

OPTICS

Fourth Edition

INSTRUCTOR'S SOLUTIONS MANUAL

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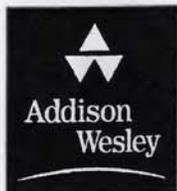
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Chapter 2 Solutions

- 2.1 $(0.003)(2.54 \times 10^{-2}/580 \times 10^{-9}) = \text{number of waves} = 131, c = \nu\lambda,$
 $\lambda = c/\nu = 3 \times 10^8/10^{10}, \lambda = 3 \text{ cm. Waves extend } 3.9 \text{ m.}$
- 2.2 $\lambda = c/\nu = 3 \times 10^8/5 \times 10^{14} = 6 \times 10^{-7} \text{ m} = 0.6\mu \text{ m.}$
 $\lambda = 3 \times 10^8/60 = 5 \times 10^6 \text{ m} = 5 \times 10^3 \text{ km.}$
- 2.3 $v = \lambda\nu = 5 \times 10^{-7} \times 6 \times 10^8 = 300 \text{ m/s.}$
- 2.4 The time between the crests is the period, so $\tau = 1/2 \text{ s}$; hence
 $\nu = 1/\tau = 2.0 \text{ Hz.}$ As for the speed $v = L/t = 4.5 \text{ m}/1.5 \text{ s} = 3.0 \text{ m/s.}$ We
 now know $\tau, \nu,$ and v and must determine $\lambda.$ Thus,
 $\lambda = v/\nu = 3.0 \text{ m/s}/2.0 \text{ Hz} = 1.5 \text{ m.}$
- 2.5 $v = \nu\lambda = 3.5 \times 10^3 \text{ m/s} = \nu(4.3 \text{ m}); \nu = 0.81 \text{ kHz.}$
- 2.6 $v = \nu\lambda = 1498 \text{ m/s} = (440 \text{ Hz})\lambda; \lambda = 3.40 \text{ m.}$
- 2.7 $v = (10 \text{ m})/(2.0 \text{ s}) = 5.0 \text{ m/s}; \nu = v/\lambda = (5.0 \text{ m/s})/(0.50 \text{ m}) = 10 \text{ Hz.}$
- 2.8 $v = \nu\lambda = (\omega/2\pi)\lambda$ and so $\omega = (2\pi/\lambda)v.$

| 2.9 θ | $-\pi/2$ | $-\pi/4$ | 0 | $\pi/4$ | $\pi/2$ | $3\pi/4$ |
|-------------------------|---------------|---------------|---------------|---------------|---------------|---------------|
| $\sin \theta$ | -1 | $-\sqrt{2}/2$ | 0 | $\sqrt{2}/2$ | 1 | $\sqrt{2}/2$ |
| $\cos \theta$ | 0 | $\sqrt{2}/2$ | 1 | $\sqrt{2}/2$ | 0 | $-\sqrt{2}/2$ |
| $\sin(\theta - \pi/4)$ | $-\sqrt{2}/2$ | -1 | $-\sqrt{2}/2$ | 0 | $\sqrt{2}/2$ | 1 |
| $\sin(\theta - \pi/2)$ | 0 | $-\sqrt{2}/2$ | -1 | $-\sqrt{2}/2$ | 0 | $\sqrt{2}/2$ |
| $\sin(\theta - 3\pi/4)$ | $\sqrt{2}/2$ | 0 | $-\sqrt{2}/2$ | -1 | $-\sqrt{2}/2$ | 0 |
| $\sin(\theta + \pi/2)$ | 0 | $\sqrt{2}/2$ | 1 | $\sqrt{2}/2$ | 0 | $-\sqrt{2}/2$ |

| θ | π | $5\pi/4$ | $3\pi/2$ | $7\pi/4$ | 2π |
|-------------------------|--------------|---------------|---------------|---------------|---------------|
| $\sin \theta$ | 0 | $-\sqrt{2}/2$ | -1 | $-\sqrt{2}/2$ | 0 |
| $\cos \theta$ | -1 | $-\sqrt{2}/2$ | 0 | $\sqrt{2}/2$ | 1 |
| $\sin(\theta - \pi/4)$ | $\sqrt{2}/2$ | 0 | $-\sqrt{2}/2$ | -1 | $-\sqrt{2}/2$ |
| $\sin(\theta - \pi/2)$ | 1 | $\sqrt{2}/2$ | 0 | $-\sqrt{2}/2$ | -1 |
| $\sin(\theta - 3\pi/4)$ | $\sqrt{2}/2$ | 1 | $\sqrt{2}/2$ | 0 | $-\sqrt{2}/2$ |
| $\sin(\theta + \pi/2)$ | -1 | $-\sqrt{2}/2$ | 0 | $\sqrt{2}/2$ | 1 |

$\sin \theta$ leads $\sin(\theta - \pi/2)$.

