. True
16. False. The dependence of the speed of light on wavelength is called *dispersion*.
17. False. The index of refraction is *likely different* for red and blue light in the same material.
18. False. *When light enters a medium of higher index of refraction,* the angle of incidence is greater than the angle of refraction.
19. True
20. False. As a light wave refracts from air into glass, the only quantity to remain constant is the *frequency.*
21. False. The symbol *c* is used in reference to the speed of light *in a vacuum*.
22. True
23. False. Diffraction of waves decreases as the width of the slit *increases*.
24. True
25. False. Light waves diffract *the same amount* as water waves.
26. False. Newton's corpuscular theory of light *did have* an explanation for the small amount of diffraction displayed by visible light *that could be observed with the techniques of his time.*
27. True
28. True
29. False. For angles of less than 10°, the sine and *tangent* of the angle are approximately equal.
30. False. An advantage of fibre optic technology is that large amounts of information can be transmitted *with few losses over large distances.*
31. **(a)** (vii)
(b) (v)
(c) (i)
(d) (vi)
(e) (ii)
(f) (iv)
(g) (iii)

Understanding

32. Answers may vary. Sample answer:

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

$$[n_2 \sin\theta_2] = \left[\frac{c}{v_2}\right]\left[\frac{\text{opposite}}{\text{hypotenuse}}\right]$$

$$= \frac{\left[\frac{\cancel{\text{m}}}{\cancel{\text{s}}}\right]\left[\frac{\cancel{\text{m}}}{\cancel{\text{m}}}\right]}{\left[\frac{\cancel{\text{m}}}{\cancel{\text{s}}}\right]}$$

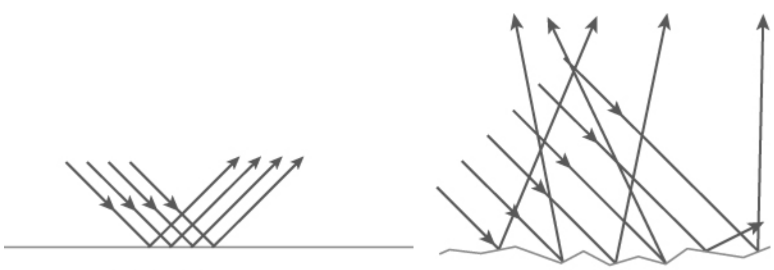
$$[n_2 \sin\theta_2] = 1$$

The quantity $n_2 \sin\theta_2$ has no units. It is dimensionless.

33. (a) Answers may vary. Sample answers: To see laser light, the wavelength used in the laser must fall within the range of wavelengths that our eyes can detect. Laser light is invisible when it travels through the air because the density of air molecules is very low, and the light does not reflect from enough of the molecules for us to see it. When laser light hits a white screen, the light reflects from the screen to your eye and you can see it.

(b) Answers may vary. Sample answers: To see the laser light, one could introduce smoke, fog, dry ice vapour, or chalk dust into the air. These substances have enough small particles for some of the laser light to reflect to your eye.

34. Answers may vary. Sample answer: When parallel light rays reflect off smooth water, all the rays have the same angle of incidence and the same angle of reflection. The reflected light remains a reasonably well-defined beam. When parallel light rays reflect off rough water, the light rays are reflected in a variety of directions and no longer look like a beam of light.



smooth water rough water

35. Sample answer: As white light enters a prism, the light is refracted. Since the index of refraction of the prism is slightly different for the different colours that compose white light, each colour is refracted at a slightly different angle. The red light refracts the least, and the violet light refracts the most. When the light exits the prism, the light refracts again. Again, the red light refracts less than the blue light. Since the light enters and exits the prism through faces that are not parallel, the colours are spread out more and more by each refraction. The final result is the visible spectrum on the far side of the prism.

36. Sample answer: Newton thought of light as a stream of small particles, and Huygens thought of light as a series of wave fronts. Newton's light particles changed direction because of their mass and the effect of gravity, and Huygens' wave fronts spread out between and around objects. Newton's light particles bend toward the normal when moving into a medium with higher wave speed, and Huygens' wave fronts bend toward the normal when moving into a medium with lower wave speed. According to Newton's particle theory, light does not need a medium in which to travel, which is true.
Additional information: To Newton, the mass of the light particle was responsible for colour; to Huygens, the wavelength of light was responsible for colour.
37. Sample answer: In Young's double-slit experiment, light from a single source passed through two slits and made a pattern on a screen on the other side. The pattern consisted of many white, coloured, and dark lines called fringes. When a coloured filter was placed in front of the light, Young observed a pattern of evenly spaced coloured and dark fringes. Interpreting the bright and dark fringes as maxima and minima of a wave pattern was consistent with similar patterns observed in water waves. A particle model of light would predict that there should be two fuzzy streaks of light on the screen as the particles passed individually through one slit or the other and landed on the screen. The observations in Young's experiment disagreed completely with particle model predictions and was in complete agreement with a wave model for light.
38. Answers may vary. Sample answer: Advantages: Fibre optic cables provide reliable, long-distance transmission of large amounts of data. Since they have no moving parts, they can withstand a lot of rough treatment and bad weather. Disadvantages: Installation of fibre optic cable everywhere on Earth is expensive. If the fibre optic cables ever do need to be fixed, it is extremely difficult to splice them without leaving a scar, which destroys the cable's total internal reflection ability.

Analysis and Application

39. Given: $\lambda = 650 \text{ nm} = 6.5\times10^{-7} \text{ m}$; $\Delta d = 1.0 \text{ cm} = 1.0\times10^{-2} \text{ m}$
Required: N, number of wavelengths in Δd
Analysis: $N = \dfrac{\Delta d}{\lambda}$
Solution:
$$\begin{aligned} N &= \frac{\Delta d}{\lambda} \\ &= \frac{1.0\times10^{-2} \text{ m}}{6.5\times10^{-7} \text{ m}} \\ N &= 1.5\times10^{4} \end{aligned}$$
Statement: About 1.5×10^4, or 15 000, wavelengths of red light would fit across a fingernail.
40. Given: $f = 88.7 \text{ MHz} = 8.87 \times 10^7 \text{ Hz}$; $v = 3.0 \times 10^8 \text{ m/s}$
Required: λ
Analysis: Rearrange the universal wave equation, $v = f\lambda$, to solve for wavelength;
$$v = f\lambda$$
$$\lambda = \frac{v}{f}$$

Solution: $\lambda = \dfrac{v}{f}$

$$= \frac{3.0\times10^{8}\ \text{m}/\cancel{\text{s}}}{8.87\times10^{7}\ \cancel{\text{Hz}}}$$

$$\lambda = 3.4\ \text{m}$$

Statement: The wavelength of the radio waves is 3.4 m.

41. Given: D = 4.4 ly; $c = 3.0 \times 10^8$ m/s

Required: D, in metres

Analysis: Use $\Delta d = v\Delta t$ to determine how far light travels in one year. This gives the conversion between light years and metres. Then multiply Δd by 4.4 ly to calculate D in metres.

Solution: $\Delta d = v\Delta t$

$$= (3.0\times10^{8}\ \frac{\text{m}}{\cancel{\text{s}}})(1\ \cancel{\text{y}})\times\frac{3600\ \cancel{\text{s}}}{1\ \cancel{\text{h}}}\times\frac{24\ \cancel{\text{h}}}{1\ \cancel{\text{d}}}\times\frac{365.25\ \cancel{\text{d}}}{1\ \cancel{\text{y}}}$$

$$\Delta d = 9.47\times10^{15}\ \text{m}\ \text{(one extra digit carried)}$$

$$D = (4.4\ \cancel{\text{ly}})\times\frac{9.47\times10^{15}\ \text{m}}{1\ \cancel{\text{ly}}}$$

$$D = 4.2\times10^{16}\ \text{m}$$

Statement: The distance to Alpha Centauri is 4.2×10^{16} m.

