Section 10.1: Interference in Thin Films

Tutorial 1 Practice, page 507

1. The second soap film is thicker. The longer wavelength of the second film means the film at that point must be thicker for constructive interference to occur.

2. Given: $n_{\text{soap film}} = 1.33$; $\lambda = 745 \text{ nm} = 7.45 \times 10^{-7} \text{ m}$

Required: t

Analysis: Phase changes occur at both reflections, so use the formula for destructive interference; use $m = 0$;

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

Solution:

$$t = \frac{\left(m + \frac{1}{2}\right)\lambda}{2n_{\text{soap film}}}$$

$$= \frac{\left(0 + \frac{1}{2}\right)7.45 \times 10^{-7} \text{ m}}{2(1.33)}$$

$$t = 1.40 \times 10^{-7} \text{ m}$$

Statement: The smallest thickness of soap film capable of producing reflective destructive interference with a wavelength of 745 nm in air is 1.40×10^{-7} m.

3. Given: $n_{\text{oil}} = 1.50$; $\lambda = 510 \text{ nm} = 5.10 \times 10^{-7} \text{ m}$

Required: t

Analysis: The yellow light undergoes a phase change at the air–oil reflection interface, but not at the oil–water interface. Since we do not want to see the yellow light, use the formula for destructive interference; use $n = 1$; $2t = \frac{n\lambda}{n_{\text{oil}}}$; $t = \frac{n\lambda}{2n_{\text{oil}}}$

Solution:

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

$$= \frac{(1)5.10 \times 10^{-7} \text{ m}}{2(1.50)}$$

$$t = 1.70 \times 10^{-7} \text{ m}$$

Statement: The oil slick needs to be 1.70×10^{-7} m thick for the yellow light be invisible.

4. Given: $n_{\text{coating}} = 1.38$; $\lambda = 610 \text{ nm} = 6.1 \times 10^{-7} \text{ m}$

Required: t

Analysis: The red light undergoes a phase change at both the air–coating reflection interface and the coating–lens interface. Since we do not want to see the red light, use the formula for destructive interference; use m = 0;

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

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

$$= \frac{(0.5)6.1 \times 10^{-7} \text{ m}}{2(1.38)}$$

$$t = 1.1 \times 10^{-7} \text{ m}$$

Statement: The thickness of the magnesium fluoride anti-reflection coating needs to be 1.1×10^{-7} m.

Mini Investigation: Observing a Thin Film on Water, page 507

A. Sample answer: The dark areas represent areas where destructive interference occurs.

B. Sample answer: The patterns were caused by different thicknesses of the film and the different wavelengths of light.

C. Sample answer: The pattern changed when the colour of the light changed because the thicknesses of oil cause destructive interference for some colours.

Tutorial 2 Practice, page 510

1. Given: t = 0.012 cm = 1.2×10^{-4} m; L = 10.8 cm = 1.08×10^{-1} m; 2.4 mm = 7 cycles of alternating patterns; 2.4 mm = 2.4×10^{-3} m

Required: λ

Analysis: Calculate Δx, the separation between the fringes. Then rearrange the equation $\Delta x = \dfrac{L\lambda}{2t}$ to solve for wavelength; $\lambda = \dfrac{2t\Delta x}{L}$.

Solution: Calculate Δx:

$$\Delta x = \frac{2.4 \times 10^{-3} \text{ m}}{7}$$

$\Delta x = 3.43 \times 10^{-4} \text{ m}$ (one extra digit carried)

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

$$= \frac{2\left(1.2\times10^{-4}\ \text{m}\right)\left(3.43\times10^{-4}\ \cancel{\text{m}}\right)}{1.08\times10^{-1}\ \cancel{\text{m}}}$$

$$\lambda = 7.6\times10^{-7}\ \text{m}$$

Statement: The wavelength of the light is 7.6×10^{-7} m.

2. Given: L = 6.0 cm = 6.0×10^{-2} m; λ = 730 nm = 7.30×10^{-7} m; there are 62 cycles of alternating light patterns in L

Required: t

Analysis: Δx, the separation between the fringes, is given by $\frac{L}{62}$; $\Delta x = \frac{6.0\ \times10^{-2}\ \text{m}}{62}$.

Rearrange the equation $\Delta x = \frac{L\lambda}{2t}$ to solve for thickness; $t = \frac{L\lambda}{2\Delta x}$.

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

$$= \frac{\left(6.0\times10^{-2}\ \text{m}\right)\left(7.3\times10^{-7}\ \cancel{\text{m}}\right)}{2\left(\frac{6.0\times10^{-2}\ \cancel{\text{m}}}{62}\right)}$$

$$t = 2.3\times10^{-7}\ \text{m}$$

Statement: The thickness of the paper is 2.3×10^{-5} m.

Research This: Thin Films and Cellphones, page 510

A. Answers may vary. Sample answer: Cellphones have several layers of thin films. The infrared light incident on the screen enters the top layer, and the other layers turn this energy into visible light. The multiple layers amplify the light energy so that it is visible.

B. Answers may vary. Sample answer: As of late 2010, applying night vision technology to glasses and cellphones is still in the research phase. Given adequate financing, this technology could be implemented in cellphones within a year or two.

C. Answers may vary. Sample answer: For this technology to become usable, more research needs for the thin film technology to be practical to be added to glasses or cellphone screens. There may be a cost barrier as well, which is typical of new inventions. However, this barrier would be overcome as the application became more widespread.

D. Answers may vary. Presentations or summaries should include more information based on the research and could include images, schematics, and equations.

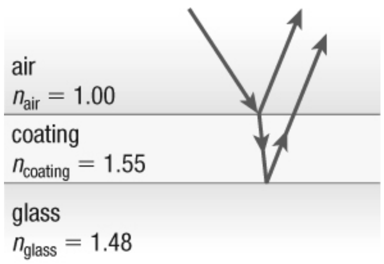
Section 10.1 Questions, page 511

1. Given: $n_{\text{coating}} = 1.55$; $n_{\text{lens}} = 1.48$; $t = 177.4\text{ nm} = 1.774 \times 10^{-7}\text{ m}$

Required: λ

Analysis: Phase changes occur at the air–coating interface but not at the coating–lens interface. For minimal reflection, use the formula for destructive interference, $2t = \dfrac{n\lambda}{n_{\text{coating}}}$, to solve for wavelength; $\lambda = \dfrac{2t(n_{\text{coating}})}{n}$ use $n = 1$.

Solution:



$$\begin{aligned}\lambda &= \frac{2t(n_{\text{coating}})}{n} \\ &= \frac{2(1.774 \times 10^{-7}\text{ m})(1.55)}{1} \\ &= 5.50 \times 10^{-7}\text{ m}\end{aligned}$$

$$\lambda = 550\text{ nm}$$

Statement: The wavelength of the light that is minimally reflected is 550 nm.

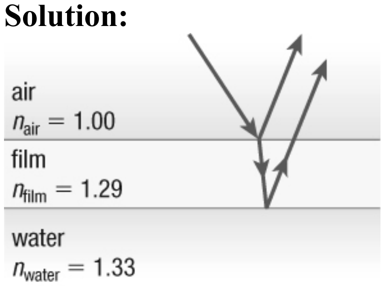
2. Given: $n_{\text{film}} = 1.29$; $\lambda = 7.00 \times 10^{-7}\text{ m}$; $n = 1$

Required: t

Analysis: Phase changes occur at the air–film interface and at the film–water interface. For maximum reflection, use the formula for constructive interference; $2t = \dfrac{n\lambda}{n_{\text{film}}}$;

$t = \dfrac{n\lambda}{2n_{\text{film}}}$.

Solution:



$$t = \frac{n\lambda}{2n_{\text{film}}}$$
$$= \frac{(1)7.00\times10^{-7}\ \text{m}}{2(1.29)}$$
$$t = 2.71\times10^{-7}\ \text{m}$$
Statement: The thickness of the film is 2.71×10^{-7} m.

3. Given: $n_{\text{film}} = 1.35$; $n_{\text{glass}} = 1.50$; $\lambda_{\text{red}} = 6.00\times10^{-7}\ \text{m}$

Required: t

Analysis: Phase changes occur at the air–film interface and at the film–glass interface. For maximum reflection, use the formula for constructive interference, $2t = \frac{n\lambda}{n_{\text{film}}}$; $t = \frac{n\lambda}{2n_{\text{film}}}$. Use $n = 1$.

Solution:
$$t = \frac{n\lambda}{2n_{\text{film}}}$$
$$= \frac{(1)6.00\times10^{-7}\ \text{m}}{2(1.35)}$$
$$t = 2.22\times10^{-7}\ \text{m}$$
Statement: The thickness of the soapy water film is 2.22×10^{-7} m.

4. Given: $n_{\text{film}} = 1.35$; $n_{\text{glass}} = 1.10$; $\lambda = 6.00\times10^{-7}\ \text{m}$

Required: t

Analysis: Phase changes occur at the air–film interface but not at the film–glass interface. For maximum reflection, use the formula for constructive interference, $2t = \frac{\left(m+\frac{1}{2}\right)\lambda}{n_{\text{film}}}$; $t = \frac{\left(m+\frac{1}{2}\right)\lambda}{2n_{\text{film}}}$. Use $m = 0$.

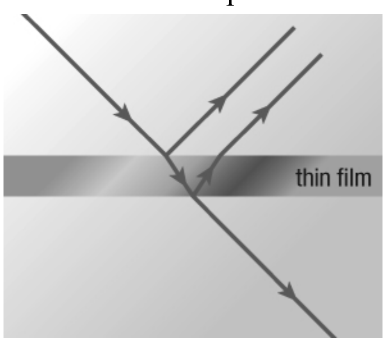
Solution: $t = \dfrac{\left(m + \frac{1}{2}\right)\lambda}{2n_{\text{film}}}$

$$t = \frac{\left(0 + \frac{1}{2}\right)\lambda}{2n_{\text{film}}}$$
$$= \frac{(0.5)(6.00 \times 10^{-7}\ \text{m})}{2(1.35)}$$
$$t = 1.11 \times 10^{-7}\ \text{m}$$

Statement: When the index of refraction of the glass plate changes to 1.10, the thickness of the soapy water film becomes 1.11×10^{-7} m.

5. The interference between reflections on the top and bottom of the soap film produces the colours. No, the bubble is not of uniform thickness. It is thinnest in the blue bands because this is the condition for which there is constructive interference with the smallest thickness of film. The film is thickest in the red areas.

6. An incident ray of light reflects from both the top surface of a soap film and the bottom surface of the soap film. More light is reflected than passes through the film. This gives the appearance of brightness on the top of the soap film and less bright, or darker, on the bottom of the soap film.



7. Given: $n_{\text{glass}} = 1.55$; $n_{\text{water}} = 1.33$; $\lambda_1 = 5.60 \times 10^{-7}\ \text{m}$; $\lambda_2 = 4.00 \times 10^{-7}\ \text{m}$

Required: t

Analysis: Phase changes occur at the air–film interface but not at the film–glass interface. For maximum reflection, use the equation for constructive interference; $2t = \dfrac{\left(m + \frac{1}{2}\right)\lambda}{n_{\text{film}}}$; $t = \dfrac{\left(m + \frac{1}{2}\right)\lambda}{2n_{\text{film}}}$. Use $m = 0, 1, 2, 3, 4, ...$ for each wavelength to see which value produces a thickness that results in both lights being reflected.

