Unit 4 Review, pages 560–567

Knowledge

1. (b)
2. (a)
3. (d)
4. (c)
5. (d)
6. (b)
7. (c)
8. (a)
9. (a)
10. (a)
11. (a)
12. (c)
13. (b)
14. (d)
15. (a)
16. (b)
17. (c)
18. (a)
19. False. Radio waves go through *fewer* cycles per second than X-rays.
20. False. *If a group of waves travels at the same speed*, light waves with higher frequencies have *shorter* wavelengths, and light waves with lower frequencies have *longer* wavelengths.
21. False. In a ripple tank, a decrease in the frequency of the two vibrating sources causes a *decrease* in the number of nodal lines.
22. True
23. False. The wave model of light *can* explain all wave properties of light.
24. True
25. True
26. True
27. True
28. False. For a diffraction grating, the angular separation of the maxima is generally *large* because the slit spacing is so small.
29. True
30. The law of reflection states that a wave is reflected from a surface such that the angle of incidence equals the angle of reflection.
31. Speed and wavelength determine the frequency of a wave.
32. In materials in which the index of refraction is high, the speed of a wave decreases.
33. A node is a point in a standing wave where the displacement is always zero. An antinode is a point in a standing wave halfway between two nodes at which the largest displacement, or amplitude, occurs. A nodal line is a line or curve along which destructive interference results in zero displacement, that is, where a series of crests and troughs meet resulting in zero amplitude.
34. The 1 cm opening will produce the largest diffraction because it is the smallest opening compared to the wavelength of the water wave.

35. When a wave encounters a barrier that has an opening that is similar in size to the wavelength, the part of the wave that passes through the opening will diffract into the region beyond the barrier.
36. The wavelength and the slit width are the quantities that determine the amount of diffraction of a wave due to a single slit.
37. When the source separation in a ripple tank increases, the nodal lines become more tightly spaced.
38. According to Newton's particle model, the speed of the light particles increased as they entered a medium with a greater index of refraction. As the particles moved faster, their path moved closer to the normal in the second medium.
39. I think that the wave model provides a better explanation of polarization. Polarized light consists of transverse disturbances that can be aligned with the polarization axis of a polarizing substance. Particles cannot account for such alignments, but waves can.
40. Huygens's principle states that each point on a wave front is the source of a spherical wavelet that spreads out at the wave's speed.
41. Early attempts to demonstrate interference of light were difficult because the sources of light that were used were out of phase. In addition, it was difficult to produce two sources of monochromatic light with exactly the same frequency.
42. To solve the problem of phase difference in the light sources, Young used a single source (sunlight) for his experiment. As a result, changes in phase were uniform, allowing him to observe interference.
43. The wave theory could not explain how light travelled through the vacuum of space without a medium.
44. If the two slits in Young's experiment had a smaller separation, the fringes in the interference pattern would be more spread out.
45. The frequency of a light wave is the same in a vacuum as it is in a piece of glass.
46. To form Newton's rings, make an air wedge with two pieces of glass, and shine light on the wedge. The change in the phase of the light as it reflects between the glass piece of the air wedge, along with the gradually increasing path length through the air, causes destructive interference between light waves, thus forming the dark rings.
47. If I increase the wavelength of light passing through the aperture of an optical instrument, then the instrument's resolution decreases.
48. In single-slit diffraction, as the slit width decreases, the distance between maxima and minima increases.
49. The more slits there are in a diffraction grating, the greater the spread, or dispersion, of the wavelengths of light.
50. The speed of light rays of different wavelengths in a vacuum is same. Therefore, the ratio of their speeds is 1:1.
51. Three methods of polarizing light are polarization by reflection, polarization by absorption, and polarization by scattering.
52. The optical activity of molecules in a solution changes the orientation of the electric wave in light. By passing polarized light through the solution, the polarization of the light rotates through a certain angle. By turning the second polarizer until the light passing through the solution has maximum intensity, the angle of optical activity can be determined and measured.

53. Brewster's angle is the angle of incidence at which the direction of a reflected portion of a light wave is perpendicular to the direction of the refracted portion of the wave. If unpolarized light is incident at Brewster's angle, the reflected light is completely polarized.

Understanding

54. Answer may vary. Sample answer will include some of the following information. Both light waves and water waves are transverse and reflect from a barrier, refract when they change speeds, diffract around barriers and through openings, and interfere constructively and destructively. They differ in that there are two transverse wave components to light (oscillating electric and magnetic fields), and water waves require a medium (water), whereas light does not. Light can be polarized, but water waves cannot be polarized.

55. According to Snell's law, the ratio of the index of refraction of the incident medium to the index of refraction of the refracting medium equals the ratio of the sines of the angle of refraction to the angle of incidence: $\frac{n_\text{i}}{n_\text{R}} = \frac{\sin\theta_\text{R}}{\sin\theta_\text{i}}$. For total internal reflection, $\sin\theta_\text{R} = 1$, so $\frac{n_\text{i}}{n_\text{R}} = \frac{1}{\sin\theta_\text{i}}$. In addition, $\sin\theta_\text{i} \leq 1$, so $\frac{n_\text{i}}{n_\text{R}} > 1$. This can only be true if n_i is greater than n_R.

56. After passing through a flat plane of glass, all wavelengths of light emerge in the same direction of propagation. A prism's triangular shape means that different wavelengths emerge in different directions, producing different colours.

57. (a) At a point where constructive interference takes place, the waves will combine to form waves with amplitudes greater than the amplitude of each individual wave. The boat will therefore rise higher.

(b) At a point where destructive interference takes place, the waves will combine to form waves with amplitudes that are smaller than the amplitude of each individual wave. The boat will therefore drop after destructive interference. If the destructively interfering waves are of equal amplitude, the boat will remain vertically stationary on the water.

58. We can hear sound around a corner because the sound waves diffract around the corner. We cannot see light around a corner because light has a much smaller wavelength than sound, so it diffracts much less.

59. Newton assumed that corpuscles of light moved faster in a medium with a higher index of refraction. This was consistent with the behaviour of particles that moved closer to the normal at higher speeds. Later, it was demonstrated that light actually moves slower in media with a higher index of refraction.

60. (a) Three properties of light accounted for by both models are rectilinear propagation, reflection, and refraction.

(b) Three properties of light not accounted for by the particle model are interference, diffraction, and polarization.

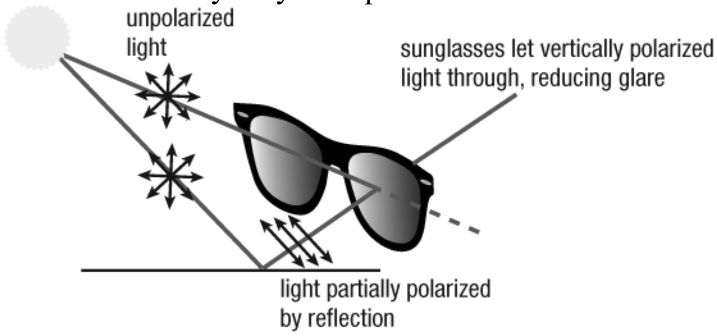
(c) Light does not need a medium in which to travel.

61. Radio waves have much longer wavelengths than visible light, so it would be easier to create two slits for interference and to measure the separations of the fringes. Only the invisibility of the waves would make the demonstration challenging.