42. Sample answer: Pyrex and vegetable oil have almost the same index of refraction. When light passes from one medium to the other, there is little refraction. With no perceived boundary between the Pyrex and the oil, very little light is reflected and refracted. With no reflected light, we do not see the test tube.

43. Given: $\Delta d = 1.1$ billion kilometres $= 1.1\times10^{12}$ m; $v = 3.0\times10^{8}$ m/s

Required: Δt

Analysis: Rearrange the definition of speed, $v = \dfrac{\Delta d}{\Delta t}$, to solve for time. Then convert the time to hours; $v = \dfrac{\Delta d}{\Delta t}$; $\Delta t = \dfrac{\Delta d}{v}$

Solution:

$$\Delta t = \frac{\Delta d}{v}$$

$$= \frac{1.1\times10^{12}\ \cancel{\text{m}}}{3.0\times10^{8}\ \dfrac{\cancel{\text{m}}}{\text{s}}}$$

$$= (3.667\times10^{3}\ \cancel{\text{s}})\times\frac{1\ \text{h}}{3600\ \cancel{\text{s}}}$$

$$\Delta t = 1.0\ \text{h}$$

Statement: It takes 1.0 h for the message to travel from Cassini to Earth.

44. Given: $n = 1.51$; $c = 3.0 \times 10^8$ m/s
Required: v

Analysis: Rearrange the equation $n = \frac{v}{c}$ to solve for speed;

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

Solution:
$$\begin{aligned} v &= \frac{c}{n} \\ &= \frac{3.0 \times 10^8 \text{ m/s}}{1.51} \\ v &= 2.0 \times 10^8 \text{ m/s} \end{aligned}$$

Statement: The speed of light in Plexiglas is 2.0×10^8 m/s.

45. Given: $v = 0.55c$; $c = 3.0 \times 10^8$ m/s
Required: n

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

Solution:
$$\begin{aligned} n &= \frac{c}{v} \\ &= \frac{c}{0.55c} \\ n &= 1.8 \end{aligned}$$

Statement: The index of refraction of the transparent material is 1.8.

46. Given: $n_{\text{Pyrex}} = 1.47$; $n_{\text{water}} = 1.33$; $\lambda_{\text{vacuum}} = 5.30 \times 10^{-7}$ m
Required: λ_{Pyrex}; λ_{water}

Analysis: Rearrange the alternative definition of index of refraction, $n = \frac{\lambda_1}{\lambda_2}$, to solve for λ_2;

$n = \frac{\lambda_1}{\lambda_2}$; $\lambda_2 = \frac{\lambda_1}{n}$

Solution:
$$\begin{aligned} \lambda_2 &= \frac{\lambda_1}{n} \\ \lambda_{\text{Pyrex}} &= \frac{\lambda_{\text{vacuum}}}{n_{\text{Pyrex}}} \\ &= \frac{5.30 \times 10^{-7} \text{ m}}{1.47} \\ &= 3.61 \times 10^{-7} \text{ m} \\ \lambda_{\text{Pyrex}} &= 361 \text{ nm} \end{aligned}$$

$$\begin{aligned} \lambda_2 &= \frac{\lambda_1}{n} \\ \lambda_{\text{water}} &= \frac{\lambda_{\text{vacuum}}}{n_{\text{water}}} \\ &= \frac{5.30 \times 10^{-7} \text{ m}}{1.33} \\ &= 3.98 \times 10^{-7} \text{ m} \\ \lambda_{\text{water}} &= 398 \text{ nm} \end{aligned}$$

Statement: The light has a wavelength of 361 nm in Pyrex and 398 nm in water.

47. Given: $\theta_1 = 52.0°$; $n_1 = 1.33$; $n_2 = 1.46$

Required: θ_2

Analysis: Rearrange the equation $n_1 \sin\theta_1 = n_2 \sin\theta_2$ to solve for θ_2;

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

$$\sin\theta_2 = \frac{n_1 \sin\theta_1}{n_2}$$

$$\theta_2 = \sin^{-1}\left(\frac{n_1 \sin\theta_1}{n_2}\right)$$

Solution:

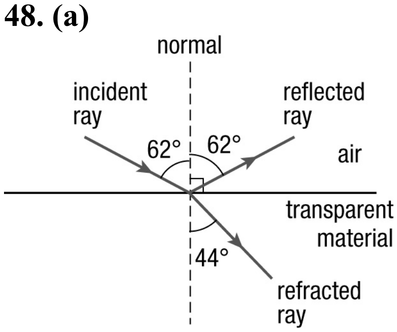
$$\theta_2 = \sin^{-1}\left(\frac{n_1 \sin\theta_1}{n_2}\right)$$

$$= \sin^{-1}\left(\frac{(1.33)\sin 52.0°}{1.46}\right)$$

$$\theta_2 = 45.9°$$

Statement: The angle of refraction is 45.9°.

48. (a)



(b) Given: $\theta_1 = 62°$; $n_1 = 1.0003$; $\theta_2 = 44°$

Required: n_2

Analysis: Rearrange the equation $n_1 \sin\theta_1 = n_2 \sin\theta_2$ to solve for n_2;

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

$$n_2 = \frac{n_1 \sin\theta_1}{\sin\theta_2}$$

Solution: $n_2 = \dfrac{n_1 \sin\theta_1}{\sin\theta_2}$

$$= \frac{(1.0003)\sin 62°}{\sin 44°}$$

$$n_2 = 1.27$$

Statement: The index of refraction of the transparent material is 1.27.

(c) Given: $n = 1.27$; $c = 3.0\times10^8$ m/s

Required: v

Analysis: Rearrange the equation $n = \dfrac{v}{c}$ to solve for speed;

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

Solution: $v = \dfrac{c}{n}$

$$= \frac{3.0\times10^8\ \text{m/s}}{1.27}$$

$$v = 2.4\times10^8\ \text{m/s}$$

Statement: The speed of light in the block is 2.4×10^8 m/s.

49. (a) Given: sketch of light travelling through a rectangular prism from top to bottom; $\theta_1 = 65°$; $n_1 = 1.0003$; $n_2 = 1.51$

Required: θ_2

Analysis: Rearrange the equation $n_1 \sin\theta_1 = n_2 \sin\theta_2$ to solve for θ_2;

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

$$\sin\theta_2 = \frac{n_1 \sin\theta_1}{n_2}$$

$$\theta_2 = \sin^{-1}\left(\frac{n_1 \sin\theta_1}{n_2}\right)$$

Solution:

$$\theta_2 = \sin^{-1}\left(\frac{n_1 \sin\theta_1}{n_2}\right)$$

$$= \sin^{-1}\left(\frac{(1.0003)\sin 65°}{1.51}\right)$$

$$= 36.90°\ \text{(two extra digits carried)}$$

$$\theta_2 = 37°$$

Statement: The angle of refraction as the light enters the block is 37°.

(b) Given: $\theta_1 = 65°$; $w = 21$ cm; $n_2 = 1.51$; $\theta_2 = 36.90°$

Required: lateral displacement of light ray, d

Analysis: Use the width of the block and the tangent ratio to determine the distance on the right face between the emergent ray and the dashed line. Then calculate the perpendicular distance between these lines.

Solution: On the right face of the block, both the light ray and the dashed line meet the Plexiglas–air boundary below the point of incidence on the left face.