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

For λ_1, there are a number of thicknesses that will reflect the light.

For $m = 0$:

$$t = \frac{\left(m + \frac{1}{2}\right)\left(5.60 \times 10^{-7}\ \text{m}\right)}{2(1.55)}$$

$$t = 0.903 \times 10^{-7}\ \text{m}$$

For $m = 1$:

$$t = \frac{\left(m + \frac{1}{2}\right)\left(5.60 \times 10^{-7}\ \text{m}\right)}{2(1.55)}$$

$$t = 2.710 \times 10^{-7}\ \text{m}$$

For $m = 2$:

$$t = \frac{\left(m + \frac{1}{2}\right)\left(5.60 \times 10^{-7}\ \text{m}\right)}{2(1.55)}$$

$$t = 4.516 \times 10^{-7}\ \text{m}$$

For $m = 3$:

$$t = \frac{\left(m + \frac{1}{2}\right)\left(5.60 \times 10^{-7}\ \text{m}\right)}{2(1.55)}$$

$$t = 6.323 \times 10^{-7}\ \text{m}$$

For λ_2, there are also a number of thicknesses that will reflect the light.

For $m = 0$:

$$t = \frac{\left(m + \frac{1}{2}\right)\left(4.00 \times 10^{-7}\ \text{m}\right)}{2(1.55)}$$

$$t = 0.645 \times 10^{-7}\ \text{m}$$

For $m = 1$:

$$t = \frac{\left(m + \frac{1}{2}\right)\left(4.00 \times 10^{-7}\ \text{m}\right)}{2(1.55)}$$

$$t = 1.935 \times 10^{-7}\ \text{m}$$

For $m = 2$:

$$t = \frac{\left(m + \frac{1}{2}\right)\left(4.00 \times 10^{-7}\ \text{m}\right)}{2(1.55)}$$

$$t = 3.226 \times 10^{-7}\ \text{m}$$

For $m = 3$:

$$t = \frac{\left(m + \frac{1}{2}\right)\left(4.00 \times 10^{-7}\ \text{m}\right)}{2(1.55)}$$

$$t = 4.516 \times 10^{-7}\ \text{m}$$

The smallest common thickness is $4.516 \times 10^{-7}\ \text{m}$.

Statement: The smallest thickness of glass that will reflect both colours is 4.52×10^{-7} m.

Section 10.2: Single-Slit Diffraction

Tutorial 1 Practice, page 516

1. When light travels from air to a medium that is denser than air, such as water, the light is refracted and the wavelength of the light shortens. According to the equation $\lambda = \frac{w\Delta y}{L}$, λ is proportional to Δy, so when λ is reduced, the central maximum will also be reduced. So the central maximum would be narrower if the equipment were submerged in water.

2. Given: $\lambda = 7.328 \times 10^{-7}$ m; $w = 43$ µm $= 4.3 \times 10^{-5}$ m; $L = 3.0$ m

Required: Δy

Analysis: Rearrange the equation $\lambda = \frac{w\Delta y}{L}$ to solve for the distance between adjacent minima;

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

Solution:

$$\begin{aligned}\Delta y &= \frac{L\lambda}{w}\\ &= \frac{(3.0\text{ m})(7.328 \times 10^{-7} \times 10^{-7}\ \cancel{\text{m}})}{4.3 \times 10^{-5}\ \cancel{\text{m}}}\\ &= 5.1 \times 10^{-2}\text{ m}\\ \Delta y &= 5.1\text{ cm}\end{aligned}$$

Statement: The separation of adjacent minima is 5.1 cm.

3. Given: $w = 3.00 \times 10^{-6}$m; $\theta_1 = 25.0°$

Required: λ

Analysis: The angle between the first dark fringes is equal to the angle for the width of the central maximum, which is twice the angle for the first dark fringe, given by $w\sin\theta_n = \lambda$. In this case, $n = 1$ and $2\theta = 25.0°$; $\lambda = w\sin\theta_n$.

Solution:

$$\begin{aligned}2\theta &= 25.0°\\ \theta &= 12.5°\\ \lambda &= w\sin\theta_n\\ &= (3.0 \times 10^{-6}\text{m})\sin 12.5°\\ \lambda &= 6.49 \times 10^{-7}\text{m}\end{aligned}$$

Statement: The wavelength of the light is 6.49×10^{-7} m.

4. Given: $\theta_a = 56°$; $\theta_b = 34°$

Required: $\frac{w_a}{w_b}$

Analysis: The formula that relates the angles, the common wavelength, and the slit sizes is $w\sin\theta_n = \lambda$; $w_a \sin\theta_a = \lambda$ and $w_b \sin\theta_b = \lambda$. Divide the equations to determine the ratio $\frac{w_a}{w_b}$.

Solution: $\dfrac{w_a \sin\theta_a}{w_b \sin\theta_b} = \dfrac{\not\lambda}{\not\lambda}$

$$\frac{w_a}{w_b} = \frac{\sin\theta_b}{\sin\theta_a}$$

$$= \frac{\sin 34°}{\sin 56°}$$

$$\frac{w_a}{w_b} = 0.67$$

Statement: The ratio of the slit widths, $\dfrac{w_a}{w_b}$, is 0.67.

Section 10.2 Questions, page 519

1. Given: single-slit diffraction; λ = 794 nm = 7.94×10^{-7} m; L = 1.0 m
n = 9, y_9 = 6.48 cm = 0.0648 m

Required: w

Analysis: $\Delta y = \dfrac{y_9}{n}$; $\Delta y = \dfrac{\lambda L}{w}$

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

Solution: $\Delta y = \dfrac{y_9}{n}$

$$= \frac{0.0648 \text{ m}}{9}$$

$$\Delta y = 7.2 \times 10^{-3} \text{m}$$

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

$$= \frac{(7.94 \times 10^{-7} \not{\text{m}})(1.0 \text{ m})}{7.2 \times 10^{-3} \not{\text{m}}}$$

$$w = 1.1 \times 10^{-3} \text{ m}$$

Statement: The width of the slit is 1.1×10^{-4} m.

2. Given: single-slit diffraction; λ = 600 nm = 6.00×10^{-7} m; θ_1 = 6.9°

Required: w

Analysis: The first dark fringe is located where $w\sin\theta_n = \lambda$. Rearrange the equation $w\sin\theta_n = \lambda$ to solve for slit width; $w = \dfrac{\lambda}{\sin\theta_n}$.

Solution: $w = \dfrac{\lambda}{\sin\theta_1}$

$= \dfrac{6.00\times10^{-7}\text{ m}}{\sin 6.9°}$

$w = 5.0\times10^{-6}\text{ m}$

Statement: The width of the slit is 5.0×10^{-6} m.

3. Given: single-slit diffraction; λ = 450 nm = 4.50×10^{-7} m; L = 10.0 m;
w = 0.15 mm = 1.5×10^{-4} m

Required: y, the distance between the first and third dark fringes

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

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

$= \dfrac{(4.50\times10^{-7}\text{ m})(10.0\not{\text{m}})}{1.50\times10^{-4}\not{\text{m}}}$

$= 3.0\times10^{-2}\text{ m}$

$y = 2\Delta y$

$= 6.0\times10^{-2}\text{ m}$

y = 6.0 cm

Statement: The distance between the first and third dark fringes is 6.0 cm.

4. Given: single-slit diffraction; λ = 550 nm = 5.50×10^{-7} m; L = 2.0 m;
y_1 = 5.5 mm = 5.5×10^{-3} m

Required: w

Analysis: Rearrange the equation $y_1 = \dfrac{\lambda L}{w}$ to solve for slit width; $w = \dfrac{\lambda L}{y_1}$

Solution: $w = \dfrac{\lambda L}{y_1}$

$= \dfrac{(5.50\times10^{-7}\text{ m})(2.0\not{\text{m}})}{5.50\times10^{-3}\not{\text{m}}}$

$= 2.0\times10^{-4}\text{ m}$

w = 0.20 mm

Statement: The width of the slit is 0.20 mm.

5. Given: single-slit diffraction; λ = 630 nm = 6.30×10^{-7} m; L = 3.0 m;
w = 0.25 mm = 2.5×10^{-4} m

Required: $2\Delta y$, the width of the central maximum

Analysis: Multiply the equation $\Delta y = \dfrac{\lambda L}{w}$ by 2 to obtain $2\Delta y$.

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

$$= \frac{2\left(6.30\times10^{-7}\text{ m}\right)\left(3.0\ \cancel{\text{m}}\right)}{2.50\times10^{-4}\ \cancel{\text{m}}}$$

$$= 1.5\times10^{-2}\text{ m}$$

$2\Delta y$= 1.5 cm

Statement: The width of the central maximum is 1.5 cm.

6. Given: $\Delta y = 0.120\text{ cm} = 1.20\times10^{-3}\text{ m}$; $w = 0.0295\text{ cm} = 2.95\times10^{-4}\text{ m}$; $L = 60.0\text{ cm} = 0.60\text{ m}$

Required: λ

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

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

$$= \frac{(2.95\times10^{-4}\text{ m})(1.20\times10^{-3}\ \cancel{\text{m}})}{6.0\times10^{-1}\ \cancel{\text{m}}}$$

$\lambda = 5.90\times10^{-7}\text{ m}$

Statement: The wavelength of the yellow light is $5.90\times10^{-7}\text{ m}$.

7. (a) The distance between successive maxima in single-slit diffraction is given by $\Delta y = \dfrac{\lambda L}{w}$. If I double the wavelength, λ, then the distance Δy will also double. The angles of the maxima and the minima would be approximately doubled.

(b) If I multiplied both the wavelength, λ, and the slit width, *w*, in the equation $\Delta y = \dfrac{\lambda L}{w}$ by 2, the 2s will cancel each other out. Therefore, there will be no effect on Δy. The interference pattern will be the same.

8. Blue light has an average wavelength of 475 nm, and green light has an average wavelength of 510 nm. If I replaced the blue light with the green light, then I would be increasing the wavelength. Therefore, spacing of the intensity maxima would be greater.

9. Given: single-slit diffraction

Required: θ_{10}

Analysis: Assume the width of a typical doorway is *w* = 0.92 m. Assume the visible light has a wavelength of 500 nm. Rearrange the equation $\sin\theta_n = \dfrac{n\lambda}{w}$ to solve for the angle;

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

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

$$= \sin^{-1}\left(\frac{(10)\left(5.00\times10^{-7}\ \cancel{\text{m}}\right)}{0.92\ \cancel{\text{m}}}\right)$$

$$= \sin^{-1}\left(5.43\times10^{-6}\right)$$

$$\theta_{10} = 3.1\times10^{-4\circ}$$

Statement: The angle of the tenth minimum for a doorway that is 0.92 m wide is $3.1 \times 10^{-4\circ}$.

10. To improve the resolution of a digital image, I could use more pixels per square centimetre. Or, I could use a wider aperture (size of slit) to increase the resolution. However, the wider aperture would reduce the depth of field (range of the focus).

11. I would be able to resolve the double stars in Mizar with the telescope because, in addition to enlarging the image, the telescope's aperture is wider than the aperture in my eye. The wider aperture increases the resolution, allowing me to see the two stars.

12. In a double-slit interference pattern, there are more intensity maxima than in a single-slit interference pattern. In the double-slit interference pattern, there is less space between fringes because the second slit causes additional destructive interference.

