17.32 Let the hydrogen cell length be \( \ell = 75 \text{ cm} \). Then the light passing through the cell has wavelength \( \lambda_H = \lambda/n_H \) and the phase shift between the two light beams in the interferometer is:

\[
\Delta \phi = \frac{2\pi}{\lambda} L_2 - \left( \frac{2\pi}{\lambda} (L_1 - \ell) + \frac{2\pi}{\lambda_H} \ell \right) = \frac{2\pi}{\lambda} (L_2 - L_1 + \ell (1 - n))
\]

For constructive interference, this phase difference must equal \( 2\pi m \). Thus:

\[
m\lambda = L_2 - L_1 + \ell (1 - n)
\]

and so

\[
n = \frac{L_2 - L_1 - m\lambda}{\ell} + 1 = \frac{99.0 \text{ mm} - m (589 \text{ nm})}{75 \text{ cm}} + 1 = \frac{99.0 \times 10^{-6} \text{ m}}{75 \times 10^{-2} \text{ m}} + 1 - \frac{m (589 \times 10^{-9} \text{ m})}{75 \times 10^{-2} \text{ m}}
\]

Thus the value of \( m \) is not very important as long as it is less than about 50. We find:

\[
n = 1.00013
\]

17.34 See solutions manual.

17.36 The minimum resolvable angle for a circular aperture, according the the Rayleigh criterion, is \( \theta \approx 1.22 \lambda/D \). To achieve the same resolution with a radio telescope (\( \lambda \approx 1 \text{ m} \)) as with an optical telescope (\( \lambda \approx 500 \text{ nm} \)) the ratio of the diameters must be

\[
\frac{D_{\text{radio}}}{D_{\text{opt}}} = \frac{\lambda_{\text{radio}}}{\lambda_{\text{opt}}} = \frac{1 \text{ m}}{500 \times 10^{-9} \text{ m}} = 2 \times 10^6
\]

Thus the radio telescope needs to be about a million times bigger.

17.38 The tweeter forms a source which is like a rectangular slit of width \( a = 30 \text{ cm} \). The first minimum in the diffraction pattern occurs at \( \sin \theta = \lambda/a \). For \( f = 2 \text{ kHz} \) sound, \( \lambda = (340 \text{ m/s})/(2 \times 10^3 \text{ Hz}) = 0.17 \text{ m} \), and the first minimum is at

\[
\sin \theta_{\text{min}} = \frac{0.17 \text{ m}}{0.3 \text{ m}} = 0.567 \Rightarrow \theta_{\text{min}} = \sin^{-1} 0.567 = 35^\circ
\]

Thus the sound will be heard clearly only for listeners within about 35° of the direction directly in front of the speaker.

17.40,42 See solutions manual

17.44 The angular separation of the stars is:

\[
\theta_{\text{sep}} = \frac{d}{R} = \frac{10^{16} \text{ m}}{5.1 \times 10^{17} \text{ m}} = 2 \times 10^{-8} \text{ rad} = 2 \times 10^{-8} \frac{180^\circ}{\pi} \frac{3600''}{1^\circ} = 4 \times 10^{-3}''
\]

To resolve the stars, we need a telescope with diameter \( D \), where \( \sin \theta_{\text{sep}} = \sin \theta_{\text{min}} = 1.22 \lambda/D \). Since the angles are \( \ll 1 \text{ rad} \), we have:

\[
D = \frac{1.22\lambda}{\theta_{\text{sep}}} = 1.22 \frac{500 \times 10^{-9} \text{ m}}{2 \times 10^{-8}} = 31 \text{ m}
\]

which is much larger than any telescope currently in existence. Thus the stars cannot be
resolved using visible light. With UV (300 nm) light, we would need:

\[ D = \frac{1.22\lambda}{\theta_{\text{sep}}} = 1.22 \frac{300 \times 10^{-9} \text{ m}}{2 \times 10^{-8}} = 18 \text{ m} \]

