

OPTICS

Fourth Edition

INSTRUCTOR'S SOLUTIONS MANUAL

Eugene Hecht

Adelphi University

Mark Coffey

University of Colorado

Paul Dolan

Northeastern Illinois University



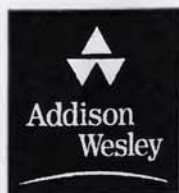
San Francisco Boston New York
Cape Town Hong Kong London Madrid Mexico City
Montreal Munich Paris Singapore Sydney Tokyo Toronto

ISBN 0-8053-8578-9

Copyright © 2002 Pearson Education, Inc., publishing as Addison Wesley, 1301 Sansome St., San Francisco, CA 94111. All rights reserved. Manufactured in the United States of America. This publication is protected by Copyright and permission should be obtained from the publisher prior to any prohibited reproduction, storage in a retrieval system, or transmission in any form or by any means, electronic, mechanical, photocopying, recording, or likewise. To obtain permission(s) to use material from this work, please submit a written request to Pearson Education, Inc., Permissions Department, 1900 E. Lake Ave., Glenview, IL 60025. For information regarding permissions, call 847/486/2635.

Many of the designations used by manufacturers and sellers to distinguish their products are claimed as trademarks. Where those designations appear in this book, and the publisher was aware of a trademark claim, the designations have been printed in initial cap or all caps.

4 5 6 7 8 9 10 —BTP— 05 04 03 02 01



www.aw.com/physics

Contents

Chapter 2 Solutions	1
Chapter 3 Solutions	7
Chapter 4 Solutions	15
Chapter 5 Solutions	30
Chapter 6 Solutions	45
Chapter 7 Solutions	52
Chapter 8 Solutions	61
Chapter 9 Solutions	72
Chapter 10 Solutions	80
Chapter 11 Solutions	87
Chapter 12 Solutions	93
Chapter 13 Solutions	97

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

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) $\lambda = (4.0 - 0.0) \text{ m} = 4.0$ 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) $\lambda = (30.0 - 0.0) \text{ cm} = 30.0$ 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, $-R_2 = R = R_1$, 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
 $\mathcal{D}_1 = (n-1)/R_1 = (1.5-1)/2.5 \text{ cm} = 0.2 \text{ cm}^{-1}.$

$$\begin{aligned} \mathcal{T}_{21} &= \begin{bmatrix} 1 & 0 \\ d_{21}/n & 1 \end{bmatrix} \quad (6.24) \\ &= \begin{bmatrix} 1 & 0 \\ 1.2/1.5 & 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0.8 & 1 \end{bmatrix} \\ \mathcal{R}_2 &= \begin{bmatrix} 1 & -\mathcal{D}_2 \\ 0 & 1 \end{bmatrix} \end{aligned}$$

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 $T = 306 \text{ K}$, $\lambda_{\max} = 2.8978 \times 10^{-3} \text{ m K}/T = 9.45 \times 10^{-6} \text{ m} = 9.5 \mu\text{m}$ (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 $T = 2.8978 \times 10^{-3} \text{ m K}/\lambda_{\max} = 2.8978 \times 10^{-3} \text{ m K}/4.65 \times 10^{-7} \text{ m} = 6230 \text{ K}$.
- 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

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