62. Sample answer: The observation of double-slit interference was more convincing as evidence for the wave theory of light because particle theory had an explanation for diffraction in terms of particle collisions, but was unable to explain double-slit interference.
63. Incandescent light bulbs do not produce light waves that are in phase or at the same frequency over a period of time. As a result, no interference pattern will exist for sufficient time to allow the human eye to observe.
64. For a thin film covering a piece of glass, the light rays reflect at both the air–film boundary and the film–glass boundary, so both reflections change phase. They remain in phase after reflecting, and constructive interference happens when twice the thickness of the film is equal to whole-number multiples of the wavelength of light used. For a thin film surrounded by air, the light rays change phase when they reflect from the air–film boundary, but not when they reflect at the film–air boundary inside the film. As a result, if twice the thickness of the film equals whole-number multiples of the wavelength of light used, then the light rays will be out of phase and will interfere destructively. For constructive interference to take place in this situation, twice the thickness of the film must be a half wavelength longer. Therefore, the equation for constructive interference in one situation is identical to the equation for destructive interference in the other.
65. At the central maximum, the amount of destructive interference that takes place between pairs of out-of-phase wave fronts is at a minimum. At the first-order maximum, more of the individual wave fronts interfere destructively in pairs, so the overall intensity of the recombined light is much less than at the central maximum.
66. The ratio is $\frac{\lambda}{w} = \frac{1}{2}$.
67. Sample answer: Resolution is the ability of an optical device to separate two images. Diffraction decreases resolution. By using a larger aperture, diffraction is reduced and resolution is improved.
68. Sample answer: A diffraction grating allows a more precise measurement of the diffraction of different wavelengths than a prism. Increasing the number of slits gives a sharper peak, and each colour has multiple peaks that allow for multiple measurements.
69. If I immersed the apparatus for the investigation in water, the wavelength of the light decreases. As a result, the fringes will be spaced closer together.
70. Polarization is evidence that light can be oriented in one direction. In the wave theory, this is the direction of oscillation of the electromagnetic waves. Polarization experiments can also demonstrate the superposition of different waves.
71. **(a)** Intensity is greatest when the polarizer axis is parallel to the electric field of the light, allowing the light to pass through most easily. So at 0°, the intensity is at its maximum.
(b) Intensity is smallest when the polarizer axis is perpendicular to the electric field of the light, allowing little to no light to pass through. So at 90°, the intensity is zero, which is the minimum.

(c) Malus's law states that the change in intensity depends on the square of the cosine of the angle between the axis of the polarizer and the electric field of the light wave: $I_{out} = \cos^2 \theta I_{in}$. This produces a maximum value at 0° and zero intensity at 90°.

72. Answers may vary. Sample answer:



Analysis and Application

73. Given: $\theta_1 = 25°$; $n_{air} = 1.0003$; $n_{2\ red} = 1.459$; $n_{2\ blue} = 1.467$

Required: $\Delta\theta$, the difference between $\theta_{2\ red}$ and $\theta_{2\ blue}$

Analysis: Rearrange the equation $n_1 \sin\theta_1 = n_2 \sin\theta_2$ to calculate θ_2 for both the red and the blue light; $\sin\theta_2 = \dfrac{n_1 \sin\theta_1}{n_2}$. Then subtract the difference.

Solution:

Red light:

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

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

$$= \sin^{-1}\left(\frac{(1.0003)\sin 25°}{1.459}\right)$$

$\theta_{2\ red} = 16.843°$ (two extra digits carried)

Blue light:

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

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

$$= \sin^{-1}\left(\frac{(1.0003)\sin 25°}{1.467}\right)$$

$\theta_{2\ blue} = 16.748°$ (two extra digits carried)

The difference in the angles of refraction is

$$\Delta\theta = 16.843° - 16.748°$$

$$= 0.095°$$

$$\Delta\theta = 0.1°$$

Statement: The difference in the angles of refraction is 0.1°.

74. Given: $\theta_1 = 35.0°$; $n_1 = 1.0003$; $n_2 = 1.50$

Required: θ_2

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

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

$$\begin{aligned}\theta_2 &= \sin^{-1}\left(\frac{n_1 \sin\theta_1}{n_2}\right)\\ &= \sin^{-1}\left(\frac{(1.0003)\sin 35.0°}{1.50}\right)\\ \theta_2 &= 22.5°\end{aligned}$$

Statement: The angle of refraction of the light through the glass is 22.5°.

75. Given: $\theta_1 = 25.0°$; $n_1 = 1.0003$; $n_2 = 1.33$

Required: θ_2

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

Solution:

$$\begin{aligned}\sin\theta_2 &= \frac{n_1 \sin\theta_1}{n_2}\\ \theta_2 &= \sin^{-1}\left(\frac{n_1 \sin\theta_1}{n_2}\right)\\ &= \sin^{-1}\left(\frac{(1.0003)\sin 25.0°}{1.33}\right)\\ \theta_2 &= 18.5°\end{aligned}$$

Statement: The angle of refraction of the water is 18.5°.

76. Given: $\theta_1 = 22.5°$; $n_1 = 1.0003$; $n_2 = 1.33$

Required: θ_2

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

Solution:

$$\begin{aligned}\sin\theta_2 &= \frac{n_1 \sin\theta_1}{n_2}\\ \theta_2 &= \sin^{-1}\left(\frac{n_1 \sin\theta_1}{n_2}\right)\\ &= \sin^{-1}\left(\frac{(1.0003)\sin 22.5°}{1.33}\right)\\ \theta_2 &= 16.7°\end{aligned}$$

Statement: The angle of refraction is 16.7°.

77. Given: $n_{\text{diamond}} = 2.42$; $n_{\text{air}} = 1.0003$

Required: θ_c, critical angle for diamond–air boundary

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

Solution:

$$\begin{aligned}\theta_c &= \sin^{-1}\left(\frac{n_{\text{air}}}{n_{\text{diamond}}}\right)\\ &= \sin^{-1}\left(\frac{1.0003}{2.42}\right)\\ \theta_c &= 24.4^\circ\end{aligned}$$

Statement: The critical angle for a diamond–air boundary is 24.4°.

78. Given: $\theta_c = 42.4^\circ$; $n_{\text{air}} = 1.0003$

Required: n_{acrylic}

Analysis: Rearrange the equation $\sin\theta_c = \dfrac{n_2}{n_1}$ to solve for index of refraction; $n_1 = \dfrac{n_2}{\sin\theta_c}$.

Solution:

$$\begin{aligned}n_1 &= \frac{n_2}{\sin\theta_c}\\ &= \frac{1.0003}{\sin 42.4^\circ}\\ n_1 &= 1.48\end{aligned}$$

Statement: The index of refraction of acrylic is 1.48.

79. Given: $n_1 = 1.0003$; $n_2 = 1.60$; $\lambda_1 = 485$ nm

Required: λ_2

Analysis: Rearrange the equation $\dfrac{n_2}{n_1} = \dfrac{\lambda_1}{\lambda_2}$ to solve for wavelength; $\lambda_2 = \dfrac{n_1\lambda_1}{n_2}$.

Solution: $$\begin{aligned}\lambda_2 &= \frac{n_1\lambda_1}{n_2}\\ &= \frac{(1.0003)(485 \text{ nm})}{1.60}\\ \lambda_2 &= 303 \text{ nm}\end{aligned}$$

Statement: The wavelength of cyan light in the flint glass is 303 nm.

80. Given: two-source interference; λ = 1.4 m; d = 8.6 m; n = 3
Required: θ_3 for destructive interference
Analysis: $d \sin\theta_n = \left(n - \frac{1}{2}\right)\lambda$; $\theta_n = \sin^{-1}\left(\left(n - \frac{1}{2}\right)\frac{\lambda}{d}\right)$
Solution:

$$\theta_n = \sin^{-1}\left(\left(n - \frac{1}{2}\right)\frac{\lambda}{d}\right)$$
$$= \sin^{-1}\left(\left(3 - \frac{1}{2}\right)\frac{1.4\ \cancel{\text{m}}}{8.6\ \cancel{\text{m}}}\right)$$
$$\theta_3 = 24^\circ$$

Statement: The angle of the third nodal line is 24°.
81. (a) Given: two-source interference; P_2S_1 = 23.0 cm = 23.0 × 10^{-2} m;
P_2S_2 = 25.5 cm = × 10^{-2} m; n = 2
Required: λ
Analysis: $|P_nS_1 - P_nS_2| = \left(n - \frac{1}{2}\right)\lambda$; $\lambda = \dfrac{|P_nS_1 - P_nS_2|}{n - \frac{1}{2}}$
Solution:

$$\lambda = \frac{|P_nS_1 - P_nS_2|}{n - \frac{1}{2}}$$
$$= \frac{|23.0 \times 10^{-2}\ \text{m} - 25.5\ \times 10^{-2}\ \text{m}|}{2 - \frac{1}{2}}$$
$$= 1.667 \times 10^{-2}\ \text{m (two extra digits carried)}$$
$$\lambda = 0.017\ \text{m}$$

Statement: The wavelength of the waves is 0.017 m.
(b) Given: v = 7.5 m/s; λ = 1.667 × 10^{-2} m
Required: f
Analysis: Rearrange the universal wave equation, $v = f\lambda$, to solve for frequency; $f = \frac{v}{\lambda}$
Solution:

$$f = \frac{v}{\lambda}$$
$$= \frac{7.5\ \cancel{\text{m}}/\text{s}}{1.667 \times 10^{-2}\ \cancel{\text{m}}}$$
$$f = 450\ \text{Hz}$$

Statement: The frequency of the waves is 450 Hz.