2.10

| x | $-\lambda/2$ | $-\lambda/4$ | 0 | $\lambda/4$ | $\lambda/2$ | $3\lambda/4$ | λ |
|-----------------------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
| $\kappa x = 2\pi/\lambda x$ | $-\pi$ | $-\pi/2$ | 0 | $\pi/2$ | π | $3\pi/2$ | 2π |
| $\cos(\kappa x - \pi/2)$ | $-\sqrt{2}/2$ | $-\sqrt{2}/2$ | $\sqrt{2}/2$ | $\sqrt{2}/2$ | $-\sqrt{2}/2$ | $-\sqrt{2}/2$ | $\sqrt{2}/2$ |
| $\cos(\kappa x + 3\pi/4)$ | $\sqrt{2}/2$ | $\sqrt{2}/2$ | $-\sqrt{2}/2$ | $-\sqrt{2}/2$ | $\sqrt{2}/2$ | $\sqrt{2}/2$ | $-\sqrt{2}/2$ |

2.11

| t | $-\tau/2$ | $-\tau/4$ | 0 | $\tau/4$ | $\tau/2$ | $3\tau/4$ | τ |
|--------------------------|---------------|---------------|--------------|---------------|---------------|---------------|--------------|
| $\omega t = 2\pi/\tau$ | $-\pi$ | $-\pi/2$ | 0 | $\pi/2$ | π | $3\pi/2$ | π |
| $\sin(\omega t + \pi/4)$ | $-\sqrt{2}/2$ | $-\sqrt{2}/2$ | $\sqrt{2}/2$ | $\sqrt{2}/2$ | $-\sqrt{2}/2$ | $-\sqrt{2}/2$ | $\sqrt{2}/2$ |
| $\sin(\pi/4 - \omega t)$ | $-\sqrt{2}/2$ | $\sqrt{2}/2$ | $\sqrt{2}/2$ | $-\sqrt{2}/2$ | $-\sqrt{2}/2$ | $\sqrt{2}/2$ | $\sqrt{2}/2$ |

2.12 Comparing y with Eq. (2.13) tells us that $A = 0.02$ m. Moreover, $2\pi/\lambda = 157 \text{ m}^{-1}$ and so $\lambda = 2\pi/(157 \text{ m}^{-1}) = 0.0400$ m. The relationship between frequency and wavelength is $v = \nu\lambda$, and so $\nu = v/\lambda = 1.2 \text{ m/s}/0.0400 \text{ m} = 30 \text{ Hz}$. The period is the inverse of the frequency, and therefore $\tau = 1/\nu = 0.033$ s.

2.13 (a) $\lambda = (4.0 - 0.0) \text{ m} = 4.0 \text{ m}$. (b) $v = \nu\lambda$, so $\nu = v/\lambda = (20.0 \text{ m/s})/(4.0 \text{ m}) = 5.0 \text{ Hz}$. (c) Eq. (2.28) $\psi(x, t) = A \sin(kx - \omega t + \epsilon)$. From the figure, $A = 0.020$ m; $k = 2\pi/\lambda = 2\pi/(4.0 \text{ m}) = 0.5\pi \text{ m}^{-1}$; $\omega = 2\pi\nu = 2\pi(5.0 \text{ Hz}) = 10.0\pi \text{ rad/s}$

At $t = 0, x = 0, \psi(0, 0) = -0.020$ m;
 $\psi(0, 0) = (0.020 \text{ m}) \sin(0.5\pi(0) - 10.0\pi(0) + \epsilon) = (0.020 \text{ m}) \sin(\epsilon)$;
 $\sin(\epsilon) = -1; \epsilon = -\pi/2. \psi(x, t) = (0.020 \text{ m}) \sin(0.5\pi x - 10.0\pi t - \pi/2)$