Calculate the distance d_1 of the light ray to below the point of incidence:

$$\tan 65° = \frac{d_1}{w}$$

$$d_1 = (21 \text{ cm}) \tan 65°$$

$$d_1 = 45.03 \text{ cm} \text{ (two extra digits carried)}$$

Calculate the distance d_2 of the dashed line to below the point of incidence:

$$\tan 36.90° = \frac{d_2}{w}$$

$$d_2 = (21 \text{ cm}) \tan 36.90°$$

$$d_2 = 15.76 \text{ cm} \text{ (two extra digits carried)}$$

The light ray and the dashed line exit the block at 65° to the normal. These points are a distance D apart:

$$D = d_1 - d_2$$

$$= 45.03 \text{ cm} - 15.76 \text{ cm}$$

$$D = 29.27 \text{ cm} \text{ (two extra digits carried)}$$

Calculate the perpendicular distance d between the emergent ray and the dashed line:

$$\cos 65° = \frac{d}{D}$$

$$d = (29.27 \text{ cm}) \cos 65°$$

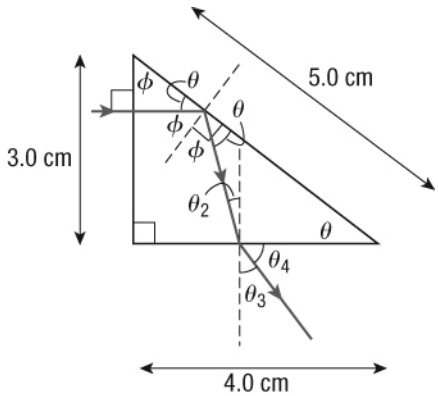
$$d = 12 \text{ cm}$$

Statement: The refracted light ray is laterally displaced by 12 cm.

50. (a) Given: triangular prism with sides 3.0 cm, 4.0 cm, and 5.0 cm; light ray incident on 3.0 cm face; $\theta_1 = 0.0°$; $n = 1.65$

Required: θ_n, angle of deviation of emergent ray

Analysis: Draw a sketch of the problem, and calculate the angles in the prism, θ and ϕ, using the tangent function. The light does not refract entering the prism because it is normal to the left face. From the diagram, the angle of incidence on the right face is ϕ. Show that total internal reflection occurs at this face. Then use the diagram to determine θ_2, the angle of incidence on the bottom face. Use Snell's law, $n_3 \sin\theta_3 = n_2 \sin\theta_2$, to solve for the angle of refraction of the emergent ray. Then calculate the angle of deviation.



Solution: Use the tangent ratio to determine θ and ϕ:

$$\tan\theta = \frac{3.0\ \cancel{m}}{4.0\ \cancel{m}}$$

$$\theta = 36.87° \text{ (two extra digits carried)}$$

$$\phi = 90° - \theta$$

$$= 90° - 36.87°$$

$$\phi = 53.13° \text{ (two extra digits carried)}$$

Solve for the critical angle for a flint glass-to-air boundary:

$$\theta_c = \sin^{-1}\left(\frac{n_{\text{air}}}{n_{\text{flint glass}}}\right)$$

$$= \sin^{-1}\left(\frac{1.0003}{1.65}\right)$$

$$\theta_c = 37.3°$$

Since ϕ is greater than the critical angle, the ray is reflected toward the bottom face of the prism. From the diagram, the angle of incidence θ_2 on the bottom face is

$$\theta_2 = 90° - 2\theta$$

$$= 90° - 2(36.87°)$$

$$\theta_2 = 16.26° \text{ (two extra digits carried)}$$

Calculate the angle of refraction θ_3 using Snell's law:

$$n_3 \sin\theta_3 = n_2 \sin\theta_2$$

$$\theta_3 = \sin^{-1}\left(\frac{n_2 \sin\theta_2}{n_3}\right)$$

$$= \sin^{-1}\left(\frac{(1.65)\sin 16.26°}{1.0003}\right)$$

$$\theta_3 = 27.51° \text{ (two extra digits carried)}$$

Calculate the angle of deviation from the horizontal:

$$\begin{aligned}\theta_4 &= 90° - \theta_3 \\ &= 90° - 27.51° \\ &= 62.49°\end{aligned}$$

$\theta_4 = 62°$

Statement: The angle of deviation between the incident red ray and the emergent red ray is 62°.

(b) Given: $\theta_1 = 0.0°$; $n = 1.67$

Required: angle of deviation of emergent ray

Analysis: The solution follows the solution to part (a) up until the light ray refracts out of the prism at the bottom face. Continue the solution from that point.

Solution: Calculate the angle of refraction θ_3 using Snell's law, using $n = 1.67$ for violet light in flint glass:

$$n_3 \sin\theta_3 = n_2 \sin\theta_2$$

$$\begin{aligned}\theta_3 &= \sin^{-1}\left(\frac{n_2 \sin\theta_2}{n_3}\right) \\ &= \sin^{-1}\left(\frac{(1.67)\sin 16.26°}{1.0003}\right)\end{aligned}$$

$\theta_3 = 27.87°$ (two extra digits carried)

Calculate the angle of deviation from the horizontal:

$$\begin{aligned}\theta_4 &= 90° - \theta_3 \\ &= 90° - 27.87° \\ &= 62.13°\end{aligned}$$

$\theta_4 = 62°$

Statement: The angle of deviation between the incident violet ray and the emergent violet ray is 62°. This angle of deviation differs from that of the red ray by less than 1°.

51. (a) Given: $n_{\text{Pyrex}} = 1.47$; $n_{\text{air}} = 1.0003$

Required: θ_c

Analysis: $\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$

Solution:

$$\begin{aligned}\theta_c &= \sin^{-1}\left(\frac{n_{\text{air}}}{n_{\text{Pyrex}}}\right) \\ &= \sin^{-1}\left(\frac{1.0003}{1.47}\right)\end{aligned}$$

$\theta_c = 42.9°$

Statement: The critical angle for a Pyrex-to-air interface is 42.9°.

(b) Given: $n_{\text{Pyrex}} = 1.47$; $n_{\text{water}} = 1.33$

Required: θ_c

Analysis: $\theta_c = \sin^{-1}\left(\dfrac{n_2}{n_1}\right)$

Solution: $\theta_c = \sin^{-1}\left(\dfrac{n_{\text{water}}}{n_{\text{Pyrex}}}\right)$

$$= \sin^{-1}\left(\frac{1.33}{1.47}\right)$$

$$\theta_c = 64.8°$$

Statement: The critical angle for a Pyrex-to-water interface is 64.8°.

(c) Given: $n_{\text{water}} = 1.33$; $n_{\text{air}} = 1.0003$

Required: θ_c

Analysis: $\theta_c = \sin^{-1}\left(\dfrac{n_2}{n_1}\right)$

Solution:

$$\theta_c = \sin^{-1}\left(\frac{n_{\text{air}}}{n_{\text{water}}}\right)$$

$$= \sin^{-1}\left(\frac{1.0003}{1.33}\right)$$

$$\theta_c = 48.8°$$

Statement: The critical angle for a water-to-air interface is 48.8°.

52. (a) The light ray bends toward the normal.

(b) Given: $n_1 = 1.0003$; $n_2 = 1.44$; $\theta_1 = 33°$

Required: θ_2

Analysis: Rearrange the equation $n_1 \sin\theta_1 = n_2 \sin\theta_2$ to solve for θ_2;

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

$$\sin\theta_2 = \frac{n_1 \sin\theta_1}{n_2}$$

$$\theta_2 = \sin^{-1}\left(\frac{n_1 \sin\theta_1}{n_2}\right)$$

Solution: $\theta_2 = \sin^{-1}\left(\dfrac{n_1 \sin\theta_1}{n_2}\right)$

$$= \sin^{-1}\left(\frac{(1.0003)\sin 33°}{1.44}\right)$$

$$\theta_2 = 22°$$

Statement: The angle of refraction inside the fibre optic cable is 22°.