Section 10.3: The Diffraction Grating
Tutorial 1 Practice, page 523

1. Slit separation and number of lines are related by the equation $w = \frac{1}{N}$. As N increases, w decreases. The diffraction grating with 10 000 lines/cm has more lines per centimetre than the second diffraction grating, so the separation between adjacent principal maxima in the first grating would have to be smaller.

2. Given: λ = 660 nm $= 6.60 \times 10^{-7}$ m; N = 8500 lines/cm; m = 1

Required: θ, the angular separation between successive maxima

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

Solution:

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

$$= \frac{1}{8500 \text{ lines/}\cancel{\text{cm}}} \times \frac{1 \text{ m}}{100 \ \cancel{\text{cm}}}$$

$$w = 1.176 \times 10^{-6} \text{ m (two extra digits carried)}$$

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

$$\sin\theta_1 = \frac{(1)(6.60 \times 10^{-7} \ \cancel{\text{m}})}{1.176 \times 10^{-6} \ \cancel{\text{m}}}$$

$$\theta_1 = 34°$$

Statement: The angular separation of successive maxima is $34°$.

3. Given: λ = 694.3 nm $= 6.943 \times 10^{-7}$ m; m = 3; θ_3 = 22.0°

Required: N

Analysis: Use the equation $m\lambda = w \sin\theta_m$ to calculate the slit separation; $w = \frac{m\lambda}{\sin\theta_m}$. Then use the equation $w = \frac{1}{N}$ to determine the number of grating lines; $N = \frac{1}{w}$.

Solution:

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

$$= \frac{(3)(6.943 \times 10^{-7} \text{ m})}{\sin 22.0°}$$

$$w = 5.5602 \times 10^{-6} \text{ m (one extra digit carried)}$$

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

$$= \frac{1}{5.5602 \times 10^{-6}\ \cancel{\text{m}}} \times \frac{1\ \cancel{\text{m}}}{100\ \text{cm}}$$

$$N = 1798\ \text{lines/cm}$$

Statement: The grating has 1798 lines per centimetre.

Research This: Blu-ray Technology, page 524

A. Answers may vary. Sample answer: The technology is called Blu-ray because it uses a blue laser instead of the red laser used in DVDs.
B. Answers may vary. Sample answer: In Blu-ray technology, the data are placed on the top of a disc coated with a polycarbonate layer. There are pits in the disc. Each pit contains a signal that is interpreted as a zero or a one, much like a computer. The laser reads the pits.
C. Answers may vary. Sample answer: Blu-ray technology can hold more data than CDs and DVDs. The quantity of data is at least five times greater than the quantity that a DVD can store, which means that images can be much more detailed on Blu-ray discs. Blu-ray is also able to play much faster than CDs and DVDs.
D. Answers may vary. Sample answer: The improvements are possible through the use of the blue laser, which has a much smaller wavelength than the red laser used with CD and DVD players. Blu-ray technology can also store information on as many as 20 layers within the disc.
E. Answers may vary. Sample answer: The images are sharpest from Blu-ray discs. Answers will vary based on presentation format, but students should show at least three images to demonstrate the representative features of the three technologies. Hazards associated with using high-power lasers such as the lasers used in Blu-ray technology should be included. For example, if the laser is pointed at a person's eyes, that person's eyesight could be damaged.

Section 10.3 Questions, page 525

1. The surface of a CD has many closely spaced parallel lines, like a diffraction grating. Consequently, when white light reflects from the surface of a CD, we see a rainbow-like pattern because the surface acts like a diffraction grating.
2. Given: $N = 2800$ lines/cm

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

Solution:

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

$$= \frac{1}{2800\ \text{lines/cm}}$$

$$= 3.6 \times 10^{-4}\ \text{cm}$$

$$w = 3.6 \times 10^{-6}\ \text{m}$$

Statement: The distance between two lines in the diffraction grating is 3.6×10^{-6} m.

3. Given: $N = 10\ 000$ lines/cm; $\theta_1 = 31.2°$; $\theta_2 = 36.4°$; $\theta_3 = 47.5°$

Required: λ_1, λ_2, λ_3

Analysis: Use the equation $w = \frac{1}{N}$ to calculate the slit separation. Then use the equation $m\lambda = w\sin\theta_m$ to determine the wavelength for each value of m; $\lambda = \frac{w\sin\theta_m}{m}$.

Solution:

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

$$\begin{aligned} w &= \frac{1}{10\ 000 \text{ lines/cm}} \\ &= 1.0 \times 10^{-4} \text{ cm} \\ w &= 1.0 \times 10^{-6} \text{ m} \end{aligned}$$

For m = 1:

$$\begin{aligned} \lambda &= \frac{w\sin\theta_m}{m} \\ &= \frac{(1.0 \times 10^{-6} \text{ m})\sin 31.2°}{1} \\ &= 5.18 \times 10^{-7} \text{ m} \\ \lambda &= 518 \text{ nm} \end{aligned}$$

For m = 3:

$$\begin{aligned} \lambda &= \frac{w\sin\theta_m}{m} \\ &= \frac{(1.0 \times 10^{-6} \text{ m})\sin 47.5°}{3} \\ &= 2.46 \times 10^{-7} \text{ m} \\ \lambda &= 246 \text{ nm} \end{aligned}$$

For m = 2:

$$\begin{aligned} \lambda &= \frac{w\sin\theta_m}{m} \\ &= \frac{(1.0 \times 10^{-6} \text{ m})\sin 36.4°}{2} \\ &= 2.97 \times 10^{-7} \text{ m} \\ \lambda &= 297 \text{ nm} \end{aligned}$$

Statement: The wavelengths that produce these maxima are 518 nm, 297 nm, and 246 nm.

4. Given: N = 6000 lines/cm; w = 2.0 cm; λ = 450 nm = 4.50×10^{-7} m; m = 1

Required: θ

Analysis: Divide the number of slits, N, by the length of the slit:
$\frac{6000 \text{ lines/cm}}{2} = 3000 \text{ lines/cm}$. Then use $w = \frac{1}{N}$ to calculate the slit separation, and rearrange the equation $m\lambda = w\sin\theta_m$ to calculate the angle; $\sin\theta_m = \frac{m\lambda}{w}$.

Solution:

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

$$w = \frac{1}{3000 \text{ lines/}\cancel{\text{cm}}} \times \frac{1 \text{ m}}{100 \ \cancel{\text{cm}}}$$

$w = 3.333 \times 10^{-6}$ m (two extra digits carried)

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

$$= \frac{(1)(4.50 \times 10^{-7} \ \cancel{\text{m}})}{3.333 \times 10^{-6} \ \cancel{\text{m}}}$$

$\theta = 7.8°$

Statement: Blue light produces the first intensity maximum at $7.8°$.

5. Given: λ = 600.0 nm = 6.000 × 10^{-7} m; w = 25 µm = 2.5 × 10^{-5} m; m = 1

Required: θ

Analysis: $m\lambda = w\sin\theta_m$; $\sin\theta_m = \frac{m\lambda}{w}$

Solution:

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

$$= \frac{(1)(6.000 \times 10^{-7} \ \cancel{\text{m}})}{2.5 \times 10^{-5} \ \cancel{\text{m}}}$$

$\theta = 1.4°$

Statement: The first-order maximum in intensity is at the angle $1.4°$.

6. Given: λ = 780 nm = 7.80×10^{-7} m; L = 10 m; Δy = 0.50 m; m = 1

Required: w

Analysis: Use the sine ratio to calculate θ_1. Then rearrange the equation $m\lambda = w\sin\theta_m$ to calculate the slit separation; $w = \frac{m\lambda}{\sin\theta_m}$.

Solution:

$$\sin\theta = \frac{0.50 \text{ m}}{10 \text{ m}}$$

$\sin\theta = 0.05$

$$w = \frac{m\lambda}{\sin\theta_1}$$

$$= \frac{(1)(7.80 \times 10^{-7} \text{ m})}{0.05}$$

$w = 1.6 \times 10^{-5}$ m

Statement: The spacing between the lines in the diffraction grating is 1.6×10^{-5} m.

7. Given: N = 300 lines/cm; L = 0.84 m; Δy = 3.6 cm = 0.036 m; m = 3

Required: λ

Analysis: Use $w = \dfrac{1}{N}$ to calculate the slit separation. Use the tan ratio to calculate θ_3. Then rearrange the equation $m\lambda = w\sin\theta_m$ to calculate the wavelength; $\lambda = \dfrac{w\sin\theta_m}{m}$.

Solution:

$$w = \frac{1}{N}$$
$$= \frac{1}{300\ \text{lines/}\cancel{\text{cm}}} \times \frac{1\ \text{m}}{100\ \cancel{\text{cm}}}$$
$$w = 3.333 \times 10^{-5}\ \text{m}\ \text{(two extra digits carried)}$$

$$\tan\theta = \frac{0.036\ \cancel{\text{m}}}{0.84\ \cancel{\text{m}}}$$
$$\theta = 2.454° \quad \text{(two extra digits carried)}$$

$$\lambda = \frac{w\sin\theta_m}{m}$$
$$= \frac{(3.333\times 10^{-5})\sin 2.454°}{3}$$
$$= 4.76\times 10^{-7}\ \text{m}$$
$$\lambda = 480\ \text{nm}$$

Statement: The wavelength of the light is 480 nm.

8. Given: $N = 3000$ lines/cm; $\lambda = 5.4\times 10^{-7}$ m

Required: maximum value of m

Analysis: Use $w = \dfrac{1}{N}$ to calculate the slit separation. Then use the equation $m\lambda = w\sin\theta_m$ to determine the angle in terms of m; $\sin\theta_m = \dfrac{m\lambda}{w}$.

Solution:

$$w = \frac{1}{N}$$
$$= \frac{1}{3000\ \text{lines/}\cancel{\text{cm}}} \times \frac{1\ \text{m}}{100\ \cancel{\text{cm}}}$$
$$w = 3.333 \times 10^{-6}\ \text{m}\ \text{(two extra digits carried)}$$

For a maximum m, $\sin\theta_m < 1.0$:

$$\sin\theta_m = \frac{m\lambda}{w}$$
$$= \frac{(m)(5.4\times10^{-7}\ \text{m})}{3.333\times10^{-6}\ \text{m}}$$
$$\sin\theta_m = 0.1620m$$

We need

$$0.1620m < 1.0$$
$$m < \frac{1.0}{0.1620}$$
$$m < 6.17$$
$$m = 6$$

Statement: The maximum order number possible is the 6th order.

9. (a) Given: w = 0.50 nm = 5.0×10^{-10} m; λ = 0.050 nm = 5.0×10^{-11} m

Required: θ_1, θ_2, θ_3

Analysis: Use the equation $m\lambda = w\sin\theta_m$ to calculate the angles; $\sin\theta_m = \dfrac{m\lambda}{w}$.