82. Given: double-slit interference; $x_7 - x_1 = 5.8$ cm $= 5.8 \times 10^{-2}$ m; $L = 3.50$ m; $d = 2.2\times10^{-4}$ m

Required: λ

Analysis: The distance between the bright fringes corresponds to 6 fringe separations: $x_7 - x_1 = 6\Delta x$. Determine Δx, and then rearrange the equation $\Delta x = \dfrac{L\lambda}{d}$ to solve for wavelength; $\lambda = \dfrac{d\Delta x}{L}$

Solution:

$$x_7 - x_1 = 6\Delta x$$
$$\Delta x = \frac{x_7 - x_1}{6}$$
$$= \frac{5.8\times10^{-2}\text{ m}}{6}$$
$$\Delta x = 9.667\times10^{-3}\text{ m (two extra digits carried)}$$

$$\lambda = \frac{d\Delta x}{L}$$
$$= \frac{(2.2\times10^{-4}\text{ m})(9.667\times10^{-3}\ \cancel{\text{m}})}{3.50\ \cancel{\text{m}}}$$
$$= 6.1\times10^{-7}\text{ m}$$
$$\lambda = 610\text{ nm}$$

Statement: The wavelength of the source is 610 nm. This wavelength corresponds to red light.

83. Given: double-slit interference; $n = 2$ dark fringe; $\theta_2 = 5.1°$

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

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

Solution:

$$\frac{d}{\lambda} = \frac{n - \frac{1}{2}}{\sin\theta_n}$$
$$= \frac{2 - \frac{1}{2}}{\sin 5.1°}$$
$$\frac{d}{\lambda} = 17$$

Statement: The ratio of the slit separation to the wavelength is 17:1.

84. Given: double-slit interference; $d = 0.018$ mm $= 1.8 \times 10^{-5}$ m; $n = 5$ dark fringe; $\theta_5 = 8.2°$

Required: λ

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

Solution: $\lambda = \dfrac{d\sin\theta_n}{n-\dfrac{1}{2}}$

$= \dfrac{(1.8\times10^{-5}\text{ m})\sin 8.2°}{5-\dfrac{1}{2}}$

$= 5.7\times10^{-7}\text{ m}$

$\lambda = 570\text{ nm}$

Statement: The wavelength of the light is 570 nm.

85. Given: double-slit interference; λ = 638 nm = 6.38 × 10^{-7} m; m = 3 bright fringe; $\theta_3 = 8.0°$

Required: d

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

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

$= \dfrac{(3)(6.38\times10^{-7}\text{ m})}{\sin 8.0°}$

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

Statement: The slit separation is 1.4 × 10^{-5} m.

86. Given: double-slit interference; λ = 633 nm = 6.33 × 10^{-7} m; d = 0.100 mm = 1.00 × 10^{-4} m; L = 2.10 m

Required: x_1, n = 1 dark fringe position

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

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

$x_1 = \dfrac{\left(1-\dfrac{1}{2}\right)(2.10\text{ m})(6.33\times10^{-7}\ \cancel{\text{m}})}{1.00\times10^{-4}\ \cancel{\text{m}}}$

$x_1 = 6.65\times10^{-3}\text{ m}$

Statement: The first-order dark fringe occurs at 6.65 × 10^{-3} m from the central maximum.

87. (a) Given: double-slit interference; $d = 0.042$ mm $= 4.2 \times 10^{-5}$ m; $L = 4.00$ m;
$\Delta x = 5.5 \text{ cm} = 5.5\times10^{-2} \text{ m}$
Required: λ

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

Solution:
$$\begin{aligned}\lambda &= \frac{d\Delta x}{L}\\ &= \frac{(4.2\times10^{-5} \text{ m})(5.5\times10^{-2} \cancel{\text{m}})}{(4.00 \cancel{\text{m}})}\\ &= 5.775\times10^{-7} \text{ m (two extra digits carried)}\\ \lambda &= 580 \text{ nm}\end{aligned}$$

Statement: The wavelength of the light is 580 nm.

(b) Given: $c = 3.0\times10^{8}$ m/s; $\lambda = 5.775\times10^{-7}$ m
Required: f

Analysis: $c = f\lambda$; $f = \dfrac{c}{\lambda}$

Solution:
$$\begin{aligned}f &= \frac{c}{\lambda}\\ &= \frac{3.0\times10^{8}\ \frac{\cancel{\text{m}}}{\text{s}}}{5.775\times10^{-7}\ \cancel{\text{m}}}\\ f &= 5.2\times10^{14} \text{ Hz}\end{aligned}$$

Statement: The frequency of the light is 5.2×10^{14} Hz.

88. Given: double-slit interference; $\lambda = 639$ nm $= 6.39 \times 10^{-7}$ m; $L = 2.80$ m; $n = 1$;
$d = 0.048$ mm $= 4.8\times10^{-5}$ m
Required: x_1, $n = 1$ dark fringe position

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

Solution:
$$\begin{aligned}x_n &= \left(n - \frac{1}{2}\right)\frac{L\lambda}{d}\\ &= \frac{\left(1 - \frac{1}{2}\right)(2.80 \text{ m})(6.39\times10^{-7} \cancel{\text{m}})}{4.8\times10^{-5} \cancel{\text{m}}}\\ x_1 &= 1.9\times10^{-2} \text{ m}\end{aligned}$$

Statement: The first dark fringe occurs at 1.9×10^{-2} m from the central maximum.

89. Given: double-slit interference; d = 0.5 mm = 5 × 10^{-4} m; L = 1.0 m;
$x_{11} - x_1 = 1.0 \text{ cm} = 1.0 \times 10^{-2} \text{ m}$

Required: λ

Analysis: The distance between the fringes corresponds to 10 fringe separations: $x_{11} - x_1 = 10\Delta x$. Determine Δx and rearrange the equation $\Delta x = \dfrac{L\lambda}{d}$ to solve for wavelength; $\lambda = \dfrac{d\Delta x}{L}$.

Solution:

$$x_{11} - x_1 = 10\Delta x$$
$$\Delta x = \frac{x_{11} - x_1}{10} = \frac{1.0 \times 10^{-2} \text{ m}}{10}$$
$$\Delta x = 1 \times 10^{-3} \text{ m}$$

$$\lambda = \frac{d\Delta x}{L} = \frac{(5 \times 10^{-4} \text{ m})(1 \times 10^{-3} \cancel{\text{m}})}{(1.0 \cancel{\text{m}})} = 5 \times 10^{-7} \text{ m}$$
$$\lambda = 500 \text{ nm}$$

Statement: The wavelength of the light used is 500 nm.

90. Given: double-slit interference; λ = 480 nm = 4.8 × 10^{-7} m; L = 2.0 m;
$d = 3.0 \text{ mm} = 3.0 \times 10^{-3} \text{ m}$

Required: separation between m = 8 bright fringe and n = 3 dark fringe

Analysis: Use the equations $x_m = \dfrac{mL\lambda}{d}$ with m = 8 and $x_n = \left(n - \dfrac{1}{2}\right)\dfrac{L\lambda}{d}$ with n = 3 to locate the two fringe positions. Then calculate the difference of these positions to determine the required separation.

Solution:

$$x_m = \frac{mL\lambda}{d} = \frac{8(2.0 \text{ m})(4.8 \times 10^{-7} \cancel{\text{m}})}{3.0 \times 10^{-3} \cancel{\text{m}}}$$
$$x_8 = 25.6 \times 10^{-4} \text{ m} \text{ (one extra digit carried)}$$

$$x_n = \left(n - \frac{1}{2}\right)\frac{L\lambda}{d} = \frac{\left(3 - \frac{1}{2}\right)(2.0 \text{ m})(4.8 \times 10^{-7} \cancel{\text{m}})}{3.0 \times 10^{-3} \cancel{\text{m}}}$$
$$x_3 = 8.0 \times 10^{-4} \text{ m}$$

The separation is
$$x_8 - x_3 = 25.6 \times 10^{-4} \text{ m} - 8.0 \times 10^{-4} \text{ m} = 1.8 \times 10^{-3} \text{ m}$$

Statement: The separation between the third dark fringe and the eighth bright fringe is 1.8×10^{-3} m.