53. (a) Given: $v = 1.6\times10^8$ m/s; $c = 3.0\times10^8$ m/s

Required: n

Analysis: $n = \dfrac{v}{c}$

Solution: $n = \dfrac{c}{v}$

$$= \frac{3.0\times10^8 \text{ m/s}}{1.6\times10^8 \text{ m/s}}$$

$= 1.88$ (one extra digit carried)

$n = 1.9$

Statement: The index of refraction of the liquid is 1.9.

(b) Given: $n = 1.88$; $\lambda_2 = 440$ nm

Required: λ_1

Analysis: Rearrange the equation $n = \dfrac{\lambda_1}{\lambda_2}$ to solve for λ_1.

$$n = \frac{\lambda_1}{\lambda_2}$$

$$\lambda_1 = n\lambda_2$$

Solution: $\lambda_1 = n\lambda_2$

$= (1.88)(440 \text{ nm})$

$\lambda_1 = 830$ nm

Statement: The wavelength of the light ray in a vacuum is 830 nm.

54. Given: $n_{\text{ethyl}} = 1.36$; $n_{\text{air}} = 1.0003$

Required: θ_c

Analysis: $\theta_c = \sin^{-1}\left(\dfrac{n_2}{n_1}\right)$

Solution:

$$\theta_c = \sin^{-1}\left(\frac{n_{\text{air}}}{n_{\text{ethyl}}}\right)$$

$$= \sin^{-1}\left(\frac{1.0003}{1.36}\right)$$

$$\theta_c = 47.4°$$

Statement: The critical angle for an ethyl alcohol-to-air interface is 47.4°.

55. Given: $n_{\text{glycerin}} = 1.47$; $n_{\text{water}} = 1.33$

Required: θ_c

Analysis: $\theta_c = \sin^{-1}\left(\dfrac{n_2}{n_1}\right)$

Solution: $\theta_c = \sin^{-1}\left(\frac{n_{\text{water}}}{n_{\text{glycerin}}}\right)$

$$= \sin^{-1}\left(\frac{1.33}{1.47}\right)$$

$$\theta_c = 64.8°$$

Statement: The critical angle for a glycerin-to-water interface is 64.8°.

56. Given: $n_{\text{diamond}} = 2.42$; $n_{\text{glass}} = 1.52$

Required: θ_c

Analysis: $\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$

Solution:

$$\theta_c = \sin^{-1}\left(\frac{n_{\text{glass}}}{n_{\text{diamond}}}\right)$$

$$= \sin^{-1}\left(\frac{1.52}{2.42}\right)$$

$$\theta_c = 38.9°$$

Statement: The critical angle for a diamond-to-crown glass interface is 38.9°.

57. Given: $n_{\text{water}} = 1.33$; $n_{\text{air}} = 1.0003$; $d = 35$ cm

Required: D, diameter of light cone disc on the pond's surface

Analysis: The light is shining in all directions from the small light source at the bottom of the pond. Light that reaches the surface with an angle of incidence less than the critical angle will refract out of the water. All the other light rays will be reflected internally. First determine the critical angle going from water to air using $\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$. Then use the tangent ratio to solve for the disc's radius, r, and then diameter, D.

Solution:

$$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

$$= \sin^{-1}\left(\frac{1.0003}{1.33}\right)$$

$\theta_c = 48.77°$ (two extra digits carried)

$$\frac{r}{d} = \tan\theta_c$$

$$r = d\tan\theta_c$$

$$= (35\text{ cm})\tan 48.77°$$

$r = 39.94$ cm (two extra digits carried)

$$D = 2r$$

$$= 2(39.94\text{ cm})$$

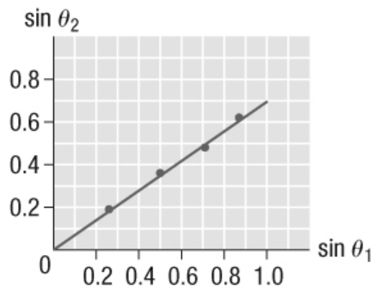
$$D = 80\text{ cm}$$

Statement: The diameter of the disc of light is 80 cm.

58. (a) Complete a data table. Plot the $\sin\theta_2$ versus $\sin\theta_1$ graph.

Table

θ_1	θ_2	$\sin\theta_1$	$\sin\theta_2$
15°	11°	0.2588	0.1908
30°	21°	0.5	0.3584
45°	29°	0.7071	0.4848
60°	38°	0.8660	0.6157



(b) Given: data and graph from part (a)
Required: slope of graph, n_{acrylic}
Analysis: Draw a line to show the trend of the data. The line should start at the origin because when the angle of incidence is 0°, the angle of refraction is also 0°. The line of best fit should pass as close to the data points as possible. Some data points will be above the line of good fit and some will be below. Determine the slope of this line by selecting two points on the line and calculating using $\text{slope} = \dfrac{\text{rise}}{\text{run}}$. The graph is a plot of $\sin\theta_2$ versus $\sin\theta_1$, so the slope gives an average value of $\dfrac{\sin\theta_2}{\sin\theta_1}$. From Snell's law, the index of refraction is $n = \dfrac{\sin\theta_1}{\sin\theta_2}$. The reciprocal of the slope will give the index of refraction.
Solution: Two points on the line of good fit are (0, 0) and (1, 0.71).
Calculate the slope:

$$\begin{aligned}\text{slope} &= \frac{\text{rise}}{\text{run}} \\ &= \frac{0.71-0}{1.0-0} \\ \text{slope} &= 0.71\end{aligned}$$

Calculate the index of refraction:

$$\begin{aligned}n_{\text{acrylic}} &= \frac{1}{\text{slope}} \\ &= \frac{1}{0.71} \\ n_{\text{acrylic}} &= 1.41\end{aligned}$$

Statement: The slope of the line is 0.71, and the index of refraction of acrylic is 1.41.

59. Given: double-slit interference; $d = 0.085\text{ mm} = 8.5\times10^{-5}\text{ m}$; $\lambda = 590\text{ nm} = 5.9\times10^{-7}\text{ m}$; $L = 1.10\text{ m}$

Required: Δx, the bright fringe separation

Analysis: $\Delta x = \dfrac{L\lambda}{d}$

Solution:

$$\begin{aligned}\Delta x &= \frac{L\lambda}{d}\\ &= \frac{(1.10\text{ m})(5.9\times10^{-7}\ \cancel{\text{m}})}{8.5\times10^{-5}\ \cancel{\text{m}}}\\ \Delta x &= 7.6\times10^{-3}\text{ m}\end{aligned}$$

Statement: The bright fringe separation is 7.6×10^{-3} m, or 7.6 mm.

60. Answers may vary. Sample answer: Suggested topics include fibre optics for communication, fibre optics in medicine, spectroscopy using diffraction, and telescope arrays in the visible or infrared. Answers should focus on the economic and social impact of the technologies. Students could comment on the benefits to patients undergoing surgery with fibre optics instruments, and how the surgery is much less invasive than traditional surgery. Students could comment on the impact of fibre optic technology to communications.