Solution:

For m = 1:

$$\sin\theta_m = \frac{m\lambda}{w}$$
$$= \frac{(1)(5.0\times10^{-11}\ \cancel{\text{m}})}{5.0\times10^{-10}\ \cancel{\text{m}}}$$
$$\theta = 5.7°$$

For m = 2:

$$\sin\theta_m = \frac{m\lambda}{w}$$
$$= \frac{(2)(5.0\times10^{-11}\ \cancel{\text{m}})}{5.0\times10^{-10}\ \cancel{\text{m}}}$$
$$\theta = 12°$$

For m = 3:

$$\sin\theta_m = \frac{m\lambda}{w}$$
$$= \frac{(3)(5.0\times10^{-11}\ \cancel{\text{m}})}{5.0\times10^{-10}\ \cancel{\text{m}}}$$
$$\theta = 17°$$

Statement: The angles for the first three maxima are $5.7°$, $12°$, and $17°$.

(b) $w = 5.0\times10^{-10}$ m; λ = 600 nm = 6.0×10^{7} m; m = 1

Required: θ_1

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

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

$$= \frac{(1)(6.0\times10^{-9}\ \cancel{\text{m}})}{5.0\times10^{-10}\ \cancel{\text{m}}}$$

$$= 1.2$$

$$\theta_1 = \text{ no angle possible}$$

Statement: The angle for the first bright fringe does not exist.

(c) The wavelength 600 nm is within the range of visible light, but no fringe angle was possible in part (b). Visible light is not usually diffracted by crystal lattices. It may be possible to get a fringe but only if the wavelength of the light is sufficiently short.

10. Given: $\lambda_A = 5.00\times10^2$ nm $= 5.00\times10^{-7}$ m; $\theta_A = 20.0°$; $\theta_B = 18.0°$; $m = 1$

Required: $n_{\text{atmosphere}}$

Analysis: Use the equation $m\lambda = w\sin\theta_m$ to calculate *w*; $w = \dfrac{m\lambda}{\sin\theta_m}$. Then use the same equation with the value of *w* and the new angle, θ_B, to calculate the wavelength in the planet's atmosphere. Take the ratio of the wavelengths to determine the index of refraction for the planet's atmosphere, $n_{\text{atmosphere}} = \dfrac{\lambda_A}{\lambda_B}$.

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

$$= \frac{(1)(5.0\times10^{-7}\ \text{m})}{\sin 20.0°}$$

$$w = 1.462\times10^{-6}\ \text{m (one extra digit carried)}$$

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

$$= \frac{(1.462\times10^{-6}\ \text{m})\sin 18.0°}{1}$$

$$\lambda_B = 4.518\times10^{-7}\ \text{m (one extra digit carried)}$$

$$n_{\text{atmosphere}} = \frac{\lambda_A}{\lambda_B}$$

$$= \frac{5.00\times10^{-7}\ \cancel{\text{m}}}{4.518\times10^{-7}\ \cancel{\text{m}}}$$

$$n_{\text{atmosphere}} = 1.11$$

Statement: The index of refraction of the planet's atmosphere is 1.11.

Section 10.4: Electromagnetic Radiation

Tutorial 1 Practice, page 530

1. Given: f = 107.1 MHz = 1.071×10^8 Hz; $c = 3.0 \times 10^8$ m/s

Required: λ

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

Solution:
$$\begin{aligned}\lambda &= \frac{c}{f}\\ &= \frac{3.0\times10^8\ \text{m/}\cancel{\text{s}}}{1.071\times10^8\ \cancel{\text{Hz}}}\\ \lambda &= 2.8\ \text{m}\end{aligned}$$

Statement: The wavelength of the signal is 2.8 m.

2. Given: $f = 3.0\times10^{17}$ Hz; $c = 3.0 \times 10^8$ m/s

Required: λ

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

Solution:
$$\begin{aligned}\lambda &= \frac{c}{f}\\ &= \frac{3.0\times10^8\ \text{m/}\cancel{\text{s}}}{3.0\times10^{17}\ \cancel{\text{Hz}}}\\ &= 1.0\ \times10^{-9}\,\text{m}\\ \lambda &= 1.0\ \times10^{-7}\,\text{cm}\end{aligned}$$

Statement: The wavelength of the X-rays is 1.0×10^{-7} cm.

3. Given: λ = 638 nm = 6.38×10^{-7} m; $c = 3.0 \times 10^8$ m/s

Required: T

Analysis: $\lambda f = c$
$$\begin{aligned}f &= \frac{c}{\lambda}\\ T &= \frac{1}{f}\\ T &= \frac{\lambda}{c}\end{aligned}$$

Solution:
$$\begin{aligned}T &= \frac{\lambda}{c}\\ &= \frac{6.38\times10^{-7}\ \cancel{\text{m}}}{3.0\times10^8\ \cancel{\text{m}}\text{/s}}\\ T &= 2.1\times10^{-15}\ \text{s}\end{aligned}$$

Statement: The period of the wave is 2.1×10^{-15} s.

4. Given: $f = 60$ Hz; $x = 5.0 \times 10^3$ km $= 5.0 \times 10^6$ m; $c = 3.0 \times 10^8$ m/s
Required: n, number of wavelengths
Analysis: Calculate the wavelength of the electrical transmission using the universal wave equation, $c = \lambda f$; $\lambda = \dfrac{c}{f}$. Then divide the wavelength by the distance across North America; $n = \dfrac{\lambda}{x}$.

Solution:

$$\lambda = \frac{c}{f} = \frac{3.0 \times 10^8 \text{ m/s}}{60 \text{ Hz}}$$
$$\lambda = 5.0 \times 10^6 \text{ m}$$

$$n = \frac{\lambda}{x} = \frac{5.0 \times 10^6 \text{ m}}{5.0 \times 10^6 \text{ m}}$$
$$n = 1$$

Statement: The number of wavelengths of the electrical transmission required to cross North America is 1.

Section 10.4 Questions, page 531

1. Given: $f = 5.0 \times 10^{14}$ Hz; $c = 3.0 \times 10^8$ m/s
Required: λ
Analysis: $c = \lambda f$; $\lambda = \dfrac{c}{f}$

Solution:

$$\lambda = \frac{c}{f} = \frac{3.0 \times 10^8 \text{ m/}\cancel{\text{s}}}{5.0 \times 10^{14} \cancel{\text{Hz}}} = 6.0 \times 10^{-7} \text{ m}$$
$$\lambda = 6.0 \times 10^2 \text{ nm}$$

Statement: The wavelength of the light in the CD player is 6.0×10^2 nm.

2. Given: $\lambda = 550$ nm $= 5.50 \times 10^{-7}$ m; $c = 3.0 \times 10^8$ m/s
Required: f
Analysis: $\lambda f = c$

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

Solution:

$$f = \frac{c}{\lambda} = \frac{3.0 \times 10^8 \cancel{\text{m}}\text{/s}}{5.50 \times 10^{-7} \cancel{\text{m}}}$$
$$f = 5.5 \times 10^{14} \text{ Hz}$$

Statement: The frequency of the light that is most sensitive to the human eye is 5.5×10^{14} Hz.

3. Given: $f_1 = 88\text{ MHz} = 8.8\times10^7\text{ Hz}$; $f_2 = 108\text{ MHz} = 1.08\times10^8\text{ Hz}$; $c = 3.0\times10^8\text{ m/s}$

Required: λ_1, λ_2

Analysis: $\lambda f = c$

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

Solution:

$$\lambda_1 = \frac{c}{f_1} = \frac{3.0\times10^8\text{ m/s}}{8.8\times10^7\text{ Hz}}$$

$$\lambda_1 = 3.4\text{ m}$$

$$\lambda_2 = \frac{c}{f_2} = \frac{3.0\times10^8\text{ m/s}}{1.08\times10^8\text{ Hz}}$$

$$\lambda_2 = 2.8\text{ m}$$

Statement: The wavelengths of the FM radio stations range from 3.4 m to 2.8 m.

4. Given: $\lambda = 0.10\text{ nm} = 1.0\times10^{-10}\text{ m}$; $c = 3.0\times10^8\text{ m/s}$

Required: f

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

Solution:

$$f = \frac{c}{\lambda} = \frac{3.0\times10^8\text{ m/s}}{1.0\times10^{-10}\text{ m}}$$

$$f = 3.0\times10^{18}\text{ Hz}$$

Statement: The frequency of the X-ray is 3.0×10^{18} Hz.

5. (a) Given: $\lambda = 12.24\text{ cm} = 1.224\times10^{-1}\text{ m}$; $c = 3.0\times10^8\text{ m/s}$

Required: f

Analysis: $\lambda f = c$

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

Solution:

$$f = \frac{c}{\lambda} = \frac{3.0\times10^8\text{ m/s}}{1.224\times10^{-1}\text{ m}}$$

$$f = 2.5\times10^9\text{ Hz}$$

Statement: The frequency of the X-ray wave is 2.5×10^9 Hz.

(b) Most microwave ovens contain rotating carousels to heat the food evenly. By rotating the food, the nodes cannot heat the same spot all the time, so the food cooks more evenly. With a microwave wavelength of 12 cm, the nodes are located within the oven itself.

6. Given: f = 2.4 GHz = 2.4×10^9 Hz; c = 3.0×10^8 m/s
Required: λ
Analysis: $c = \lambda f$

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

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

$$= \frac{3.0 \times 10^8 \text{ m/}\cancel{\text{s}}}{2.4 \times 10^9 \ \cancel{\text{Hz}}}$$

$$= 1.25 \ \times 10^{-1} \text{m}$$

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

Statement: The wavelength of the radio waves in the cordless phone is 12 cm.
7. Given: f = 680 kHz = 6.80×10^5 Hz; c = 3.0×10^8 m/s
Required: λ
Analysis: $\lambda f = c$

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

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

$$= \frac{3.0 \times 10^8 \text{ m/}\cancel{\text{s}}}{6.80 \times 10^5 \ \cancel{\text{Hz}}}$$

$$= 4.4 \ \times 10^2 \text{ m}$$

$$\lambda = 440 \text{ m}$$

Statement: The wavelength of the broadcasting frequency used by 680 News is 440 m.
8. Given: w = 6.0 cm = 6.0×10^{-2} m; f = 7.5 GHz = 7.5×10^9 Hz; c = 3.0×10^8 m/s; m = 1
Required: θ
Analysis: First calculate the wavelength using the universal wave equation, $c = \lambda f$; $\lambda = \frac{c}{f}$. Then use the equation $m\lambda = w \sin\theta_m$ to calculate the angle; $\sin\theta_m = \frac{m\lambda}{w}$.

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

$$= \frac{3.0 \times 10^8 \ \cancel{\text{m}}\text{/s}}{7.5 \times 10^9 \ \cancel{\text{Hz}}}$$

$$\lambda = 4.0 \ \times 10^{-2} \text{ m}$$

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

$$\sin\theta = \frac{(1)(4.0\times10^{-2}\ \text{m})}{6.0\times10^{-2}\ \text{m}}$$

$$\theta = 42°$$

Statement: The angle from the central maximum to the first diffraction minimum is $42°$.

9. Some of the radiation in the electromagnetic spectrum is only detectable in deep space because Earth's atmosphere absorbs the radiation at several different wavelengths, so it does not pass through the atmosphere to the surface. To be able to detect these portions of the electromagnetic spectrum, the detectors have to be in space, above Earth's atmosphere. Some examples of electromagnetic radiation from space that does not reach Earth's surface are some wavelengths of infrared radiation from distant objects, X-rays, and gamma rays.

Additional information: All objects emit infrared radiation. To avoid interfering with very faint astronomical objects emitting infrared radiation, the detectors (telescopes) need to be kept extremely cold. That is only possible in deep space.