91. Given: double-slit interference; $\lambda = 6.5 \times 10^{-7}$ m; $d = 1.0$ mm $= 1.0 \times 10^{-3}$ m; $L = 1.0$ m

Required: separation between $m = 5$ bright fringe and $n = 3$ dark fringe

Analysis: Use the equations $x_m = \dfrac{mL\lambda}{d}$ with $m = 5$ and $x_n = \left(n - \dfrac{1}{2}\right)\dfrac{L\lambda}{d}$ with $n = 3$ to locate the two fringe positions. Then calculate the difference of these positions to determine the required separation.

Solution:
$$x_m = \frac{mL\lambda}{d}$$
$$= \frac{(5)(1.0\ \text{m})(6.5\times10^{-7}\ \cancel{\text{m}})}{1.0\times10^{-3}\ \cancel{\text{m}}}$$
$$x_5 = 3.25\times10^{-3}\ \text{m}\ \ \text{(one extra digit carried)}$$
$$x_n = \left(n-\frac{1}{2}\right)\frac{L\lambda}{d}$$
$$= \frac{\left(3-\frac{1}{2}\right)(1.0\ \text{m})(6.5\times10^{-7}\ \cancel{\text{m}})}{1.0\times10^{-3}\ \cancel{\text{m}}}$$
$$x_3 = 1.625\times10^{-3}\ \text{m}\ \ \text{(two extra digits carried)}$$

Calculate the separation:
$$x_5 - x_3 = 3.25\times10^{-3}\ \text{m} - 1.625\times10^{-3}\ \text{m}$$
$$= 1.6\times10^{-3}\ \text{m}$$

Statement: The separation between the third dark fringe and the fifth bright fringe is 1.6×10^{-3} m.

92. Given: double-slit interference; $\lambda = 656$ nm $= 6.56 \times 10^{-7}$ m; $L = 1.50$ m; $m = 4$ bright fringe; $x_4 = 48.0$ mm $= 4.80\times10^{-2}$ m

Required: d

Analysis: Rearrange the equation $x_m = \dfrac{mL\lambda}{d}$ to determine the slit separation; $d = \dfrac{mL\lambda}{x_m}$.

Solution:
$$d = \frac{mL\lambda}{x_m}$$
$$= \frac{(4)(1.50\ \text{m})(6.56\times10^{-7}\ \cancel{\text{m}})}{4.80\times10^{-2}\ \cancel{\text{m}}}$$
$$d = 8.20\times10^{-5}\ \text{m}$$

Statement: The slit separation is 8.20×10^{-5} m.

93. Given: double-slit interference under water; λ_1 = 465 nm = 4.65×10^{-7} m; $d = 5.00 \times 10^{-4}$ m; L = 50.0 cm = 0.500 m; $n_1 = 1.0003$; $n_2 = 1.33$

Required: Δx

Analysis: $\dfrac{n_2}{n_1} = \dfrac{\lambda_1}{\lambda_2}$; $\lambda_2 = \dfrac{n_1\lambda_1}{n_2}$; $\Delta x = \dfrac{L\lambda}{d}$

Solution:

$$\begin{aligned}\lambda_2 &= \frac{n_1\lambda_1}{n_2}\\ &= \frac{(1.0003)(4.65 \times 10^{-7}\ \text{m})}{1.33}\\ &= 3.4973 \times 10^{-7}\ \text{m}\ \text{(two extra digits carried)}\end{aligned}$$

$$\begin{aligned}\Delta x &= \frac{L\lambda}{d}\\ &= \frac{(0.500\ \text{m})(3.4973 \times 10^{-7}\ \cancel{\text{m}})}{5.00 \times 10^{-4}\ \cancel{\text{m}}}\\ \Delta x &= 3.50 \times 10^{-4}\ \text{m}\end{aligned}$$

Statement: The fringe separation distance is 3.50×10^{-4} m.

94. Given: n_{oil} = 1.40; λ = 410 nm = 4.10×10^{-7} nm

Required: t

Analysis: Use the formula for constructive interference of two waves when phase changes occur in only one reflection. Use m = 0; $2t = \dfrac{\left(m + \frac{1}{2}\right)\lambda}{n_{\text{oil}}}$; $t = \dfrac{\left(m + \frac{1}{2}\right)\lambda}{2n_{\text{oil}}}$.

Solution:

$$\begin{aligned}t &= \frac{\left(m + \frac{1}{2}\right)\lambda}{2n_{\text{oil}}}\\ &= \frac{\left(0 + \frac{1}{2}\right)\lambda}{2n_{\text{oil}}}\\ &= \frac{(0.5)(4.10 \times 10^{-7}\ \text{m})}{2(1.40)}\\ t &= 7.3 \times 10^{-8}\,\text{m}\end{aligned}$$

Statement: The minimum thickness of the oil slick is 7.3×10^{-8} m.

95. Given: n_{coating} = 1.38; λ = 582 nm = 5.82×10^{-7} nm

Required: t

Analysis: Use the formula for destructive interference of two waves when phase changes occur at both reflections and m = 0; $2t = \dfrac{\left(m + \frac{1}{2}\right)\lambda_{\text{light}}}{n_{\text{coating}}}$; $t = \dfrac{\left(m + \frac{1}{2}\right)\lambda}{2n_{\text{coating}}}$

Solution: $t = \dfrac{\left(m + \dfrac{1}{2}\right)\lambda}{2n_{\text{coating}}}$

$$= \frac{\left(0 + \dfrac{1}{2}\right)(5.82 \times 10^{-7}\ \text{m})}{2(1.38)}$$

$$t = 1.05 \times 10^{-7}\,\text{m}$$

Statement: The minimum thickness of the coating is 1.05×10^{-7} m.

96. Given: $n_{\text{coating}} = 1.62$; $\lambda = 587\ \text{nm} = 5.87 \times 10^{-7}\ \text{m}$

Required: t

Analysis: The light undergoes a phase change at the air–coating boundary interface but not at the coating–glass boundary. We do not want to see the light, so use the formula for destructive interference of the two waves and use $n = 1$ and $n = 2$;

$$2t = \frac{n\lambda}{n_{\text{coating}}};\ t = \frac{n\lambda}{2n_{\text{coating}}}$$

Solution:

For $n = 1$:

$$t = \frac{n\lambda}{2n_{\text{coating}}}$$

$$= \frac{(1)(5.87 \times 10^{-7}\ \text{m})}{2(1.62)}$$

$$t = 1.81 \times 10^{-7}\,\text{m}$$

For $n = 2$:

$$t = \frac{(2)\lambda}{2n_{\text{coating}}}$$

$$= \frac{(2)(5.87 \times 10^{-7}\ \text{m})}{2(1.62)}$$

$$t = 3.62 \times 10^{-7}\,\text{m}$$

Statement: The two smallest possible non-zero values for the coating thickness are $1.81 \times 10^{-7}\ \text{m}$ and $3.62 \times 10^{-7}\ \text{m}$.

97. Given: $\lambda = 566\ \text{nm} = 5.66 \times 10^{-7}\ \text{m}$; $t = 121\ \text{nm} = 1.12 \times 10^{-7}\ \text{m}$

Required: n_{coating}

Analysis: Assume that the light undergoes a phase change at both the air–coating boundary and the coating–glass boundary. Since we do not want to see the light, use the formula for destructive interference of the two waves and $m = 0$;

$$2t = \frac{\left(m + \dfrac{1}{2}\right)\lambda}{n_{\text{coating}}};\ n_{\text{coating}} = \frac{\left(m + \dfrac{1}{2}\right)\lambda}{2t}$$

Solution: $n_{\text{coating}} = \dfrac{\left(m+\frac{1}{2}\right)\lambda}{2t}$

$$= \frac{\left(0+\frac{1}{2}\right)\left(5.66\times10^{-7}\ \cancel{\text{m}}\right)}{1.21\times10^{-7}\ \cancel{\text{m}}}$$

$n_{\text{coating}} = 1.17$

Statement: The index of refraction of the coating is 1.17. Note that our assumption about phase change is correct.