61. Given: two-source interference; $n = 2$; $\text{P}_2\text{S}_1 = 16.3\text{ cm}$; $\text{P}_2\text{S}_2 = 21.9\text{ cm}$

Required: λ

Analysis: Rearrange the equation $\left|\text{P}_n\text{S}_1 - \text{P}_n\text{S}_2\right| = \left(n - \dfrac{1}{2}\right)\lambda$ to solve for wavelength;

$$\begin{aligned}\left|\text{P}_n\text{S}_1 - \text{P}_n\text{S}_2\right| &= \left(n - \frac{1}{2}\right)\lambda\\ \lambda &= \frac{\left|\text{P}_n\text{S}_1 - \text{P}_n\text{S}_2\right|}{n - \frac{1}{2}}\end{aligned}$$

Solution:

$$\begin{aligned}\lambda &= \frac{\left|\text{P}_2\text{S}_1 - \text{P}_2\text{S}_2\right|}{2 - \frac{1}{2}}\\ &= \frac{\left|16.3\text{ cm} - 21.9\text{ cm}\right|}{2 - \frac{1}{2}}\\ \lambda &= 3.73\text{ cm}\end{aligned}$$

Statement: The wavelength of the waves is 3.73 cm.

62. Given: two-source interference; d = 4.5 cm; total of 10 nodal lines

Required: λ

Analysis: The interference pattern is symmetric about the central line, so there are 5 nodal lines on each side of the centre. This means that $\sin\theta_5 \le 1$ but $\sin\theta_6 > 1$. Rearrange the equation $d\sin\theta_n = \left(n - \dfrac{1}{2}\right)\lambda$ to solve for wavelength, and use n = 5 and $\sin\theta_5 = 1$;

$$d\sin\theta_n = \left(n - \frac{1}{2}\right)\lambda$$
$$\lambda = \frac{d\sin\theta_n}{n - \frac{1}{2}}$$

Solution: $d\sin\theta_n = \left(n - \frac{1}{2}\right)\lambda$
$$\lambda = \frac{d\sin\theta_5}{5 - \frac{1}{2}}$$
$$= \frac{(4.5\text{ cm})(1)}{4.5}$$
$$\lambda = 1.0\text{ cm}$$

Statement: The wavelength of the water waves is 1.0 cm.

63. Given: two-source interference; d = 14 m; total of 12 nodal lines

Required: λ

Analysis: The interference pattern is symmetric about the central line. So there are 6 nodal lines on each side of the centre line. This means that $\sin\theta_6 \le 1$ but that $\sin\theta_7 > 1$. Rearrange the equation $d\sin\theta_n = \left(n - \frac{1}{2}\right)\lambda$ to solve for wavelength, with n = 6 and $\sin\theta_6 = 1$;

$$d\sin\theta_n = \left(n - \frac{1}{2}\right)\lambda;\ \lambda = \frac{d\sin\theta_n}{n - \frac{1}{2}}$$

Solution: $\lambda = \dfrac{d\sin\theta_6}{6 - \frac{1}{2}}$
$$= \frac{(14\text{ m})(1)}{5.5}$$
$$\lambda = 2.5\text{ m}$$

Statement: The wavelength of the water waves is 2.5 m.

64. Answers may vary. Sample answer: To increase the number of nodal lines, the angle given by $d\sin\theta_n = \left(n - \frac{1}{2}\right)\lambda$ of each nodal line must become smaller. Equivalently, the position given by $x_n = \left(n - \frac{1}{2}\right)\frac{L\lambda}{d}$ of each nodal line must become smaller. Finally, the spacing between nodal lines given by $\Delta x = \frac{L\lambda}{d}$ must become smaller.

(a) According to the universal wave equation, $v = f\lambda$, when the frequency increases and the speed stays the same, the wavelength decreases. The above three relations show that when the wavelength decreases, the nodal lines get closer together. In addition, there are more nodal lines. Therefore, when the frequency increases, the number of nodal lines increases.

(b) As in part (a), when the wavelength decreases, the number of nodal lines increases.
(c) From the above three relations, when the separation between the sources increases, the nodal lines get closer together and the number of nodal lines increases.
65. (a) Given: two-source interference; $n = 3$; $d = 7.2$ cm; $f = 7.0$ Hz; $P_3S_1 = 30.0$ cm; $P_3S_2 = 37$ cm
Required: λ
Analysis: Rearrange the equation $|P_nS_1 - P_nS_2| = \left(n - \frac{1}{2}\right)\lambda$ to solve for wavelength;

$$|P_nS_1 - P_nS_2| = \left(n - \frac{1}{2}\right)\lambda$$
$$\lambda = \frac{|P_nS_1 - P_nS_2|}{n - \frac{1}{2}}$$

Solution: $\lambda = \dfrac{|P_3S_1 - P_3S_2|}{3 - \frac{1}{2}}$

$$= \frac{|30.0 \text{ cm} - 37 \text{ cm}|}{2.5}$$
$$\lambda = 2.8 \text{ cm}$$

Statement: The wavelength of the waves is 2.8 cm.
(b) Given: $f = 7.0$ Hz; $\lambda = 2.8$ cm
Required: v
Analysis: $v = f\lambda$
Solution: $v = f\lambda$

$$= (7.0 \text{ Hz})(2.8 \text{ cm})$$
$$v = 20 \text{ cm/s}$$

Statement: The wave speed is 20 cm/s.
66. Given: two-source interference; $d = 400$ m; $f = 1.0 \times 10^6$ Hz; $c = 3.0 \times 10^8$ m/s
Required: θ_1, for constructive interference
Analysis: Rearrange the universal wave equation, $c = f\lambda$, to solve for the wavelength of the radio waves; $\lambda = \dfrac{c}{f}$. Then use the equation $\sin\theta_m = \dfrac{m\lambda}{d}$ to solve for θ_1, using $m = 1$.

Solution:

$$\lambda = \frac{c}{f}$$
$$= \frac{3.0 \times 10^8 \text{ m/s}}{1.0 \times 10^6 \text{ Hz}}$$
$$\lambda = 300 \text{ m}$$

$$\sin\theta_m = \frac{m\lambda}{d}$$
$$\sin\theta_1 = \frac{(1)(300 \cancel{\text{m}})}{400 \cancel{\text{m}}}$$
$$\theta_1 = \sin^{-1}\left(\frac{3}{4}\right)$$
$$\theta_1 = 49^\circ$$

Statement: The first angle for which the signal strength is a maximum is 49°.

67. (a) Given: two-source interference; $d = 14$ cm; $f = 3.1$ Hz; $\Delta d = 30.0$ cm; $\Delta t = 1.8$ s
Required: λ
Analysis: First determine the wave speed from the distance–time equation, $v = \frac{\Delta d}{\Delta t}$. Then rearrange the universal wave equation, $v = f\lambda$, to solve for wavelength; $\lambda = \frac{v}{f}$.

Solution:
$$\begin{aligned} v &= \frac{\Delta d}{\Delta t} \\ &= \frac{30.0\text{ cm}}{1.8\text{ s}} \\ v &= 16.67\text{ cm/s (two extra digits carried)} \end{aligned}$$

$$\begin{aligned} \lambda &= \frac{v}{f} \\ &= \frac{16.67\text{ cm/}\cancel{\text{s}}}{3.1\ \cancel{\text{Hz}}} \\ &= 5.376\text{ cm (two extra digits carried)} \\ \lambda &= 5.4\text{ cm} \end{aligned}$$

Statement: The wavelength of the waves is 5.4 cm.
(b) Given: $d = 14$ cm; $\lambda = 5.376$ cm
Required: total number of nodal lines
Analysis: There is an equal number of nodal lines on each side of the central maximum. Use $d\sin\theta_n = \left(n - \frac{1}{2}\right)\lambda$ to determine the largest possible *n* where $\sin\theta_n \leq 1$.