10. Television correspondents in a distant part of the world are so far away that their responses are delayed due to the travel time of the signal. There is also the time required to process the signal.

11. (a) Given: $f = 75$ MHz $= 75 \times 10^6$ Hz; $d = 134$ m; $c = 3.0 \times 10^8$ m/s

Required: type of interference

Analysis: Calculate the wavelength of the signal, $c = \lambda f$; $\lambda = \frac{c}{f}$. Divide the distance by wavelength.

Solution:

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

$$= \frac{3.0\times10^8\ \text{m/s}}{75\times10^6\ \text{Hz}}$$

$$\lambda = 4\ \text{m}$$

$$\frac{134\ \text{m}}{4\ \text{m}} = 33\frac{1}{2}\ \text{wavelengths}$$

The interference is constructive interference because the path difference is a half-whole-number multiple of the wavelength, and there is a 180° phase change from the reflection.

Statement: The kind of interference that results is constructive interference.

(b) The signal is now being reflected from 134 m – 42 m = 92 m, which is exactly 23 wavelengths. This is now destructive interference because the path difference is a whole-number multiple of wavelengths, and there is a 180° phase change from the reflection.

12. Answers may vary. The report should explain how an antenna converts electrical currents into electromagnetic radiation and that an antenna can be either a transmitter or a receiver. The size of the antenna will depend on the type of signals being transmitted. For example, the wavelengths of FM signals are 2 m to 4 m. Generally, the length of the antenna should be about half the wavelength of the radio waves you are trying to send or receive.

Section 10.5: Polarization of Light

Mini Investigation: Observing Polarization from Reflection, page 534

A. Sample answer: When the second filter is rotated, the bright light is blocked out completely.
B. Answers may vary. Sample answer: Glare on a surface is reduced when I use a Polaroid filter because the polarizer blocks some of the light travelling through the filter. I see less of the light reflecting from the surface, therefore reducing the glare.
C. Answers may vary. Sample answer: Variations in light seen from changing the location of a Polaroid filter against various regions of the sky occur because polarized light in different parts of the sky reaches me at different angles. Depending on the angle, light rays either pass through the filter or are blocked by the filter.

Research This: Holography, page 536

A. Answers may vary. Sample answer: Holography is the process of making three-dimensional images, called holograms, on a single film. To produce a hologram, a laser beam is split into two halves by a beam splitter. One half of the laser beam reflects off a mirror to the object that will be made into a hologram, and reflects onto a photographic plate. The hologram is created on the photographic plate. The other half of the laser beam, called the reference beam, does not come into contact with the object. The reference beam travels to the photographic plate. On the photographic plate, both beams intersect and interfere with each other, producing the hologram.
B. Sample answer: To make a hologram, the materials required are a laser, a beam splitter, a mirror, a photographic plate, and the object that will be the hologram.
C. Answers may vary. Sample answer: For holography to work, the laser beam must be polarized. The beams are reflected at Brewster's angle, so they are perfectly polarized. Polarization results in a clearer hologram.
D. Answers may vary. Sample answer: Holography is used for security. For example, holograms are used on money and credit cards because holograms are difficult to counterfeit (although it is getting easier to duplicate holograms). Holography is also used in art and interactive graphics. Novel applications of holography are data storage, museum tour guides who are holograms, and holograms as jewellery.
E. Answers may vary. Sample answer: Presentations will include the key points from the student's research, from questions A to D, and could include an actual hologram, if a kit is available. The presentation could also include images from the Internet of a hologram and an illustration of the setup and equipment required.

Section 10.5 Questions, page 537

1. The light waves in polarized light vibrate in a single plane, whereas the light waves in unpolarized light vibrate in several different planes.
2. To test whether a pair of sunglasses has polarizing lenses or simply darkened plastic lenses, I would hold two of the same kind of lenses together and rotate them relative to each other to look for changes in transmission intensity. I could also test the lenses by rotating one of the lenses in front of my eyes to see how reflections from different objects change. With either method, if light intensity changes depending on the angles of incidence and refraction, the lenses are polarized.
3. Selective absorption polarizes light with a polarizing material. This polarizing material transmits only a certain polarization of light and absorbs the other polarizations. Light that leaves

the polarizing material is always linearly polarized along the direction of the axis of the polarizing material.

Polarization by reflection polarizes reflected light by the motion of electric charges within the reflecting material. The charges can vibrate more easily in a direction that leads to them emitting light polarized parallel to the surface.

Scattering polarizes light because the light scatters from air molecules with a polarization that depends on the direction of the scatter. Observers in a particular direction only see light with a certain polarization.

4. (a) If I place a sheet of Polaroid, whose transmission axis is parallel to the transmission axis of the polarizer, between a polarizer and an analyzer, the light will not change. This is because the sheet of Polaroid and the polarizer have parallel axes, so the light leaving the polarizer is unchanged after passing through the Polaroid filter.

(b) If I place a sheet of Polaroid, whose transmission axis is parallel to the transmission axis of the analyzer, between a polarizer and an analyzer, the light will not change. This is because the sheet of Polaroid and the analyzer have parallel axes, so the light leaving the analyzer is unchanged after passing through the Polaroid filter.

(c) If I place a sheet of Polaroid, whose transmission axis is at 45°, between a polarizer and an analyzer, more light will get through because light leaving the intermediate Polaroid is now at 45° polarization with respect to the final polarization axis.

5. The sky often looks very different when viewed wearing polarizing sunglasses than otherwise because of the different polarizations of light from different directions in the sky.

6. The light reflected from the surface of a still pond is horizontally polarized. When light is reflected from a surface, the reflected light is completely polarized parallel to the surface, which, in the case of the still pond, is horizontally. If the axis of the polarizer is set vertically, the reflected light will be completely absorbed, thus showing that the reflected light was horizontally polarized.

7. The sky appears blue because light from the Sun encounters small particles in the atmosphere, which scatter the waves. Shorter waves are scattered more than longer waves. Since the blue portion of the visible light spectrum has shorter wavelengths, the sky appears blue.

8. Given: I_{in} = 250 candelas; I_{out} = 17 % of I_{in} = (0.17)(250 candelas)

Required: θ

Analysis: $I_{out} = I_{in}\cos^2\theta$; $\cos^2\theta = \dfrac{I_{out}}{I_{in}}$

Solution:
$$\begin{aligned}\cos^2\theta &= \frac{I_{out}}{I_{in}}\\ &= \frac{(0.17)(250\ \cancel{\text{candelas}})}{250\ \cancel{\text{candelas}}}\\ &= 0.17\\ \cos\theta &= 0.412\ \text{(one extra digit carried)}\\ \theta &= 66^\circ\end{aligned}$$

Statement: The polarization angle of the incident light with respect to the polarization angle of the filter is 66°.

9. Given: $n_1 = 1.00$; $n_2 = 1.54$
Required: θ_B

Analysis: $\tan\theta_B = \dfrac{n_2}{n_1}$

Solution: $\tan\theta_B = \dfrac{n_2}{n_1}$

$$\tan\theta_B = \frac{1.54}{1.00}$$

$$\theta_B = 57°$$

Statement: The angle of incidence that results in perfectly polarized light is 57°. This angle is called Brewster's angle.

10. Answers may vary. Sample answer: Materials are able to reflect polarized light when the light source is unpolarized because electrons in the material's surface emit light with a polarization perpendicular to the electron's direction of vibration. Electrons on the material surface can vibrate much more easily parallel to the surface than perpendicular to the surface. The light reflected by the surface is light emitted by the surface electrons, so the electrons' parallel vibrations produce mostly perpendicularly polarized light.

11. Polarized sunglasses can make it easier to see through the window on a sunny day because the window partially polarizes sunlight through reflection. This light can then be filtered out using glasses with a different polarization.

12. Yes, it is possible for light intensity to be unaffected by a polarization filter if all the incoming light has the same polarization angle as the filter.

13. Answers may vary. Sample answer: 3D movies show two images overlaid on each other, one for each eye of the viewer. One method of projecting the images is to project the two images with different polarizations. The viewer wears glasses with filters in each eyepiece, which are also polarized differently to match the two images. This way, the light from only one of the images reaches each eye, and each eye sees a different image. The differences in the images' perspective create the impression of viewing a three-dimensional object.

14. Answers may vary. Sample answers: Each lens of the glasses has a different polarizing filter so only the light from the movie that is similarly polarized is seen through that lens and the other light is blocked. Therefore, each eye sees a different image, which produces the three-dimensional effect.

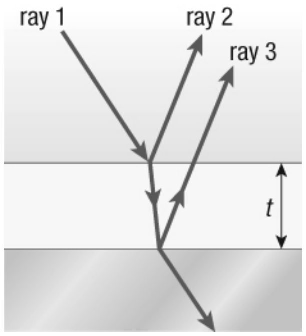
Chapter 10 Review, pages 550–555

Knowledge

1. (d)
2. (d)
3. (d)
4. (c)
5. (a)
6. (a)
7. (d)
8. (a)
9. (a)
10. (b)
11. (c)
12. (c)
13. (d)
14. (b)
15. (a)
16. True
17. True
18. True
19. False. The *wave theory* of light best explains the bright and dark fringes surrounding the central maximum in a single-slit diffraction demonstration.
20. False. To achieve the best possible resolution of their images, astronomers try to *minimize* the effects of diffraction from distant stars.
21. False. Doubling the wavelength will increase the diameter of the central maximum by *two* times.
22. True
23. False. A CD is a good example of a *reflection* grating.
24. True
25. False. Diffraction gratings will display interference patterns for *all wavelengths* if the slit spacing is appropriate.
26. False. Gamma rays travel through a vacuum *at the same speed* as microwaves.
27. False. Microwave ovens work by radiating the food with waves of selected frequencies that interact strongly with water molecules. (Microwaves have *no effect* on carbon dioxide.)
28. False. Light from the Sun is *not polarized* before reflecting off particles in the atmosphere.
29. True
30. False. Lidar technology relies on *laser* light.
31. True
32. True
33. False. All technology is *not* beneficial and *has* shortcomings.

Understanding

34. (a), (b) Sample answer: In the diagram, rays 2 and 3 should both undergo a phase change, so rays 2 and 3 are 180° out of phase if $t = \frac{1}{2}\lambda$.



(a) Changing the wavelength of the light will result in varying amounts of reflection because each wavelength of light has a different ideal thickness in the coating.
(b) Changing the angle of incidence of the light will result in varying amounts of reflection because the thickness of the coating is determined with the assumption that light hits the surface perpendicularly.

35. The path difference between these two reflected rays is $2t$.

36. (a) Sample answer: A thin film refers to a coating or film applied to optical devices, such as lenses. The film is so thin that it is not visible, comparable to the wavelength of light or some whole-number multiple of the wavelength of light.
(b) To achieve optical interference, the thickness of the transparent film should be approximately zero, and the path length difference between rays reflected from the top and bottom surfaces is of the order of one wavelength (or half of one wavelength) of the ray of light.

37. Sample answer: In thick films, the rays reflected from both the bottom and top surfaces of the film may not leave the surface at the same location. This is due to the much longer distance that the ray reflecting from the bottom surface has to travel, making it impossible to see interference effects.

38. Sample answer: As monochromatic light passes through a small opening, the wavelength of the light and the slit width will affect the angle of diffraction. A longer wavelength of light will diffract more, and decreasing the size of the slit opening allows the light to diffract more as well.