98. Given: n_{coating} = 1.36; λ = 524 nm = 5.24×10^{-7} m

Required: t

Analysis: The light undergoes a phase change at both the air–coating boundary and the coating–glass boundary. We see the green light, so use the formula for constructive interference of the two waves and n = 1; $2t = \dfrac{n\lambda_{\text{light}}}{n_{\text{coating}}}$; $t = \dfrac{n\lambda_{\text{light}}}{2n_{\text{coating}}}$.

Solution: $t = \dfrac{n\lambda}{2n_{\text{coating}}}$

$$= \frac{(1)(5.24\times10^{-7}\ \text{m})}{2(1.36)}$$

$t = 1.93\times10^{-7}\,\text{m}$

Statement: The thickness of the alcohol film is 1.93×10^{-7} m.

99. Given: $n_{\text{soap}} = 1.33$; $t = 109$ nm = 1.09×10^{-7} m

Required: λ

Analysis: The light undergoes a phase change at the air–soap boundary but not at the soap–air boundary. We want to see the light, so use the formula for constructive interference; $2t = \dfrac{\left(m+\frac{1}{2}\right)\lambda}{n_{\text{soap}}}$; $\lambda = \dfrac{2tn_{\text{soap}}}{\left(m+\frac{1}{2}\right)}$. To determine the longest wavelength, choose the smallest value for m: m = 0.

Solution: $\lambda = \dfrac{2tn_{\text{soap}}}{\left(m+\dfrac{1}{2}\right)}$

$$= \frac{2\left(1.09\times10^{-7}\ \text{m}\right)\left(1.33\right)}{\left(0+\dfrac{1}{2}\right)}$$

$$\lambda = 5.80\times10^{2}\ \text{nm}$$

Statement: The wavelength of the light that is most constructively reflected is 5.80×10^2 nm.

100. Given: $\lambda = 628\ \text{nm} = 6.28\times10^{-7}\ \text{m}$; there are 36 cycles of alternating light patterns in L

Required: t

Analysis: $\Delta x = \dfrac{L}{36}$; $\Delta x = \dfrac{L\lambda}{2t}$; $t = \dfrac{L\lambda}{2\Delta x}$

Solution: $t = \dfrac{L\lambda}{2\Delta x}$

$$= \frac{\cancel{L}\left(6.28\times10^{-7}\ \text{m}\right)}{2\left(\dfrac{\cancel{L}}{36}\right)}$$

$$t = 1.1\times10^{-5}\ \text{m}$$

Statement: The thickness of the plastic sheet is 1.1×10^{-5} m.

101. Given: $\lambda = 529\ \text{nm} = 5.29\times10^{-7}\ \text{m}$; $t = 7.62\times10^{-5}\ \text{m}$

Required: n, the number of bright fringes

Analysis: $n = \dfrac{L}{\Delta x}$; $\Delta x = \dfrac{L\lambda}{2t}$

$$n = \frac{L}{\Delta x}$$

$$= \frac{\cancel{L}}{\dfrac{\cancel{L}\lambda}{2t}}$$

$$n = \frac{2t}{\lambda}$$

Solution: $n = \dfrac{2t}{\lambda}$

$$= \frac{2\left(7.62\times10^{-5}\ \cancel{\text{m}}\right)}{5.29\times10^{-7}\ \cancel{\text{m}}}$$

$n = 288$

Statement: The number of bright fringes seen along the wedge is 288.

102. Given: λ = 532 nm = 5.32×10^{-7} m; L = 15.4 cm = 1.54×10^{-1} m; Δx = 1.4 mm = 1.4×10^{-3} m

Required: t

Analysis: $\Delta x = \dfrac{L\lambda}{2t}$

$$2t = \frac{L\lambda}{\Delta x}$$

$$t = \frac{L\lambda}{2\Delta x}$$

Solution: $t = \dfrac{L\lambda}{2\Delta x}$

$$= \frac{(1.54\times10^{-1}\ \text{m})(5.32\times10^{-7}\ \cancel{\text{m}})}{(2)(1.4\times10^{-3}\ \cancel{\text{m}})}$$

$t = 2.9\times10^{-5}$ m

Statement: The thickness of the metal foil is 2.9×10^{-5} m.

103. (a) Sample answer: The large dark space in the soap film at the top is uniform in thickness. It is also the right thickness to cause destructive interference for reflected yellow light.

(b) As time goes on, the film will get thinner at the top and thicker toward the bottom as gravity pulls the soap down. I expect to see bands of yellow and dark drifting downward.

(c) The two adjacent bright bands correspond to using m = 0 and m = 1 in the constructive interference formula, $2t = \dfrac{\left(m+\frac{1}{2}\right)\lambda}{n_{\text{soap}}}$; $t = \dfrac{\left(m+\frac{1}{2}\right)\lambda}{2n_{\text{soap}}}$.

Subtract t at $m = 0$ from t at $m = 1$:

$$\frac{\left(1+\frac{1}{2}\right)\lambda}{2n_{\text{soap}}}-\frac{\left(0+\frac{1}{2}\right)\lambda}{2n_{\text{soap}}}=\frac{\left(\frac{3}{2}-\frac{1}{2}\right)\lambda}{2n_{\text{soap}}}$$

$$\frac{\left(1+\frac{1}{2}\right)\lambda}{2n_{\text{soap}}}-\frac{\left(0+\frac{1}{2}\right)\lambda}{2n_{\text{soap}}}=\frac{\lambda}{2n_{\text{soap}}}$$

The difference in thickness of the soap film in the first two bands is $\dfrac{\lambda}{2n_{\text{soap}}}$.

(d) Given: $n_{\text{soap}} = 1.33$; $n_{\text{air}} = 1.00$; $\lambda = 587\ \text{nm} = 5.87\times10^{-7}\ \text{m}$

Required: t

Analysis: Assume the light source is between the loop and your eye. The light undergoes a phase change at the air–soap boundary but not at the soap–air boundary. To have a dark band, use the formula for destructive interference of the two waves. The lowest dark band is the third dark band, so $n = 3$.

$$2t = \frac{n\lambda}{n_{\text{soap}}}$$

$$t = \frac{n\lambda}{2n_{\text{soap}}}$$

Solution: $t = \dfrac{n\lambda}{2n_{\text{soap}}}$

$$= \frac{(3)(5.87\times10^{-7}\ \text{m})}{2(1.33)}$$

$$t = 6.62\times10^{-7}\,\text{m}$$

Statement: The thickness of the soap film in the lowest dark band is 6.62×10^{-7} m.

104. Given: λ = 425 nm = 4.25×10^{-7} m; w = 0.35 mm = 3.5×10^{-4} m; L = 2.0 m

Required: $2\Delta y$

Analysis: The distance between adjacent minima is Δy; multiply Δy by 2.

$$\lambda = \frac{w\Delta y}{L}$$

$$\Delta y = \frac{L\lambda}{w}$$

Solution: $2\Delta y = \dfrac{2L\lambda}{w}$

$$= \frac{2(2.0\ \text{m})(4.25\times10^{-7}\ \cancel{\text{m}})}{3.5\times10^{-4}\ \cancel{\text{m}}}$$

$$2\Delta y = 4.9\times10^{-3}\ \text{m}$$

Statement: The width of the central maximum is 4.9×10^{-3} m.

105. Given: $w = 5.60\times10^{-4}$m; $L = 3.00$ m; $\Delta y = 3.5$ mm $= 3.5\times10^{-3}$ m

Required: λ

Analysis: $\lambda = \dfrac{w\Delta y}{L}$

Solution: $\lambda = \dfrac{w\Delta y}{L}$

$$= \frac{(5.60\times10^{-4}\ \text{m})(3.5\times10^{-3}\ \cancel{\text{m}})}{3.00\ \cancel{\text{m}}}$$

$$= 6.533\times10^{-7}\ \text{m}$$

$$\lambda = 650\ \text{nm}$$

Statement: The wavelength of the light is 650 nm.

106. (a) Given: $w = 1.08\times10^{-6}$ m; $\lambda = 589$ nm $= 5.89\times10^{-7}$ m

Required: θ_1

Analysis: $\sin\theta_n = \dfrac{n\lambda}{w}$

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

Solution: $\theta_n = \sin^{-1}\left(\dfrac{n\lambda}{w}\right)$

$$\theta_1 = \sin^{-1}\left(\frac{(1)(5.89\times10^{-7}\ \cancel{\text{m}})}{1.08\times10^{-6}\ \cancel{\text{m}}}\right)$$

$$\theta_1 = 33.0^\circ$$

Statement: The angle of the first minimum is 33.0°.