2.14 (a) $\lambda = (30.0 - 0.0) \text{ cm} = 30.0 \text{ cm}$. (c) $v = \nu\lambda$, so $\nu = v/\lambda = (100 \text{ cm/s})/(30.0 \text{ cm}) = 3.33 \text{ Hz}$

- 2.24 $\psi(0, t) = A \cos(kvt + \pi) = -A \cos(kvt) = -A \cos(\omega t)$, then
 $\psi(0, \tau/2) = -A \cos(\omega\tau/2) = -A \cos(\pi) = A$,
 $\psi(0, 3\tau/4) = -A \cos(3\omega\tau/4) = -A \cos(3\pi/2) = 0$.
- 2.25 Since $\psi(y, t) = (y - vt)A$ is only a function of $(y - vt)$, it does satisfy the conditions set down for a wave. Since $\partial^2\psi/\partial y^2 = \partial^2\psi/\partial t^2 = 0$, this function is a solution of the wave equation. However, $\psi(y, 0) = Ay$ is unbounded, so cannot represent a localized wave profile.
- 2.26 $k = \pi 3 \times 10^6 \text{ m}^{-1}$, $\omega = \pi 9 \times 10^{14} \text{ Hz}$, $v = \omega/k = 3 \times 10^8 \text{ m/s}$.
- 2.27 $d\psi/dt = \partial\psi/\partial x dx/dt + (\partial\psi/\partial y)(dy/dt)$ and let $y = t$ whereupon $d\psi/dt = \partial\psi/\partial x(\pm v) + \partial\psi/\partial t = 0$ and the desired result follows immediately.
- 2.28 $\varphi/dt = (\partial\varphi/\partial x)(dx/dt) + \partial\varphi/\partial t = 0 = k(dx/dt) - kv$ and this is zero provided $dx/dt = \pm v$, as it should be. For the particular wave of Problem 2.20, $\varphi/dt = \partial\varphi/\partial y(\pm v) + \partial\varphi/\partial t = \pi 3 \times 10^6(\pm v) + \pi 9 \times 10^{14} = 0$ and the speed is $-3 \times 10^8 \text{ m/s}$.
- 2.29 $-a(bx + ct)^2 = -ab^2(x + ct/b)^2 = g(x + vt)$ and so $v = c/b$ and the wave travels in the negative x -direction. Using Eq. (2.34) $(\partial\psi/\partial t)_z/(\partial\psi/\partial x)_t = -[A(-2a)(bx + ct)ce^{-a(bx+ct)^2}]/[A(-2a)(bx + ct)be^{-a(bx + ct)^2}] = -c/b$; the minus sign tells us that the motion is in the negative x -direction.
- 2.30 $\psi(z, 0) = A \sin(kz + \epsilon)$; $\psi(-\lambda/12, 0) = A \sin(-\pi/6 + \epsilon) = 0.866$;
 $\psi(\lambda/6, 0) = A \sin(\pi/3 + \epsilon) = 1/2$; $\psi(\lambda/4, 0) = A \sin(\pi/2 + \epsilon) = 0$.
 $A \sin(\pi/2 + \epsilon) = A(\sin \pi/2 \cos \epsilon + \cos \pi/2 \sin \epsilon) = A \cos \epsilon = 0$, $\epsilon = \pi/2$.
 $A \sin(\pi/3 + \pi/2) = A \sin(5\pi/6) = 1/2$; therefore $A = 1$, hence
 $\psi(z, 0) = \sin(kz + \pi/2)$.
- 2.31 Both (a) and (b) are waves since they are twice differentiable functions of $z - vt$ and $x + vt$, respectively. Thus for (a) $\psi = a^2(z - bt/a)^2$ and the velocity is b/a in the positive z -direction. For (b) $\psi = a^2(x + bt/a + c/a)^2$ and the velocity is b/a in the negative x -direction.