39. No, the maxima created by a diffraction grating do not all have the same intensity. The central maximum is the brightest, and the maxima become less intense as distance from the centre increases.

40. Sample answer: FM radio waves have a shorter wavelength than AM radio waves. Consequently, FM radio waves do not diffract as well as the AM waves do around mountains or Earth's curvature, so FM waves lose reception before the AM waves.

41. Sample answer: Sound waves are compression longitudinal waves in a medium. Radio waves are electromagnetic waves that do not need a medium. Radio waves travel as electromagnetic waves at the speed of light through the air from the company's radio station to the personal radio device. The radio then plays a sound wave that reaches the listener's ear.

42. Radio waves are transverse waves, with the electric field in the same plane, parallel to the antenna. If the receiving antenna is horizontal and the incident waves are vertically aligned, the charges in the antenna will not be free to oscillate with sufficient amplitude to hear a signal.
43. Sample answer: Optically active refers to transparent materials that rotate the direction of polarized light. Very small voltages can manipulate these materials and create images on a larger screen. Most digital watches, calculators, and cellphone displays make use of polarizing filters and optically active materials.
44. To tell whether or not a pair of sunglasses is polarized, I would put on the glasses and tilt my head side to side. If the intensity of reflected glare changes as my head tilts, then the glasses are polarized. Alternatively, I could take two pairs of the same glasses and hold the lenses perpendicular to each other. If all the light is blocked out, the glasses are polarized.

Analysis and Application

45. (a) Given: $n_{\text{soap film}} = 1.35$; $t = 2.50 \times 10^{-7}$ m; $m = 0, 1, 2$

Required: λ

Analysis: Only one wave has a phase change on reflection. Use the formula for constructive interference of two waves when phase change occurs in only one reflection;

$$2t = \frac{\left(m + \frac{1}{2}\right)\lambda}{n_{\text{soap film}}}; \ \lambda = \frac{2tn_{\text{soap film}}}{\left(m + \frac{1}{2}\right)}$$

Solution:
For $m = 0$:

$$\lambda = \frac{2tn_{\text{soap film}}}{\left(m + \frac{1}{2}\right)} = \frac{2(2.50 \times 10^{-7} \text{ m})(1.35)}{\left(0 + \frac{1}{2}\right)}$$

$$\lambda = 1.35 \times 10^{-6} \text{ m}$$

For $m = 1$:

$$\lambda = \frac{2(2.50 \times 10^{-7} \text{ m})(1.35)}{\left(1 + \frac{1}{2}\right)}$$

$$\lambda = 4.50 \times 10^{-7} \text{ m}$$

For $m = 2$:

$$\lambda = \frac{2(2.50 \times 10^{-7} \text{ m})(1.35)}{\left(2 + \frac{1}{2}\right)}$$

$$\lambda = 2.70 \times 10^{-7} \text{ m}$$

Statement: The three longest wavelengths are 1.35×10^{-6} m, 4.50×10^{-7} m, and 2.70×10^{-7} m.
(b) Visible light falls within the range of 4×10^{-7} m to 7×10^{-7} m. Therefore, the only visible wave in part (a) is the wavelength 4.50×10^{-7} m, when $m = 1$.

46. Given: $t = 250 \text{ nm} = 2.50 \times 10^{-7} \text{ m}$; $\lambda = 500 \text{ nm} = 5.00 \times 10^{-7} \text{ m}$

Required: n_{film}

Analysis: Only one wave has a phase change on reflection. Use the formula for constructive interference of two waves when phase change occurs in only one reflection;

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

Since the thickness of the film is half the wavelength of the light, use *m* = 1. (*m* = 0 leads to an impossible index of refraction, *n*.)

Solution:
$$n_{\text{film}} = \frac{\left(m + \frac{1}{2}\right)\lambda}{2t}$$
$$= \frac{\left(1 + \frac{1}{2}\right)\left(5.00 \times 10^{-7} \cancel{\text{m}}\right)}{2\left(2.50 \times 10^{-7} \cancel{\text{m}}\right)}$$
$$n_{\text{film}} = 1.50$$

Statement: The index of refraction of the plastic film is 1.50.

47. (a)
$$\lambda_{\text{film}} = \frac{\lambda_{\text{air}}}{n}$$
$$= \frac{560 \text{ nm}}{1.45}$$
$$\lambda_{\text{film}} = 390 \text{ nm}$$

The wavelength of the light in the film is 390 nm.

(b) There is a phase change at both the air–film and film–glass surfaces because in each case the index of refraction of the reflecting surface is higher than the index of refraction of the incident medium.

(c) Given: $n_{\text{film}} = 1.45$; $\lambda = 560 \text{ nm} = 5.60 \times 10^{-7} \text{ m}$

Required: t

Analysis: Use the formula for constructive interference of two waves when phase change occurs at both reflections. Use *n* = 1 for minimum thickness.

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

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

$$= \frac{(1)(5.60\times10^{-7}\ \text{m})}{2(1.45)}$$

$$t = 190\ \text{nm}$$

Statement: The minimum thickness of film that will create constructive interference is 190 nm.

48. Given: $\lambda = 6.50\times10^{-7}$ m; $L = 6.0$ cm $= 6.0\times10^{-2}$ m; there are 25 cycles of alternating light patterns along L

Required: t

Analysis: $\Delta x = \dfrac{6.0\ \times10^{-2}\ \text{m}}{25}$

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

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

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

$$= \frac{(6.0\times10^{-2}\ \text{m})(6.5\times10^{-7}\ \cancel{\text{m}})}{2\left(\dfrac{6.0\ \times10^{-2}\ \cancel{\text{m}}}{25}\right)}$$

$$t = 8.1\times10^{-6}\ \text{m}$$

Statement: The hair is 8.1×10^{-6} m thick.

49. (a) Given: $n_{\text{film}} = 1.39$; $\lambda = 5.40\times10^{-7}$ m

Required: t

Analysis: Use the formula for destructive interference of two waves when phase change occurs at both reflections. Use $m = 0$ for minimum thickness.

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

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

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

$$= \frac{\left(0 + \dfrac{1}{2}\right)\left(5.40 \times 10^{-7}\ \text{m}\right)}{2(1.39)}$$

$$t = 9.71 \times 10^{-8}\ \text{m}$$

Statement: The minimum thickness of film that will create destructive interference is 9.71×10^{-8} m.

(b) For the next two possible thicknesses, use $m = 1$ and $m = 2$.

Solution:

For $m = 1$:

$$t = \frac{\left(1 + \dfrac{1}{2}\right)\left(5.40 \times 10^{-7}\ \text{m}\right)}{2(1.39)}$$

$$t = 2.91 \times 10^{-7}\ \text{m}$$

For $m = 2$:

$$t = \frac{\left(2 + \dfrac{1}{2}\right)\left(5.40 \times 10^{-7}\ \text{m}\right)}{2(1.39)}$$

$$t = 4.85 \times 10^{-7}\ \text{m}$$

Statement: The next two smallest thicknesses of film that will create destructive interference are 2.91×10^{-7} m and 4.85×10^{-7} m.

50. Given: $\lambda = 630$ nm

Analysis: Light rays reflecting off the CD surface will change phase whether they are reflecting at the top of a pit or at the bottom. The depth of the pit is t, so the one ray travels $2t$ farther. For destructive interference, this distance must be $\dfrac{1}{2}\lambda$;

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

$$t = \frac{1}{4}\lambda$$

Solution:

$$t = \frac{1}{4}\lambda$$

$$= \frac{1}{4}(630\ \text{nm})$$

$$t = 160\ \text{nm}$$

Statement: The minimum pit depth is 160 nm.

51. Given: $n = 1.70$; $\lambda = 630$ nm
Required: t
Analysis: Light rays reflecting off the CD surface will change phase whether they are reflecting at the top of a pit or at the bottom. The depth of the pit is t, so the one ray travels $2t$ farther. For destructive interference this distance must be $\frac{1}{2}\lambda$. However, the rays are travelling in the plastic medium, so the wavelength of the light is $\lambda_{\text{plastic}} = \frac{\lambda_{\text{normal}}}{n_{\text{plastic}}}$;

$$2t = \frac{1}{2}\lambda$$
$$t = \frac{1}{4}\lambda$$

Solution:
$$\lambda_{\text{plastic}} = \frac{\lambda_{\text{normal}}}{n_{\text{plastic}}} = \frac{630 \text{ nm}}{1.70}$$
$$\lambda_{\text{plastic}} = 371 \text{ nm}$$

$$t = \frac{1}{4}\lambda_{\text{plastic}} = \frac{1}{4}(371 \text{ nm})$$
$$t = 93 \text{ nm}$$

Statement: The minimum pit depth needed to produce destructive interference is 93 nm.

52. Given: $\lambda = 420 \text{ nm} = 4.20 \times 10^{-7}$ m; there are 25 cycles of alternating light patterns in L
Required: t
Analysis: $L = 25\Delta x$;

$$\Delta x = \frac{L\lambda}{2t}$$
$$2t = \frac{L\lambda}{\Delta x}$$
$$2t = \frac{25\Delta x\lambda}{\Delta x}$$
$$t = \frac{25\lambda}{2}$$

Solution: $t = \frac{25\lambda}{2}$

$$= \frac{(25)(4.20\times 10^{-7}\ \text{m})}{2}$$

$$t = 5.3\times 10^{-6}\ \text{m}$$

Statement: The plate spacing at the right edge is 5.3×10^{-6} m.

53. Given: $t = 3.5\ \mu\text{m} = 3.5 \times 10^{-6}$ m

Required: λ

Analysis: Since the waves reflect off the mirrors an even number of times, they will emerge in phase and interfere constructively if $2t$ is a multiple of λ;

$$2t = n\lambda$$

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

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

$$\lambda = \frac{(2)(3.5\times 10^{-6}\ \text{m})}{n}$$

We need $600\ \text{nm} < \lambda < 700\ \text{nm}$.

By trial and error,

For $n = 10$:

$$\lambda = \frac{(2)(3.5\times 10^{-6}\ \text{m})}{10}$$

$$\lambda = 700\ \text{nm}$$

For $n = 11$:

$$\lambda = \frac{(2)(3.5\times 10^{-6}\ \text{m})}{11}$$

$$= 636\ \text{nm}$$

$$\lambda = 640\ \text{nm}$$

For $n = 12$:

$$\lambda = \frac{(2)(3.5\times 10^{-6}\ \text{m})}{12}$$

$$= 583\ \text{nm}$$

$$\lambda = 580\ \text{nm}$$

Statement: The only possible wavelength values are 640 nm and 700 nm.

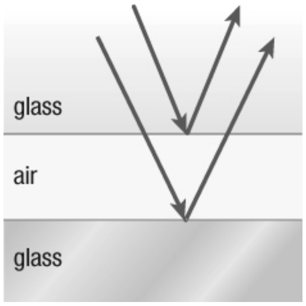
54. (a) Given: $\lambda = 350\ \text{nm} = 3.5 \times 10^{-7}$ m; $n_{\text{air}} = 1.00$

Required: t

Analysis: For the glass to appear bright, there needs to be constructive interference. Phase change occurs at the air–glass surface but not at the glass–air surface. Use the formula for constructive interference and $m = 0$. Include a diagram.