Solution:
$$\begin{aligned} d\sin\theta_n &= \left(n - \frac{1}{2}\right)\lambda \\ \sin\theta_n &= \frac{\left(n - \frac{1}{2}\right)\lambda}{d} \\ 1 &\geq \frac{\left(n - \frac{1}{2}\right)\lambda}{d} \\ \frac{d}{\lambda} + \frac{1}{2} &\geq n \\ \frac{14\ \cancel{\text{cm}}}{5.376\ \cancel{\text{cm}}} + \frac{1}{2} &\geq n \\ 3.104 &\geq n \\ n &= 3 \end{aligned}$$

Statement: There are 3 nodal lines on each side, and 6 nodal lines in total.

68. (a) Answers may vary. Sample answer: Two optical phenomena adequately explained by both the particle model and the wave model of light are rectilinear propagation and reflection. Another phenomenon is that light particles have kinetic energy. Waves also carry energy.
(b) Answers may vary. Sample answer: Two optical phenomena not adequately explained by the particle model are refraction and dispersion.
(c) Scientists at Huygens' time thought that light needed an invisible medium in which to travel, called the ether. Huygens' wave model does not explain the ether. Also, a major objection to Huygens' wave model of light was that waves spread out in all directions.
69. Answers may vary. Answers should include some of the following points. Rectilinear propagation and reflection of light can be explained by a wave model of light. Young's double-slit experiment confirmed the light undergoes interference, another wave property. When the speed of light in a medium was measured to be slower than in vacuum, the wave properties of refraction, colour, and dispersion were confirmed.
70. Given: double-slit interference; λ = 658 nm = 6.58 × 10^{-7} m; $m = 3$ bright fringe; $\theta_3 = 2.8°$
Required: d
Analysis: $d \sin\theta_m = m\lambda$
Solution: $d \sin\theta_m = m\lambda$

$$\begin{aligned} d &= \frac{m\lambda}{\sin\theta_m} \\ &= \frac{(3)(6.58\times10^{-7}\text{ m})}{\sin 2.8°} \\ &= 4.0\times10^{-5}\text{ m} \\ d &= 0.040\text{ mm} \end{aligned}$$

Statement: The slit spacing is 0.040 mm.
71. Given: double-slit interference; λ = 650 nm = 6.50 × 10^{-7} m; d = 2.1 × 10^{-4} m; L = 5.0 m
Required: Δx
Analysis: $\Delta x = \frac{L\lambda}{d}$
Solution:

$$\begin{aligned} \Delta x &= \frac{L\lambda}{d} \\ &= \frac{(5.0\text{ m})(6.50\times10^{-7}\ \cancel{\text{m}})}{2.1\times10^{-4}\ \cancel{\text{m}}} \\ \Delta x &= 1.5\times10^{-2}\text{ m} \end{aligned}$$

Statement: The fringe separation at the centre of the pattern is 1.5 × 10^{-2} m, or 1.5 cm.

72. Given: double-slit interference; $d = 7.3\times10^{-4}$ m; $L = 6.5$ m; $\Delta x = 4.3$ mm $= 4.3\times10^{-3}$ m
Required: λ
Analysis: Rearrange the equation $\Delta x = \dfrac{L\lambda}{d}$ to solve for wavelength;

$$\Delta x = \frac{L\lambda}{d}$$
$$\lambda = \frac{d\Delta x}{L}$$

Solution:

$$\begin{aligned}\lambda &= \frac{d\Delta x}{L}\\ &= \frac{(7.3\times10^{-4}\text{ m})(4.3\times10^{-3}\ \cancel{\text{m}})}{(6.5\ \cancel{\text{m}})}\\ \lambda &= 4.8\times10^{-7}\text{ m}\end{aligned}$$

Statement: The wavelength of the source is 4.8×10^{-7} m, or 480 nm.

73. The distance between dark fringes and the distance between bright fringes in a double-slit experiment is $\Delta x = \dfrac{L\lambda}{d}$.

(a) Answers may vary. Sample answer: If I move the screen farther away, I increase *L*. This will increase the spacing of the red and dark fringes.
(b) Sample answer: If I block one of the slits, I will lose the interference pattern. I will see an image of the single slit.
(c) Sample answer: If I replace the red filter with a green one, I decrease the wavelength. Now the green and dark fringes will be closer together.
(d) Sample answer: If I use white light, I will see a pattern of white and dark fringes at the central region of the pattern. On each side, I will see fringes of spectra (rainbows) of visible light that spread out more and more the farther I look from the centre.

74. Given: double-slit interference; $d = 2.2\times10^{-4}$ m; $L = 3.0$ m; $x_7 - x_1 = 6.0$ cm $= 6.0\times10^{-2}$ m
Required: λ
Analysis: The distance between the nodal lines corresponds to 6 fringes: $x_7 - x_1 = 6\Delta x$.
Calculate Δx, then rearrange the equation $\Delta x = \dfrac{L\lambda}{d}$ to solve for wavelength; $\lambda = \dfrac{d\Delta x}{L}$.

Solution:

$$\begin{aligned}x_7 - x_1 &= 6\Delta x\\ \Delta x &= \frac{x_7 - x_1}{6}\\ &= \frac{6.0\text{ cm}}{6}\\ &= 1.0\text{ cm}\\ \Delta x &= 1\times10^{-2}\text{ m}\end{aligned}$$

$$\begin{aligned}\lambda &= \frac{d\Delta x}{L}\\ &= \frac{(2.2\times10^{-4}\text{ m})(1.0\times10^{-2}\ \cancel{\text{m}})}{(3.0\ \cancel{\text{m}})}\\ \lambda &= 7.3\times10^{-7}\text{ m}\end{aligned}$$

Statement: The wavelength of the source is 7.3×10^{-7} m, or 730 nm.

75. Given: double-slit interference; L = 7.7 m; λ = 4.9 × 10^{-7} m; m = 3 maxima;
$x_3 - x_3{}' = 32.9\times10^{-2}$ m
Required: d
Analysis: The m = 3 maxima are equidistant from the central maximum. So their separation corresponds to 6 fringe spacings, Δx. Calculate Δx, and rearrange the equation $\Delta x = \dfrac{L\lambda}{d}$ to solve for d;

$$\Delta x = \frac{L\lambda}{d}$$
$$d = \frac{L\lambda}{\Delta x}$$

Solution:
$$\begin{aligned}\Delta x &= \frac{x_3 - x_3{}'}{6} \\ &= \frac{32.9\times10^{-2}\ \text{m}}{6} \\ \Delta x &= 5.483\times10^{-2}\ \text{m}\ \ \text{(one extra digit carried)}\end{aligned}$$

$$\begin{aligned}d &= \frac{L\lambda}{\Delta x} \\ &= \frac{(7.7\ \text{m})(4.9\times10^{-7}\ \cancel{\text{m}})}{(5.483\times10^{-2}\ \cancel{\text{m}})} \\ d &= 6.9\times10^{-5}\ \text{m}\end{aligned}$$

Statement: The slit spacing is 6.9 × 10^{-5} m.

76. Given: double-slit interference; d = 0.35 mm = 3.5 × 10^{-4} m; L = 1.5 m;
$\Delta x = 2.4\ \text{mm} = 2.4\times10^{-3}$ m
Required: λ
Analysis: Rearrange the equation $\Delta x = \dfrac{L\lambda}{d}$ to solve for wavelength;

$$\Delta x = \frac{L\lambda}{d}$$
$$\lambda = \frac{d\Delta x}{L}$$

Solution:
$$\begin{aligned}\lambda &= \frac{d\Delta x}{L} \\ &= \frac{(3.5\times10^{-4}\ \text{m})(2.4\times10^{-3}\ \cancel{\text{m}})}{(1.5\ \cancel{\text{m}})} \\ \lambda &= 5.6\times10^{-7}\ \text{m}\end{aligned}$$

Statement: The wavelength is 5.6 × 10^{-7} m, or 560 nm.