(b) By examining the calculation in part (a), we see that replacing $n = 1$ by $n = 2$ or higher leads to a value for $\sin\theta$ that is greater than 1.0. Therefore, there is no second minimum.

107. Given: $\lambda = 1.15\times10^{-6}$ m; $\theta_4 = 8.4^\circ$; $n = 4$

Required: w

Analysis: $\sin\theta_n = \dfrac{n\lambda}{w}$; $w = \dfrac{n\lambda}{\sin\theta_n}$

Solution: $w = \dfrac{n\lambda}{\sin\theta_n}$

$$= \frac{(4)(1.15\times10^{-6}\ \text{m})}{\sin 8.4°}$$

$$w = 3.1\times10^{-5}\ \text{m}$$

Statement: The width of the slit is 3.1×10^{-5} m.

108. Given: $\lambda = 639\ \text{nm} = 6.39\times10^{-7}\ \text{m}$; $w = 4.2\times10^{-4}\ \text{m}$; $L = 3.50\ \text{m}$

Required: Δy

Analysis: $\Delta y = \dfrac{\lambda L}{w}$

Solution: $\Delta y = \dfrac{\lambda L}{w}$

$$= \frac{\left(6.39\times10^{-7}\ \text{m}\right)\left(3.50\ \cancel{\text{m}}\right)}{\left(4.2\times10^{-4}\ \cancel{\text{m}}\right)}$$

$$\Delta y = 5.3\times10^{-3}\ \text{m}$$

Statement: The separation between the maxima is $5.3\times10^{-3}\ \text{m}$.

109. Sample answer: X-rays have very high energy and will pass through any mirror in a traditional telescope. This problem is avoided by having the rays come in at an angle so that they bounce off an initial mirror and then bounce of more mirrors, after which they come to a focus. Telescopes are designed so that each mirror is most efficient at reflecting a particular range of X-ray wavelengths. A large aperture is not necessary for this process.

110. Sample answer: The spacing between fringes became smaller. This could happen if the wavelength became smaller, if the slit width became bigger, or if the screen distance were shortened.

111. (a) Given: $f = 22.5\ \text{GHz} = 2.25\times10^{10}\ \text{Hz}$; $w = 1.9\ \text{cm} = 1.9\times10^{-2}\ \text{m}$; $L = 0.45\ \text{m}$

Required: length of B; length of C

Analysis: To predict the values for B and C, I will calculate them. If I had access to the equipment, I could check my predicted answers by doing the experiment and measuring the results. Rearrange the universal wave equation, $c = \lambda f$, to calculate wavelength; $\lambda = \dfrac{c}{f}$. Then use $\Delta y = \dfrac{\lambda L}{w}$ to calculate B. To calculate C, use trigonometry C.

Solution: $\Delta y = \dfrac{\lambda L}{w}$

$$= \frac{\left(1.333\times10^{-2}\ \text{m}\right)\left(0.45\ \cancel{\text{m}}\right)}{1.9\times10^{-2}\ \cancel{\text{m}}}$$

$$= 0.3157\ \text{m}\ \text{(two extra digits carried)}$$

$$\Delta y = 0.32\ \text{m}$$

A, B, and C form a right-angled triangle. Use the Pythagorean theorem:

$$C^2 = \left(0.45\text{ m}\right)^2 + \left(0.3157\text{ m}\right)^2$$

$$C = 0.55\text{ m}$$

Statement: The values for B and C are 0.32 m and 0.55 m, respectively.

112. Given: $w = 20.0\text{ cm} = 2.00 \times 10^{-1}\text{ m}$; $\theta = 36°$

Required: λ

Analysis: Use the formula for minima and $n = 1$; $\sin\theta_n = \dfrac{n\lambda}{w}$;

$$\lambda = \frac{w\sin\theta_n}{n}$$

Solution:
$$\begin{aligned}\lambda &= \frac{w\sin\theta_n}{n}\\ &= \frac{(2.00\times10^{-1}\text{ m})\sin 36°}{1}\\ &= 1.176\times10^{-1}\text{ m}\\ \lambda &= 12\text{ cm}\end{aligned}$$

Statement: The wavelength of the microwaves is 12 cm.

113. (a) By making the aperture of a telescope larger, we can reduce the amount of diffraction.

(b) An Airy disk consists of a bright central spot surrounded by concentric rings of light.

(c) A reflecting telescope uses multiple mirrors to form an image. A refracting telescope uses lenses with no obstructions (mirrors) to form an image. With no obstructions in its optical path, a refracting telescope should give the clearest image.

114. For a diffraction grating to display only first-order maxima, it must have a wide dispersion and cause the second-order maxima to appear at an angle greater than 90°. For any given wavelength, the dispersion of a diffraction grating is inversely proportional to the separation of the lines, so by adding more lines per centimetre to the grating, the dispersion is increased.

115. Given: $w = 2.1 \times 10^{-6}$ m; $L = 2.96$ m; $\lambda_1 = 411\text{ nm} = 4.11 \times 10^{-7}$ m; $\lambda_2 = 664\text{ nm} = 6.64 \times 10^{-7}$ m; $m = 1$

Required: Δy; θ

Analysis: Rearrange the formula $m\lambda = w\sin\theta_m$ to solve for θ for both wavelengths; $\sin\theta_m = \dfrac{m\lambda}{w}$; then use trigonometry to calculate the width of the light spectrum.

Solution:

For λ_1:

$$\sin\theta_m = \frac{m\lambda_1}{w}$$

$$\sin\theta_1 = \frac{(1)\left(4.11\times10^{-7}\ \cancel{\text{m}}\right)}{2.1\times10^{-6}\ \cancel{\text{m}}}$$

$\theta_1 = 11.29°$ (two extra digits carried)

For λ_2:

$$\sin\theta_1 = \frac{(1)\left(6.64\times10^{-7}\ \cancel{\text{m}}\right)}{2.1\times10^{-6}\ \cancel{\text{m}}}$$

$\theta_1 = 18.43°$ (two extra digits carried)

By trigonometry, the positions of the colour bands are $(2.96\text{ m})\sin 11.29° = 0.58\text{ m}$ and $(2.96\text{ m})\sin 18.43° = 0.94\text{ m}$.

Statement: For the 411 nm wavelength, the angle and position are 11° and 0.58 m; for the 664 nm wavelength, the angle and position are 18° and 0.94 m.

116. Given: $N = 5100$ lines/cm; $\theta_2 = 33°$; $m = 2$

Required: λ

Analysis: Use the equation $w = \frac{1}{N}$ to calculate the slit separation. Then rearrange the equation $m\lambda = w\sin\theta_m$ to calculate the wavelength; $\lambda = \frac{w\sin\theta_m}{m}$.

Solution:

$$\begin{aligned} w &= \frac{1}{N} \\ &= \frac{1}{5100\text{ lines/cm}} \\ &= 1.96\times10^{-4}\text{ cm} \\ w &= 1.96\times10^{-6}\text{ m} \end{aligned}$$

$$\begin{aligned} \lambda &= \frac{w\sin\theta_m}{m} \\ &= \frac{(1.96\times10^{-5}\text{ m})\sin 33°}{2} \end{aligned}$$

$\lambda = 530$ nm

Statement: The wavelength of the light is 530 nm.

117. Given: $N = 8600$ lines/cm; $\theta_1 = 26.6°$; $\theta_2 = 41.1°$

Required: λ_1, λ_2

Analysis: Use $w = \frac{1}{N}$ to calculate the slit separation. Rearrange the equation $m\lambda = w\sin\theta_m$ to calculate the wavelengths; $\lambda = \frac{w\sin\theta_m}{m}$.