17.46 1 arc second is \( \frac{1}{3600} \) degrees or \( \frac{1}{3600} \frac{\pi}{180} = 4.85 \times 10^{-6} \text{ rad} \). So the diffraction limit is reached with a telescope of diameter \( D \), where:

\[ 4.85 \times 10^{-6} = 1.22 \frac{\lambda}{D} \]

So:

\[ D = \frac{1.22 \frac{\lambda}{4.85 \times 10^{-6}}} = 1.22 \frac{600 \times 10^{-9} \text{ m}}{4.85 \times 10^{-6}} = 0.15 \text{ m} = 15 \text{ cm} \]

Astronomers use bigger telescopes because they can gather more light. Many interesting objects are very faint. The area of the telescope determines how much light it can gather, and \( A \propto D^2 \). The Shane telescope, with \( D = 3.0 \text{ m} \), gathers \((300/15)^2 = 400\) times as much light as a 15 cm diameter telescope.

The Hubble telescope \((D = 2.4 \text{ m})\) has a resolution of:

\[ \theta_{\text{min}} = 1.22 \frac{600 \times 10^{-9} \text{ m}}{2.4 \text{ m}} = 3 \times 10^{-7} \text{ rad} = \frac{3 \times 10^{-7} \text{ rad}}{4.85 \times 10^{-6} (\text{rad/m})} = 0.06'' \]

at 600 nm. It can make use of its higher resolution because it is above the earth’s atmosphere, in orbit.

17.48 The maxima in a double slit interference pattern are given by

\[ \sin \theta = m \frac{\lambda}{d} \] (3)

The minima in the diffraction pattern for a rectangular slit are given by:

\[ \sin \theta = n \frac{\lambda}{a} \] (4)

If the ninth interference fringe is missing, then \( m = 9 \) in equation 3 gives the same angle as \( n = 1 \) in equation 4:

\[ 9 \frac{\lambda}{d} = \frac{\lambda}{a} \Rightarrow d = 9a = 9(1.5 \mu \text{m}) = 13.5 \mu \text{m} \]

So the slit separation is 14 \( \mu \text{m} \).

17.50 The maxima in a double slit interference pattern are given by

\[ \sin \theta = m \frac{\lambda}{d} \] (5)

The minima in the diffraction pattern for a rectangular slit are given by:

\[ \sin \theta = n \frac{\lambda}{a} \] (6)

If the fourth interference fringe is missing, then \( m = 4 \) in equation 5 gives the same angle as \( n = 1 \) in equation 6:

\[ 4 \frac{\lambda}{d} = \frac{\lambda}{a} \Rightarrow d = 4a = 4(1.2 \mu \text{m}) = 4.8 \mu \text{m} \]
Chapter 33

Electromagnetic Waves

33.1 The electric field amplitude may be determined by use of Eqn. (33.8):

\[ B_0 = \frac{E_0}{c} \]

or

\[ E_0 = cB_0 \]

\[ = (3.00 \times 10^8 \text{ m/s}) (1.56 \times 10^{-8} \text{ T}) \]

\[ = 4.68 \text{ V/m} \]

33.2 1.5 \times 10^{-9} \text{ T}; the \(-y\)-direction.

33.3 The magnetic field amplitude, \( B_0 \), is given by:

\[ B_0 = \frac{E_0}{c} \]

Note, the unit vector \( \mathbf{E} \) is \( \left( \hat{x} + \hat{y} \right) / \sqrt{2} \), so

\[ B_0 = \frac{(6.0 \text{ V/m}) \sqrt{2}}{(3.0 \times 10^8 \text{ m/s})} \]

\[ = 2.8 \times 10^{-8} \text{ T} \]

Since the direction of propagation is in the \(+z\)-direction, \( \mathbf{B} \) must lie in the \( x-y \)-plane (since EM waves are transverse waves). Furthermore, \( \mathbf{B} \) must be perpendicular to \( \mathbf{E} \). Therefore

\[ \mathbf{B} = (2.8 \times 10^{-8} \text{ T}) \left( \frac{\hat{x} + \hat{y}}{\sqrt{2}} \right) \]

