

OPTICS

Fourth Edition

INSTRUCTOR'S SOLUTIONS MANUAL

Eugene Hecht

Adelphi University

Mark Coffey

University of Colorado

Paul Dolan

Northeastern Illinois University



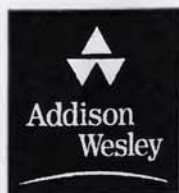
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Chapter 2 Solutions

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 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 τ , ν , and v and must determine λ . 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 $\sin(\theta - \pi/2)$.

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
$\cos(\kappa x - \pi/2)$	$-\sqrt{2}/2$	$-\sqrt{2}/2$	$\sqrt{2}/2$	$\sqrt{2}/2$	$-\sqrt{2}/2$	$-\sqrt{2}/2$	$\sqrt{2}/2$
$\cos(\kappa x + 3\pi/4)$	$\sqrt{2}/2$	$\sqrt{2}/2$	$-\sqrt{2}/2$	$-\sqrt{2}/2$	$\sqrt{2}/2$	$\sqrt{2}/2$	$-\sqrt{2}/2$

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	$3\pi/2$	2π
$\sin(\omega t + \pi/4)$	$-\sqrt{2}/2$	$-\sqrt{2}/2$	$\sqrt{2}/2$	$\sqrt{2}/2$	$-\sqrt{2}/2$	$-\sqrt{2}/2$	$\sqrt{2}/2$
$\sin(\pi/4 - \omega t)$	$-\sqrt{2}/2$	$\sqrt{2}/2$	$\sqrt{2}/2$	$-\sqrt{2}/2$	$-\sqrt{2}/2$	$\sqrt{2}/2$	$\sqrt{2}/2$

- 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) $(\partial\psi/\partial t)_x/(\partial\psi/\partial x)_t = -[A(-2a)(bx + ct)ce^{-a(bx+ct)^2}]/[A(-2a)(bx + ct)be^{-a(bx+ct)^2}] = -c/b$; 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) $1/f = 1/f_1 + 1/f_2 - d/f_1 f_2 = 1/(+20) + 1/(-20) - 10/(20)(-20);$
 $f = +40 \text{ cm.}$ 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 $T = 673 \text{ K}$, area of each face is $A = 10^{-2} \text{ m}^2$, $\sigma = 5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$, then $0.97AI_e = 0.97A\sigma T^4 = 110 \text{ W}$.
- 13.2 $0.97I_e = 0.97\sigma(T^4 - T_e^4) = 76.9 \text{ W/m}^2$ with $T = 306 \text{ K}$ and $T_e = 293 \text{ K}$ is the temperature of the environment. Then $0.97AI_e = 108 \text{ W}$ for the radiated power.
- 13.3 $I_e = 22.8 \times 10^4 \text{ W/m}^2$, $T = (I_e/\sigma)^{1/4} = 1420 \text{ K}$.
- 13.4 $E \sim T^4$, so the energy radiated increases by a factor of 10^4 .
- 13.5 $T = 306 \text{ K}$, $\lambda_{\max} = 2.8978 \times 10^{-3} \text{ mK}/T = 9.45 \times 10^{-6} \text{ m} = 9.5 \mu\text{m}$ (in the infrared).
- 13.6 If the blackbody is at $T = 293 \text{ K}$, then $\lambda_{\max} = 2.8978 \times 10^{-3} \text{ m K}/T = 9.9 \mu\text{m}$ (in the IR).
- 13.7 $T = 4.0 \times 10^4 \text{ K}$, $\nu_{\max} = c/\lambda_{\max} = cT/2.8978 \times 10^{-3} \text{ m K} = 4.1 \times 10^{15} \text{ Hz}$ (in the UV).
- 13.8 $T = 2.8978 \times 10^{-3} \text{ m K}/\lambda_{\max} = 2.8978 \times 10^{-3} \text{ mK}/4.65 \times 10^{-7} \text{ m} = 6230 \text{ K}$.
- 13.9 $T = 2.8978 \times 10^{-3} \text{ m K}/\lambda_{\max} = 4300 \text{ K}$.
- 13.10 We have for the total radiated power per unit area of the blackbody

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