Solution: $w = \dfrac{1}{N}$

$$= \frac{1}{8600 \text{ lines/cm}}$$
$$= 1.16 \times 10^{-4} \text{ cm}$$
$$w = 1.16 \times 10^{-6} \text{ m}$$

For m = 1 and θ = 26.6°:

$$\lambda_1 = \frac{w \sin\theta_m}{m}$$
$$= \frac{(1.16 \times 10^{-6} \text{ m}) \sin 26.6°}{1}$$
$$\lambda_1 = 5.2 \times 10^{-7} \text{ m}$$

For m = 1 and θ = 41.1°:

$$\lambda_2 = \frac{w \sin\theta_m}{m}$$
$$= \frac{(1.16 \times 10^{-6} \text{ m}) \sin 41.1°}{1}$$
$$\lambda_2 = 7.6 \times 10^{-7} \text{ m}$$

Statement: The wavelengths of the observed light are 5.2×10^{-7} m and 7.6×10^{-7} m.

118. (a) (b) The smallest possible value of $\sin\theta$ is the number of lines per metre times the wavelength, and this value must be less than 1 to produce a maximum. Thus, the maximum wavelength is the inverse of the number of lines per metre. At 26 000 lines/cm, only wavelengths less than 3.80×10^{-7} m, or 380 nm, will produce a maximum, and light with wavelengths in this range are not in the visible spectrum.

Evaluation

119. Answers may vary. Sample answer: Water waves are visible and we can measure them without sophisticated technology. To observe interference and diffraction of light, we need more sophisticated equipment.

120. No, I am not guaranteed better reception if my cellphone provider adds a second tower because the signal from the two towers could interfere destructively and reduce the quality of the reception.

121. (a) Given: radio wave transmitter and radio wave receiver; reflected signal has half-wavelength phase shift on reflection; $\Delta d = 0.40 \text{ km} = 400 \text{ m}$; $h = 62.0 \text{ m}$

Required: longest λ for constructive interference

Analysis: Calculate the real path difference between the direct signal and the reflected signal. Then, including the extra half-wavelength phase shift for reflection, use the fact that the effective path difference must be a whole number of wavelengths for constructive interference.

Solution: The reflected signal reflects off the ground at the midpoint of the towers, so divide 400 m by 2: 200 m. The distance the signal travels is the hypotenuse of a right-angled triangle on the way down to the ground and the same again on the way up to the receiver:

$$d = 2\sqrt{(200 \text{ m})^2 + (62.0 \text{ m})^2}$$
$$d = 418.78 \text{ m} \text{ (two extra digits carried)}$$

The direct signal travels 400 m. Calculate the real path difference:

418.78 m – 400 m = 18.78 m

The effective path difference is $18.78 \text{ m} + \frac{1}{2}\lambda$. For constructive interference, this is equal to a whole number of wavelengths:

$$18.78 \text{ m} + \frac{1}{2}\lambda = m\lambda$$

The smallest possible value for m is $m = 1$:

$$18.78 \text{ m} + \frac{1}{2}\lambda = 1\lambda$$

$$18.78 \text{ m} = \frac{1}{2}\lambda$$

$$\lambda = 38 \text{ m}$$

Statement: The longest possible wavelength for constructive interference is 38 m.

(b) Given: radio wave transmitter and radio wave receiver; reflected signal has half-wavelength phase shift on reflection; $\Delta d = 0.40 \text{ km} = 400 \text{ m}$; $h = 62.0 \text{ m}$

Required: longest λ for destructive interference

Analysis: The problem is similar to part (a) except that the effective path difference must be $\left(n - \frac{1}{2}\right)\lambda$.

Solution: $18.78 \text{ m} + \frac{1}{2}\lambda = \left(n - \frac{1}{2}\right)\lambda$

The smallest possible value for n, is $n = 2$:

$$18.78 \text{ m} + \frac{1}{2}\lambda = \frac{3}{2}\lambda$$

$$18.78 \text{ m} = \lambda$$

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

Statement: The longest possible wavelength for destructive interference is 19 m.

122. (a) Yes, the image of the slit in the mirror is coherent with the slit itself. The two light rays come from a single source and share a fixed phase relationship.

(b) The two branches of the light wave will interfere with each other at the screen, so the screen shows a double-slit interference pattern.

(c) The fringe closest to the mirror surface is bright. The path distance will be about the same for both paths, and the light does not have a phase change when reflecting from the mirror. The waves should be in phase with each other and will interfere constructively.

123. Given: $\lambda = 583 \text{ nm} = 5.83 \times 10^{-7} \text{ m}$; there are 32 cycles of alternating light patterns in L

Required: t

Analysis: $\Delta x = \frac{L}{32}$

$$L = 32\Delta x$$

$$\Delta x = \frac{L\lambda}{2t}$$

$$2t = \frac{32\cancel{\Delta x}\lambda}{\cancel{\Delta x}}$$

$$t = 16\lambda$$

Solution: $t = 16\lambda$

$$= 16(5.83 \times 10^{-7} \text{ m})$$

$$t = 9.3 \times 10^{-6} \text{ m}$$

Statement: The thickness varies from 0 m to 9.3 × 10^{-6} m.

124. Given: $\lambda = 685 \text{ nm} = 6.85 \times 10^{-7}$ m; d = 6.5 mm = 6.5×10^{-3} m

Required: θ

Analysis: $\sin\theta_1 = \dfrac{1.22\lambda}{d}$

Solution: $\sin\theta_1 = \dfrac{1.22\lambda}{d}$

$$= \frac{1.22(6.85 \times 10^{-7} \cancel{\text{m}})}{6.5 \times 10^{-3} \cancel{\text{m}}}$$

$$\theta_1 = 0.0074°$$

Statement: The angle between the central and first dark fringes is 0.0074°.

125. (a) Telescope B has a smaller aperture than telescope A, so telescope B should experience more diffraction.

(b) Magnification for telescope A is 200 times (2 × 100 = 200). Magnification for telescope B is 100 times (2 × 50 = 100).

(c) The rule suggests that the maximum magnification for the telescope in the advertisement is 150 times (2 × 75 = 150). I do not believe the advertisement; the magnification appears to be greatly exaggerated.

126. Given: θ_1 = 30°; f = 12 kHz = 1.2×10^4 Hz; v = 1.40 × 10^3 m/s

Required: w

Analysis: Rearrange the universal wave equation, $v = \lambda f$; to calculate wavelength, $\lambda = \dfrac{v}{f}$. Then rearrange the equation $\sin\theta_m = \dfrac{\left(m + \frac{1}{2}\right)\lambda}{w}$ to calculate the width of the vibrating surface of the transmitter, $w = \dfrac{\left(m + \frac{1}{2}\right)\lambda}{\sin\theta_m}$. Use m = 1.

Solution:

$$\lambda = \frac{v}{f} \qquad w = \frac{\left(m + \frac{1}{2}\right)\lambda}{\sin\theta_m}$$

$$= \frac{1.40 \times 10^3 \text{ m/}\cancel{\text{s}}}{1.2 \times 10^4 \text{ }\cancel{\text{Hz}}} \qquad = \frac{\left(1 + \frac{1}{2}\right)(1.17 \times 10^{-1} \text{ m})}{\sin 30°}$$

$$\lambda = 1.17 \times 10^{-1} \text{ m} \qquad w = 0.35 \text{ m}$$

Statement: The width of the vibrating surface of the transmitter is 0.35 m.

127. Sample answer: When we want to "see" objects using different wavelengths of electromagnetic radiation, we want the best resolution possible. The best resolution is achieved by reducing diffraction. For a fixed aperture, a smaller wavelength means less diffraction. X-rays have much smaller wavelengths than radio waves, so X-rays would allow for better resolution.

128. Given: λ = 400 nm to 750 nm = 4.0×10^{-7} m to 7.5×10^{-7} m

Required: N

Analysis: $m\lambda = w\sin\theta_m$; $N = \frac{1}{\lambda}$. For exactly two spectral orders to be visible, use $\theta_2 = 90°$ and m = 2.

Solution: $m\lambda = w\sin\theta_m$

$$2\lambda = w\sin 90°$$

$$2\lambda = w(1)$$

$$w = 2\lambda$$

$$N = \frac{1}{w}$$

$$N = \frac{1}{2\lambda}$$

Longer wavelengths have maxima farther from the centre. Use $\lambda = 7.5 \times 10^{-7}$ m:

$$N = \frac{1}{2(7.50 \times 10^{-7} \text{ m})}$$

$$= 6.67 \times 10^5 \text{ lines/m}$$

$$= 6.67 \times 10^3 \text{ lines/cm}$$

$$N = 6700 \text{ lines/cm}$$

Statement: The maximum number of lines for this grating is 6700 lines/cm.