33.4 \( \mathbf{E} = (0.13 \text{ V/m}) \hat{y} \cos \left\{ \sqrt{\frac{\pi}{1.0 \text{ mm}}} (x - ct) \right\} \)

33.5 The magnitude of the Poynting vector by c.f. Example (33.2):

\[ \langle |\mathbf{S}| \rangle = \frac{|\mathbf{E} \times \mathbf{B}|}{\mu_0} \]

\[ = \frac{E_0B_0 |\cos^2 (kx - \omega t)|}{\mu_0} \]

\[ = \frac{E_0^2}{2c\mu_0} \]

Since

\[ \langle |\mathbf{S}| \rangle = 2 \times 10^{-8} \text{ W/m}^2 \]

we have

\[ E_0 = \sqrt{2c\mu_0 \langle |\mathbf{S}| \rangle} \]

\[ = \sqrt{2 \left( 3 \times 10^8 \text{ m/s} \right) \left( 4\pi \times 10^{-7} \text{ H/m} \right)} \]

\[ = 4 \times 10^{-3} \text{ V/m} \]

33.6 The diameter of the laser beam is 2.4 \text{ m}.\]

33.7 The time-averaged magnitude of \( \mathbf{S} \) is given c.f. Example 33.2:

\[ \langle |\mathbf{S}| \rangle = \frac{E_0^2}{2c\mu_0} \]

\[ = \frac{(3.0 \text{ V/m})^2}{2 \left( 3 \times 10^8 \text{ m/s} \right) \left( 4\pi \times 10^{-7} \text{ H/m} \right)} \]

\[ = 0.012 \text{ W/m}^2 \]

The rate at which momentum is transported is given by Eqn. (33.10):
we obtain
\[ B'(z + dz) - B(z) = \varepsilon_0\mu_0 \frac{d}{dt} (-E dz) \]

Since \( B(z + dz) = B(z) \),
\[ \frac{\partial E}{\partial t} = 0. \]

So neither \( E \) nor \( B \) can change in time, which means the wave does not propagate.

33.18 \( \mathbf{E}_0 = (36 \, \text{V/m}) (-\sqrt{3}\mathbf{x} + \mathbf{z}) \)

33.19 The wave vector magnitude is
\[ k = \frac{2\pi}{\lambda} = \frac{2\pi}{c} f = \frac{2\pi (16.5 \times 10^6 \, \text{Hz})}{(3.00 \times 10^8 \, \text{m/s})} = 0.346 \, \text{rad/m} \]

Thus
\[ \mathbf{k} = (0.346 \, \text{rad/m}) \mathbf{x} \]

The magnetic field amplitude is
\[ B_0 = \frac{E_0}{c} = \frac{(0.792 \, \text{V/m})}{(3.00 \times 10^8 \, \text{m/s})} = 2.64 \times 10^{-9} \, \text{T} \]

33.20
\[ \mathbf{E} = (1.43 \, \text{V/m}) (-\mathbf{x}) \cos \{ (37.7 \, \text{rad/m}) y - 2\pi [(1.80 \, \text{GHz}) t + 0.331] \} \]
\[ \mathbf{B} = (4.75 \, \text{nT}) \mathbf{z} \cos \{ (37.7 \, \text{rad/m}) y - 2\pi [(1.80 \, \text{GHz}) t + 0.331] \} \]

33.21 The electric field vector amplitude of the superposed wave is
\[ \mathbf{E}_0 = E_{01} \mathbf{y} + E_{02} \mathbf{z} = (0.44 \, \text{V/m}) (\mathbf{y} + \mathbf{z}) \]

Amplitude:
\[ B_0 = 2.1 \times 10^{-9} \, \text{T} \]