77. Given: double-slit interference; $d = 0.050\ \text{mm} = 5.0\times10^{-5}$ m; $\lambda = 4.8\times10^{-7}$ m; $L = 1.0$ m
Required: Δx
Analysis: $\Delta x = \dfrac{L\lambda}{d}$

Solution: $\Delta x = \dfrac{L\lambda}{d}$

$$= \frac{(1.0\text{ m})(4.8\times10^{-7}\ \cancel{\text{m}})}{5.0\times10^{-5}\ \cancel{\text{m}}}$$

$$\Delta x = 9.6\times10^{-3}\text{ m}$$

Statement: The separation of consecutive bright bands is 9.6×10^{-3} m, or 9.6 mm.

78. Given: double-slit interference; d = 0.100 mm = 1.00×10^{-4} m; L = 1.25 m;
$\Delta x = 4.95\times10^{-3}$ m

Required: λ

Analysis: Rearrange the equation $\Delta x = \dfrac{L\lambda}{d}$ to solve for wavelength;

$$\Delta x = \frac{L\lambda}{d}$$

$$\lambda = \frac{d\Delta x}{L}$$

Solution: $\lambda = \dfrac{d\Delta x}{L}$

$$= \frac{(1.00\times10^{-4}\text{ m})(4.95\times10^{-3}\ \cancel{\text{m}})}{(1.25\ \cancel{\text{m}})}$$

$$\lambda = 3.96\times10^{-7}\text{ m}$$

Statement: The wavelength is 3.96×10^{-7} m, or 396 nm.

79. Given: double-slit interference; L = 175 cm = 1.75 m; Δx = 7.7 mm = 7.7×10^{-3} m;
$\lambda = 5.5\times10^{-7}$ m

Required: d

Analysis: Rearrange the equation $\Delta x = \dfrac{L\lambda}{d}$ to solve for the slit spacing;

$$\Delta x = \frac{L\lambda}{d}$$

$$d = \frac{L\lambda}{\Delta x}$$

Solution: $d = \dfrac{L\lambda}{\Delta x}$

$$= \frac{(1.75\text{ m})(5.5\times10^{-7}\ \cancel{\text{m}})}{(7.7\times10^{-3}\ \cancel{\text{m}})}$$

$$d = 1.2\times10^{-4}\text{ m}$$

Statement: The slit spacing is 1.2×10^{-4} m, or 0.12 mm.

80. Given: double-slit interference; λ = 530 nm = 5.3 × 10^{-7} m;
bright fringe separation, $\Delta\theta_m = 2.1°$

Required: d

Analysis: The m = 0 bright fringe is along the central line. So the m = 1 fringe is at $\theta_1 = 2.1°$.
Rearrange the equation $d\sin\theta_m = m\lambda$ to solve for the slit separation;

$$d\sin\theta_m = m\lambda$$

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

Solution: $d = \dfrac{m\lambda}{\sin\theta_m}$

$$= \frac{(1)(5.3\times10^{-7}\text{ m})}{\sin 2.1°}$$

$$d = 1.4\times10^{-5}\text{ m}$$

Statement: The separation between the slits is 1.4 × 10^{-5} m.

81. Given: double-source interference; d = 550 m; f = 790 MHz = 7.9 × 10^8 Hz;
$L = 12\text{ km} = 1.2\times10^4\text{ m}$

Required: m = 1 constructive interference position x_1

Analysis: Rearrange the universal wave equation, $c = f\lambda$, to solve for the wavelength of the signal; $\lambda = \dfrac{c}{f}$. Then use the equation $x_m = \dfrac{mL\lambda}{d}$.

Solution: $\lambda = \dfrac{c}{f}$

$$= \frac{3.0\times10^8\text{ m}/\cancel{\text{s}}}{7.9\times10^8\ \cancel{\text{Hz}}}$$

$$\lambda = 0.3796\text{ m (two extra digits carried)}$$

$$x_m = \frac{mL\lambda}{d}$$

$$= \frac{(1)(1.2\times10^4\text{ m})(0.3796\ \cancel{\text{m}})}{(550\ \cancel{\text{m}})}$$

$$x_1 = 8.3\text{ m}$$

Statement: You must walk 8.3 m north to have an optimal signal again.

82. Given: double-slit interference; $\lambda_A = 490\text{ nm} = 4.9\times10^{-7}\text{ m}$; $\lambda_B = 560\text{ nm} = 5.6\times10^{-7}\text{ m}$;
$d = 0.44\text{ mm} = 4.4\times10^{-4}\text{ m}$; $L = 1.4\text{ m}$

Required: for each wavelength, n = 2 dark fringe angle θ_2 and position x_2

Analysis: $x_n = \left(n-\dfrac{1}{2}\right)\dfrac{L\lambda}{d}$; first, rearrange the equation $d\sin\theta_n = \left(n-\dfrac{1}{2}\right)\lambda$ to solve for the angle;

$$d\sin\theta_n = \left(n-\frac{1}{2}\right)\lambda$$

$$\theta_n = \sin^{-1}\left(\frac{\left(n-\frac{1}{2}\right)\lambda}{d}\right)$$

Solution: For $\lambda_A = 490$ nm:

$$\theta_2 = \sin^{-1}\left(\frac{\left(2-\frac{1}{2}\right)\lambda}{d}\right)$$
$$= \sin^{-1}\left(\frac{(1.5)(4.9\times10^{-7}\ \cancel{m})}{4.4\times10^{-4}\ \cancel{m}}\right)$$
$$\theta_2 = 0.096°$$

$$x_2 = \left(2-\frac{1}{2}\right)\frac{L\lambda}{d}$$
$$= \frac{(1.5)(1.4\text{ m})(4.9\times10^{-7}\ \cancel{m})}{4.4\times10^{-4}\ \cancel{m}}$$
$$= 2.3\times10^{-3}\text{ m}$$
$$x_2 = 0.23\text{ cm}$$

For $\lambda_B = 560$ nm:

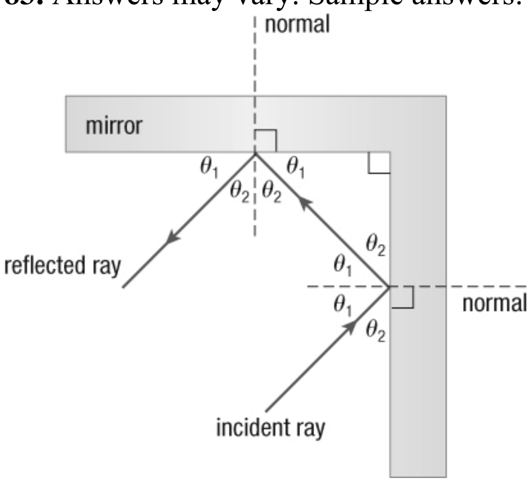
$$\theta_2 = \sin^{-1}\left(\frac{\left(2-\frac{1}{2}\right)\lambda}{d}\right)$$
$$= \sin^{-1}\left(\frac{(1.5)(5.6\times10^{-7}\ \cancel{m})}{4.4\times10^{-4}\ \cancel{m}}\right)$$
$$\theta_2 = 0.11°$$

$$x_2 = \left(2-\frac{1}{2}\right)\frac{L\lambda}{d}$$
$$= \frac{(1.5)(1.4\text{ m})(5.6\times10^{-7}\ \cancel{m})}{4.4\times10^{-4}\ \cancel{m}}$$
$$= 2.7\times10^{-3}\text{ m}$$
$$x_2 = 0.27\text{ cm}$$

Statement: The second-order dark fringe for the 490 mm light occurs at 0.096° or 0.23 cm. The second-order dark fringe for the 560 mm light occurs at 0.11° or 0.27 cm.