129. Given: $n_{\text{soap film}} = 1.33$; $N = 520$ lines/mm; $\theta = 17°$; $n = 1$; $m = 1$

Required: t

Analysis: Calculate the slit width using the equation $w = \frac{1}{N}$. Then rearrange the equation $m\lambda = w\sin\theta_m$ to determine the wavelength; $\lambda = \frac{w\sin\theta_m}{m}$. The white light changes phase at the air–soap boundary but not at the soap–air boundary. A dark band is created, so use the destructive interference formula, $2t = \frac{n\lambda}{n_{\text{soap film}}}$; $t = \frac{n\lambda}{2n_{\text{soap film}}}$.

Solution:

$$w = \frac{1}{N}$$
$$= \frac{1}{520\ \text{mm}^{-1}}$$
$$w = 1.818 \times 10^{-3}\ \text{mm (two extra digits carried)}$$

$$\lambda = \frac{w\sin\theta_m}{m}$$
$$= \frac{(1.818 \times 10^{-3}\ \text{mm})\sin 17°}{1}$$
$$= 5.62 \times 10^{-4}\ \text{mm}$$
$$\lambda = 5.62 \times 10^{-7}\ \text{m (one extra digit carried)}$$

$$t = \frac{(1)\lambda}{2n_{\text{soap film}}}$$
$$= \frac{5.62 \times 10^{-7}\ \text{m}}{(2)(1.33)}$$
$$t = 2.1 \times 10^{-7}\ \text{m}$$

Statement: The minimum possible thickness of the soap film is 2.1×10^{-7} m.

130. Lightning produces strong changing electric and magnetic fields, which propagate together as electromagnetic waves at different frequencies. The waves at radio frequencies can therefore be picked up by a receiver, and are heard as pops or whistles.

131. Answers may vary. Sample answer: Holograms were originally difficult to duplicate, but hologram printers have come down in price, so it is possible to counterfeit holograms more easily now. NOtES is a new technology that creates structures that are easy to recognize visually but difficult to reproduce because they involve the creation of perforations on a nanoscale. I think the NOtES technology is more effective because the equipment necessary is too involved and too expensive for a counterfeiter to invest in.

Students' responses should also include an example of the student's preferred technology being used in an application not mentioned in the text, for example, a shimmering pendant or other piece of jewellery.

132. Answers may vary. Sample answer: Some pros of GPS technology are that GPS units are easy to use, they can be used for navigation anywhere in the world, and they use the most efficient route when navigating. A con of GPS technology is that GPS units in cars can be a distraction, which can lead to car accidents. GPS units can also sometimes provide incorrect information.

Reflect on Your Learning

133. Answers may vary. Sample answer: Learning about the interference and diffraction of water waves gave me a way to visualize light waves and understand how light waves work because they are very similar to water waves, except in wavelength.

134. Answers may vary. Sample answer: I would like to learn more about the history of fibre optics in telecommunications. I want to know how this idea was created and how it has improved over the years. I would also like to learn about future applications of fibre optics in telecommunications, and how future technology can benefit society. Perhaps my interest in fibre optics technology will lead to a career in that field.

135. Answers may vary. Sample answer: The information that I learned in this unit gave me a basic understanding about diffraction gratings.

136. Answers may vary. Sample answer: I would like to know why astronomical observatories use different regions of the electromagnetic spectrum, the different properties of the different regions, and what types of information astronomers learn from each region of the electromagnetic spectrum.

137. Answers may vary. Sample answer: Based on what I know about GPS technology, it does change the way I think about privacy: with all the devices that use this technology, it means we can potentially be tracked and located by anyone.

138. Answers may vary. Sample answer: The unit on light in grade 10 was mainly about optical images and the geometry of light. The grade 12 unit goes into much more mathematical detail about light, especially in the area of light interference, and is more about the physics of light.

Research

139. Answers may vary. This report should describe fibre optic cables as strands of optically pure glass, as thin as a human hair, that carry digital information over long distances. The students may discuss advantages compared to wire cables, such as being less expensive, having higher carrying capacity and less signal degradation, being nonflammable, lightweight, and flexible, and being able to carry light signals as well as digital signals. Some disadvantages include price and fragility; they can be affected by chemicals; they can become opaque when exposed to radiation, and they require special technology to connect pieces together.

140. Answers may vary. Sample answers could include points such as the following: Diffraction gratings were first produced over 200 years ago. Early manufacturing of diffraction gratings used mechanical ruling engines. Later methods used photolithographic techniques. A more current method uses a photosensitive gel sandwiched between two substrates. A holographic interference pattern exposes the gel, which is later developed. Some applications use crystals as gratings for short wavelength rays, such as X-rays. Students' reports should also describe the size of gratings possible, which may have as few as 4000 lines/mm. The smallest gratings currently made are CDs.

141. Answers may vary. Students' reports should describe how rainbows are created using the principles of refraction studied in this unit. They should also explain the polarization of the light of a rainbow caused by reflection inside raindrops, the angle of which is close to Brewster's angle. A secondary rainbow can be explained as double reflections inside the raindrops at angles slightly different than those for the primary rainbow. Students' reports could also include benefit by including images of rainbows.
142. Answers may vary. Students' reports should highlight some of the methods used in astronomy to overcome the distortion effects of diffraction and should include the following information: The point spread function is a mathematical means of describing the ideal or minimal distortion pattern for a telescope. Distortions can be corrected by computer software, calibration using lasers, or by situating the telescope in an ideal Earth location that has minimal light interference. The reports should also describe some of the techniques used for image processing in astronomy. Visuals could also be included.
143. (a) Answers may vary. Sample answer: Many types of lasers are used in surgeries, including a variety of dermatological applications, removal of varicose veins, corrective eye surgery, removal of cancerous tissue, and treatment of prostate conditions. Examples of the different lasers used are carbon dioxide, erbium (yttrium aluminum garnet), green light, red light, and pulsed dye lasers. Students should give examples of which lasers are used in specific applications.
(b) Answers may vary. Sample answer: There are many advantages of laser surgery over traditional invasive scalpel surgery: cutting precision, improved therapeutic results, reduced risk of infection, "bloodless" surgery with most lasers, less scarring, limited injury to normal tissue, quick recovery, and short or no hospital stay.
(c) Answers may vary. Sample answer: Disadvantages of laser surgery: the possibility of burns; some medications (including tanning lotions) are a problem because they make the skin more susceptible to burning and scarring, thus interfering with laser procedures; considerable skill by the surgeon is needed because small errors in placement can damage healthy tissue. Other disadvantages of laser surgery are that the equipment needed is costly, multiple lasers could be required for treatment, any type of local infection could complicate laser treatment, and the possibility of scarring or altered skin texture.
144. (a) Answers may vary. Sample answer: X-rays are produced during a process of radioactive decay when high-energy electrons strike a target made of a heavy metal. As electrons collide with this material, their paths are deflected by the nucleus of the metal atoms. This deflection results in the production of X-rays as the electrons lose energy.
(b) Answers may vary. Sample answer: X-ray machines consist of a long tube with an electron emitter, which is usually a tungsten filament at one end and a metal electrode at the other. The tungsten filament emits electrons when it is heated to 1000 °C. The electrons are accelerated along the tube and strike the metal, creating X-rays.
(c) Answers may vary. Sample answer: One risk of using X-rays to treat tumours is that X-rays can damage non-tumour tissue. When the damaged tissue repairs itself, it may not be able to repair property. There could also be damage to major organs such as the heart. In some cases, there is postoperative bleeding or infection.

(d) Answers may vary. Sample answer: Researchers at the University of North Carolina (UNC) have developed carbon nanotubes to replace conventional X-ray producing machines, which require high temperatures to operate. Instead of a single tungsten emitter, the UNC team uses an array of vertical carbon nanotubes that serve as hundreds of tiny electron guns. The advantage of this new technology is that X-rays are produced almost instantly when a voltage is applied, avoiding the warm-up time of traditional machines. This new multibeam X-ray source makes taking clear, high-resolution X-ray images of tumours and body organs much easier. This new machine can turn multiple nanotube emitters on and off in sequence. Therefore, it is able to take rapid pictures from different angles without moving the machine. With computer help, this can lead to three-dimensional images of a tumour with limited distortion or damage to surrounding tissue.