Now, the magnetic vector amplitude is given by
\[ \mathbf{B}_0 = \frac{k \times \mathbf{E}_0}{c} = \frac{(0.44 \, \text{V/m})}{(3 \times 10^8 \, \text{m/s})} \mathbf{x} \times (\mathbf{y} + \mathbf{z}) \]

Vector:
\[ \mathbf{B}_0 = (1.47 \times 10^{-9} \, \text{T}) (\mathbf{z} - \mathbf{y}) \]

33.22 \( \mathbf{k} = (-0.70\mathbf{x} + 0.64\mathbf{y} - 0.29\mathbf{z}) \)

33.23 Since \( \mathbf{k} = (\mathbf{x} + 2\mathbf{y}) (\frac{1}{m}) \), we have
\[ k = |\mathbf{k}| = \sqrt{(1)^2 + (2)^2} = \frac{\sqrt{5}}{m} \]

Now, since \( \omega = ck \) (in a vacuum) and
\[ f = (2\pi)^{-1} \omega \]

the frequency \( f \) is
\[ f = \frac{ck}{2\pi} = \frac{(3 \times 10^8 \, \text{m/s}) (\frac{\sqrt{5}}{m})}{2\pi} = 107 \times 10^6 \, \text{Hz} \]

The electric field vector amplitude is given by
\[ \mathbf{E}_0 = c\mathbf{B}_0 \times \mathbf{k} = (3 \times 10^8 \, \text{m/s}) (1.43 \times 10^{-10} \, \text{T}) \cdot (2\mathbf{x} - \mathbf{y} + \mathbf{z}) \times (\mathbf{x} + 2\mathbf{y}) \]
\[ = (1.92 \times 10^{-2} \, \text{V/m}) (-2\mathbf{x} + \mathbf{y} + 5\mathbf{z}) \]

33.24 a) Same
b) The first EM wave transports 4 times the energy of the other.
a) For $\theta = 37.0^\circ$

$$\frac{I_i}{I_t} = 0.638$$

b) For $\theta = 77.0^\circ$

$$\frac{I_i}{I_t} = 0.0506$$

33.42 50° (two sig. figs.)

33.43 Light with incident angle 58° is 100% polarized, implies that $\theta_B = 58^\circ$ for the air/glass interface.

<table>
<thead>
<tr>
<th>air</th>
<th>glass</th>
</tr>
</thead>
<tbody>
<tr>
<td>$n_1 = 1.0$</td>
<td>$n_2 = ?$</td>
</tr>
</tbody>
</table>

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

$$\Rightarrow n_2 = n_1 \tan \theta_B$$

$$= (1.0) \tan 58^\circ = 1.6$$

33.44 31 W/m$^2$

33.45 $I_1 = 1.6$ W/m$^2$

$$I_{t1} = I_1 \cos^2 45^\circ = 0.80 \text{ W/m}^2$$

and the transmitted field $\vec{E}_{t1}$ is along the z-axis

33.46 0.073$I_0$

33.47 The light is reflected and transmitted as shown:

$$I_{t2} = I_{t1} \cos^2 45^\circ = 0.40 \text{ W/m}^2$$

Thus, the intensity of the light has been reduced by $\frac{1}{4}$, while the axis of polarization has been restored to its original direction.

If the second transmission axis were perpendicular to the initial polarization, the intensity would still be $\frac{1}{4}$ its original value. The axis of polarization would be perpendicular to its original direction.

33.48 The electric field vector traces out an ellipse and rotates clockwise with respect to an observer looking toward the source. It is elliptically polarized, with "right-hand" polarization.

33.49 Unpolarized light of intensity $I_0$ first passes through a polarizer oriented along the vertical direction. The transmitted light has intensity $\frac{I_0}{2}$ and is linearly polarized along the vertical axis, $\vec{E}_1 \parallel z$-axis with amplitude $E_1$. 

$$p\% = \frac{0.50I_0 - 0.405I_0}{0.50I_0 + 0.405I_0}$$

$$= 10.5\% \text{ polarized}$$