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

Solution:



$$t = \frac{\left(m + \frac{1}{2}\right)\lambda}{2n_{\text{air}}}$$
$$= \frac{\left(0 + \frac{1}{2}\right)\left(3.5 \times 10^{-7}\ \text{m}\right)}{2\left(1.00\right)}$$
$$t = 8.8 \times 10^{-8}\ \text{m}$$

Statement: For the glass to appear bright, the layer of air should be 8.8×10^{-8} m thick.

(b) Given: $\lambda = 3.5 \times 10^{-7}$ m; $n_{\text{air}} = 1.00$

Required: t

Analysis: For the glass to appear opaque, there needs to be destructive interference. Phase change occurs at the air–glass interface but not at the glass–air interface. Use the formula for destructive interference and $n = 1$.

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

Solution:

$$t = \frac{n\lambda}{2n_{\text{air}}}$$
$$= \frac{(1)(3.5 \times 10^{-7}\ \text{m})}{2(1.00)}$$
$$t = 1.8 \times 10^{-7}\ \text{m}$$

Statement: For the glass to appear opaque, the layer of air should be 1.8×10^{-7} m thick.

55. Given: $t = 1.92 \times 10^{-3}$ cm = 1.92×10^{-5} m; $L = 9.8 = 9.8 \times 10^{-2}$ m; there are 6 cycles of alternating patterns in 1.23×10^{-2} m

Required: λ

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

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

$$\Delta x = \frac{1.23 \times 10^{-2}\text{ m}}{6}$$

$$\Delta x = 2.05 \times 10^{-3}\text{ m}$$

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

$$= \frac{2(1.92 \times 10^{-5}\text{ m})(2.05 \times 10^{-3}\text{ }\cancel{\text{m}})}{9.8 \times 10^{-2}\text{ }\cancel{\text{m}}}$$

$$\lambda = 8.03 \times 10^{-7}\text{ m}$$

Statement: The wavelength of the light is 8.03 × 10^{-7} m.

56. Given: $\lambda = 560\text{ nm} = 5.60 \times 10^{-7}\text{ m}$; $L = 6.3\text{ m}$; $2\Delta y = 1.3\text{ cm} = 1.3 \times 10^{-2}\text{ m}$

Required: w

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

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

$$2\Delta y = 1.3 \times 10^{-2}\text{ m}$$

$$\Delta y = 6.5 \times 10^{-3}\text{ m}$$

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

$$= \frac{(5.60 \times 10^{-7}\text{ m})(6.3\text{ }\cancel{\text{m}})}{6.5 \times 10^{-3}\text{ }\cancel{\text{m}}}$$

$$w = 540\ \mu\text{m}$$

Statement: The width of the slit is 540 µm.

57. Given: $n = 3$; $w = 8.2 \times 10^{-6}\text{ m}$; $\theta_3 = 15°$

Required: λ

Analysis: $w\sin\theta_n = n\lambda$

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

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

$$= \frac{(8.2 \times 10^{-6}\text{ m})(\sin 15°)}{3}$$

$$\lambda = 710\text{ nm}$$

Statement: The wavelength of the light is 710 nm.

58. (a) Given: $5.5\Delta y = 6.1$ cm

Required: Δy, the distance between successive maxima

Analysis: The distance to the fifth maximum is $5.5\Delta y$.

Solution:

$$5.5\Delta y = 6.1\text{ cm}$$
$$= \frac{6.1\text{ cm}}{5.5}$$
$$= 1.11\text{ cm (one extra digit carried)}$$
$$\Delta y = 1.1\text{ cm}$$

Statement: The distance between successive maxima is 1.1 cm.

(b) Given: $L = 1.5$ m; $w = 5.6 \times 10^{-5}$ m; $\Delta y = 1.11$ cm $= 1.11 \times 10^{-2}$ m

Required: λ

Analysis:

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

Solution:

$$\lambda = \frac{w\Delta y}{L}$$
$$= \frac{(5.6\times10^{-5}\text{ m})(1.11\times10^{-2}\text{ }\cancel{\text{m}})}{1.5\text{ }\cancel{\text{m}}}$$
$$\lambda = 410\text{ nm}$$

Statement: The wavelength of the violet light is 410 nm.

59. Given: $\lambda = 510$ nm $= 5.10 \times 10^{-7}$ m; $w = 17$ µm $= 1.7 \times 10^{-5}$ m; $\Delta y = 2.6$ cm $= 2.6 \times 10^{-2}$ m

Required: L

Analysis:

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

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

$$= \frac{(1.7\times10^{-5}\text{ m})(2.6\times10^{-2}\text{ }\cancel{\text{m}})}{5.10\times10^{-7}\text{ }\cancel{\text{m}}}$$
$$L = 0.87\text{ m}$$

Statement: The distance between the slit and the screen is 0.87 m.

60. Given: $N = 8000$ lines/cm; $\lambda = 660 \text{ nm} = 6.60\times10^{-7} \text{ m}$; $m = 1$

Required: θ_1

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

Solution:
$$w = \frac{1}{N}$$
$$= \frac{1}{8.0\times10^3 \text{ lines/}\cancel{\text{cm}}} \times \frac{1 \text{ m}}{100 \ \cancel{\text{cm}}}$$
$$w = 1.25\times10^{-6} \text{ m}$$

$$\sin\theta = \frac{m\lambda}{w}$$
$$= \frac{(1)(6.60\times10^{-7} \ \cancel{\text{m}})}{1.25\times10^{-6} \ \cancel{\text{m}}}$$
$$\theta = 32°$$

Statement: The red light produces a first-order maximum at $32°$.

61. (a) When the lines on one grating are perpendicular to the lines on the other grating, there will be a rectangular array of dots that are brighter in the centre and fainter to the sides.

(b) When the lines on one grating are parallel to the lines on the other grating, light will only pass through slits that line up if the gratings are touching each other. Otherwise, the light rays will not pass through. The result will be a diffraction pattern similar to a pattern produced by a diffraction grating but with spacing indicated by the slits that line up.

62. (a) Consider the case where $m = 1$. For diffraction to occur,

$$\lambda = \frac{w\sin\theta_m}{m}$$
$$= w\sin\theta_m$$
$$\lambda = (1\times10^{-8} \text{ m})\sin\theta$$
$$0 \le \sin\theta \le 1$$
$$0 \le (1\times10^{-8} \text{ m})\sin\theta \le 1\times10^{-8} \text{ m}$$
$$0 \le \lambda \le 1\times10^{-8} \text{ m}$$

Visible light has wavelengths between 380 nm and 740 nm. Visible light does not fall in the diffraction range for λ above. Therefore, visible light cannot exhibit diffraction when reflected off crystals that have a spacing of 1×10^{-8} m.

(b) The waves that will show diffraction in this situation are those with shorter wavelengths, such as ultraviolet radiation, X-rays, and gamma rays.

63. (a) Given: $\lambda = 430\text{ nm} = 4.30\times10^{-7}\text{ m}$; $\theta_1 = 16°$; $m = 1$

Required: w

Analysis: Rearrange the equation $m\lambda = w\sin\theta_m$ to calculate the slit separation;

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

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

$$= \frac{(1)(4.30\times10^{-7}\text{ m})}{\sin16°}$$

$w = 1.56\times10^{-6}\text{ m}$ (one extra digit carried)

Statement: The spacing between adjacent slits on the diffraction grating is 1.6×10^{-6} m.

(b) Given: $w = 1.56\times10^{-6}$ m

Required: N

Analysis: Rearrange the equation $w = \dfrac{1}{N}$ to determine the number of lines per centimetre; $N = \dfrac{1}{w}$

Solution:

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

$$= \frac{1}{1.56\times10^{-6}\text{ m}}$$

$N = 6400$ lines/cm

Statement: The diffraction grating has 6400 lines/cm.

64. (a) Given: $\lambda = 650\text{ nm} = 6.50\times10^{-7}\text{ m}$; $\theta_{1a} = 34°$; $\theta_{1b} = 31°$; $m = 1$

Required: w

Analysis: Rearrange the equation $m\lambda = w\sin\theta_m$ to calculate the slit separation for each angle; $w = \dfrac{m\lambda}{\sin\theta_m}$. Then average the two angles.

Solution:

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

$$= \frac{(1)(6.50\times10^{-7}\text{ m})}{0.5592}$$

$w_a = 1.162\times10^{-6}$ m (two extra digits carried)

$$w_b = \frac{m\lambda}{\sin\theta_m}$$
$$= \frac{(1)(6.50\times10^{-7}\ \text{m})}{0.5150}$$
$$w_b = 1.262\times10^{-6}\ \text{m}\ \text{(two extra digits carried)}$$

For the average:

$$w_{av} = \frac{w_a + w_b}{2}$$
$$= \frac{1.162\times10^{-6}\ \text{m} + 1.262\times10^{-6}\ \text{m}}{2}$$
$$= 1.212\times10^{-6}\ \text{m}\ \text{(two extra digits carried)}$$
$$w_{av} = 1.2\times10^{-6}\ \text{m}$$

Statement: The average slit spacing is 1.2×10^{-6} m.

(b) Given: $w = 1.212 \times 10^{-6}$ m

Required: N

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

Solution:

$$N = \frac{1}{1.212\times10^{-6}\ \cancel{\text{m}}} \times \frac{1\ \cancel{\text{m}}}{100\ \text{cm}}$$
$$N = 8300\ \text{cm}^{-1}$$

Statement: The diffraction grating has 8300 lines/cm.

(c) Since there are 8300 lines/cm, there are 4 cm × 8300 lines/cm = 33 200 lines on the CD. If there is one rotation per line, there will be 33 200 rotations, or 3.3×10^4 rotations, to read the complete CD.

(d) The rotational speed is the number of rotations divided by the time:

$$v = \frac{33200\ \text{rotations}}{50\ \text{mn}}$$
$$v = 660\ \text{rpm}$$

The rotational speed is 660 rpm.

65. Given: λ_1 = 400 nm = 4.00×10^{-7} m; λ_2 = 700 nm = 7.00×10^{-7} m; L = 4.0 m; m = 1; N = 2000 lines/cm

Required: Δy

Analysis: Determine the slit width using $w = \frac{1}{N}$; rearrange the equation $m\lambda = w\sin\theta_m$ to calculate the angle, $\sin\theta_m = \frac{m\lambda}{w}$. Then use trigonometry to calculate the width of the first-order rainbow spectrum.

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

$$= \frac{1}{2000\ \text{cm}^{-1}}$$

$$= 5.0 \times 10^{-4}\ \text{cm}$$

$$w = 5.0 \times 10^{-6}\ \text{m}$$

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

$$\sin\theta_1 = \frac{(1)(4.0 \times 10^{-7}\ \cancel{\text{m}})}{5.0 \times 10^{-6}\ \cancel{\text{m}}}$$

$$\theta_1 = 4.589° \ \ \text{(two extra digits carried)}$$

$$\sin\theta^2 = \frac{(1)(7.0 \times 10^{-7}\ \cancel{\text{m}})}{5.0 \times 10^{-6}\ \cancel{\text{m}}}$$

$$\theta_2 = 8.048° \ \ \text{(two extra digits carried)}$$

The rainbow spectrum has an angular width of $8.048° - 4.589° = 3.459°$ (two extra digits carried).

Using trigonometry, the linear width of the spectrum is $(4.0\ \text{m})\sin 3.459° = 0.24\ \text{m}$.