6.13 For both, $-R_2 = R = R$, so (6.2) becomes

$$1/f = (n - 1)[2/R + (n - 1)d/nR^2];$$

$$1/f = (1.5 - 1)[2/50 + (1.5 - 1)(5.0)/1.5(50)^2]; \quad f = 49.2 \text{ cm.}$$

$$(6.1) \quad 1/f_1 = 1/s_{o1} + 1/s_{i1}, \text{ so } 1/s_{i1} = 1/f_1 - 1/s_{o1} = 1/(49.2).$$

6.14 (6.8) $1/f = 1/f_1 + 1/f_2 - d/f_1f_2 = 1/(+20) + 1/(-20) - 10/(20)(-20)$;
 $f = +40 \text{ cm}$. The principal planes are found from (6.9) and (6.10).

$$(6.9) \quad \overline{H_{11}H_1} = fd/f_2 = (+40)(10)/(-20) = -20 \text{ cm.}$$

$$(6.10) \quad \overline{H_{22}H_2} = fd/f_1 = (+40)(10)/(20) = +20 \text{ cm.}$$

6.15 $\mathcal{R}_1 = \begin{bmatrix} 1 & -\mathcal{D}_1 \\ 0 & 1 \end{bmatrix}$ from (6.16) where

$$\mathcal{D}_1 = (n - 1)/R_1 = (1.5 - 1)/2.5 \text{ cm} = 0.2 \text{ cm}^{-1}.$$

$$\mathcal{T}_{21} = \begin{bmatrix} 1 & 0 \\ d_{21}/n & 1 \end{bmatrix} \quad (6.24)$$

$$= \begin{bmatrix} 1 & 0 \\ 1.2/1.5 & 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0.8 & 1 \end{bmatrix}$$

$$\mathcal{R}_2 = \begin{bmatrix} 1 & -\mathcal{D}_2 \\ 0 & 1 \end{bmatrix}$$

but $R_2 = \infty$, so $\mathcal{D}_2 = 0$.

$$(6.29) \quad A = \mathcal{R}_2 \mathcal{T}_{21} \mathcal{R}_1 = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 0.8 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0.2 \\ 0 & 1 \end{bmatrix} = \begin{bmatrix} 1 & 0.2 \\ 0.8 & 1.16 \end{bmatrix}$$

$$\text{Check: } |A| = 1(1.16) - 0.2(0.8) = 1.$$

6.16 Working in centimeters,

$$\mathcal{D}_1 = (2.4 - 1.9)/R_1 = 0.1 \text{ cm}^{-1}, \quad \mathcal{D}_2 = (1.9 - 2.4)/R_2 = -0.05 \text{ cm}^{-1}$$

therefore

Chapter 13 Solutions

- 13.1 $T = 673$ K, area of each face is $A = 10^{-2}$ m², $\sigma = 5.67 \times 10^{-8}$ W m⁻² K⁻⁴, then $0.97AI_e = 0.97A\sigma T^4 = 110$ W.
- 13.2 $0.97I_e = 0.97\sigma(T^4 - T_e^4) = 76.9$ W/m² with $T = 306$ K and $T_e = 293$ K is the temperature of the environment. Then $0.97AI_e = 108$ W for the radiated power.
- 13.3 $I_e = 22.8 \times 10^4$ W/m², $T = (I_e/\sigma)^{1/4} = 1420$ K.
- 13.4 $E \sim T^4$, so the energy radiated increases by a factor of 10^4 .
- 13.5 $T = 306$ K, $\lambda_{\max} = 2.8978 \times 10^{-3}$ mK/ $T = 9.45 \times 10^{-6}$ m = 9.5μ m (in the infrared).
- 13.6 If the blackbody is at $T = 293$ K, then $\lambda_{\max} = 2.8978 \times 10^{-3}$ m K/ $T = 9.9\mu$ m (in the IR).
- 13.7 $T = 4.0 \times 10^4$ K, $\nu_{\max} = c/\lambda_{\max} = cT/2.8978 \times 10^{-3}$ m K = 4.1×10^{15} Hz (in the UV).
- 13.8 $T = 2.8978 \times 10^{-3}$ m K/ $\lambda_{\max} = 2.8978 \times 10^{-3}$ mK/ 4.65×10^{-7} m = 6230 K.
- 13.9 $T = 2.8978 \times 10^{-3}$ m K/ $\lambda_{\max} = 4300$ K.
- 13.10 We have for the total radiated power per unit area of the blackbody

$$\begin{aligned}
 P(T) &= \int_0^\infty I_\lambda d\lambda = 2\pi hc^2 \int_0^\infty \frac{d\lambda}{\lambda^5 (e^{hc/\lambda k_B T} - 1)} \\
 &= 2\pi hc^2 \left(\frac{k_B T}{hc} \right)^4 \int_0^\infty \frac{x^3 dx}{(e^x - 1)},
 \end{aligned}$$