Evaluation

83. Answers may vary. Sample answers:



The angle of incidence for the second reflection, θ_2, is the complement of the angle of incidence for the first reflection, θ_1. The final ray has changed direction by $2\theta_1 + 2\theta_2 = 180°$.

84. Answers may vary. Sample answer: The plan for the special room in the haunted house will not work. If light from the friend to the person in the hallway reflects internally, then no light ray from the person in the hallway can reach the friend.

85. Answers may vary. Sample answer: I would set up a two-point source interference pattern in the ripple tank, measure the distance separating the points, and count the number of nodal lines on half the interference pattern produced. Finally, I would use the equation $\left(n-\frac{1}{2}\right)\frac{\lambda}{d} = 1$ to solve for the wavelength.

86. Answers may vary. Sample answer: The radio signal that arrives directly from the tower will interfere with the signal reflected off the wall. The distance between signal nodes equals two wavelengths. I can measure the distance between two nodes by locating a spot with no reception and then walking toward the tower until the next node. Radio waves travel at the speed of light, so once I have calculated the wavelength, I can use the universal wave equation, $c = f\lambda$, to calculate the frequency.
87. Answers may vary. Sample answer: Scientists on each side of the debate had evidence that seemed to support their viewpoint, and their viewpoint seemed to explain certain pieces of evidence. At the same time, both sides seemed to have evidence that they could not explain. Until Young's double-slit experiment, even the scientists who supported the wave model had to explain why interference of light did not appear to happen.
88. Answers may vary. Sample answer: Due to reflection, a radio wave might bounce off an obstacle and interfere with itself. The interference might produce a nodal area with no radio reception.
89. Answers may vary. Sample answer: For a double-slit experiment to be successful, the light from the sources must be coherent, and preferably monochromatic. Two miniature light bulbs do not produce coherent or monochromatic light.

Reflect on Your Learning
90. Answers may vary. Sample answer: I was amazed by the interference patterns. The interference patterns in the ripple tank were fun to work with, and the interference patterns for light were surprising. I will check on the Internet to learn more about interference of light and using light to analyze the chemicals in materials.
91. Answers may vary. Sample answer: To explain total internal reflection and refraction, I would use our experience swimming and being near a lake. When you look down into the water at the foundation of the dock or even at your legs, everything looks bent. This is refraction—light from these objects is refracted to larger angles as it leaves the water and comes to our eyes. When you swim under very still water and open your eyes, you see a distorted view of the above water scene in a small area directly above you. This is refraction too—light from every direction above is bent into a narrow cone as it enters the water. If you look sideways, you see the shiny surface of the water. This is total internal reflection. This light hits the under surface of the water at such a large angle that it cannot bend enough to leave the water. Instead, it reflects back to your eye. We do not see diffraction of light much in daily life, but we do see diffraction of water waves around and under the dock. If I had to show diffraction of light, I would use a pin hole in a piece of cardboard and a flashlight with coloured plastic as a filter. You would see coloured rings instead of a big dot.
92. Answers may vary. Sample answer: I do a lot of swimming and kayaking at the cottage. I have seen lots of the wave properties that we have studied but did not understand what I was seeing until now. One wave interference situation I have observed is the gentle swell of large lake waves with the tiny swimming wake of a duck superimposed on top. The lake wave goes one way, and the duck wake goes in a different direction.

93. Answers may vary. Sample answer: I do not completely understand diffraction of light. We saw diffraction of water waves in the ripple tank and two-source interference. We did a lot of mathematics for the two-source interference and saw that it works for light, too. Someone mentioned diffraction of light. I do not know any examples of this but think it should fit together somehow. I could search the Internet to learn more about diffraction. I could try to find some online simulations to help with the concepts. From the figures, I also noticed that we will be dealing more with light in Chapter 10.

Research

94. Answers may vary. Students should discuss fibre optics construction and uses. Students could create a drawing similar to Figure 19, page 456, in the text, to show how the light undergoes total internal reflection in a fibre optic core. After research, students could label the buffer coating. Some advantages of a fibre optic communication system are its ability to carry a lot of data, its reduced expense to maintain, compared to traditional wire systems, and the high speed of signal transmission.

95. Answers may vary. Sample answer: Thermal imaging is a method for focusing long-wavelength infrared radiation onto a detector array, which converts the intensity of the radiation into a digital output. This output can then construct a black and white image of the focused scene in a fraction of a second. Thermal imaging can be used in goggles as a night vision device. Sometimes, the output signal is colour-coded by intensity but not usually for night vision use. Other uses include medical diagnostics for imaging tumours and energy efficiency analysis of buildings.

96. Answers may vary. Sample answer: Modern variations of the double-slit experiment confirm a new wave–particle model of light. The technology uses a laser, micrometers, and a detector. The detector is a photodiode and photomultiplier module. Light is a wave and a collection of particles called photons. These photons are completely unlike Newton's corpuscles. Experiments can be performed in which the light intensity is reduced to such a low level that only one photon is emitted at a time. One can then wait while a signal builds up in the detector and observe exactly the same interference pattern that is observed with intense light. These observations support the quantum mechanical theory of light introduced in Unit 5.

97. Answers may vary. Sample answer: Students' answers should include the following points.

(a) A number of techniques including Raman spectroscopy, spectrophotometry, and auto-fluorescence spectrum measurements are used along with fibre optics to analyze skin lesions, non-melanoma tumours, and other skin conditions. Thermal imaging can also detect abnormal skin growths.

(b) Spectral analysis, using laser light, can identify abnormalities in tissue.

(c) One benefit of this type of skin analysis is that the technologies offer early easy diagnosis and treatment of skin lesions and less intrusive cosmetic procedures. A drawback of this type of skin analysis is the expense of the equipment. The costs to the professionals are passed along to the patients or the health-care system. Another drawback is the increased demand for purely cosmetic procedures.

(d) Careers include dermatology, reconstructive surgery, and aesthetics. To become a dermatologist, I need to complete a four-year pre-med undergraduate degree, then apply to medical school. After medical school, I would have to complete a five-year dermatology residency program.

98. Answers may vary. Answers should emphasize that colour vision is partly a physics question about coloured light and partly a biological and neuroscience question about how the retina absorbs light and how the brain interprets the signal.
99. Answers may vary. Students' answers should include some of the following points. A heat mirage is caused by the refraction of light in the hot layer of air just above a surface. The light from the sky close to the horizon is bent away from the normal as it passes from a denser to a less dense (hotter) air layer. The human eye will always assume that the light striking it travelled in a straight line, so the eye projects the image of the sky onto the ground causing the mirage.
100. Answers may vary. Students' answers should include some of the following points.
(a) Grimaldi was the first person to record careful observations on shadows cast by sharply defined objects. He found that, at the edges, the shadow did not terminate suddenly, as expected for straight-line propagation of light, but gradually. Shadows were larger than the objects casting them. While examining light passing through a pinhole, Grimaldi found circular light and dark bands. He called this phenomenon diffraction, the name it maintains today.
(b) Grimaldi was working before Newton during the years referred to as the "scientific revolution." During that time, natural philosophers (scientists) were overthrowing Aristotle's physics, and the modern age was emerging. The decades to come would see new theories of heat (thermodynamics), which would later be explained in terms of microscopic particle motion (kinetic theory of matter). Later, all of mechanics would be augmented by Einstein when he developed the theory of relativity. The world of the atom and nucleus would be found to disobey the classical laws of mechanics, thus requiring a new dynamics called quantum mechanics.