Statement: The width of the first-order rainbow spectrum is 0.24 m.

66. Given: λ = 660 nm = 6.60×10^{-7} m; N = 5000 lines/cm

Required: m, number of maxima

Analysis: Calculate the slit width, $w = \frac{1}{N}$; rearrange the equation $m\lambda = w\sin\theta_m$ to calculate the angle; $\sin\theta_m = \frac{m\lambda}{w}$.

The last observable maximum occurs at an angle of $90°$.

Solution:

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

$$= \frac{1}{5000\ \text{cm}^{-1}}$$

$$w = 2.0 \times 10^{-6}\ \text{m}$$

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

$$\sin 90° = \frac{m(6.60 \times 10^{-7}\ \cancel{\text{m}})}{2.0 \times 10^{-6}\ \cancel{\text{m}}}$$

$$1 = 0.33m$$

$$m = 3.03$$

Statement: There are three maxima on each side of the central maximum.

67. Given: $f = 2.0 \times 10^9$ Hz
Required: λ
Analysis: Rearrange the universal wave equation, $c = \lambda f$, to solve for wavelength;

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

Solution:

$$\begin{aligned}\lambda &= \frac{c}{f}\\ &= \frac{3.0 \times 10^8 \text{ m/}\cancel{\text{s}}}{2.0 \times 10^9 \ \cancel{\text{Hz}}}\end{aligned}$$

$\lambda = 0.15$ m

Statement: The wavelength of the signal is 0.15 m.

68. (a) Given: $\lambda = 940 \text{ nm } = 9.4 \times 10^{-7}$ m
Required: f
Analysis: Rearrange the universal wave equation, $c = \lambda f$, to solve for frequency;

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

Solution:

$$\begin{aligned}f &= \frac{c}{\lambda}\\ &= \frac{3.0 \times 10^8 \ \cancel{\text{m}}\text{/s}}{9.4 \times 10^{-7} \ \cancel{\text{m}}}\end{aligned}$$

$f = 3.2 \times 10^{14} \text{ s}^{-1}$

Statement: The frequency of the radiation is 3.2×10^{14} Hz.

(b) The radiation travels at the speed of light, 3.0×10^8 m/s;

$$\text{time} = \frac{\text{distance}}{\text{speed}}$$

$$\begin{aligned}t &= \frac{d}{s}\\ &= \frac{2.5 \ \cancel{\text{m}}}{3.0 \times 10^8 \ \cancel{\text{m}}\text{/s}}\end{aligned}$$

$t = 8.3 \times 10^{-9}$ s

It takes 8.3×10^{-9} s for the signal to reach the television.

69. Given: $f = 89 \text{ GHz} = 8.9 \times 10^{10}$ Hz
Required: λ
Analysis: Rearrange the universal wave equation, $c = \lambda f$, to solve for wavelength;

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

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

$$= \frac{3.0 \times 10^8 \text{ m/}\cancel{\text{s}}}{8.9 \times 10^{10} \ \cancel{\text{Hz}}}$$

$$\lambda = 3.4 \times 10^{-3} \text{ m}$$

Statement: The wavelength of the signal is 3.4×10^{-3} m.

70. When unpolarized light passes through a polarizing filter, only half the light passes through. So, through the first filter, $I_{\text{out}} = \frac{1}{2} I_{\text{in}}$, then $I_{\text{in 2}} = \frac{1}{2} I_{\text{in}}$.

$$\begin{aligned} I_{\text{out 2}} &= I_{\text{in 2}} \cos^2 \theta_2 \\ &= \frac{1}{2} I_{\text{in}} \cos^2 60° \\ &= \frac{1}{2} I_{\text{in}} \left(\frac{1}{2}\right)^2 \\ I_{\text{out 2}} &= \frac{1}{8} I_{\text{in}} \end{aligned}$$

The intensity of the transmitted light is $\frac{1}{8} I_{\text{in}}$.

71. Given: $I_{\text{out}} = \frac{1}{10} I_{\text{in}}$

Required: θ, the rotation angle

Analysis: When unpolarized light passes through a polarizing filter, only half the light passes through. So, through the first filter, $I_{\text{out}} = \frac{1}{2} I_{\text{in}}$, then $I_{\text{in 2}} = \frac{1}{2} I_{\text{in}}$.

Solution:

$$\begin{aligned} I_{\text{out 2}} &= I_{\text{in 2}} \cos^2 \theta_2 \\ \frac{1}{10} \cancel{I_{\text{in}}} &= \frac{1}{2} \cancel{I_{\text{in}}} \cos^2 \theta_2 \\ \frac{1}{5} &= \cos^2 \theta_2 \\ \cos^{-1}\left(\sqrt{\frac{1}{5}}\right) &= \theta_2 \\ \theta_2 &= 63° \end{aligned}$$

Statement: The rotation angle of the second polarizer relative to the first is approximately 63°.

72. (a) The angle of reflection is 61°.
(b) According to Brewster's law, the sum of the angle of reflection and the angle of refraction is 90° because the reflected ray and the refracted ray are perpendicular to each other: 90° – 61° = 29°. The angle of refraction is 29°.
(c)

$$\tan\theta_B = \frac{n_2}{n_1}$$

$$\begin{aligned} n_2 &= (\tan\theta_B)n_1 \\ &= (\tan 61°)(1.00) \\ n &= 1.8 \end{aligned}$$

The index of refraction of the material is approximately 1.8.
(d)

$$\tan\theta_B = \frac{n_2}{n_1}$$

$$\tan\theta_B = \frac{1.33}{1.00}$$

$$\theta_B = 53°$$

The angle of incidence would have to be approximately 53° to yield completely polarized light if the transparent material were water.
73. (a) The "shadow" is green because the shadow is actually light that gets through the filter. The green light must be polarized in one direction, and the red and blue light must be polarized in the perpendicular direction.
(b) If the student rotated the polarizer by 90°, the green light would be blocked and the red and blue light would transmit, producing a magenta shadow.
74. The polarizer will block out the light from the glare, but not from the bulb because the light from the bulb is linearly polarized in all directions. The polarizer blocks a different orientation of light at each angle. However, when the light is reflected off the table's surface, most of the reflected light is polarized in a certain direction. Making the polarizer perpendicular to the linearly polarized reflected light will cancel this light entirely.
75. When unpolarized light passes through a polarizing filter, only half the light passes through. So, through the first filter, $I_{\text{out 1}} = I_{\text{in 2}} = \frac{1}{2}I_0$.

$$\begin{aligned} I_{\text{out 2}} &= I_{\text{in 2}}\cos^2\theta_2 \\ &= \frac{1}{2}I_0 \cos^2 45° \\ &= \frac{1}{2}I_0\left(\frac{1}{\sqrt{2}}\right)^2 \\ I_{\text{out 2}} &= \frac{1}{4}I_0 \end{aligned}$$

Any light that passes through the third filter will be unpolarized. When unpolarized light passes through a polarizing filter, only half the light passes through. So, through the third filter:

$$I_{\text{out 3}} = \frac{1}{2}I_{\text{out 2}}$$
$$= \frac{1}{2}\left(\frac{1}{4}I_0\right)$$
$$I_{\text{out 3}} = \frac{1}{8}I_0$$

The intensity of the light that passes through all three filters is $\frac{1}{8}I_0$.

Evaluation

76. Answers may vary. Sample answer: The sentence is incorrect. The light intensity is *zero* at the point of contact of the two plates, followed by seven *alternating bright and dark fringes*.

77. Answers may vary. Sample answer: My answer would have three significant digits because the value provided for the wavelength has three significant digits. The value for the number of lines on the diffraction grating has two significant digits, but that number is "counted" and therefore does not affect how many significant digits I need to show in my answer.

78. Answers may vary. Sample answer: The analogy is not accurate. The fence blocks all "polarizations" of the rope waves except those along the picket direction. Malus's law, however, says that some light will always pass through a filter, unless the incident light is polarized at exactly 90° to the filter polarization.

79. Answers may vary. Sample answer: Publishing materials on the Internet uses no paper and ink, benefiting the environment. If Internet access is free, as in libraries, it can reach more people, which benefits society.

Reflect on Your Learning

80. Answers may vary. Sample answer: What I found most surprising in this chapter was learning why butterfly wings shimmer and are iridescent. What I found most interesting in this chapter was holography. I can learn more about these topics with further research using the Internet.

81. Answers may vary. Sample answer: I would explain the concepts of thin-film interference and polarization to a student who has not taken physics by using examples and explaining these concepts in the simplest way that I could. If my explanation is too complex, the student will not understand what I am saying. Examples allow the student to visualize what I am teaching and demonstrate some applications of the concepts.

82. Answers may vary. Sample answer: I now see the physics concepts that were explored in this chapter everywhere. Light is everywhere in our lives and I now have a basic understanding of the physics concepts of light. I also see these concepts when I where my sunglasses, see butterflies, and use any item that has a hologram that is used to prevent counterfeiting.

Research

83. (a) Sample answer: The cuticle is the outer, non-cellular layer of a butterfly's exoskeleton. Scales are tiny overlapping pieces of chitin on a butterfly's wing, which create the butterfly's colour.

(b) Sample answer: Some purposes of the colours of a butterfly are as follows: the colours function as a camouflage, absorb thermal energy, help find a mate, and can act as a warning to potential predators.

84. (a) Sample answer: The advantage of binocular vision is that it allows the bald eagle to gauge distances precisely.

(b) Sample answer: The fovea in eagles contain a much higher concentration of sensory cells than the fovea in humans, giving eagles a more detailed image. Each eagle eye has two fovea, whereas each human eye only has one.

(c) Sample answer: Each eye of a bald eagle has two eyelids. The inner eyelid keeps the eye wet and clear while also shielding the eye. The eyebrows of a bald eagle help protect them from injury and help shield their eyes from the Sun. The flexible lens of a bald eagle's eye is soft and can focus rapidly. This allows the eagle to quickly focus between near and far objects.

85. (a) The VLA stands at an elevation of 2124 m.

(b) There are 27 independent antennas present in the observatory.

(c) The diameter of one of the circular dishes is 25 m.

(d) With the VLA, astronomers observe radio galaxies, quasars, pulsars, supernova remnants, black holes, the Sun, radio-emitting stars, gamma ray bursts, other planets, astrophysical masers, and the hydrogen gas that makes up much of our galaxy.

(e) One advantage of receiving radio waves instead of other types of waves is that radio waves can penetrate clouds and are unaffected by rain, so it does not matter if it is cloudy or raining when gathering radio signals. Radio waves are also unaffected by sunlight, so radio observatories can be used at night.

86. (a) QR stands for quick response.

(b) QR codes originated in Japan, where they were first used in the automotive industry.

(c) Sample answer: QR codes can hold much more information than barcodes, such as website links and text. They are also quick and easy to scan with mobile applications, such as cellphones.

(d) Sample answer: A barcode is considered one-dimensional because the bars are in a line and the laser scans the lines. The QR code is considered two-dimensional and the symbols are not arranged in a line, so a laser cannot read the symbols. A digital camera with the QR reader software can be used to read the QR code. A laser is not needed to scan the code.

87. Answers may vary. Sample answer: Fessenden's main work was in the area called radiotelephony, in which a changing sound signal is imposed, or modulated, onto an electromagnetic wave. The modern wireless telephone, or cellphone, is one of the most recent and widespread examples of radiotelephony.